

# Tema 1: SISTEMES DE COMUNICACIÓNS

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Setembre 2021



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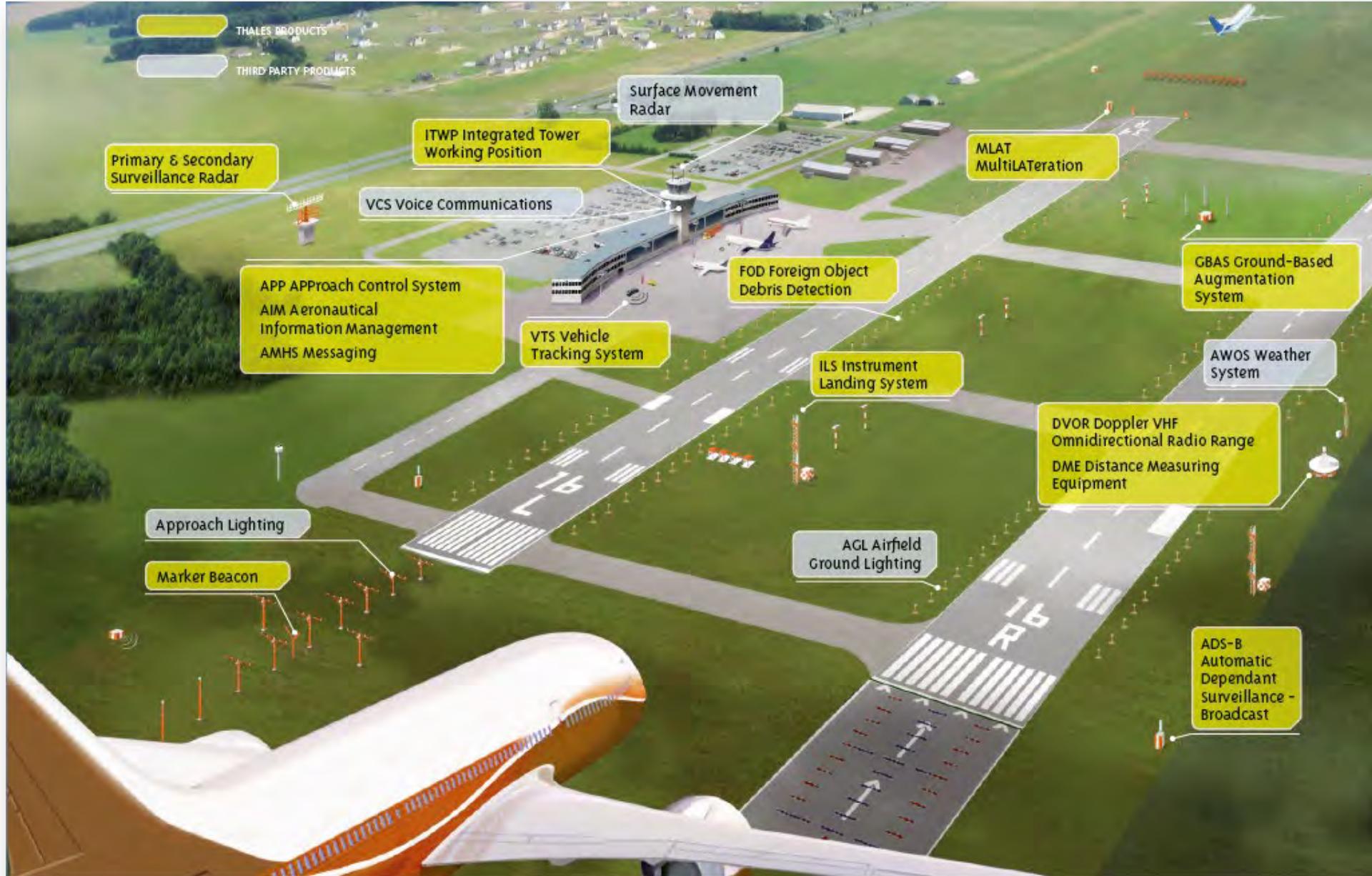
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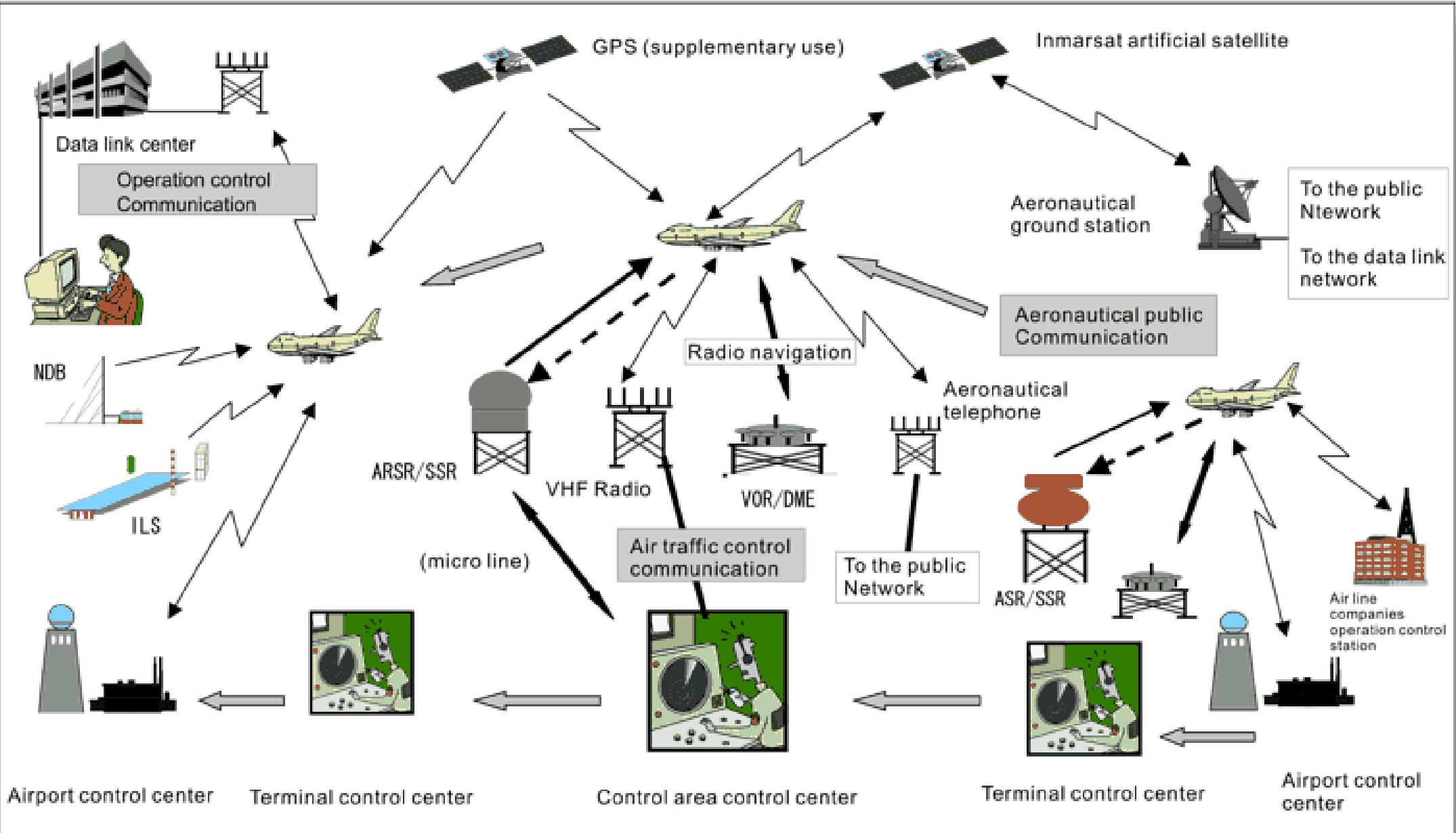
# LES COMUNICACIONS I L'AERONÀUTICA



# Entorn aeroportuari



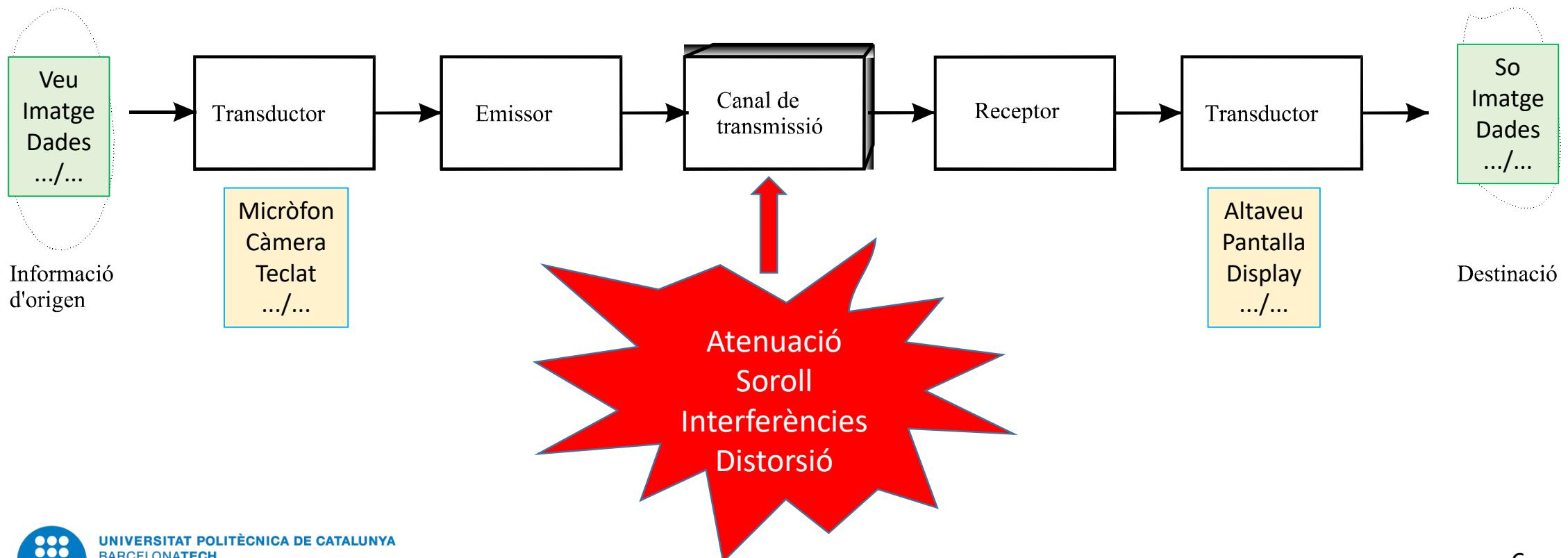
# Entorn aeronàutic



# Continguts

- Elements bàsics d'un sistema de comunicacions.
- L'espectre electromagnètic
- Unitats de mesura
- Amplada de banda i capacitat del canal
- Modes de transmissió.
- Modulació.
- Paràmetres del senyals
- Soroll
- Distorsió.

# QUÈ ÉS UN SISTEMA DE TELECOMUNICACIÓ?



# Tipus de sistemes de comunicació

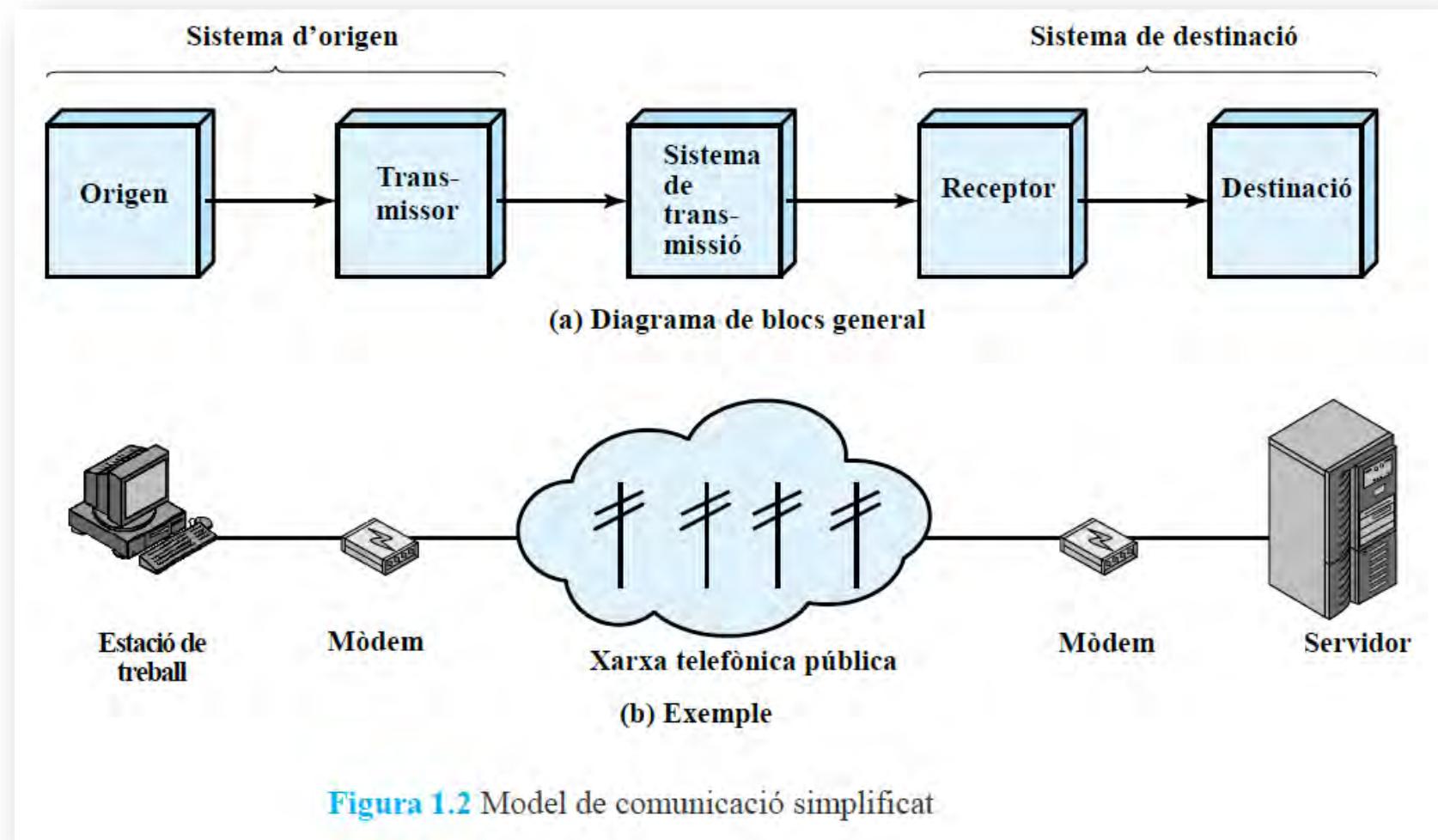
## Analògic:

- El missatge és un paràmetre físic que varia amb el temps, de forma continua o suau.
- La informació resideix en la forma d'ona.
- Es requereix **FIDELITAT**.

## Digital

- El missatge és una seqüència ordenada de símbols seleccionats d'un conjunt finit d'elements discrets.
- La informació resideix en els símbols discrets.
- Es requereix **PRECISIÓ**.

# QUÈ ÉS UN SISTEMA DE TELECOMUNICACIÓ?



# Sistema de comunicacions digital

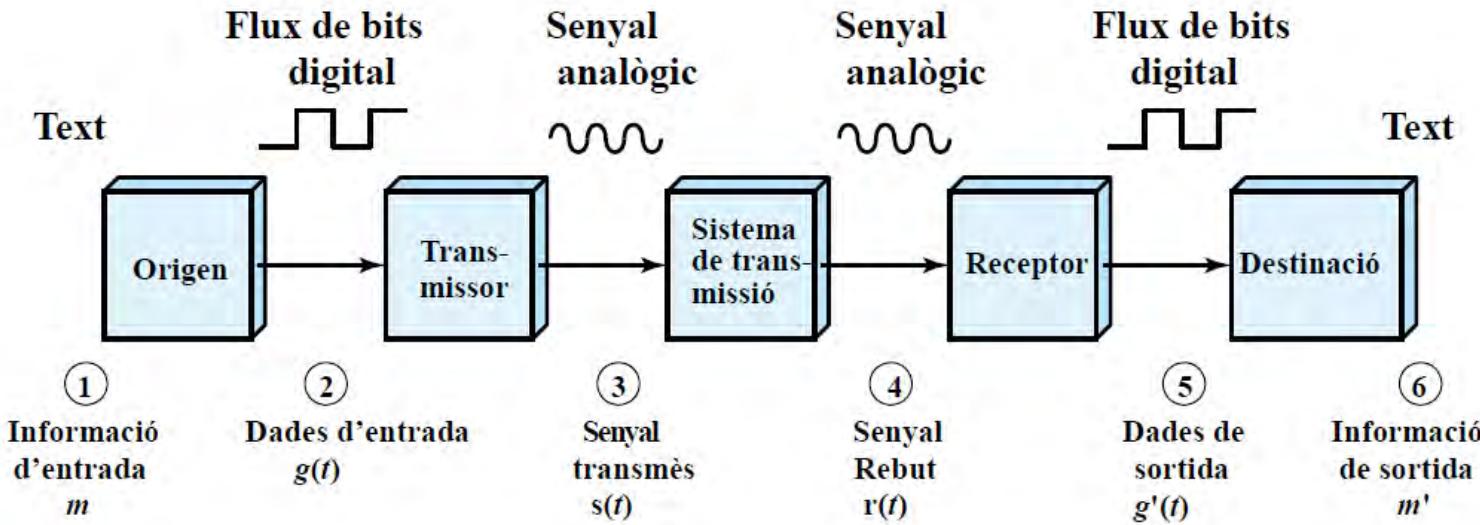


Figura 1.3 Model de comunicació de dades simplificat

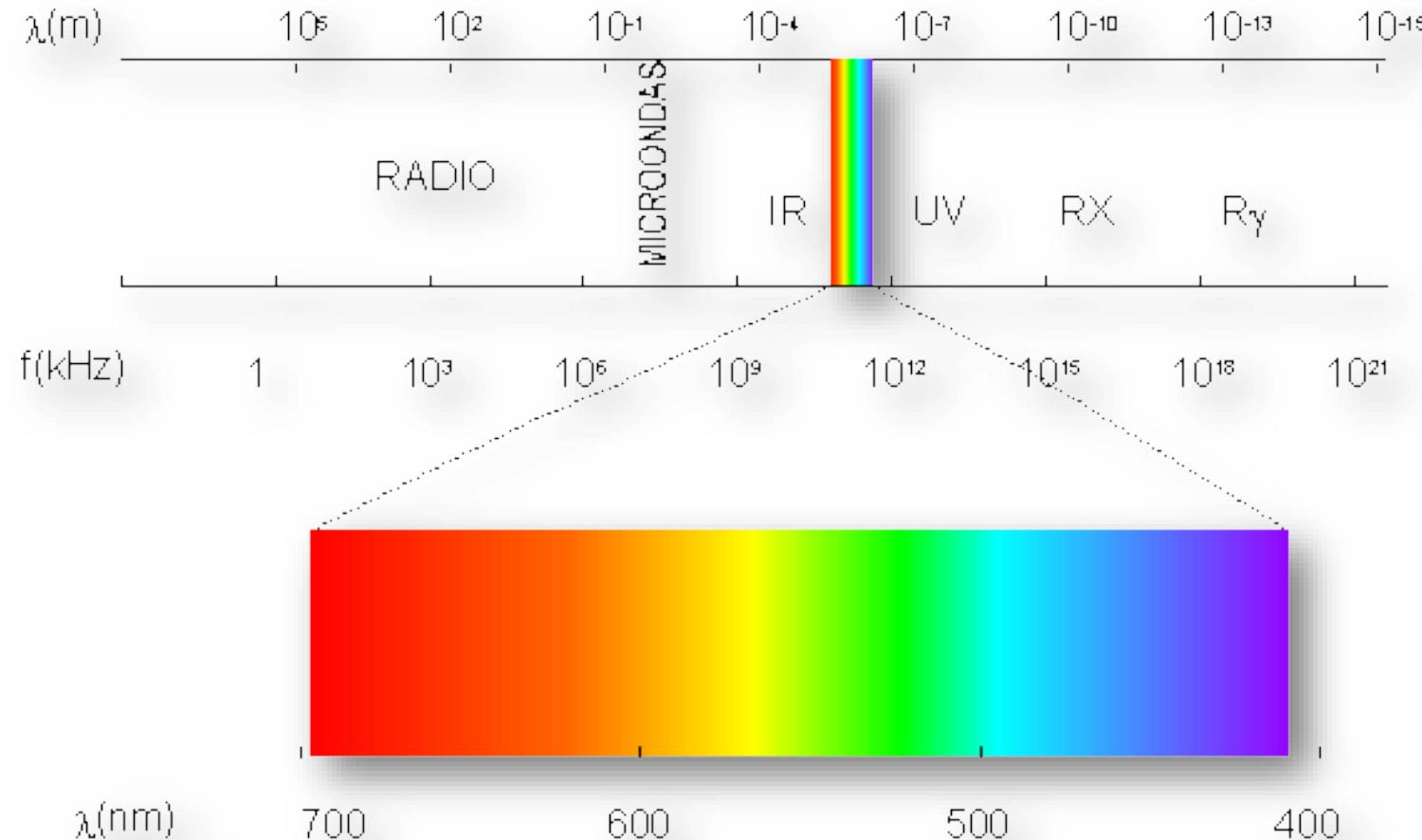
- **Origen:** aquest dispositiu genera les dades que cal transmetre; els telèfons i els ordinadors personals en són un exemple.
- **Transmissor:** normalment, les dades que genera un sistema d'origen no es transmeten directament en el format en què han estat generades. En lloc d'això, el transmissor transforma i codifica la informació de tal manera que es produeixen senyals electromagnètics que es poden transmetre a través d'un sistema de transmissió. Per exemple, un mòdem agafa un flux de bits digital d'un dispositiu connectat, com ara un ordinador personal, i transforma aquest flux en un senyal analògic que la xarxa telefònica és capaç de gestionar.
- **Sistema de transmissió:** pot ser una línia de transmissió o una xarxa complexa que connecti l'origen i la destinació.
- **Receptor:** el receptor accepta el senyal del sistema de transmissió i el converteix en un format que el dispositiu de destinació pugui gestionar. Per exemple, un mòdem acceptarà un senyal analògic que arribi des d'una xarxa o una línia de transmissió i el convertirà en un flux de bits digital.
- **Destinació:** rep les dades d'entrada del receptor.

# L'ESPECTRE RADIOELÈCTRIC

BANDES DE FREQÜÈNCIES RESERVADES A AERONÀUTICA



# L'espectre electromagnètic



La longitud d'ona ( $\lambda$ ) és la distància que recorre la ona en un període ( $T$ ) de temps o cicle, viatjant a la velocitat de la llum ( $c$ ).

$$f = \frac{1}{T}$$

$$\lambda = \frac{c}{f}$$

$$c = 3 \cdot 10^8 \text{ m/s}$$

# Efectes biològics de la radiació electromagnètica

La radiació electromagnètica **és una radiació no ionitzant** i en conseqüència els efectes biològics que es derivin de la radiofreqüència, les microones, les freqüències òptiques d'infraroig, visible, i la part baixa de l'ultraviolat **són només de tipus tèrmic**.

Aquesta afirmació és basa en el fet que per poder ionitzar l'estructura atòmica d'una molècula és necessari aplicar-hi una **energia superior a 12,4 eV**; tenint en compte que l'energia d'una ona electromagnètica s'obté com el producte de la constant de Planck ( $h=6,62607015 \cdot 10^{-34} \text{ J}\cdot\text{s}$ ) per la seva freqüència:

$$E(J) = h \cdot f = 6,62607015 \cdot 10^{-34} (\text{J}\cdot\text{s}) \times f (\text{Hz})$$

$$1 \text{ eV} = 1,602176462 \cdot 10^{-19} \text{ J}$$

Es pot deduir que per a radiacions d'RF i microones l'energia mai no superarà els  $1,24 \cdot 10^{-3} \text{ eV}$ , valor massa petit per alterar les estructures moleculars; cosa que sí que succeeix en la banda alta de l'ultraviolat, a partir d'una freqüència de  $2,99 \cdot 10^{15} \text{ Hz}$ .

# Bandes de freqüència

Establertes per la Unió Internacional de Telecomunicacions (UIT-ITU)



Denominació	Abreviatura	Freqüències	Longitud d'ona
Very Low Frequency	VLF	3 kHz - 30 kHz	100 km - 10 km
Low Frequency	LF	30 kHz - 300 kHz	10 km - 1 km
Medium Frequency	MF	300 kHz - 3 MHz	1 km - 100 m
High Frequency	HF	3 MHz - 30 MHz	100 m - 10 m
Very High Frequency	VHF	30 MHz - 300 MHz	10 m - 1 m
Ultra High Frequency	UHF	300 MHz - 3 GHz	100 cm - 10 cm
Super High Frequency	SHF	3 GHz - 30 GHz	10 cm - 1 cm
Extremly High Frequency	EHF	30 GHz - 300 GHz	10 mm - 1 mm

**Radiofreqüència:**  
freqüències  $\geq 3 \text{ MHz}$

**Microones:**  
freqüències  $\geq 1 \text{ GHz}$

# Bandes de freqüència de microones

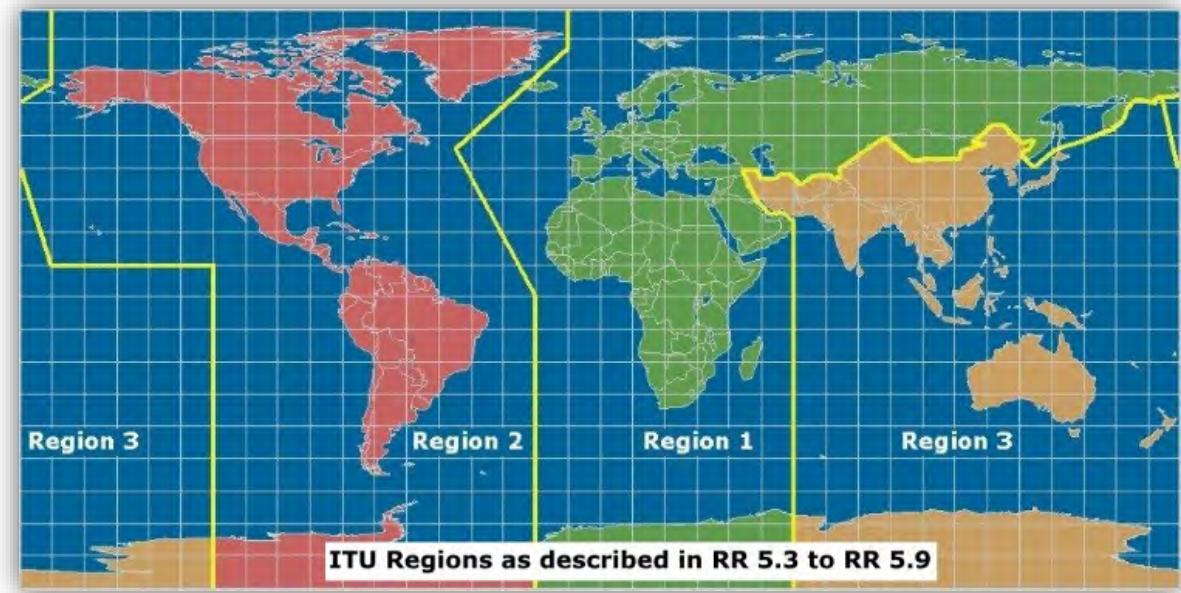
Denominació de banda	Freqüències
L	1 GHz - 2 GHz
S	2 GHz - 4 GHz
C	4 GHz - 8 GHz
X	8 GHz - 12 GHz
Ku	12 GHz - 18 GHz
K	18 GHz - 27 GHz
Ka	27 GHz - 40 GHz
V	40 – 75 GHz
W	75 – 110 GHz
mm (*)	110 – 300 GHz

(\*) The designation *mm* is derived from *millimeter wave*, and is also used to refer V and W bands, and part of the Ka band, when general information relating to the region above 30 GHz is to be conveyed.



# Assignació de freqüències aeronàutiques

- La [ITU](#), d'acord amb ICAO, en el Reglament de Radiocomunicacions (RR), assigna bandes de freqüències per a les comunicacions i els sistemes de radionavegació aeronàutics.
- A Espanya, la *Secretaría de Estado de Telecomunicaciones e Infraestructuras Digitales*, depenent del *Ministerio de Asuntos Económicos y Transformación Digital* elabora el [Quadre Nacional d'Atribucions de Freqüències \(CNAF\)](#) en el que es reserven les bandes de freqüències d'acord amb la ITU.
- El CNAF incorpora les notes d'ús nacional (UN) que detallen aspectes concrets de cada banda.





ATRIBUCIÓN A LOS SERVICIOS según el RR de la UIT		
2194 - 3230 kHz		
Región 1	Región 2	Región 3
2501 - 2502	FRECUENCIAS PATRÓN Y SEÑALES HORARIAS Investigación espacial	
2502 - 2625 FIJO MÓVIL, salvo móvil aeronáutico (R) 5.92 5.103 5.114	2502 - 2505 FRECUENCIAS PATRÓN Y SEÑALES HORARIAS	
2625 - 2650 MÓVIL MARÍTIMO RADIONAVEGACIÓN MARÍTIMA 5.92	2505 - 2850 FIJO MÓVIL	
2650 - 2850 FIJO MÓVIL, salvo móvil aeronáutico (R) 5.92 5.103		
2850 - 3025	MÓVIL AERONÁUTICO (R) 5.111 5.115	
3025 - 3155	MÓVIL AERONÁUTICO (OR)	
3155 - 3200	FIJO MÓVIL, salvo móvil aeronáutico (R) 5.116 5.117	

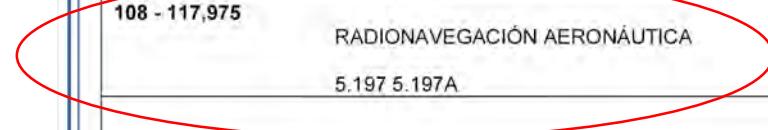
ATRIBUCIÓN NACIONAL		OBSERVACIONES
2194 - 3230 kHz		
ATRIBUCIÓN NACIONAL	USOS	OBSERVACIONES
2501 - 2502 FRECUENCIAS PATRÓN Y SEÑALES HORARIAS Investigación espacial	R R	
2502 - 2625 FIJO MÓVIL, salvo móvil aeronáutico (R)	M M	5.92 5.103 UN-114
2625 - 2650 MÓVIL MARÍTIMO RADIONAVEGACIÓN MARÍTIMA	M R	5.92 UN-114
2650 - 2850 FIJO MÓVIL, salvo móvil aeronáutico (R)	M M	5.92 5.103 UN-114
2850 - 3025 MÓVIL AERONÁUTICO (R)	R	5.111 5.115 UN-114
3025 - 3155 MÓVIL AERONÁUTICO (OR)	R	UN-0, UN-114
3155 - 3200 MÓVIL, salvo móvil aeronáutico (R) FIJO	M M	5.116 UN-114



### ATRIBUCIÓN A LOS SERVICIOS según el RR de la UIT

**75,2 - 137,175 MHz**

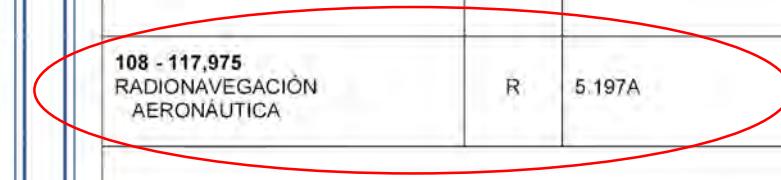
Región 1	Región 2	Región 3
<b>75,2 - 87,5</b> FIJO MÓVIL, salvo móvil aeronáutico	<b>75,2 - 75,4</b> FIJO MÓVIL 5.179	
	<b>75,4 - 76</b> FIJO MÓVIL	<b>75,4 - 87</b> FIJO MÓVIL
5.175 5.179 5.187		5.182 5.183 5.188
<b>87,5 - 100</b> RADIODIFUSIÓN	<b>76 - 88</b> RADIODIFUSIÓN Fijo Móvil 5.185	<b>87 - 100</b> FIJO MÓVIL RADIODIFUSIÓN
5.190	<b>88 - 100</b> RADIODIFUSIÓN	
<b>100 - 108</b> RADIODIFUSIÓN		
	5.192 5.194	
<b>108 - 117,975</b> RADIONAVEGACIÓN AERONÁUTICA		
	5.197 5.197A	



### ATRIBUCIÓN NACIONAL

**75,2 – 137,175 MHz**

ATRIBUCIÓN NACIONAL	USOS	OBSERVACIONES
<b>75,2 - 87,5</b> FIJO MÓVIL, salvo móvil aeronáutico	*	UN-132, UN-154, UN-156 * Usos M y C (según notas UN)
<b>87,5 - 108</b> RADIODIFUSIÓN	P	UN-17 Radiodifusión sonora en ondas métricas (FM)
<b>108 - 117,975</b> RADIONAVEGACIÓN AERONÁUTICA	R	5.197A



# Reglament de Radiocomunicacions



- **5.197 Atribución adicional:** en Repùblica Árabe Siria, la banda 108-111,975 MHz está también atribuida al servicio móvil a título secundario, a reserva de obtener el acuerdo indicado en el número 9.21. A fin de garantizar que no se produzca interferencia perjudicial a las estaciones del servicio de radionavegación aeronáutica, no se introducirán las estaciones del servicio móvil en la banda hasta que ya no la necesite para el servicio de radionavegación aeronáutica ninguna administración que pueda ser identificada en aplicación del procedimiento invocado en el número 9.21. (CMR-12)
- **5.197A Atribución adicional:** la banda 108-117,975 MHz también está atribuida a título primario al servicio móvil aeronáutico (R), exclusivamente para los sistemas que funcionan de conformidad con las normas aeronáuticas internacionales reconocidas.

Dicha utilización ha de ser conforme con la Resolución 413 (Rev.CMR-07). La utilización de la banda 108-112 MHz por el servicio móvil aeronáutico (R) se limitará a los sistemas compuestos por transmisores en tierra y los correspondientes receptores que proporcionan información de navegación en apoyo de las funciones de navegación aérea de conformidad con las normas aeronáuticas internacionales reconocidas. (CMR-07)
- **5.200 En la banda 117,975-137 MHz, la frecuencia de 121,5 MHz es la frecuencia aeronáutica de emergencia** y, de necesitarse, la frecuencia de 123,1 MHz es la frecuencia aeronáutica auxiliar de la de 121,5 MHz. Las estaciones móviles del servicio móvil marítimo podrán comunicar en estas frecuencias, en las condiciones que se fijan en el Artículo 31, para fines de socorro y seguridad, con las estaciones del servicio móvil aeronáutico. (CMR-07)
- **5.201 Atribución adicional:** en Armenia, Azerbaiyán, Belarús, Bulgaria, Estonia, Federación de Rusia, Georgia, Hungría, Irán (Repùblica Islámica del), Iraq (Repùblica del), Japón, Kazajstán, Moldova, Mongolia, Mozambique, Uzbekistán, Papua Nueva Guinea, Polonia, Kirguistán, Rumania, Tayikistán, Turkmenistán y Ucrania la banda de frecuencias 132-136 MHz está también atribuida, a título primario, al servicio móvil aeronáutico (OR). Al asignar frecuencias a las estaciones del servicio móvil aeronáutico (OR), la administración deberá tener en cuenta las frecuencias asignadas a las estaciones del servicio móvil aeronáutico (R). (CMR-15)
- **5.202 Atribución adicional:** en Arabia Saudita, Armenia, Azerbaiyán, Belarús, Bulgaria, Emiratos Árabes Unidos, Federación de Rusia, Georgia, Irán (Repùblica Islámica del), Jordania, Omán, Uzbekistán, Polonia, Repùblica Árabe Siria, Kirguistán, Rumania, Tayikistán, Turkmenistán y Ucrania, la banda de frecuencias 136-137 MHz está atribuida también a título primario al servicio móvil aeronáutico (OR). Al asignar frecuencias a las estaciones del servicio móvil aeronáutico (OR), la administración deberá tener en cuenta las frecuencias asignadas a las estaciones del servicio móvil aeronáutico (R). (CMR-15)

# CNAF – Usos Nacionales



## UN - 18 Compañías de transporte aéreo

- Se destina la subbanda de frecuencias 131,400 – 131,975 MHz exclusivamente para uso en control operacional de compañías de transporte aéreo en los aeropuertos nacionales. Las frecuencias 131,525 MHz, 131,725 MHz y 131,825 MHz dentro de esta subbanda, se encuentran reservadas para proporcionar enlaces de datos para compañías de transporte aéreo. La subbanda de frecuencias 136,700-136,975 MHz se reserva a nivel europeo por la Organización de Aviación Civil Internacional (OACI) para proporcionar enlace de datos a las compañías de transporte aéreo.
- Las subbandas de frecuencias indicadas en el párrafo anterior deberán regirse a partir del 1 de enero de 2018 por el Reglamento de Ejecución 1079/2012 de la Comisión Europea que establece como norma general un **valor de canalización de 8,33 kHz**, salvo aquellos casos excepcionales que se autorice mantener en 25 kHz.
- El uso de estas frecuencias podrá ser compartido entre distintos usuarios.

## UN - 28 Banda de frecuencias 235 a 399,9 MHz

- La banda de frecuencias 235-399,9 MHz, está destinada a uso exclusivo del Estado para sistemas del Ministerio de Defensa con excepción de las subbandas de frecuencias 380-385 MHz y 390-395 MHz que, de conformidad con la Decisión de la CEPT ECC/DEC(08)05, se destinan para redes de servicios de seguridad de las Fuerzas y Cuerpos de Seguridad del Estado y redes de servicios de emergencia en todo el territorio nacional y de la **subbanda 328,600 a 335,400 MHz atribuida al servicio de radionavegación aeronáutica (sistema ILS)**.
- Por problemas de saturación en esta banda de frecuencias en entornos urbanos de alta densidad, las solicitudes de asignación de frecuencias deberán incluir un exhaustivo plan de reutilización, que minimice las necesidades de espectro.

## UN - 19 Banda 138-144 MHz

La banda de frecuencias **138 a 144 MHz se reserva al servicio móvil aeronáutico (OR)**.

## UN - 102 Usos civiles del servicio móvil aeronáutico (OR)

- Las siguientes bandas de frecuencias bajo la consideración de uso privativo, se reservan, preferentemente, para usos civiles relacionados con **actividades aéreas tales como, aeroclubs, escuelas de vuelo, vuelo sin motor, globos aerostáticos, aviones ligeros, ultraligeros, trabajos agrícolas de fumigación, fotografía aérea y servicios aéreos contra incendios**, entre otros:
  - 122,000-123,050 MHz.
  - 123,150-123,675 MHz.
  - 129,700-130,875 MHz.
  - En estas bandas de frecuencias podrán ser utilizadas canalizaciones de 8,33 kHz o 25 kHz.
- Los dos canales con frecuencias centrales 129,975 MHz y 130,125 MHz tendrán la consideración de uso común siempre que se utilicen con una potencia radiada aparente máxima (p.r.a) de 2W.
- Se reservan los seis canales que se indican a continuación, canalizados a 25 kHz, para su utilización en actividades de lucha contra incendios de ámbito multiprovincial:
  - 122,350 MHz.
  - 122,475 MHz.
  - 123,425 MHz.
  - 129,825 MHz.
  - 130,325 MHz.
  - 130,500 MHz.

# Unitats de mesura

dB, dBm, dBW, dB $\mu$ V



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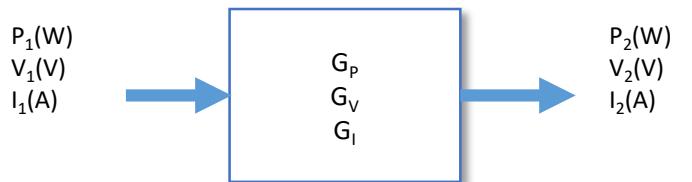
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# Magnituds elèctriques

## En DC i baixa freqüència

- Tensió (Volts: V)
- Corrent (Ampers: A)
- Potència (Watts: W)
- Impedància (Ohms:  $\Omega$ )
- Admitància (Siemens: S)
- Guany (de tensió  $G_V$ , de corrent  $G_I$ , de potència  $G_P$ ) magnituds adimensionals i valors numèrics diferents.

*Nota: No hi cap impedància de referència normalitzada*



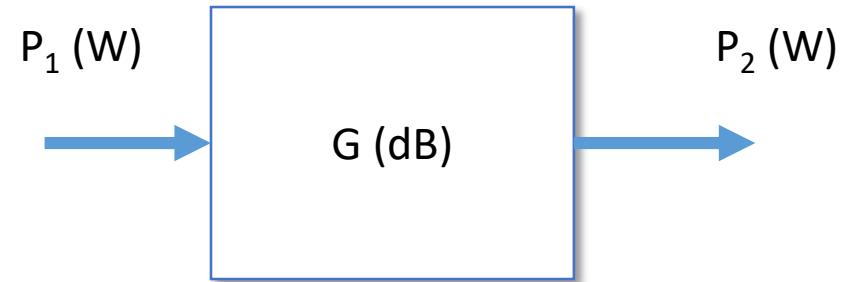
## En Radiofreqüència

- Tensió (Volts: V, dB $\mu$ V)
- Corrent (Ampers: A, dB $\mu$ A)
- Potència (Watts: W, dBm, dBW)
- Impedància normalitzada a **50  $\Omega$** , excepte per sistemes domèstics de TV que està normalitzada a 75  $\Omega$ .
- Guany (dB), de caràcter adimensional, i de **valor únic**, degut a la normalització d'impedàncies.



# El decibel (dB)

$$\text{dB} = 10 \log \frac{P_2(W)}{P_1(W)}$$



El Bel es una unitat de mesura logarítmica de la relació entre dues magnituds de potència. El decibel o dB és el 10 logaritme en base 10 d'una relació de potències, i per tant **és adimensional**. Pot expressar tant un **guany** de potència, si és >0, o una **atenuació**, si és <0.

---

Si assignem a  $P_1$  un valor concret de potència, llavors ho estem referenciant respecte d'aquest i per tant deixa de ser adimensional i **passa a ser una unitat de potència**, que les anomenen **dBm** i **dBW**, i que es defineixen de la següent manera:

$$\text{dBm} = 10 \log \frac{P(W)}{1 \text{ mW}}$$

$$\text{dBW} = 10 \log \frac{P(W)}{1 \text{ W}}$$

# El decibel

La tensió o el corrent també els podem expressar en dB's a partir de la relació d'aquestes magnituds amb la potència:

$$P = V \cdot I = \frac{V^2}{R} = I^2 \cdot R$$

$$\text{dB} = 10 \log \frac{P_2(W)}{P_1(W)} = 10 \log \frac{V_2^2/R_2}{V_1^2/R_1} = 10 \log \left( \frac{V_2}{V_1} \right)^2 + 10 \log \left( \frac{R_1}{R_2} \right) = 10 \log \frac{I_2^2 \cdot R_2}{I_1^2 \cdot R_1} = 10 \log \left( \frac{I_2}{I_1} \right)^2 + 10 \log \left( \frac{R_2}{R_1} \right)$$

Si les resistències són les mateixes –cas habitual en RF on el valor estàndard és de  $50 \Omega$ – llavors queda reduït a:

$$\text{dB} = 20 \log \frac{V_2}{V_1} = 20 \log \frac{I_2}{I_1}$$

# El decibel

Si assignem a  $V_1$  un valor concret de tensió, llavors ho estem referenciant respecte d'aquest, i en aquestes unitats les anomenen el **dBmV** i el **dB $\mu$ V** que **sí son unitats de tensió**, definides de la següent manera:

$$\text{dB}\mu\text{V} = 20 \log \frac{V(V)}{1 \mu\text{V}}$$

$$\text{dBmV} = 20 \log \frac{V(V)}{1 \text{ mV}}$$

I el mateix pel corrent, si assignem a  $I_1$  un valor concret de corrent, i en aquestes unitats les anomenen el **dBmA** i el **dB $\mu$ A** que **sí son unitats de corrent**, definides de la següent manera:

$$\text{dB}\mu\text{A} = 20 \log \frac{I(A)}{1 \mu\text{A}}$$

$$\text{dBmA} = 20 \log \frac{I(A)}{1 \text{ mA}}$$



$$\begin{aligned}P_2(\text{dBW}) &= P_1(\text{dBW}) + G(\text{dB}) \\V_2(\text{dB}\mu\text{V}) &= V_1(\text{dB}\mu\text{V}) + G(\text{dB}) \\I_2(\text{dB}\mu\text{A}) &= I_1(\text{dB}\mu\text{A}) + G(\text{dB})\end{aligned}$$

# Amplada de banda i capacitat del canal

Domini de la freqüència vs. domini del temps



# Amplada de banda:

## D'un senyal

- És la diferència entre la freqüència màxima i mínima continguda en la informació.
  - Exemple:
    - Freqüències vocals: 300 Hz – 3,3 kHz
    - Música: 20 Hz – 20 kHz
  - Vídeo analògic: 5 MHz



## D'un canal de transmissió

- És la diferència entre la freqüència màxima i mínima que pot passar pel canal de transmissió.
  - Exemples:
    - Cable d'auriculars: 20 Hz – 20 kHz
    - Parell telefònic: 300 Hz – 3,3 kHz
    - Coaxial: DC – 30 GHz
    - Fibra òptica: 700 nm – 400 nm

# Amplada de banda i capacitat del canal

- L'amplada de banda del canal ha de ser igual o més gran que l'amplada de banda del senyal a transmetre.
- L'amplada de banda és una mesura de la velocitat de transmissió del canal.
- Tant els senyals com el canal de transmissió es poden analitzar i descriure en el **domini del temps** i/o en el **domini de la freqüència**.
  - *El domini del temps és una representació Amplitud vs. Temps.*
  - *El domini de la freqüència és una representació Amplitud vs. Freqüència.*
- El temps és l'invers de la freqüència:  $t = 1/f$ , per tant,
  - *Un senyal ràpid en el temps (curta durada), tindrà molta amplada de banda.*
  - *Un senyal lent en el temps (llarga durada), tindrà poca amplada de banda.*

La relació temps-freqüència, ve donada per la **transformada de Fourier**:

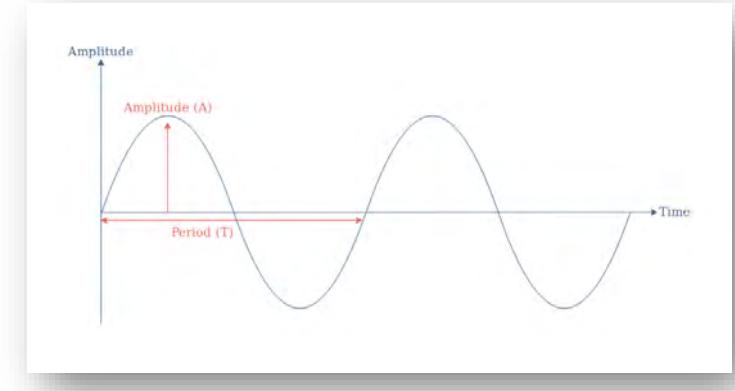
$$X(f) = \int_{-\infty}^{+\infty} x(t)e^{-j2\pi ft} dt \quad \Leftrightarrow \quad x(t) = \int_{-\infty}^{+\infty} X(f)e^{j2\pi ft} df$$

# Amplada de banda i capacitat del canal

## Senyal sinusoidal:

- Domini del temps

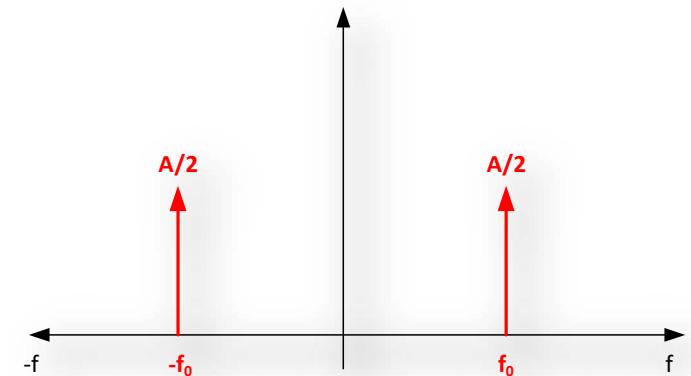
$$v(t) = A \cos(\omega_0 t) = \frac{A}{2} [e^{j\omega_0 t} + e^{-j\omega_0 t}], \quad \text{amb } \omega_0 = \frac{2\pi}{T_0} = 2\pi f_0$$



- Domini de la freqüència

$$V(f) = \int_{-\infty}^{+\infty} A \cos(\omega_0 t) e^{-j2\pi f t} dt = \frac{A}{2} \left\{ \int_{-\infty}^{+\infty} e^{j2\pi f_0 t} e^{-j2\pi f t} dt + \int_{-\infty}^{+\infty} e^{-j2\pi f_0 t} e^{-j2\pi f t} dt \right\}$$

$$V(f) = \frac{A}{2} [\delta(f - f_0) + \delta(f + f_0)]$$



# Amplada de banda i capacitat del canal

El canal introduceix **soroll**, principalment de tipus **tèrmic**, que es superposa al senyal. Es quantifica a partir de la relació entre la potència del senyal (S) i la potència del soroll (N), és a dir, la **relació senyal/soroll**, o (S/N).

La **capacitat del canal**, depèndrà del seu ample de banda, però també de la potència de soroll existent. Com menys sorollós sigui, més velocitat de transmissió tindrem.

La capacitat del canal C, expressada en bits per segon (bps) la va determinar **Claude Shannon**, a partir de la expressió:

$$C = B \cdot \log_2 [1 + (S/N)]$$

essent B l'amplada de banda en Hz del canal, i la (S/N) expressada en lineal.

Exemple:

Canal telefònic de 2,7 kHz d'amplada de banda i (S/N)=30dB,

$$C = 2,7 \cdot 10^3 \cdot \log_2 [1 + 1000] = 26,9 \text{ kbps}$$

# MEDIS DE TRANSMISSIÓ

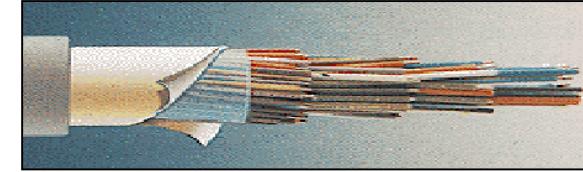
Guiats i no guiats.



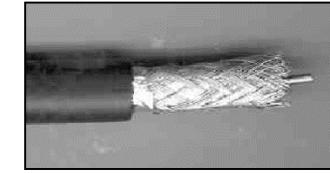
# QUINS SÓN ELS CANALS DE TRANSMISSIÓ

## Guiats o cablats:

Cable de parells de coure



Cable coaxial



Guia d'ones



Fibra òptica



## No guiats:

Transmissió ràdio



Transmissió òptica



# TECNOLOGIES DE LES XARXES DE COMUNICACIÓNS

## CABLADIES (Guiades)

- Precisen d'un mitjà físic de connexió entre l'emissor i el receptor: cable de parells, parell trenat, cable coaxial, fibra òptica.
- És un sistema tancat, que facilita el "secret" de les comunicacions.
- Precisa de canalitzacions, i de la obertura de rases, o de cablatge aeri.
- La seva capacitat és "il·limitada", només depèn del nombre i/o tipus de cables que s'utilitzin.
- La distància màxima de l'enllaç depèn de la tipologia dels cables, i dels repetidors que s'hi intercalin.
- Les canalitzacions troncals acostumen a utilitzar el domini públic viari.

## SENSE FILS (No Guiades)

- Poden ser radioelèctriques u òptiques.
- Utilitzen un bé públic que és l'espectre radioelèctric, i que està regulat pels Estats, d'acord amb les directrius que fixa la Unió Internacional de Telecomunicacions (ITU o UIT).
- Els enllaços òptics no estan tant regulats com els radioelèctrics. El seu abast és molt menor que el dels radioelèctrics però presenten una major capacitat.
- La regulació dels enllaços òptics ho és més pels aspectes de seguretat de les persones, que no pas pel d'ocupació del domini públic electromagnètic.



# Cablats o guiats

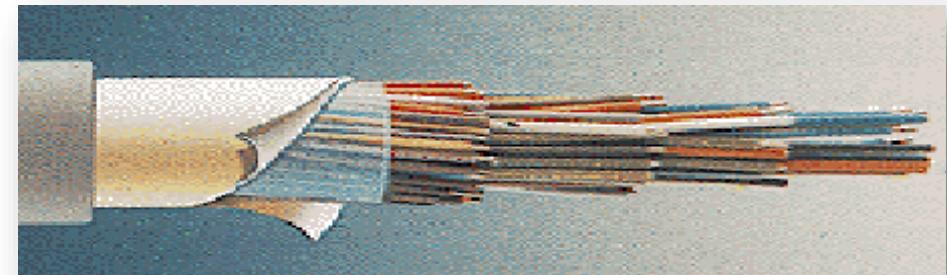


# TECNOLOGIES DE XARXES DE COMUNICACIÓNS CABLADES

- Els medis de transmissió més habituals són:

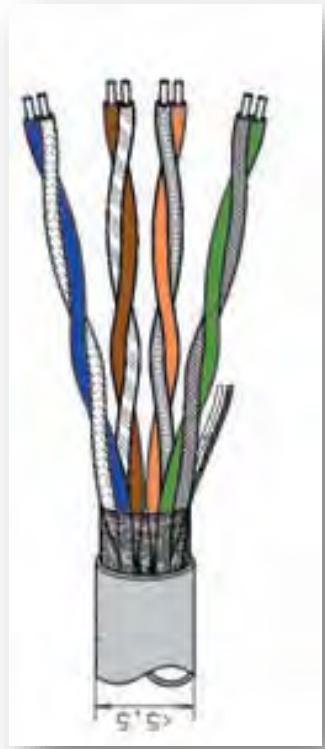
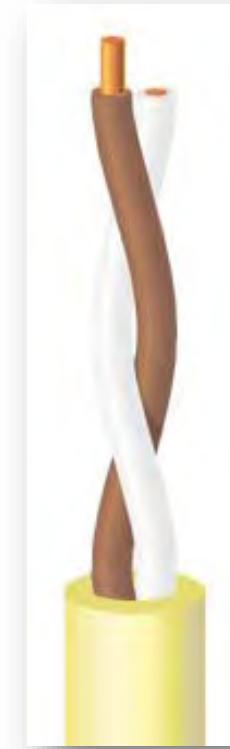
- **Cable bifilar o de parells de coure.**

- És el que s'utilitza en les instal·lacions de telefonia, i el que conforma el que es coneix com a bucle d'abonat o bucle local (subscriber loop), és a dir la connexió que connecta el terminal telefònic en el nostre edifici, fins a la centraleta telefònica més propera.
    - Es pot agrupar en un únic cable ajuntant diversos parells de forma estructurada.
    - Pensats per a freqüències vocals (màx. 3300 Hz).
    - La capacitat paràsita entre els conductors limita el seu ample de banda



# TECNOLOGIES DE XARXES DE COMUNICACIÓNS CABLADES

- Els medis de transmissió més habituals són:
  - **Parell trenat sense blindar (UTP: Unshielded Twisted Pair).**
    - És tracta d'un cable de parells, que a diferència de l'anterior, aquests estan trenats, de forma que es redueix la capacitat paràsita i la inductància mútua del cable, de forma que augmenta la seva freqüència màxima d'utilització (1 MHz).
    - També es poden agrupar diversos parells en un mateix cable.
    - Admeten una velocitat de transmissió de dades de 100 Mbps.
    - Són susceptibles a soroll i a interferències per la manca de blindatge
    - Sense repetidors admeten una distància màxima de 100 metres per transmissió de dades (Categoria 5).
    - S'utilitzen en els cablatges estructurats en edificis, tant per telefonia com per dades.



# TECNOLOGIES DE XARXES DE COMUNICACIÓNS CABLADES

- Els medis de transmissió més habituals són:
  - **Parell trenat blindat (STP: Shielded Twisted Pair).**
    - Consisteix en els cables de parells trenats, que incorporen una coberta metàl·lica connectada a massa, que actua com a blindatge i per tant el fa més immune a les interferències i als sorolls externs.
    - Les seves prestacions elèctriques són millors que les del UTP, però són més cars.
  - En funció del tipus de cable trenat, es defineixen les següents categories pels cablatges.



# CATEGORIES DE CABLATGE ESTRUCTURAT

L'especificació 568A Commercial Building Wiring Standard de l'associació Industries Electròniques e Industries de la Telecomunicació (EIA/TIA) especifica el tipus de cable UTP que s'utilitzarà en cada situació i construcció. Depenent de la velocitat de transmissió es divideix en diferents categories:

- **Categoría 1:** Fil telefònic trenat de qualitat de veu no adequat per les transmissions de dades. Les característiques de transmissió del mitjà estan especificades fins a una freqüència superior d'1 MHz.
- **Categoría 2:** Cable parell trenat sense apantallar. Les característiques de transmissió del mitjà estan especificades fins a una freqüència superior de 4 MHz. Aquest cable consta de 4 parells trenats de fil de coure.
- **Categoría 3:** Velocitat de transmissió típica de 10 Mbps per Ethernet. Amb aquest tipus de cables s'implementa les xarxes Ethernet 10BaseT. Les característiques de transmissió del mitjà estan especificades fins a una freqüència superior de 16 MHz. Aquest cable consta de quatre parells trenats de fil de coure amb tres entrellaçats per peu.
- **Categoría 4:** La velocitat de transmissió arriba fins a 20 Mbps. Les característiques de transmissió del mitjà estan especificades fins a una freqüència superior de 20 MHz. Aquest cable consta de quatre parells trenats de fil de coure.
- **Categoría 5:** És una millora de la categoria 4, pot transmetre dades fins a 1 Gbps i les característiques de transmissió del mitjà estan especificades fins a una freqüència de superior de 100 MHz. Aquest cable consta de quatre parells trenats de fil de coure.
- **Categoría 6:** És una millora de la categoria anterior, pot transmetre dades fins a 1 Gbps i les característiques de transmissió del mitjà estan especificades fins a una freqüència superior de 250 MHz.
- **Categoría 7:** És una millora de la categoria 6, pot transmetre dades fins a 1 Gbps, i les característiques de transmissió del medi estan especificades fins a una freqüència superior de 600 MHz.

Font: [https://ca.wikipedia.org/wiki/Cable\\_parell\\_trenat](https://ca.wikipedia.org/wiki/Cable_parell_trenat)



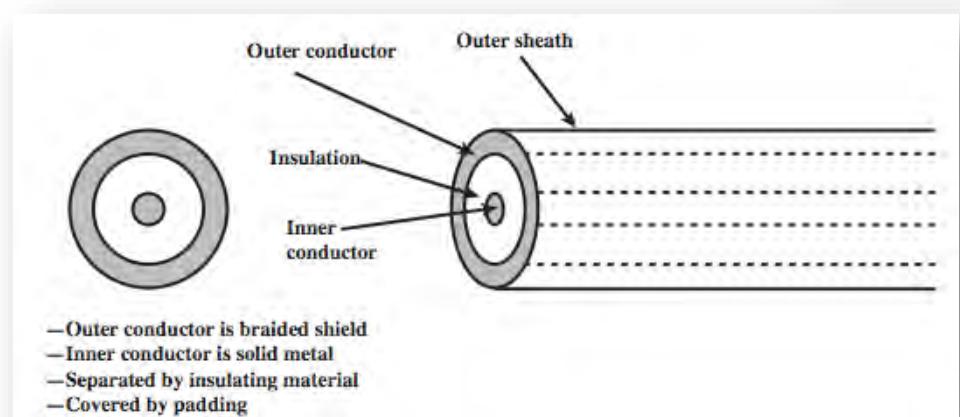
Nom	Tipus de cable	Amplada de banda	Aplicacions	Notes
Level 1		0.4 MHz	Línies de modem telefòniques	No descrit en les recomanacions EIA/TIA. No apte per sistemes moderns.
Level 2		4 MHz	Terminals ordinadors antics, ex: IBM 3270	No descrit en les recomanacions EIA/TIA. No apte per sistemes moderns.
Cat 3	UTP	16 MHz	10BASE-T and 100BASE-T4 Ethernet	Descrit en EIA/TIA-568. No s'empra per velocitats superiors a 16 Mbit/s. Actualment per cables telefònics
Cat 4	UTP	20 MHz	16 Mbit/s Token Ring	No s'empra normalment
Cat 5	UTP	100 MHz	100BASE-TX & 1000BASE-T Ethernet	Típica per xarxes LANs. Millorada per Cat5e.
Cat 5e	UTP	100 MHz	100BASE-TX & 1000BASE-T Ethernet	Cat5 millorada. Típica per xarxes LANs.
Cat 6	UTP	250 MHz	10GBASE-T Ethernet	ISO/IEC 11801 2 <sup>a</sup> Ed. (2002), ANSI/TIA 568-B.2-1. S'empra a Finlàndia segons norma del 2002 EN 50173-1.
Cat 6A	F/UTP, U/FTP	500 MHz	10GBASE-T Ethernet	Afegeix pantalla al cable. ISO/IEC 11801 2nd Ed. Am. 2. (2008), ANSI/TIA-568-C.1 (2009)
Cat 7	S/FTP, F/FTP	600 MHz	10GBASE-T Ethernet or POTS/CATV/1000BASE-T sobre cable senzill	Cable totalment apantallat. ISO/IEC 11801 2nd Ed. (2002)
Cat 7 <sub>A</sub>	S/FTP, F/FTP	1000 MHz	10GBASE-T Ethernet or POTS/CATV/1000BASE-T sobre cable senzill	Utilitza els 4 parells. ISO/IEC 11801 2nd Ed. Am. 2. (2008)
Cat 8/8.1	F/UTP, U/FTP	1600-2000 MHz	40GBASE-T Ethernet or POTS/CATV/1000BASE-T sobre cable senzill	En desenvolupament (ANSI/TIA-568-C.2-1, ISO/IEC 11801 3 <sup>a</sup> Ed.)
Cat 8.2	S/FTP, F/FTP	1600-2000 MHz	40GBASE-T Ethernet or POTS/CATV/1000BASE-T sobre cable senzill	En desenvolupament (ISO/IEC 11801 3 <sup>a</sup> Ed.)

# TECNOLOGIES DE XARXES DE COMUNICACIÓNS CABLADES

- Els medis de transmissió més habituals són:

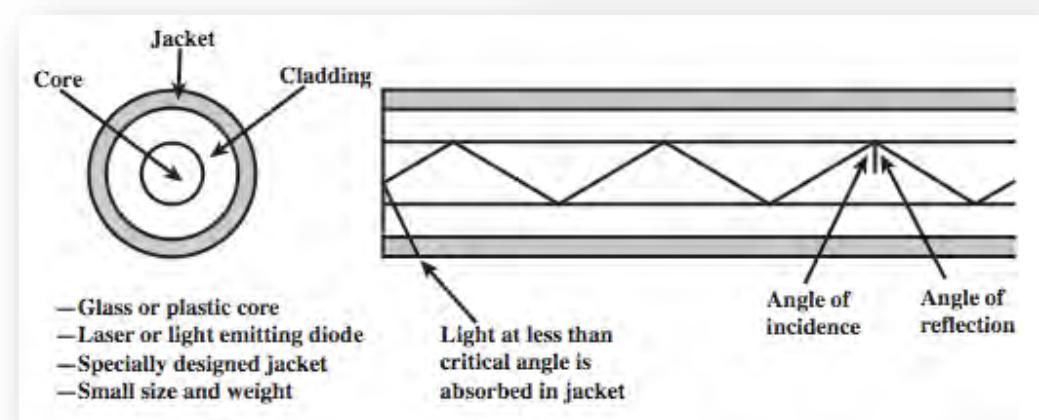
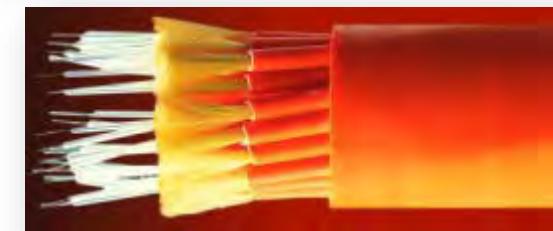
- **Cable coaxial**

- Format per dos conductors concèntrics, de forma que l'exterior de més diàmetre que l'interior, el cobreix en la seva totalitat.
  - Això proporciona:
    - Un efecte de blindatge similar al dels cables STP anteriors
    - Una atenuació molt més petita amb la distància
    - Una amplada de banda molt gran (aprox. 2 GHz)
  - S'utilitza en les xarxes de distribució de senyal de TV en edificis i en les xarxes de telecomunicacions per cable.



# TECNOLOGIES DE XARXES DE COMUNICACIÓNS CABLADES

- Els medis de transmissió més habituals són:
  - **Fibra òptica**
    - Format per un fil de material dielèctric d'unes  $50 \mu\text{m}$  de secció i que presenta un índex de refracció tal que afavoreix la propagació del feix de llum pel seu interior.
    - Aquesta fibra es pot utilitzar per construir cables òptics, que poden agrupar una o moltes fibres.
    - És immune a les interferències elèctriques.
    - Permeten cobrir grans distàncies.
    - Presenta una gran amplada de banda: 100 GHz.
    - Permet velocitats de dades de fins a 10 Gbps.

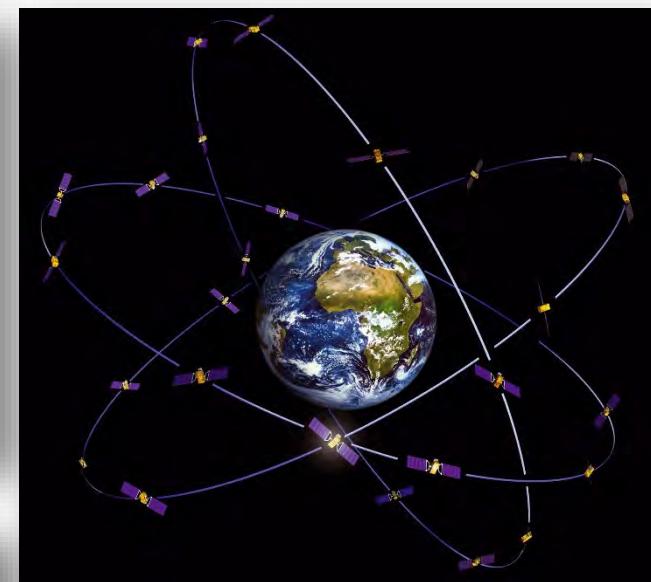
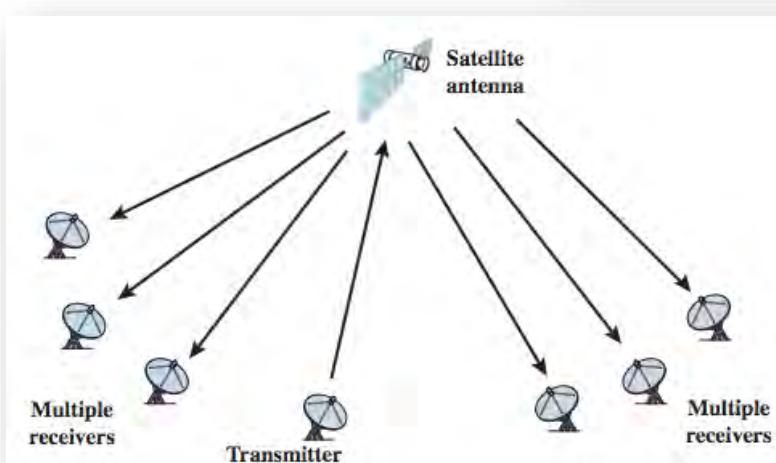


# No guiats o sense fils



# TECNOLOGIES DE XARXES DE COMUNICACIÓNS SENSE FILS

- Les xarxes de comunicacions sense fils més típiques són:
  - Xarxa de radiodifusió i TV.
  - Xarxa de telefonia mòbil cel·lular
  - Sistemes de comunicacions per satèl·lit:
    - TV-SAT
    - GPS
  - Xarxes WiFi (wireless LAN)
  - Bluetooth
  - Sistemes de radionavegació aèria
    - ILS, MLS, VOR, DME, ...
  - Sistemes de geolocalització per satèl·lit
    - GPS, EGNOS, Galileo,



# CABLADES O SENSE FILS?

## CABLADES

- La seva capacitat de transmissió només depèn del nombre de cables que formen la connexió.
- No consumeixen cap “recurs” escàs.
- Son costoses, sobre tot per la obra civil associada a les canalitzacions.
- Quan es cobreixen grans distàncies, és necessari intercalar-hi equips “repetidors” que han de regenerar el senyal transmès. La distància entre aquests repetidors dependrà del tipus de cable. Aquests equips poden ser tele-alimentats.
- En les canalitzacions cal posar-hi registres per poder-hi accedir en cas d’avaría o d’ampliació de la xarxa.
- Poden compartir infraestructures ja existents: línies d’alta tensió, canalitzacions de gas, catenàries de ferrocarril, autopistes, carreteres, vials, etc.

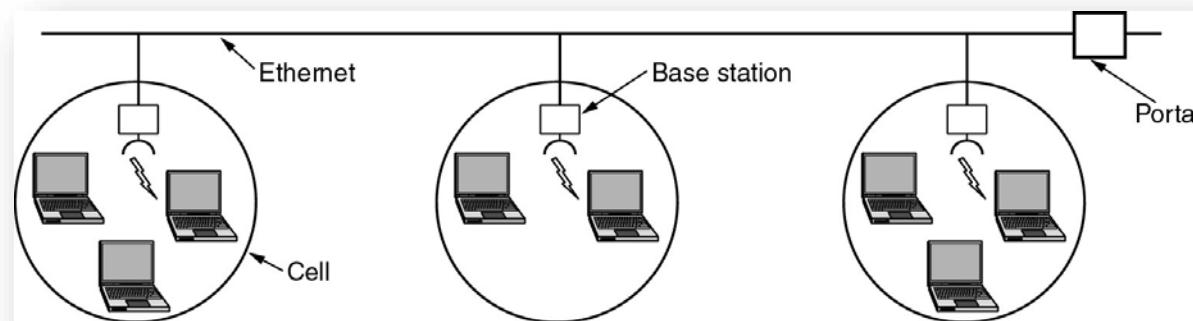
## SENSE FILS

- Precisen d’espais físics situats en llocs elevats on poder-hi ubicar les antenes i els equips transmissors.
- Aquests “sites”, precisen d’una mínima obra civil consistent en:
  - Casete o armari intempèrie
  - Subministrament elèctric i sistemes de reserva (grup electrogen, bateries, etc.)
  - Camí d'accés.
- Sovint el cost de la obra civil és més elevat que el dels equips, especialment pel que fa a la electrificació.
- La seva capacitat de transmissió és més limitada que la dels sistemes cablats.
- Consumeix un recurs escàs: l’espai radioelèctric.
- Pot cobrir grans distàncies i arribar a zones de difícil accés.
- Els sistemes de satèl·lit arriben a tot arreu; la seva barrera d’entrada és el cost per l’ús del transpondedor.

# CABLADES O SENSE FILS?

## CAL TENIR EN COMpte QUE:

- La **mobilitat** només es pot obtenir amb xarxes sense fils.
- Sovint s'utilitza un model mixt de funcionament:
  - Sistemes **cablats** per interconnectar les **xarxes troncals**, o utilitzar radioenllaços de gran capacitat per cobrir grans distàncies.
    - +
  - Utilitzar tecnologies **sense fils** per les **xarxes d'accés**:



# Requeriments d'instal·lació i de servei

Xarxes cablades



UNIVERSITAT POLITÈCNICA DE CATALUNYA

BARCELONATECH

Departament de Teoria del Senyal  
i Comunicacions

# Requeriments d'instal·lació i de servei

- La instal·lació de xarxes de comunicacions cablades requereix els següents elements:
  - Sistema de canalització
    - Aquest sistema de canalització pot adoptar diverses formes d'instal·lació en funció de si l'entorn és en interior d'edificis o és exterior.
    - El sistema de canalització haurà d'incloure un sistema de registres que permeti la instal·lació, verificació, control i modificació del cablatge instal·lat.
    - La canalització podrà ser diversa: en galeries de serveis, en canalitzacions en l'interior d'edificis, en canalitzacions subterrànies en rasa, canalitzacions aèries, sistemes de grapat en façanes d'edificis, etc.
  - Recintes de telecomunicacions
    - Espais tancats, o armaris metàl·lics, en els que s'hi ubica les dispositius electrònics (electrònica de xarxa) necessaris pel sistema de comunicacions.
  - Subministrament energètic
    - Habitualment en els recintes de telecomunicacions és necessari disposar de sistemes.
  - Sistemes de protecció
    - Compatibilitat electromagnètica
    - Privacitat

# CANALITZACIÓNS VIÀRIES

- Al contrari dels edificis d'habitatges, en els que hi ha una normativa específica per a les instal·lacions de comunicacions (ICT), no existeix una normativa específica pel que fa referència a la instal·lació de comunicacions en vials o urbanitzacions.
- La única normativa existent és la corresponent a la família de normes UNE 133100 que apliquen a les infraestructures de xarxes de telecomunicacions i que defineixen les característiques, tipologies, materials i formes de construcció de les canalitzacions destinades als serveis de telecomunicació.
- Aquesta normativa fixa les normes de seguretat a aplicar i les distàncies a mantenir entre les diferents canalitzacions.
- Habitualment en la obertura d'una rasa, s'acostuma a deixar-hi un tub amb un fil guia, amb el que, des dels registres corresponents, facilitarà la instal·lació del cable de comunicacions adient.
- S'ha de tenir en compte que en obrir un rasa, el cost de deixar-hi instal·lada una canalització amb els seus corresponents registres, no suposa un cost exorbitant de la infraestructura.

# NORMES UNE D'INFRAESTRUCTURES PER A XARXES DE TELECOMUNICACIÓ

- UNE 133100-1:2002:
  - Part 1: Canalitzacions subterrànies
- UNE 133100-2:2002:
  - Part 2: Arquetes i càmeres de registre
- UNE 133100-3:2002:
  - Part 3: Trams interurbans
- UNE 133100-4:2002:
  - Part 4: Líneas aèries
- UNE 133100-5:2002:
  - Part 5: Instal·lació en façanes

# GALERIES DE SERVEI

- En el procés d'urbanització d'un polígon o zona de construcció és recomanable preveure la instal·lació de galeries de serveis.
- Aquestes galeries subterrànies, són practicables i s'utilitzen per interconnectar tots els edificis de l'àrea urbanitzada.
- Això facilita la instal·lació dels diferents serveis: aigua, gas, electricitat i comunicacions, així com la seva posterior modificació, ampliació o supervisió, sense necessitat d'haver d'obrir noves rases.
- Si bé el cost inicial de la seva construcció acostuma a ser elevat, a llarg termini suposa un estalvi en les tasques de manteniment i ampliació dels serveis.

# EXEMPLES DE GALERIES DE SERVEI



# Requeriments d'instal·lació i de servei

Instal·lacions radioelèctriques

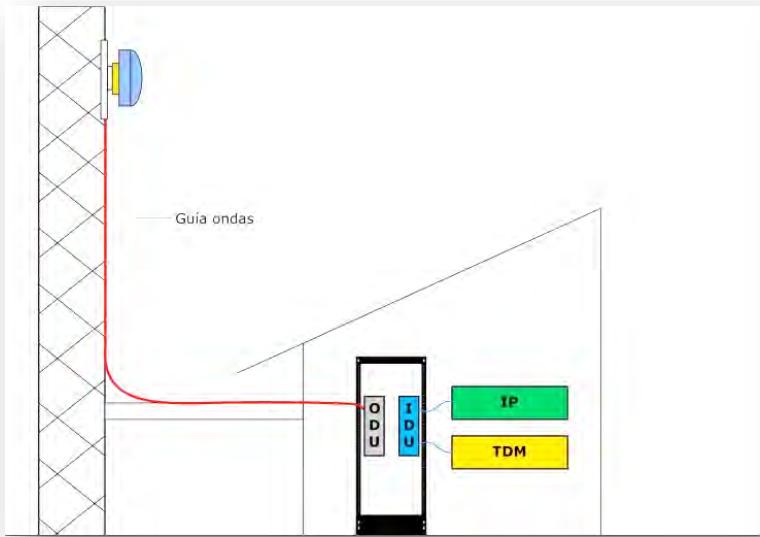


# INSTAL·LACIONS RADIOELÈCTRIQUES

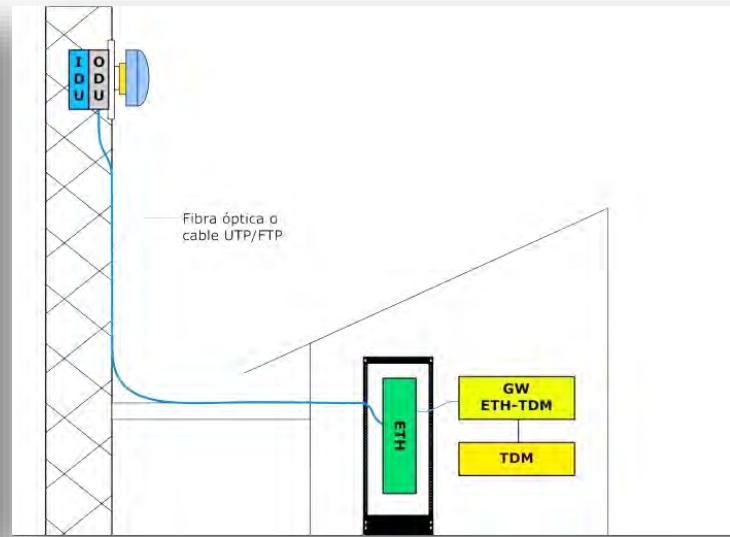
- Un centre emissor radioelèctric precisarà dels següents elements:
  - Recinte on allotjar els equips electrònics (caseta o armari)
  - Sistema radiant (màstil + antenes)
  - Sistema energètic (alimentació + reserva)
  - Camí d'accés
- La selecció de l'emplaçament del centre dependrà de la freqüència de la emissió i del mecanisme de propagació associat.
- Pel cas de les emissions de radionavegació (ILS, VOR), cal visió directa entre l'emissor i el receptor; en canvi per d'altres serveis, com ara la ràdio en FM (87-108 MHz) no és necessari.
- Sovint el cost de la obra civil (electrificació, camí d'accés) és més car que el dels equips de comunicacions.



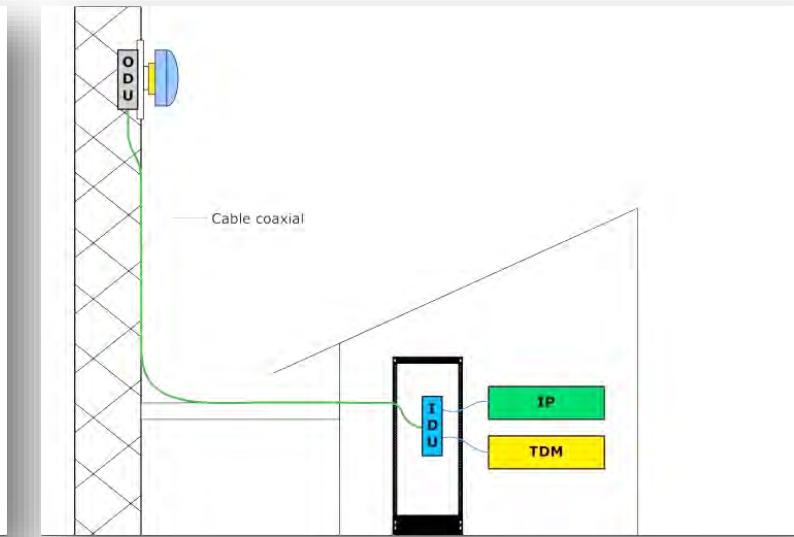
# Tipus d'instal·lacions



All indoor



All outdoor



Split mount

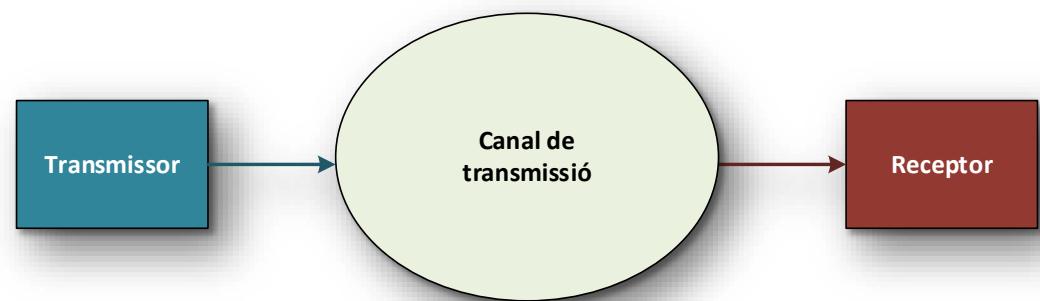
- ODU: Outdoor unit
- IDU: Indoor unit
- ETH-TDM: Ethernet over TDM (Time division múltiplex)
- IP: Internet Protocol

# Modes de Transmissió



# Tipus de transmissions

One way or SIMPLEX (SX)



Two way or FULL DUPLEX (FDX)



HALF DUPLEX (HDX)



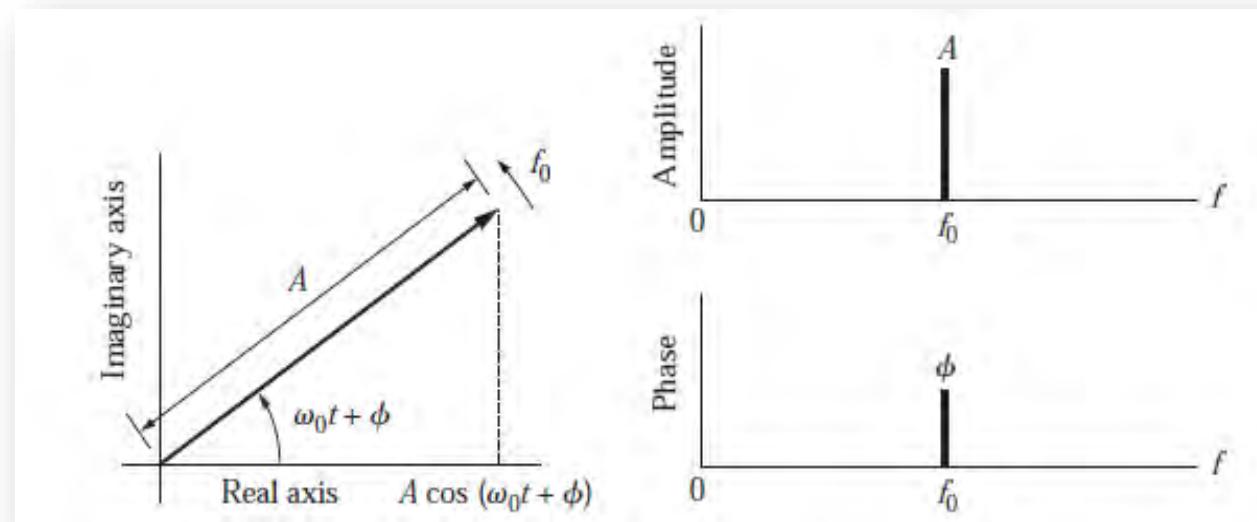
# Senyals i espectre



# Senyals i espectre

- Un senyal sinusoidal  $v(t) = A \cos(\omega_0 t + \varphi)$  el podem expressar de forma fasorial mitjançant la fórmula d'Euler:  $e^{\pm j\theta} = \cos \theta \pm j \sin \theta$

$$v(t) = A \cdot \operatorname{Re}[e^{j(\omega_0 t + \varphi)}]$$



**Espectre unilateral**  
(només freqüències positives)

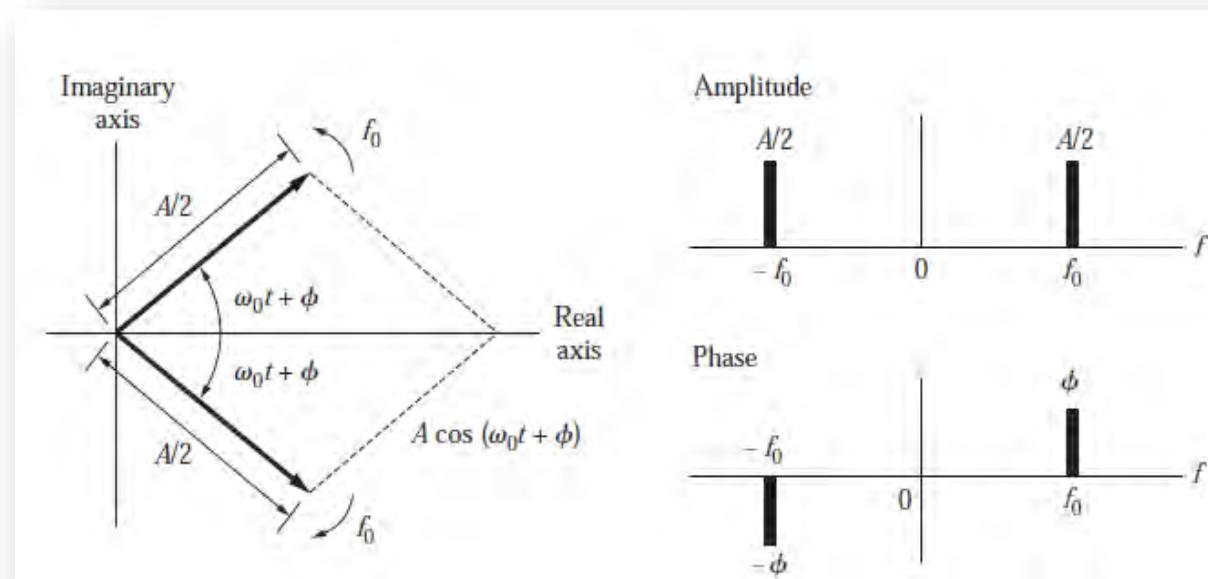
# Senyals i espectre

Si contemplam que la part real d'un nombre complex la podem obtenir a partir de la semisuma d'ell mateix amb el seu complex conjugat:

$$\operatorname{Re}(z) = \frac{1}{2}(z + z^*)$$

llavors,

$$v(t) = \frac{1}{2}A[e^{j(\omega_0 t + \phi)} + e^{-j(\omega_0 t + \phi)}]$$



**Espectre bilateral**  
(freqüències positives i negatives)

# Cas de senyals periòdics

$$v(t \pm mT_0) = v(t)$$

Valor mig d'un senyal:

$$\langle v(t) \rangle = \lim_{T \rightarrow \infty} \frac{1}{T} \int_{-T/2}^{+T/2} v(t) dt$$

Valor mig d'un senyal periòdic de període  $T_0$ :

$$\langle v(t) \rangle = \frac{1}{T_0} \int_{-T_0/2}^{+T_0/2} v(t) dt$$

Potència mitja d'un senyal:

$$P = \langle |v(t)|^2 \rangle = \frac{1}{T_0} \int_{-T_0/2}^{+T_0/2} |v(t)|^2 dt$$

*(Normalitzem a 1Ω la resistència)*

Exemple: Per  $v(t) = A \cos(\omega_0 t + \varphi)$ , tenim que:  $\langle v(t) \rangle = 0$  i que  $P = \frac{A^2}{2} \cdot \frac{1}{R} = \frac{A^2}{2}$



# Sèries de Fourier

Un **senyal periòdic** de freqüència  $f_0$  i període  $T_0$  es pot descompondre en **sèrie de Fourier**

$$v(t) = \sum_{n=-\infty}^{\infty} c_n \cdot e^{j2\pi n f_0 t}$$

amb els **coeficients** definits com:

$$c_n = \frac{1}{T_0} \int_{-T/2}^{+T/2} v(t) \cdot e^{-j2\pi n f_0 t} dt = |c_n| \cdot e^{j\phi_n}$$

per tant:

$$v(t) = \sum_{n=-\infty}^{\infty} |c_n| \cdot e^{j\phi_n} \cdot e^{j2\pi n f_0 t}$$

# Sèries de Fourier

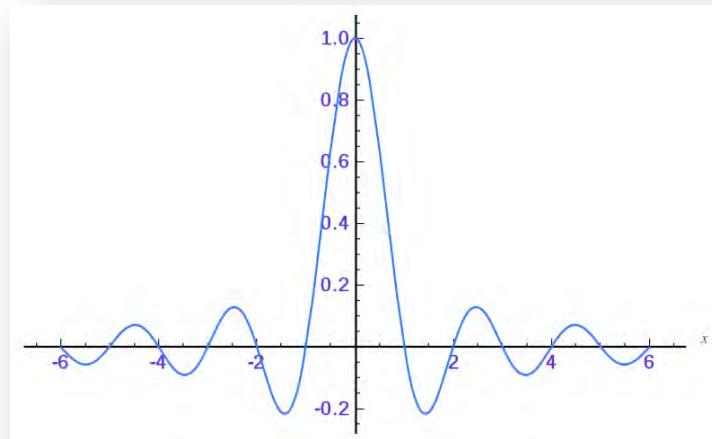
- Propietats: **múltiples sencers o harmònics**
  - Totes les freqüències són de la freqüència fonamental  $f_0$ . Espectre de ratlles espaiades  $f_0$ .
  - El **valor de continua** ( $f=0$ ) és igual al **valor mig del senyal**, i igual a  $c_0$ .
  - Si el senyal  $v(t)$  és real, llavors:
    - L'espectre té **simetria parell en mòdul**.
    - L'espectre té **simetria imparell en fase**.
  - Generalitzant, tenim la **sèrie trigonomètrica de Fourier**:

$$v(t) = c_0 + \sum_{n=-\infty}^{\infty} |2c_n| \cdot \cos(2\pi n f_0 t + \phi_n)$$

# Funció sinc

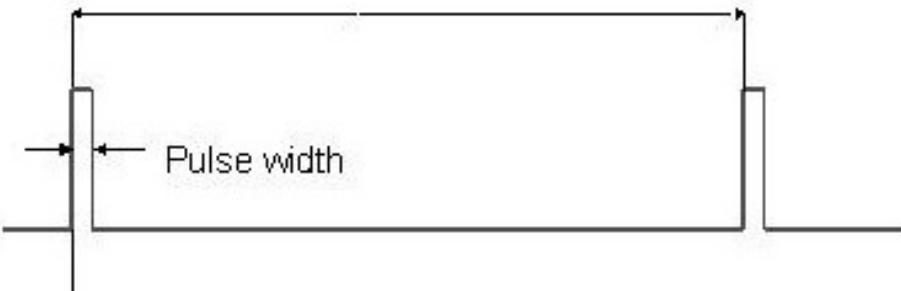
- Es defineix com:

$$\text{sinc}(\lambda) = \frac{\sin(\pi\lambda)}{\pi\lambda}$$



$\text{sinc}(\lambda)=1$ , per  $\lambda=0$   
 $\text{sinc}(\lambda)=0$ , per  $\lambda=\pm 1, \pm 2, \pm 3, \dots$

# Tren de polsos rectangulars



Característiques:

T: Període dels polsos  
τ: Amplada del pols

Cicle de treball (Duty cycle):  $\tau/T$

$$\tilde{x}(t) = A \cdot \prod \left( \frac{t}{\tau} \right)$$

$$x(t) = A \cdot \sum_{n=-\infty}^{+\infty} \prod \left( \frac{t-nT}{\tau} \right) = \sum_{-\infty}^{+\infty} c_n e^{jn\omega t} = \sum_{-\infty}^{+\infty} c_n e^{jn\frac{2\pi}{T}t}$$

$$c_n = \frac{1}{T} \int_0^T \tilde{x}(t) e^{-jn\omega t} dt = \frac{A}{T} \int_0^\tau e^{-jn\omega t} dt = A \frac{\tau}{T} \frac{\sin(n\omega \tau/2)}{n\omega \tau/2} = A \frac{\tau}{T} \frac{\sin(n\pi \tau/T)}{n\pi \tau/T} = A \frac{\tau}{T} \text{sinc}\left(n\frac{\tau}{T}\right)$$

# Teorema de Parseval de la potència

- La potència mitja d'un senyal periòdic és la suma de les potències mitges de tots els seus fasors:

$$P = \frac{1}{T_0} \int_{-T_0/2}^{+T_0/2} |v(t)|^2 dt = \frac{1}{T_0} \int_{-T_0/2}^{+T_0/2} v(t) \cdot v^*(t) \cdot dt = \sum_{n=-\infty}^{\infty} c_n \cdot c_n^* = \sum_{n=-\infty}^{\infty} |c_n|^2$$

# Transformada de Fourier

- Aplicable a senyals **no periòdics**, però **d'energia finita**, i que tenen un espectre continu, no discret.
- Pel cas d'un **pols rectangular**, no periòdic, de durada  $\tau$ , la seva potència mitja tendeix a zero, ja que ho integraríem en un temps tendint a infinit; per aquest motiu es prefereix parlar d'Energia, ja que és finita:

$$E = \int_{-\infty}^{+\infty} |v(t)|^2 dt$$

*amb la resistència normalitzada a  $1\Omega$*

$$E = A^2 \cdot \tau$$

# Transformada de Fourier

$$V(f) = \int_{-\infty}^{+\infty} v(t)e^{-j2\pi ft} dt \quad \Leftrightarrow \quad v(t) = \int_{-\infty}^{+\infty} V(f)e^{j2\pi ft} df$$

- Propietats:

- L'espectre  $V(f)$  és una funció complexa
- El valor de  $V(f)$  a freqüència zero (continua), és el valor mig de  $v(t)$ .
- Si el senyal  $v(t)$  és real, llavors l'espectre és simètric en mòdul i asimètric en fase, *-simetria hermítica-*,

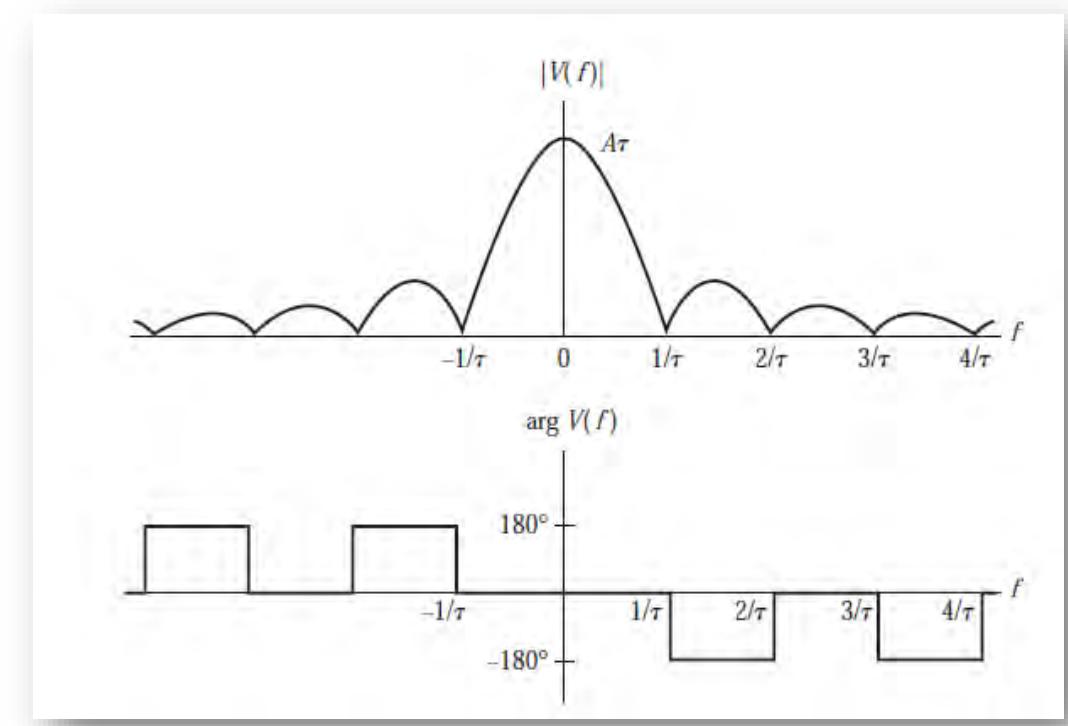
$$V(-f) = V^*(f) \Rightarrow \begin{cases} |V(-f)| = |V(f)| \\ \phi_V(-f) = -\phi_V(f) \end{cases}$$

# Transformada de Fourier

## Pols rectangular

$$v(t) = A \cdot \prod(t/\tau) = A \cdot \begin{cases} 1, & \text{per } t < \tau/2 \\ 0, & \text{per } t > \tau/2 \end{cases}$$

$$V(f) = A \int_{-\tau/2}^{-\tau/2} e^{-j2\pi f t} dt = A\tau \cdot \text{sinc}(f\tau)$$



Tot i que el seu espectre és infinit, podem considerar com a amplada de banda aproximadament  $B=1/\tau$

# Transformada de Fourier

## Propietats

- Superposició:

$$v(t) = a_1 v_1(t) + a_2 v_2(t) \Rightarrow V(f) = a_1 V_1(f) + a_2 V_2(f)$$

- Retard en el temps:

$$v(t - t_d) \Rightarrow V(f) e^{-j2\pi f t_d}$$

- Canvi d'escala:

$$v(\alpha t) \Rightarrow \frac{1}{|\alpha|} V\left(\frac{f}{\alpha}\right)$$

- Translació de freqüència o modulació complexa:

$$v(t) e^{j\omega_c t} \Rightarrow V(f - f_c)$$

- Diferenciació i integració:

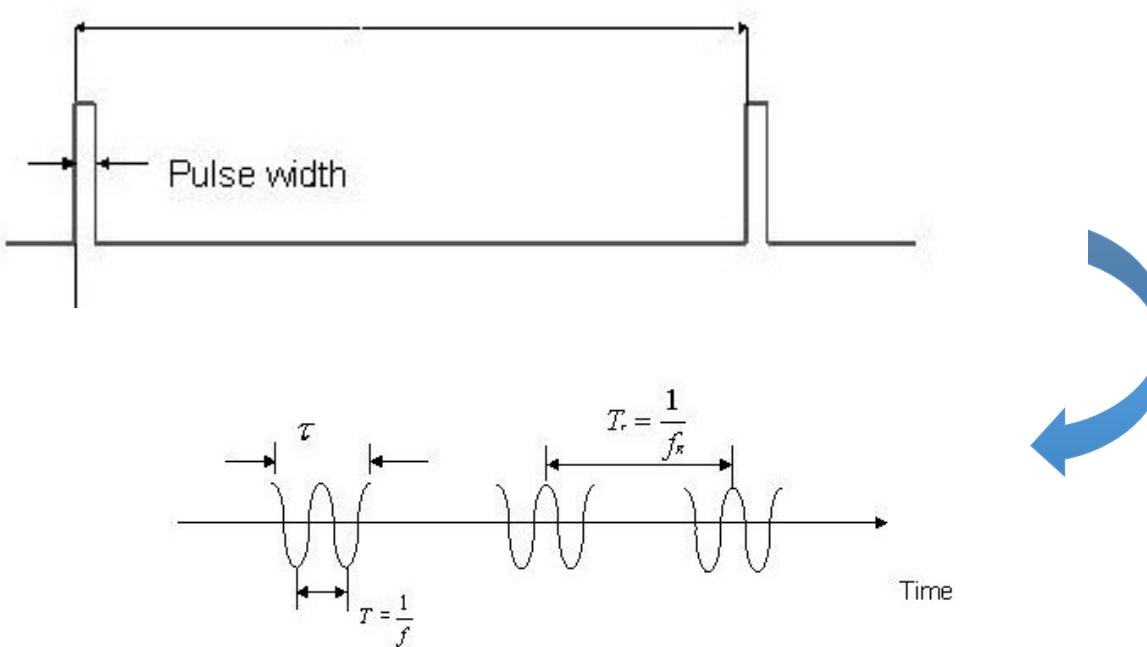
$$\frac{d}{dt} v(t) \Rightarrow j2\pi f \cdot V(f); \quad \int_{-\infty}^t v(\lambda) \cdot d\lambda \Rightarrow \frac{1}{j2\pi f} V(f)$$

- Convolució:

$$v(t) * u(t) = \int_{-\infty}^{+\infty} v(\lambda) \cdot u(t - \lambda) \cdot d\lambda \Leftrightarrow V(f) \cdot U(f)$$

$$V(f) * U(f) = \int_{-\infty}^{+\infty} V(\lambda) \cdot U(f - \lambda) \cdot d\lambda \Leftrightarrow v(t) \cdot u(t)$$

# Tren de polsos de RF



Característiques:

$T$ : Període dels polsos

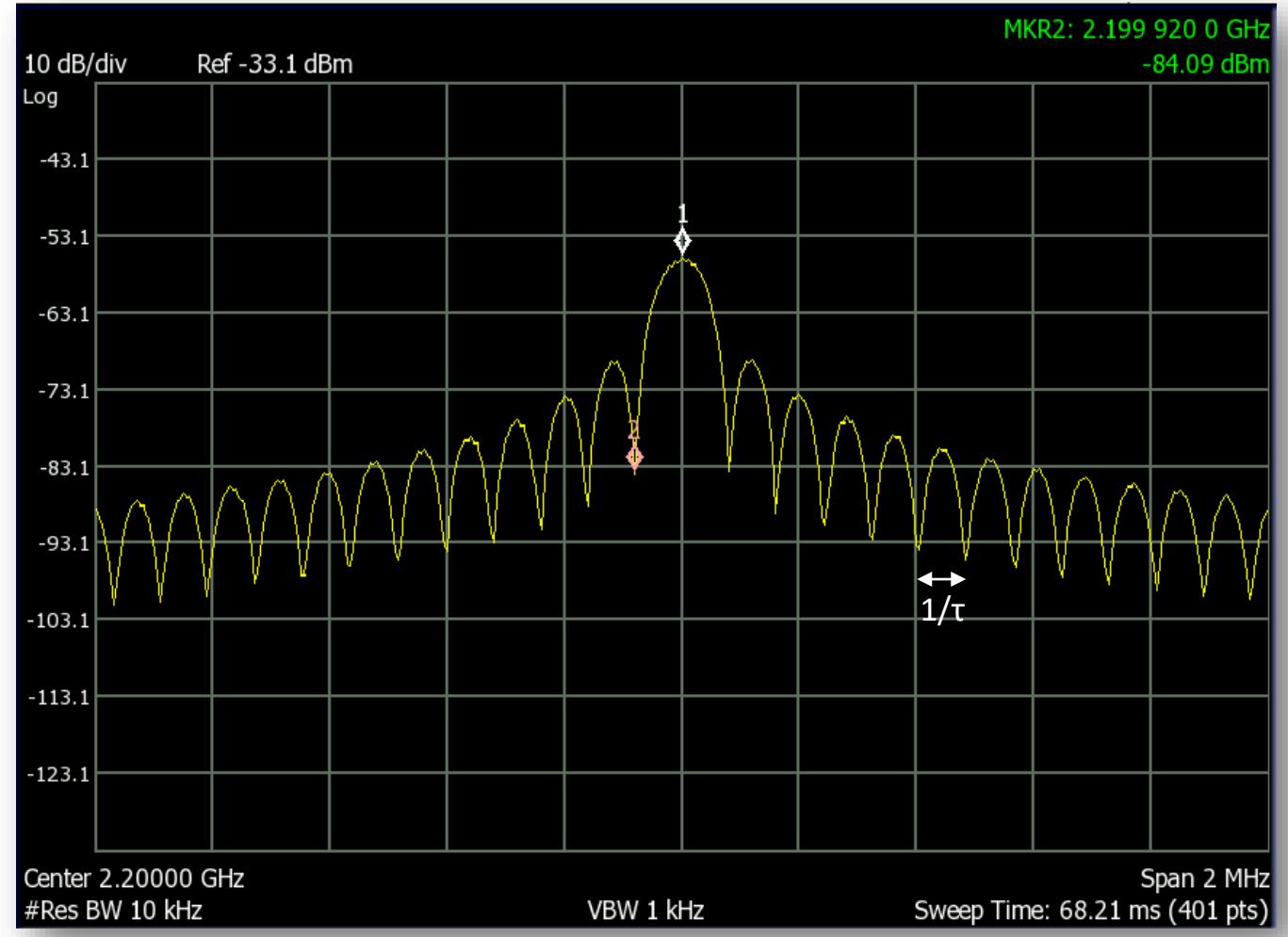
$\tau$ : Amplada del pols

$f_0$ : freqüència de transmissió (RF)

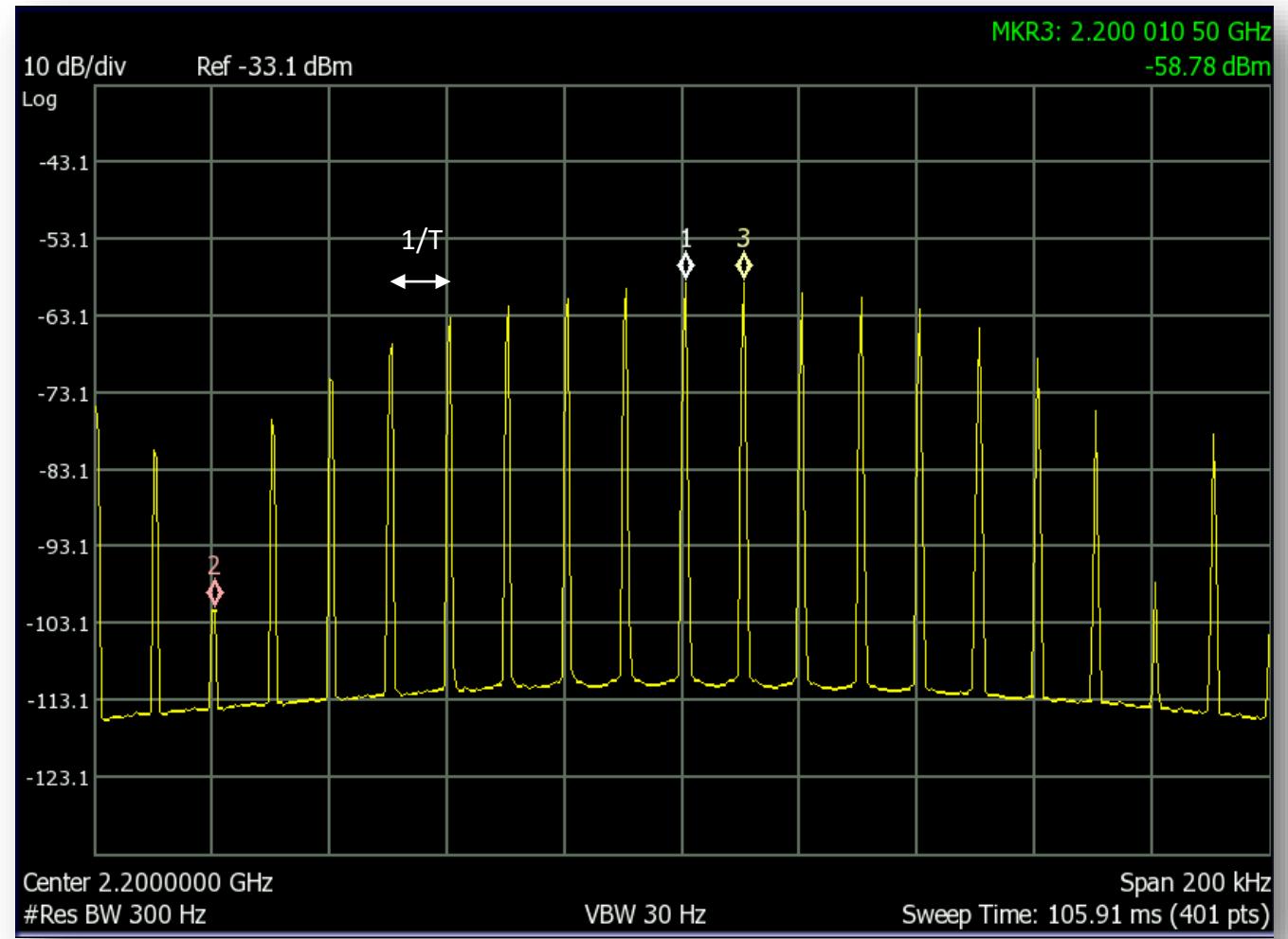
$$y(t) = \cos(2\pi f_0 t)$$

$$x(t) = A \cdot \sum_{n=-\infty}^{+\infty} \prod \left( \frac{t - nT}{\tau} \right) \cdot \cos(2\pi f_0 t)$$

# Espectre d'un tren de polsos de RF



# Espectre d'un tren de polsos de RF



# Sistemes lineals



$$v_{out}(t) = v_{in}(t) * h(t)$$

$$V_{out}(f) = V_{in}(f) \cdot H(f)$$

Operacions típiques:

$$y(t) = \pm k \cdot x(t) \Leftrightarrow H(f) = \pm k$$

$$y(t) = \frac{d}{dt} x(t) \Leftrightarrow H(f) = j2\pi f$$

$$y(t) = \int_{-\infty}^t x(\lambda) \cdot d\lambda \Leftrightarrow H(f) = \frac{1}{2\pi f}$$

$$y(t) = x(t - t_d) \Leftrightarrow H(f) = e^{-j2\pi f t_d}$$

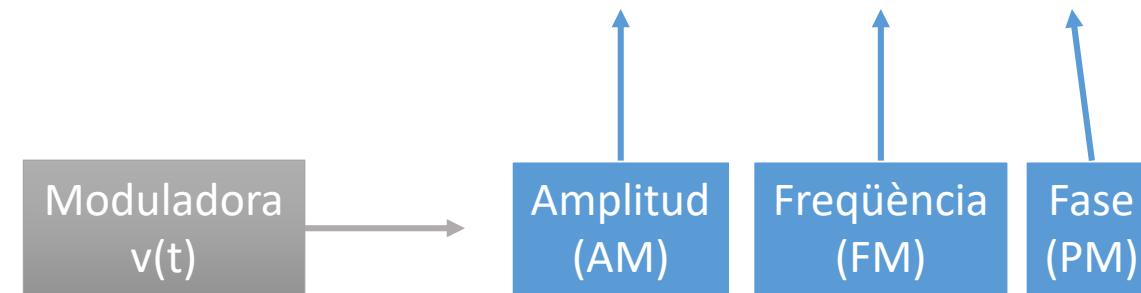
# Modulació



# Finalitat de la modulació

- Traslladar la freqüència del senyal d'informació a la banda de freqüències d'operació òptima del medi de transmissió escollit.
- Es realitza modificant l'amplitud, la freqüència o la fase, d'una sinusoide (**portadora o carrier**) utilitzant el senyal d'informació.

$$v_c(t) = \mathbf{A} \cos(2\pi f t + \varphi)$$

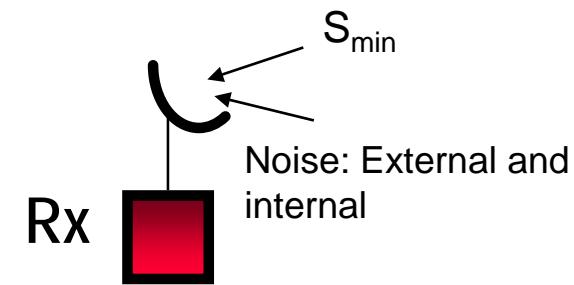


# SOROLL EN COMUNICACIÓNS



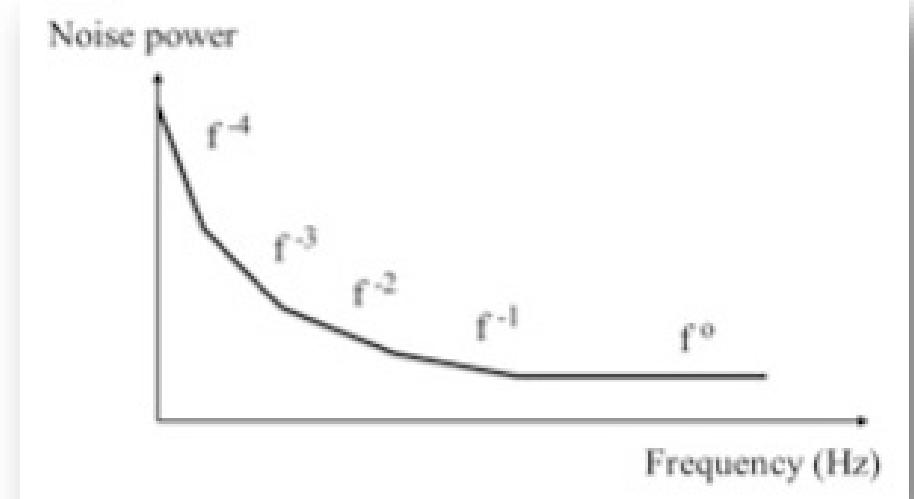
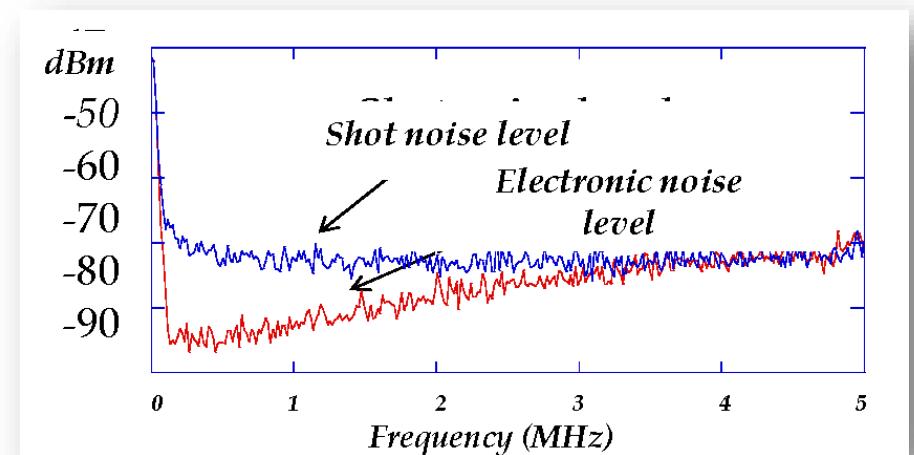
# Noise and interference

- External noise
  - Atmospheric noise
    - Dominant external noise source for  $f < 30$  MHz
    - Caused by thunderstorms all over the world
    - “Gaussian” background noise, with impulse noise in the foreground due to nearby strikes
  - Cosmic noise (“antenna temperature”)
    - Thermal (=Gaussian)
    - Lower when the antenna is pointed towards “cold” outer space
    - No filtering possible → just have to deal with it...
  - Interference
    - Usually from man-made sources (radio stations, spurious from equipment, oscillating TV antenna)
    - Can be intentional (jammers) or unintentional
- Internal noise: noise across input impedance of Rx
  - Amplifiers (noise current, noise voltage) → SHOT NOISE, FLICKER NOISE
  - Resistors, lossy cables → THERMAL NOISE



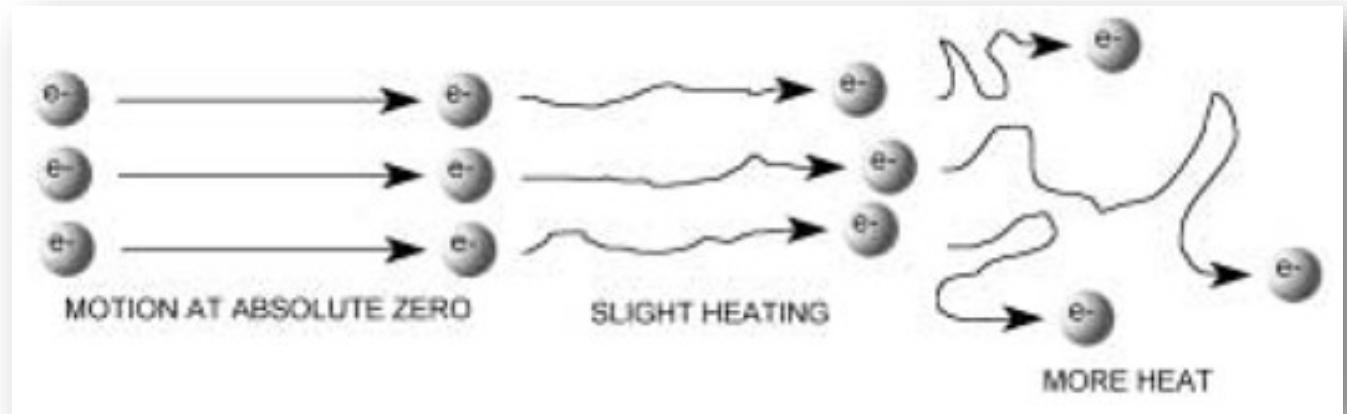
# Noise due to the semiconductors

- SHOT noise:
  - Appears in semiconductors (diodes, transistors, etc), and it is proportional to the DC current through the semiconductor union.
  - Its power spectral density **is like a white noise**, that is, equal for all the frequencies.
- FLICKER noise:
  - Has power spectral density proportional to  **$1/f$** , being  $f$  the frequency.
  - It decreases with the frequency.
  - Is the origin of the phase noise in oscillators.



# Thermal noise

- Also called Johnson noise.
- Generated by the thermal agitation of the electrons inside an electrical conductor at equilibrium.
- It depends of the temperature T of the conductor, expressed in Kelvins.

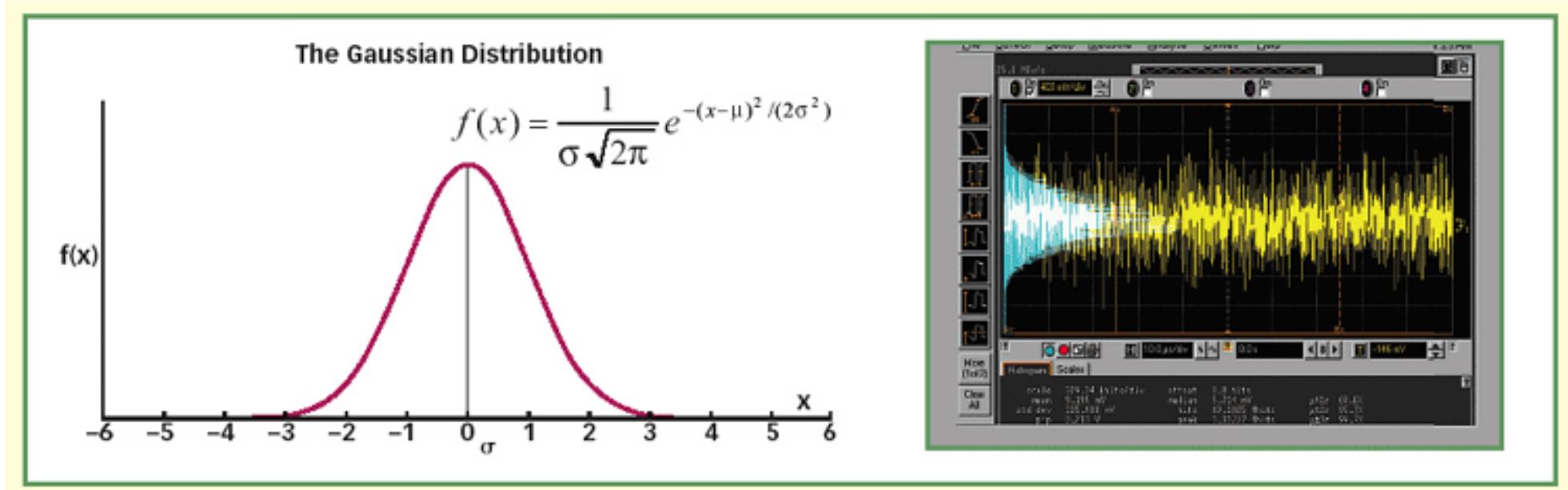


$$T(K) = T(^{\circ}C) + 273$$



$$17^{\circ}C = 290K$$

# Thermal noise



It has a Gaussian probability density function , with a zero mean value.

# Thermal noise

It has a power spectral density of:

$$S_N = kT \text{ (W/Hz)}$$

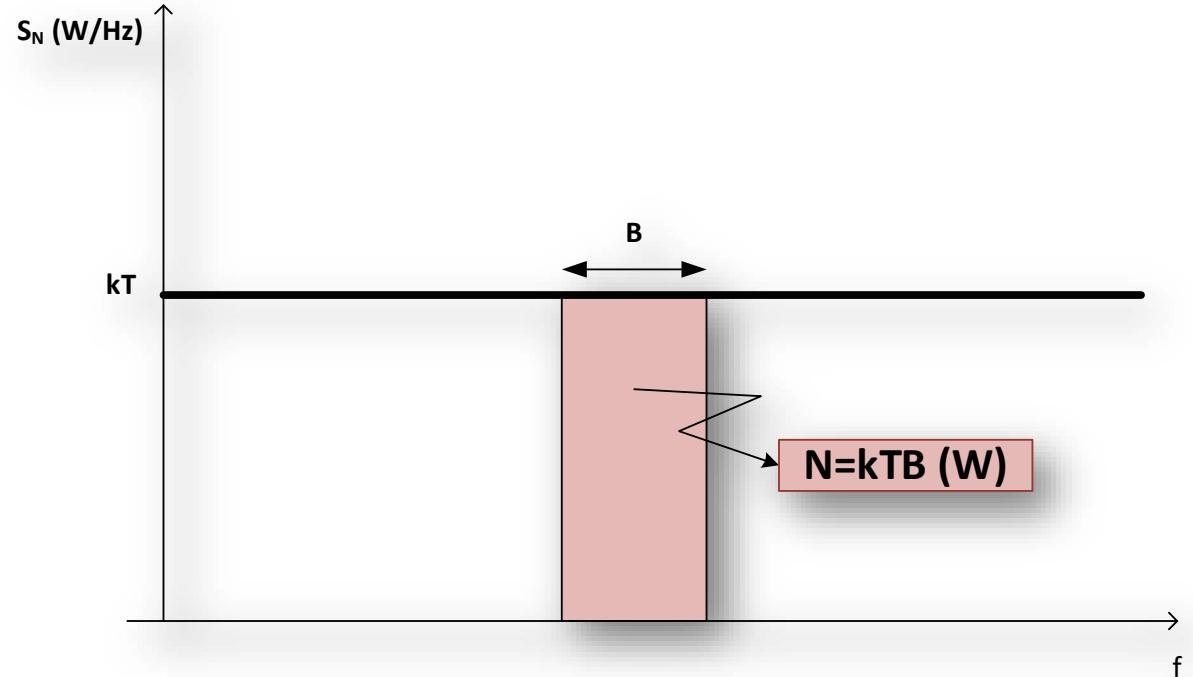
where  $k$  is the Boltzmann constant, of value:

$$k = 1,38 \cdot 10^{-23} \left( \frac{\text{W}}{\text{Hz} \cdot \text{K}} \right)$$

It's a **white noise**, because it is independent of the frequency.

The noise power obtained is proportional to the bandwidth  $B$  of the system, thus,

$$N = S_N B = kTB \text{ (W)}$$

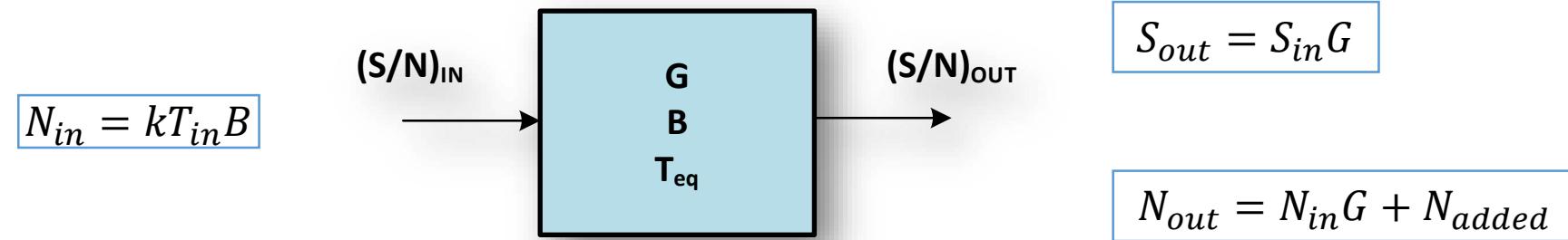


# Noise in quadrupoles:

Temperature Equivalent ( $T_{eq}$ ) at the input



# Noise in quadrupoles: Temperature Equivalent ( $T_{eq}$ ) at the input



$$N_{out} = N_{in}G + N_{added} = kT_{in}BG + N_{added}$$

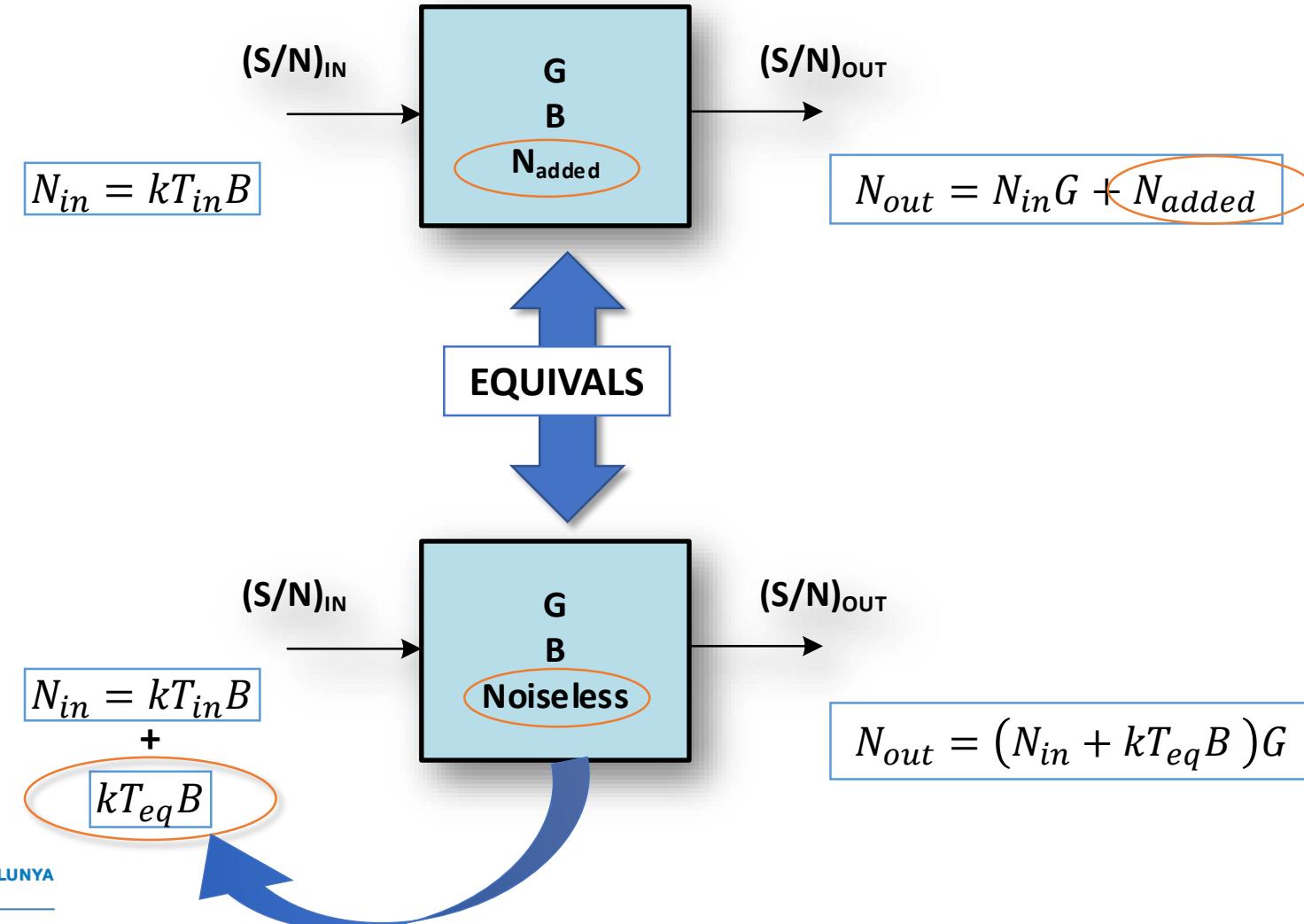
$$N_{added} \triangleq kT_{eq}BG$$

The **noise added** by the quadrupole **is equivalent** to the noise produced at his input **by a noise source** at  $T_{eq}$ .

$$N_{out} = k(T_{in} + T_{eq})BG$$

$$(S/N)_{out} = \frac{(S/N)_{in}}{\left(1 + \frac{T_{eq}}{T_{in}}\right)}$$

# Noise in quadrupoles: Temperature Equivalent (Teq) at the input



# Noise in quadrupoles:

Noise Figure (F)

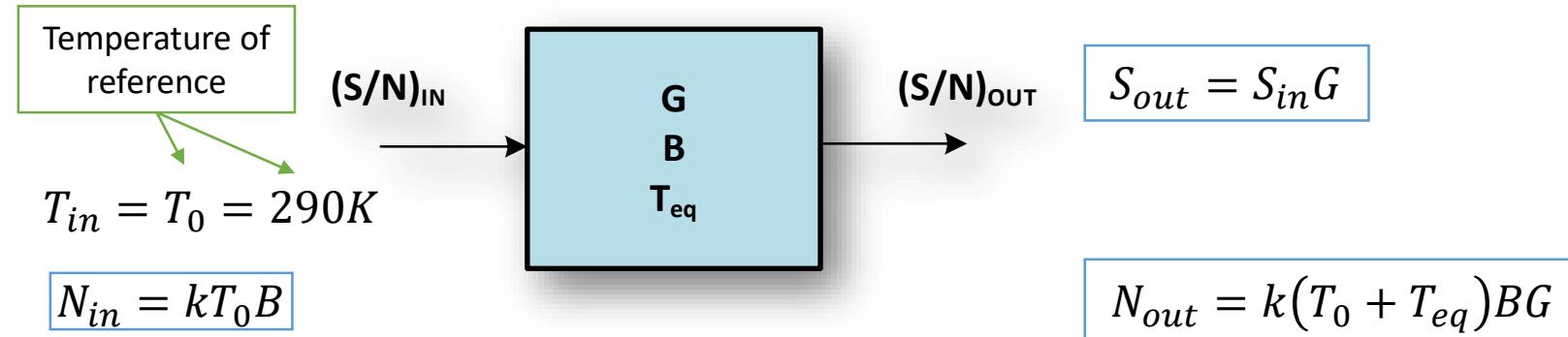


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# Noise Figure: F



**Noise Figure:**

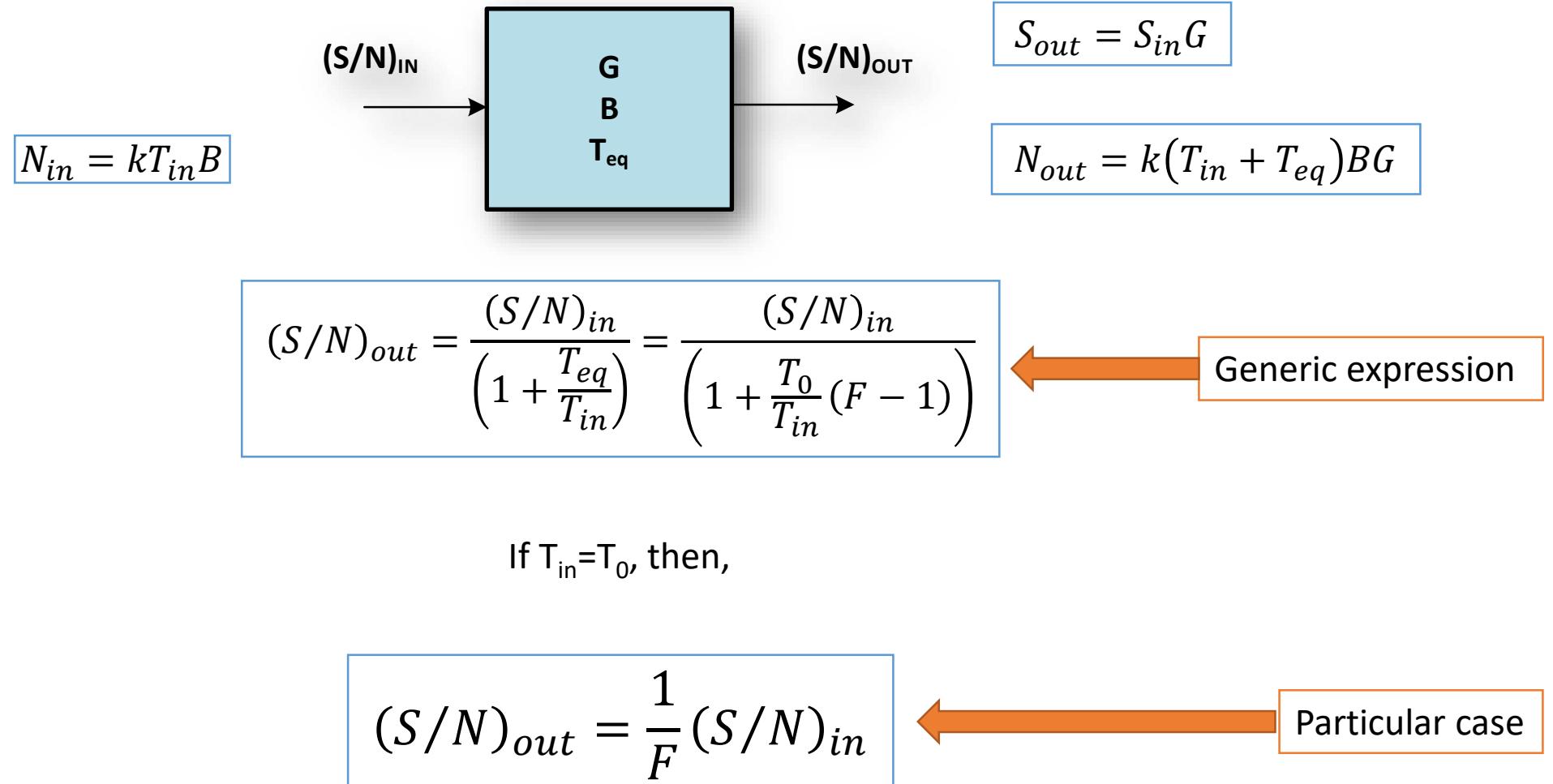
$$F \triangleq \frac{\text{Total noise output power}}{\text{Output noise power only due by an input source at } T_0}$$

$$F = \frac{k(T_0 + T_{eq})BG}{kT_0BG} = 1 + \frac{T_{eq}}{T_0}$$

Noise Factor:  $NF(dB) = 10 \log_{10}(F)$

$$T_{eq} = T_0(F - 1)$$

# Noise Figure: F



# Noise in quadrupoles:

Thermal noise in passive devices

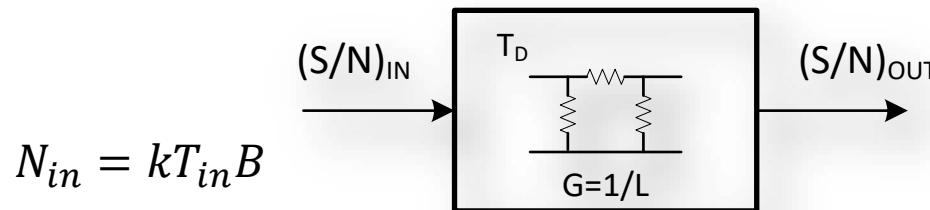


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# Thermal noise in passive devices



As a quadrupole,  $N_{out} = k(T_{in} + T_{eq})BG = k(T_{in} + T_{eq})B\frac{1}{L}$

As a passive device,  $N_{out} = kT_D B$ ,  
being  $T_D$  the physical temperature of the device

Equating both expressions,  $k(T_{in} + T_{eq})B\frac{1}{L} = kT_D B$ , we obtain,  $T_{eq} = LT_D - T_{in}$ .



General expression

If the device temperature equals the input temperature,  $T_D = T_{in}$ ,  
then  $T_{eq} = T_{in}(L - 1)$ .

And if the input temperature equals the reference temperature,  $T_{in} = T_0$ ,  
then  $T_{eq} = T_0(L - 1)$ , thus

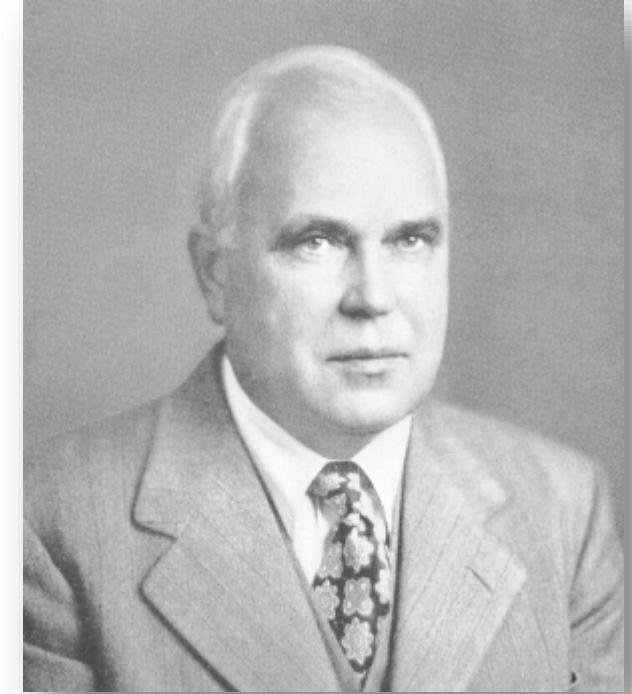
$$F = 1 + \frac{T_{eq}}{T_0} = 1 + \frac{T_0(L - 1)}{T_0} = L$$



Particular case

# Noise in quadrupoles:

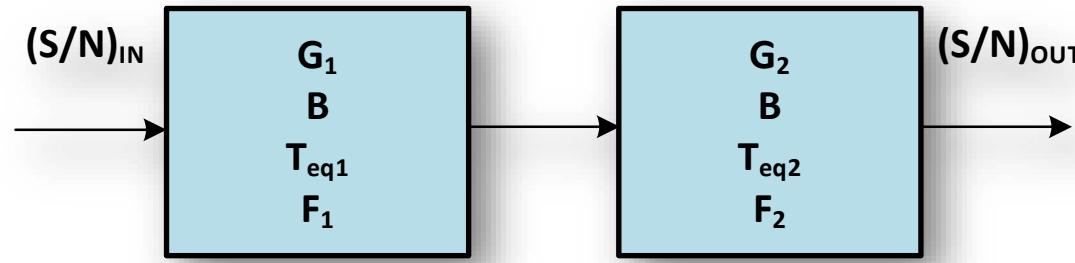
Components in cascade. Harald T. Friis noise equation.



*Harald Trap Friis (February 22, 1893 – June 15, 1976), who published as H. T. Friis, was a Danish-American radio engineer whose work at Bell Laboratories included pioneering contributions to radio propagation, radio astronomy, and radar. His two Friis formulas remain widely used.*

[https://www.smecc.org/harald\\_friis.htm](https://www.smecc.org/harald_friis.htm)

# Noise in cascaded quadrupoles



$$S_{out} = S_{in} G_1 G_2$$

$$N_{in} = kT_{in}B$$

$$N_{out} = kT_{in}BG_1G_2 + kT_{eq1}BG_1G_2 + kT_{eq2}BG_2$$

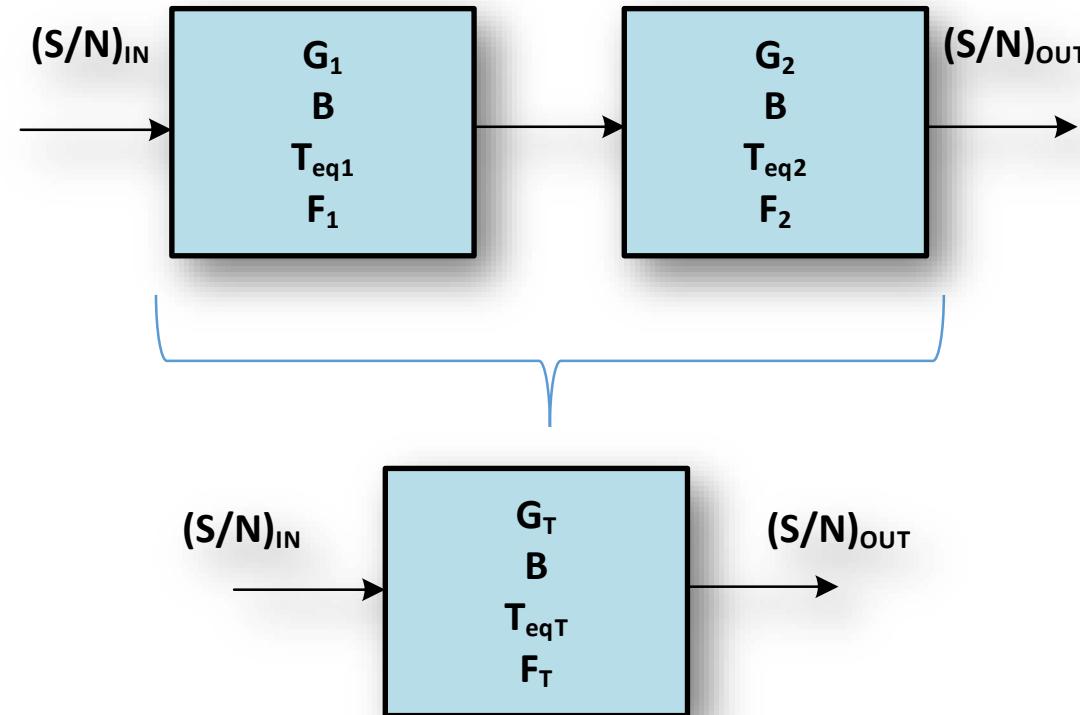
$$N_{out} = kB G_1 G_2 \left( T_{in} + T_{eq1} + \frac{T_{eq2}}{G_1} \right) = kB G_T \left( T_{in} + T_{eqT} \right)$$

$$G_T = G_1 G_2$$

$$T_{eqT} = T_{eq1} + \frac{T_{eq2}}{G_1}$$

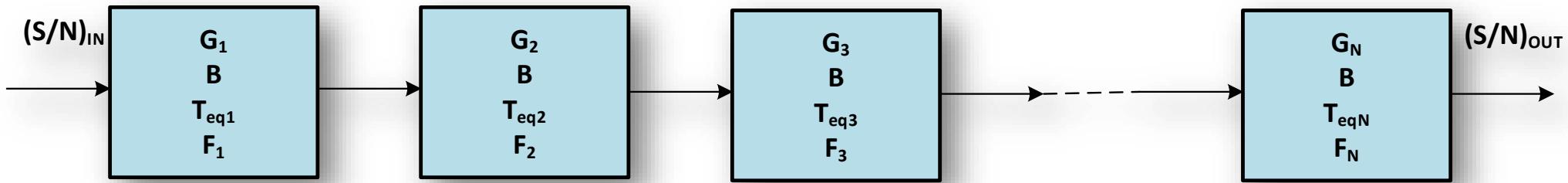
$$F_T = F_1 + \frac{F_2 - 1}{G_1}$$

# Noise in cascaded quadrupoles



$$\begin{aligned} G_T &= G_1 G_2 \\ T_{eqT} &= T_{eq1} + \frac{T_{eq2}}{G_1} \\ F_T &= F_1 + \frac{F_2 - 1}{G_1} \end{aligned}$$

# Friis noise equations



$$G_T = G_1 G_2 \cdots G_N$$

$$T_{eqT} = T_{eq1} + \frac{T_{eq2}}{G_1} + \frac{T_{eq3}}{G_1 G_2} + \cdots + \frac{T_{eqN}}{G_1 G_2 \cdots G_{N-1}}$$

$$F_T = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \cdots + \frac{F_N - 1}{G_1 G_2 \cdots G_{N-1}}$$

$$(S/N)_{out} = \frac{(S/N)_{in}}{\left(1 + \frac{T_{eqT}}{T_{in}}\right)}$$

# (S/N) Calculations



# Two options for (S/N) calculations

**The input noise only comes from the source**



$$(S/N)_{out} = \frac{(S/N)_{in}}{\left(1 + \frac{T_{eq}}{T_{in}}\right)} = \frac{(S/N)_{in}}{\left(1 + \frac{T_0}{T_{in}}(F - 1)\right)}$$

**The input noise is the addition of the source noise plus the quadrupole noise.**



$$(S/N)_{out} = \frac{S_{in}G}{N_{in}G} = (S/N)_{in}$$

# Receptor

Paràmetres



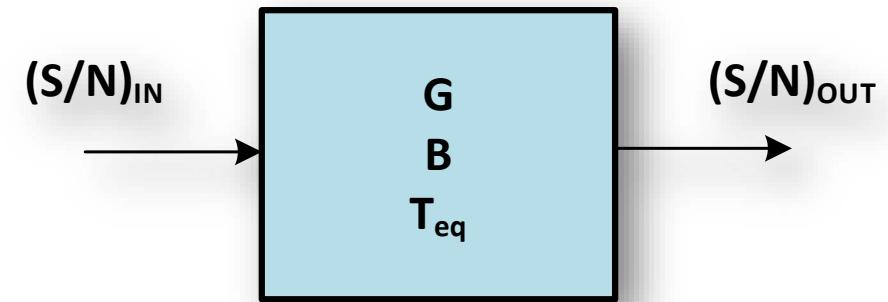
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# SENSIBILITAT

- La sensibilitat d'un receptor és la mínima potència del senyal d'entrada per tal d'obtenir a la sortida del receptor una determinada relació (S/N).
- Considerem  $T_{in} = T_0$

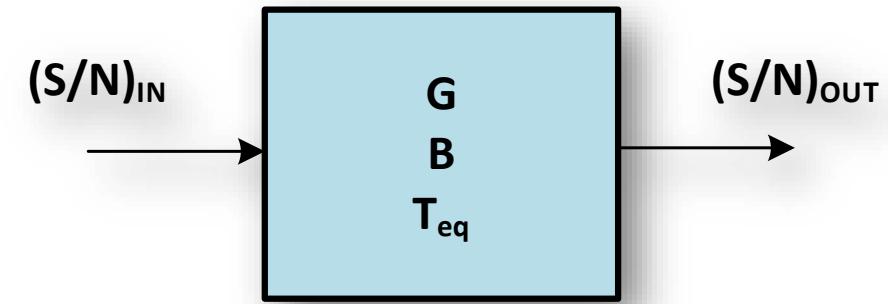


$$(S/N)_{out} = \frac{1}{F} (S/N)_{in}$$

$$SENSITIVITY = S_{in_{min}} = N_{in} F(S/N)_{out} = kT_0 BF(S/N)_{out}$$

# MÍNIM SENYAL DETECTABLE (MDS)

- Es defineix com la potència de senyal a l'entrada que a la sortida la potència del senyal sigui igual al del soroll, és a dir, que la  $(SNR)_{out} = 1$
- Considerem també  $T_{in} = T_0$
- També s'anomena “*terra de soroll*” o “*Noise floor ( $N_f$ )*” a la suma de totes les potències de soroll (tèrmic, shot, còsmic, etc.) existents a l'entrada del receptor.



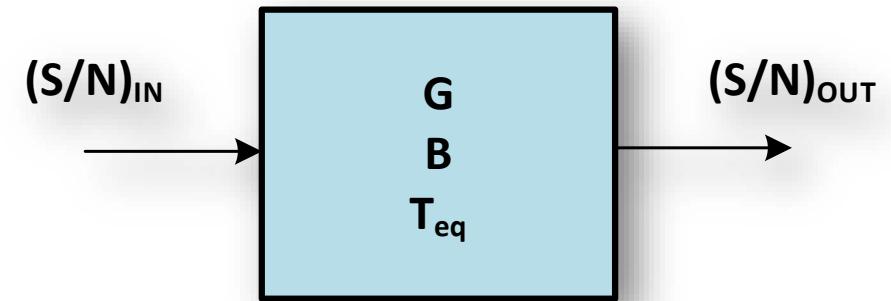
$$(S/N)_{out} = \frac{1}{F} (S/N)_{in} = 1$$

$$MDS_{in} = N_{in} F (S/N)_{out} = kT_0 BF$$

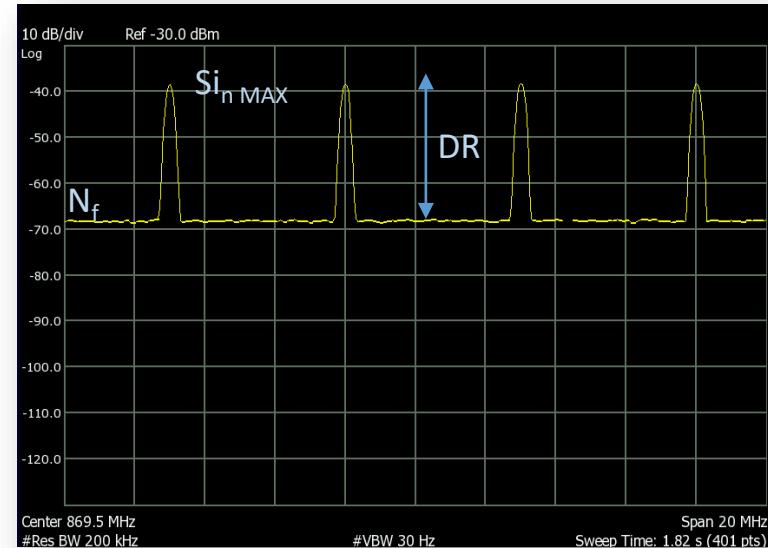


# MARGE DINÀMIC (DR)

- Es defineix com la relació entre la potència màxima d'entrada al receptor, respecte del mínim senyal detectable.



$$DR(dB) = S_{in|_{max}}(dBm) - MDS_{in}(dBm)$$



# DISTORSIÓ



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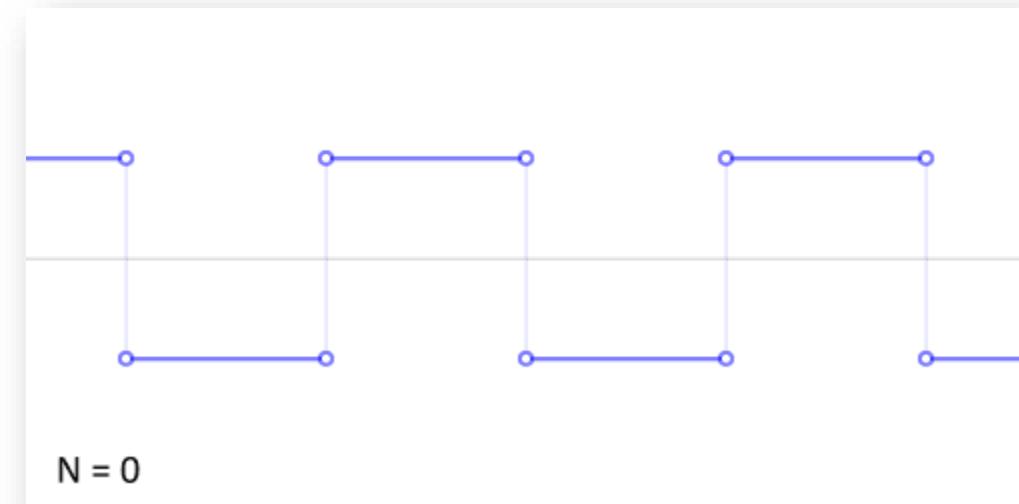
## DISTORSIÓ HARMÒNICA



$$y(t) = k_1 x(t) + k_2 x^2(t) + k_3 x^3(t)$$

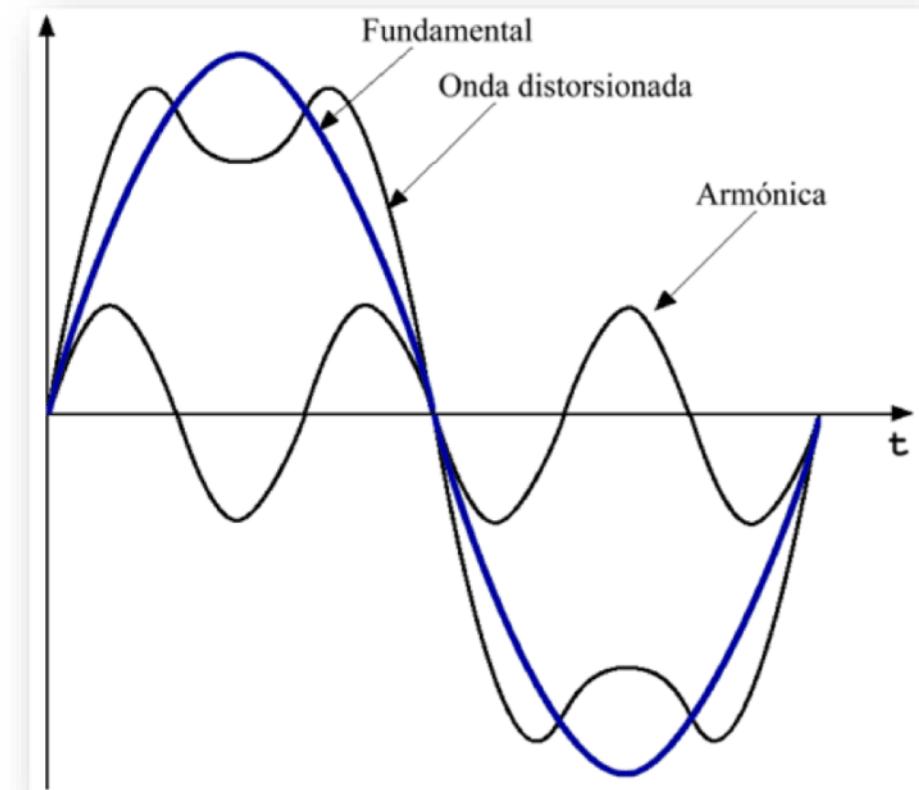
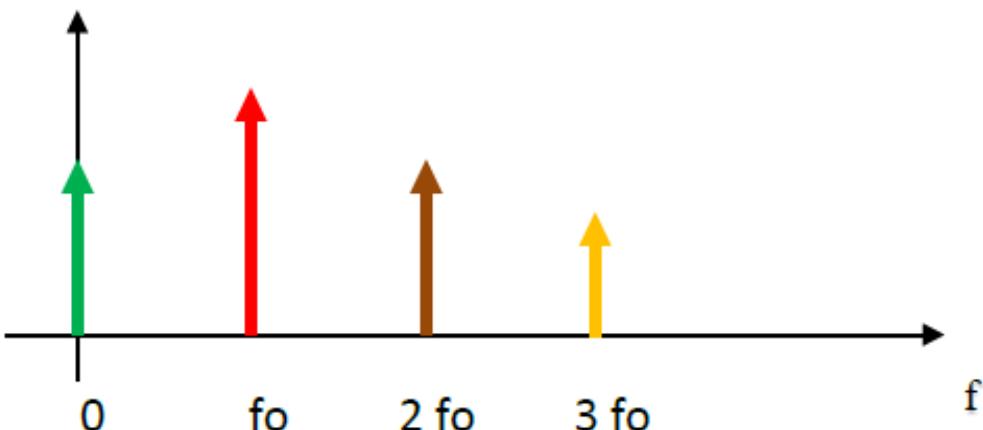
Si la entrada és un to de freqüència  $f_0$

$$x(t) = A_1 \cos(\omega_0 t)$$

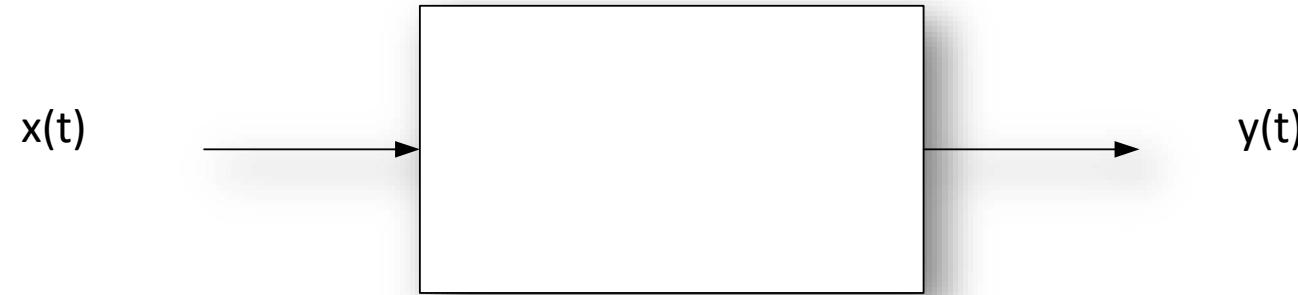


Llavors tenim:

$$y(t) = k_1 A_1 \cos(\omega_0 t) + k_2 \frac{A_1^2}{2} [1 + \cos(2\omega_0 t)] + k_3 \frac{A_1^3}{4} [3 \cos(\omega_0 t) + \cos(3\omega_0 t)]$$



## DISTORSIÓ D'INTERMODULACIÓ



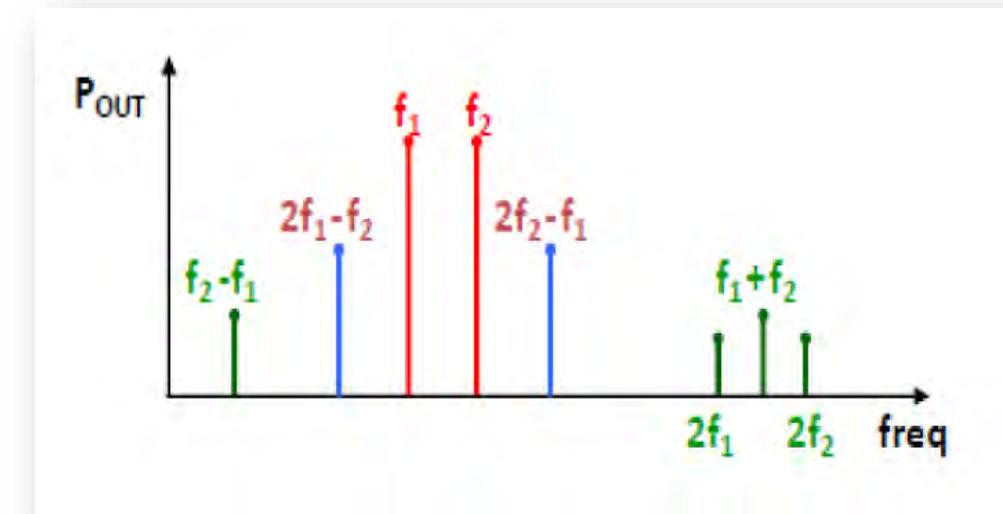
$$y(t) = k_1 x(t) + k_2 x^2(t) + k_3 x^3(t) + \dots$$

Si la entrada són 2 tons de freqüències  $f_1$  i  $f_2$

$$x(t) = A_1 \cos(\omega_1 t) + A_2 \cos(\omega_2 t)$$

Llavors tenim:

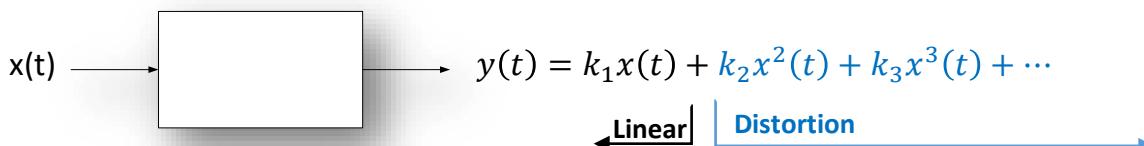
$$\begin{aligned}
 y(t) &= k_1[A_1 \cos(\omega_1 t) + A_2 \cos(\omega_2 t)] \\
 &+ k_2 \left\{ \frac{A_1^2}{2} [1 + \cos(2\omega_1 t)] + \frac{A_2^2}{2} [1 + \cos(2\omega_2 t)] + \frac{A_1 A_2}{2} [\cos[(\omega_1 + \omega_2)t] + \cos[(\omega_1 - \omega_2)t]] \right\} \\
 &+ k_3 \left\{ \frac{A_1^3}{4} [3 \cos(\omega_1 t) + \cos(3\omega_1 t)] + \frac{A_2^3}{4} [3 \cos(\omega_2 t) + \cos(3\omega_2 t)] \right. \\
 &+ A_1^2 A_2 \left[ \frac{3}{2} \cos(\omega_2 t) + \frac{3}{4} \cos[(2\omega_1 + \omega_2)t] + \frac{3}{4} \cos[(2\omega_1 - \omega_2)t] \right] \\
 &\left. + A_1 A_2^2 \left[ \frac{3}{2} \cos(\omega_1 t) + \frac{3}{4} \cos[(2\omega_2 + \omega_1)t] + \frac{3}{4} \cos[(2\omega_2 - \omega_1)t] \right] \right\}
 \end{aligned}$$



# Amplifier

Parameters:

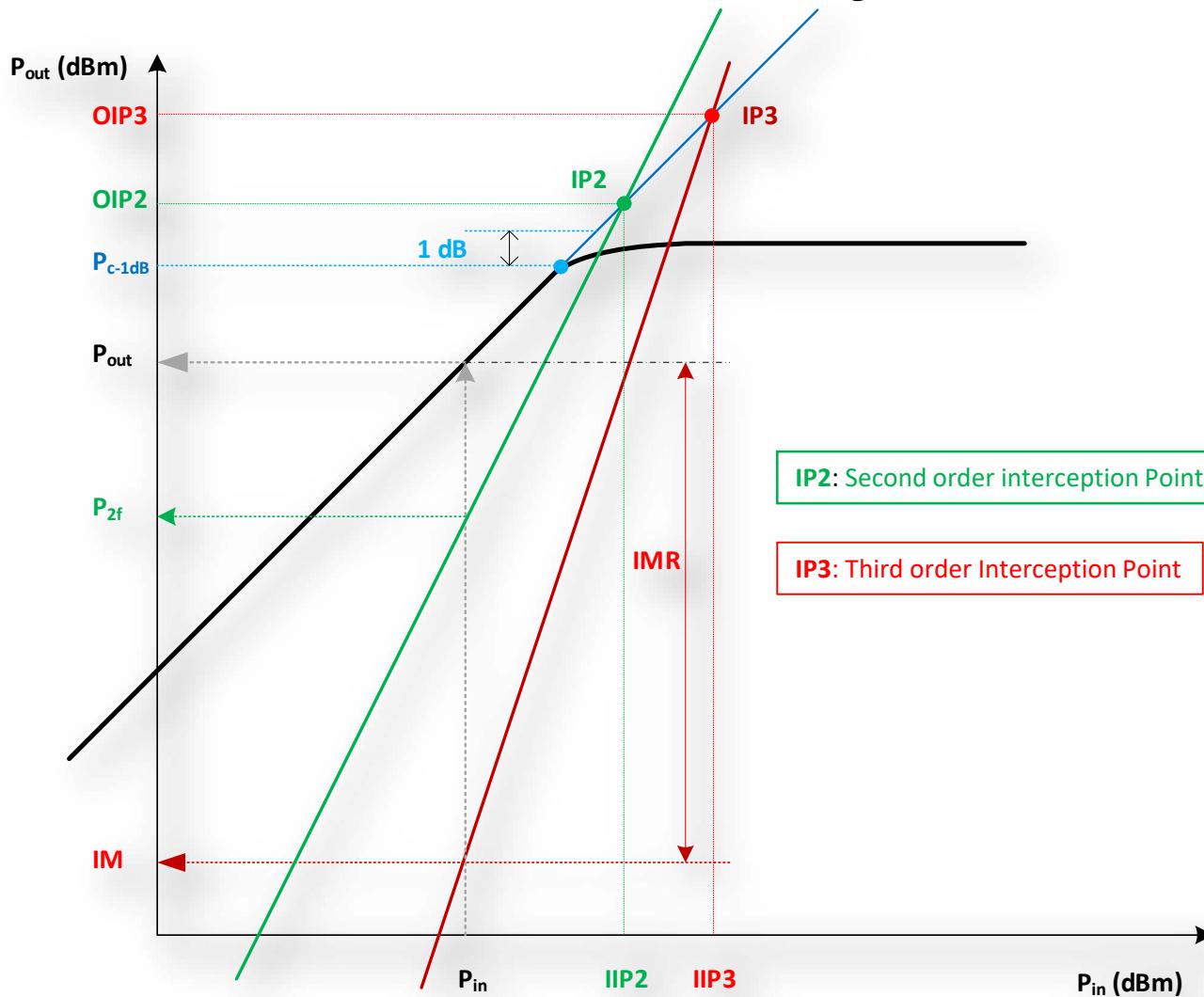
- Forward gain: **G**
- Noise figure: **F**
- **1-dB compression point**: is defined as the input power (or output power) where the gain is 1 dB less than the small signal gain; measure of power level where the device becomes non-linear.
- **Third order Interception Point (IP3)**: Non-linear behavior will introduce **InterModulation Distortion (IMD)**, and harmonics generation.



If  $x(t) = A_1 \cos(\omega_1 t) + A_2 \cos(\omega_2 t)$ , then

$$\begin{aligned}
 y(t) &= k_1[A_1 \cos(\omega_1 t) + A_2 \cos(\omega_2 t)] + k_2 \left\{ \frac{A_1^2}{2} [1 + \cos(2\omega_1 t)] + \frac{A_2^2}{2} [1 + \cos(2\omega_2 t)] + \frac{A_1 A_2}{2} [\cos((\omega_1 + \omega_2)t) + \cos((\omega_1 - \omega_2)t)] \right\} \\
 &\quad + k_3 \left\{ \frac{A_1^3}{4} [3 \cos(\omega_1 t) + \cos(3\omega_1 t)] + \frac{A_2^3}{4} [3 \cos(\omega_2 t) + \cos(3\omega_2 t)] + A_1^2 A_2 \left[ \frac{3}{2} \cos(\omega_1 t) + \frac{3}{4} \cos((2\omega_1 + \omega_2)t) + \frac{3}{4} \cos((2\omega_1 - \omega_2)t) \right] \right. \\
 &\quad \left. + A_1 A_2^2 \left[ \frac{3}{2} \cos(\omega_2 t) + \frac{3}{4} \cos((2\omega_2 + \omega_1)t) + \frac{3}{4} \cos((2\omega_2 - \omega_1)t) \right] \right\}
 \end{aligned}$$

# Intermodulation Rejection Ratio (IMR)



$$P_o \text{ (dBm)} = P_{in} \text{ (dBm)} + G(\text{dB})$$

$$P_{2f} \text{ (dBm)} = 2 \cdot P_{in} \text{ (dBm)} + K_{DH}(\text{dB})$$

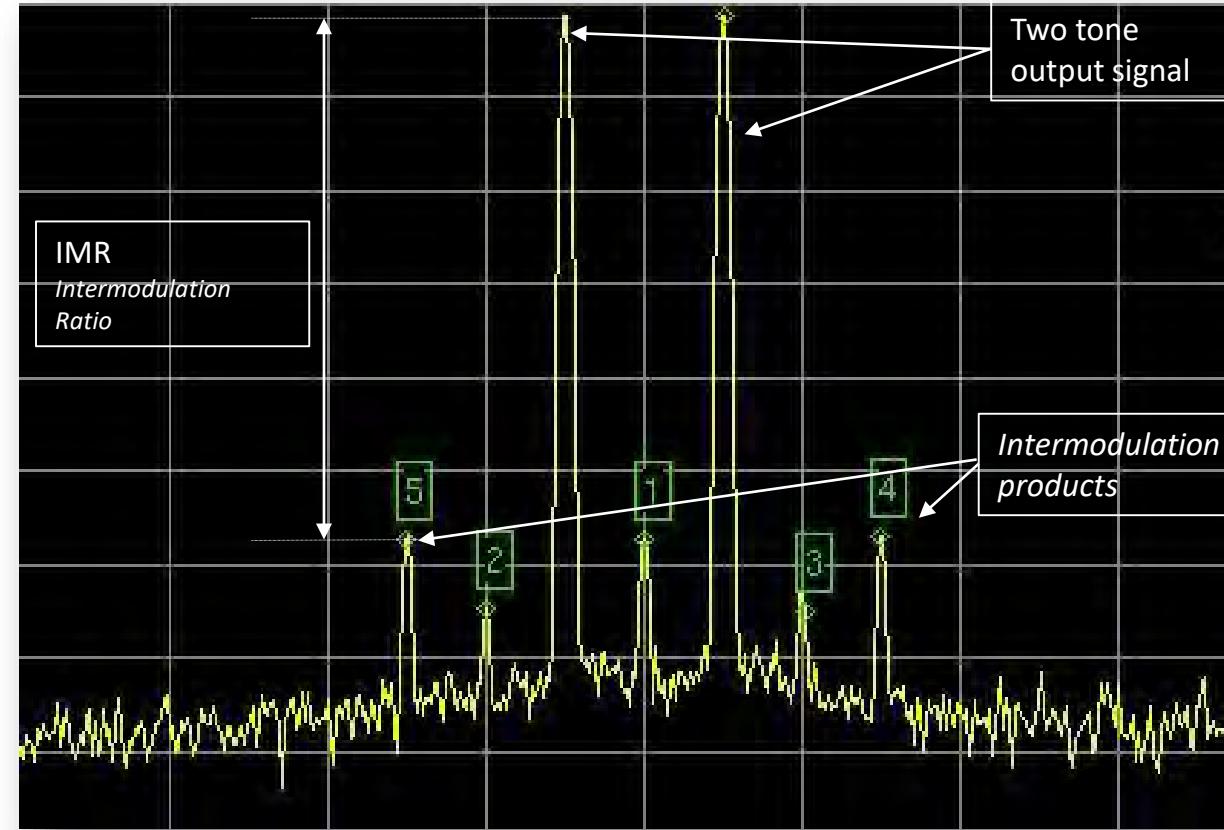
$$P_{IMD} \text{ (dBm)} = 3 \cdot P_{in} \text{ (dBm)} + K(\text{dB})$$

$$OIP3(\text{dBm}) = \frac{3P_o(\text{dBm}) - P_{IMD}(\text{dBm})}{2}$$

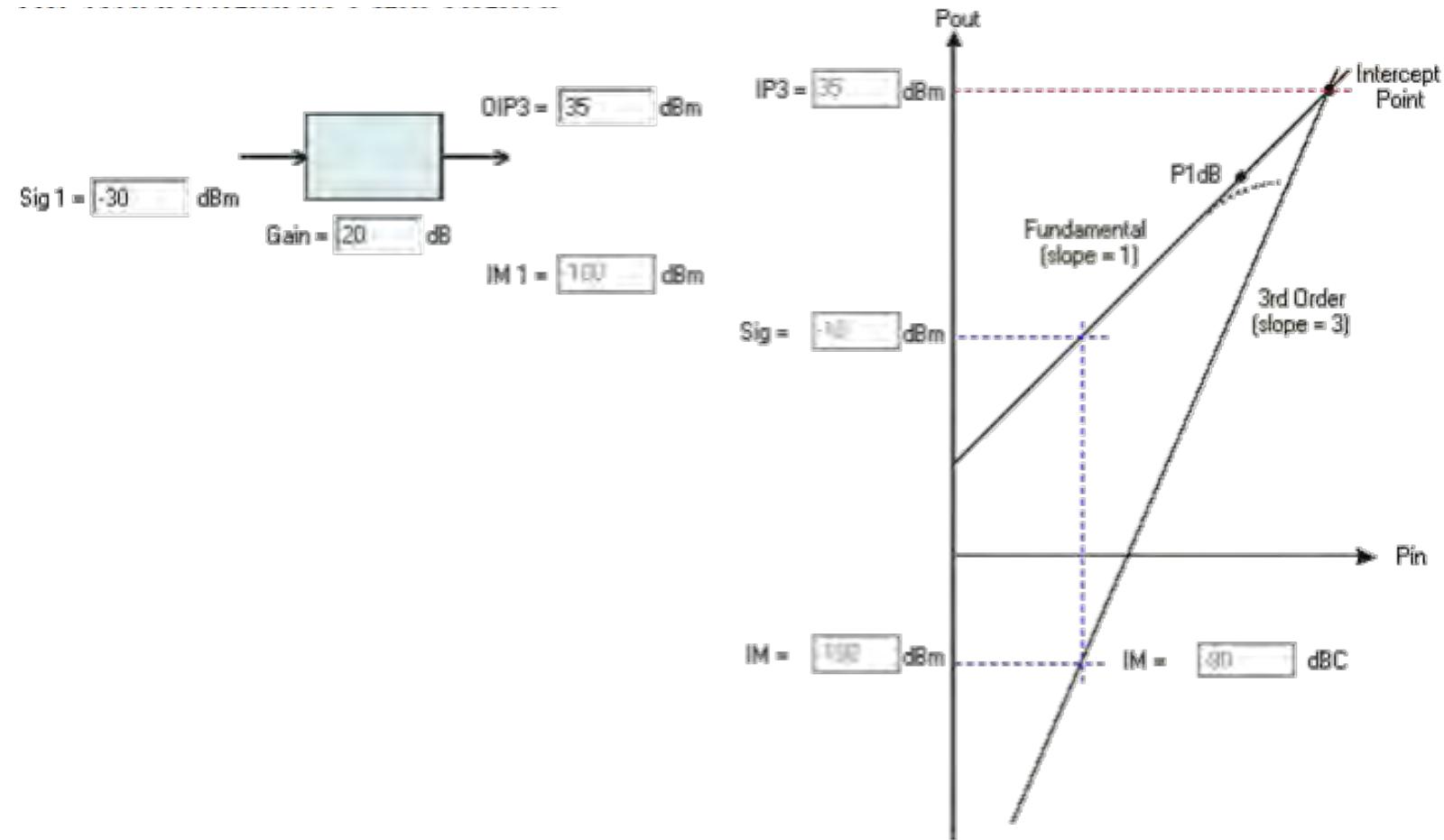
$$IMR(\text{dB}) = P_o(\text{dBm}) - P_{IMD} \text{ (dBm)}$$

$$OIP3(\text{dBm}) = P_o(\text{dBm}) + \frac{1}{2} IMR(\text{dB})$$

# TWO TONE INTERMODULATION DISTORTION

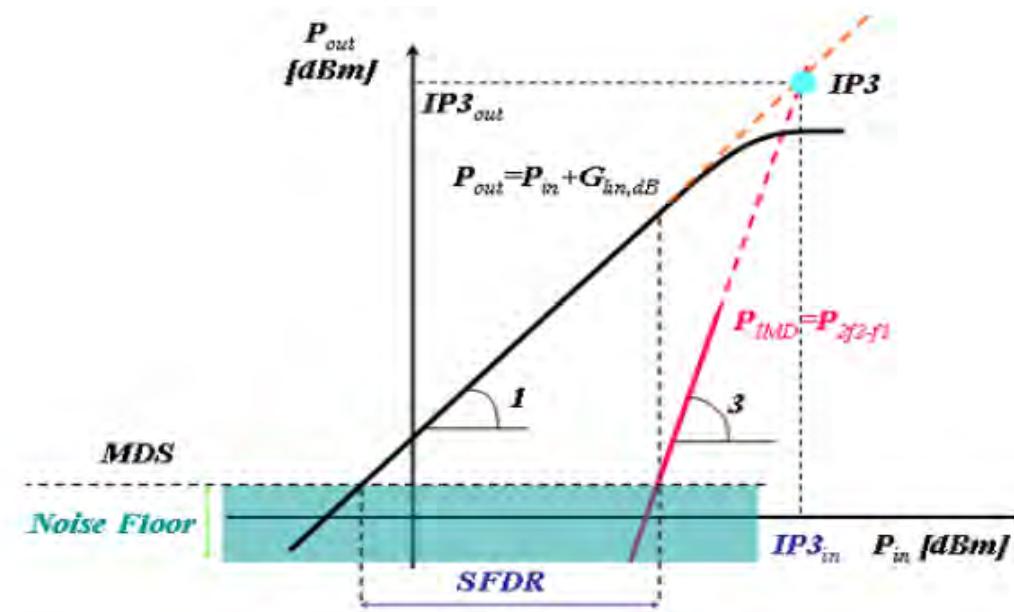
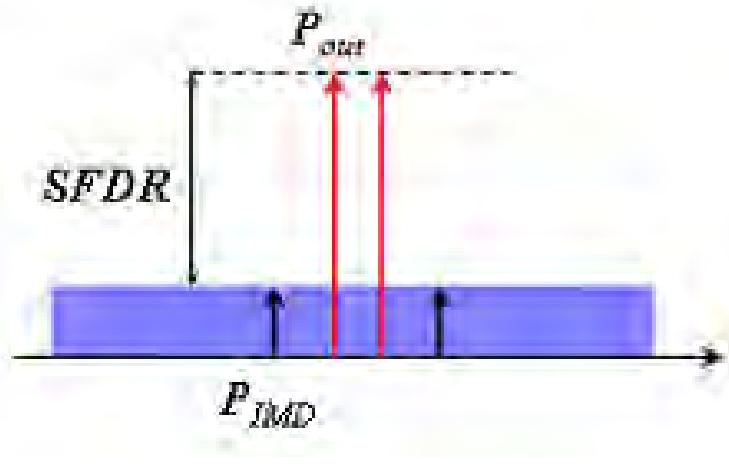


# GAIN AND INTERMODULATION



# SPURIOUS FREE DYNAMIC RANGE - SFDR

- Spurious Free Dynamic Range (SFDR) is defined as the distance between the output power level and the Minimum Detectable Signal (MDS) when the 3rd order Intermodulation products become appreciable and detectable.



$$SFDR(dB) = P_{out}(dBm) - MDS_{out}(dBm) = \frac{2}{3}[OIP3(dBm) - MDS_{out}(dBm)]$$

# EMISSORS I RECEPTORS

Principis bàsics

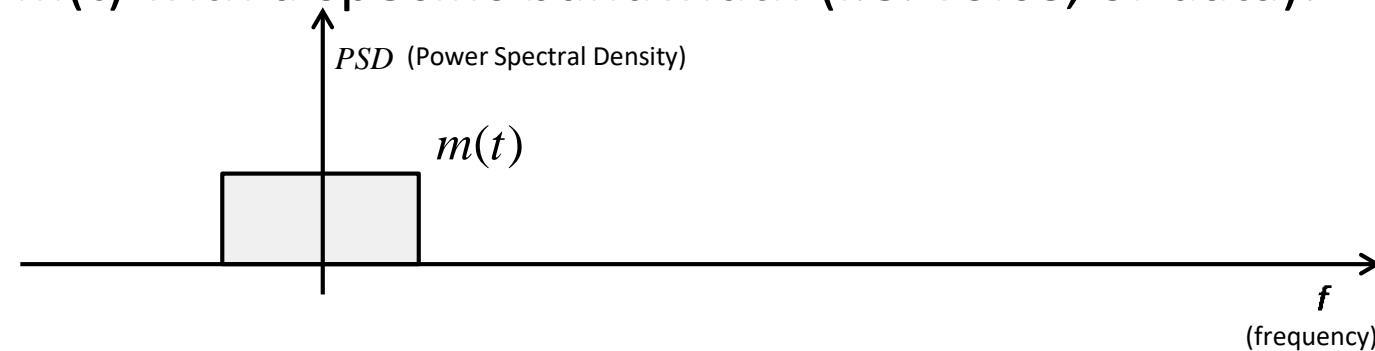


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# Up-conversion

- Assume a signal  $m(t)$  with a specific bandwidth (i.e. voice, or data):



- Up-conversion to a different carrier frequency:



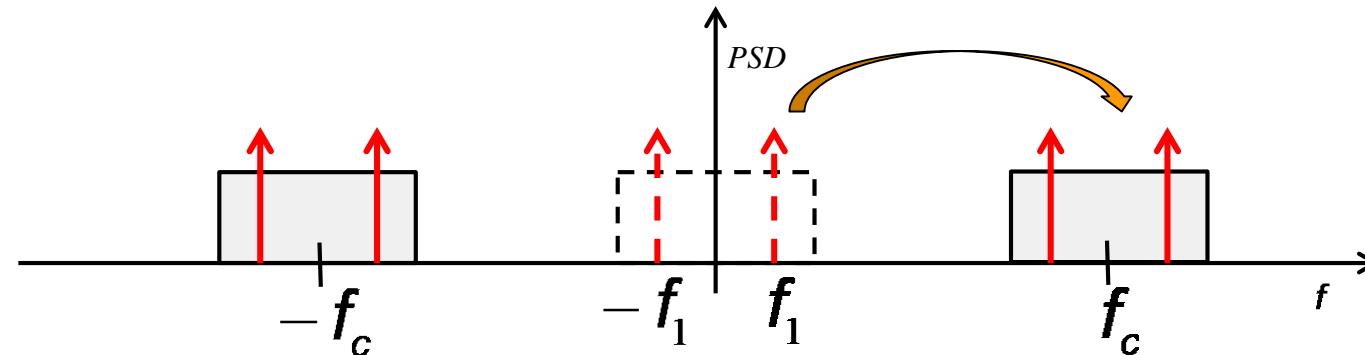
- For example: to VHF band

# Up-conversion

$$\cos(\omega_1 t)$$

- Using heterodyning (combining two frequencies to get a new one).
- Assume a single frequency component of  $m(t)$ :  $m(t) = \cos(\omega_1 t)$
- Multiply it by a single frequency component at the carrier frequency:

$$\cos(\omega_1 t) \cdot \cos(\omega_c t) = \frac{1}{2} \cos[(\omega_c - \omega_1)t] + \frac{1}{2} \cos[(\omega_c + \omega_1)t]$$



A two-side spectrum includes both positive and negative frequencies.

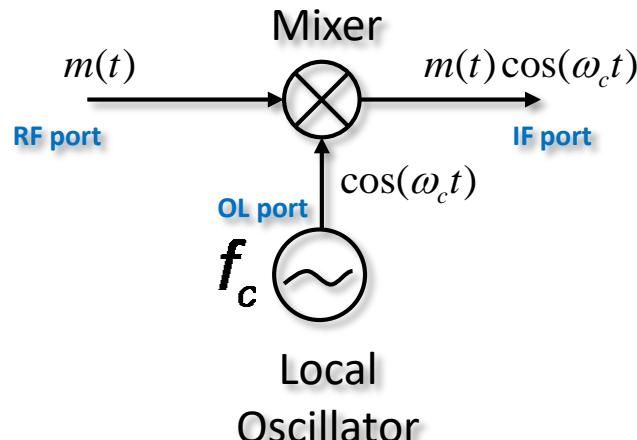
In a two-side spectrum both a positive and a negative frequency will exist for the single frequency component.

$$\omega_c = 2\pi f_c$$

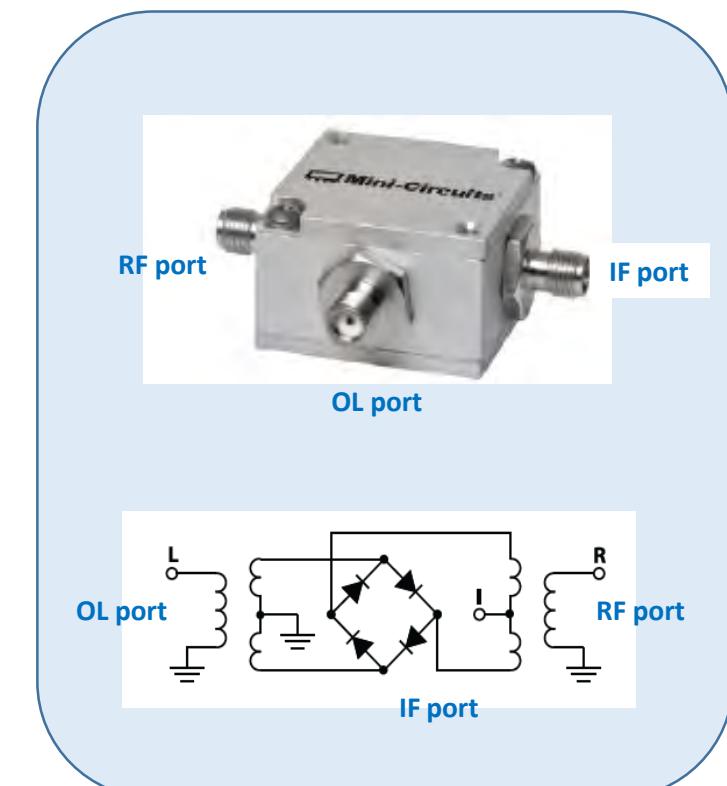
$$\omega_1 = 2\pi f_1$$

# Up-conversion

- Basic structure to perform up-conversion consists of a **mixer** and a **local oscillator**:

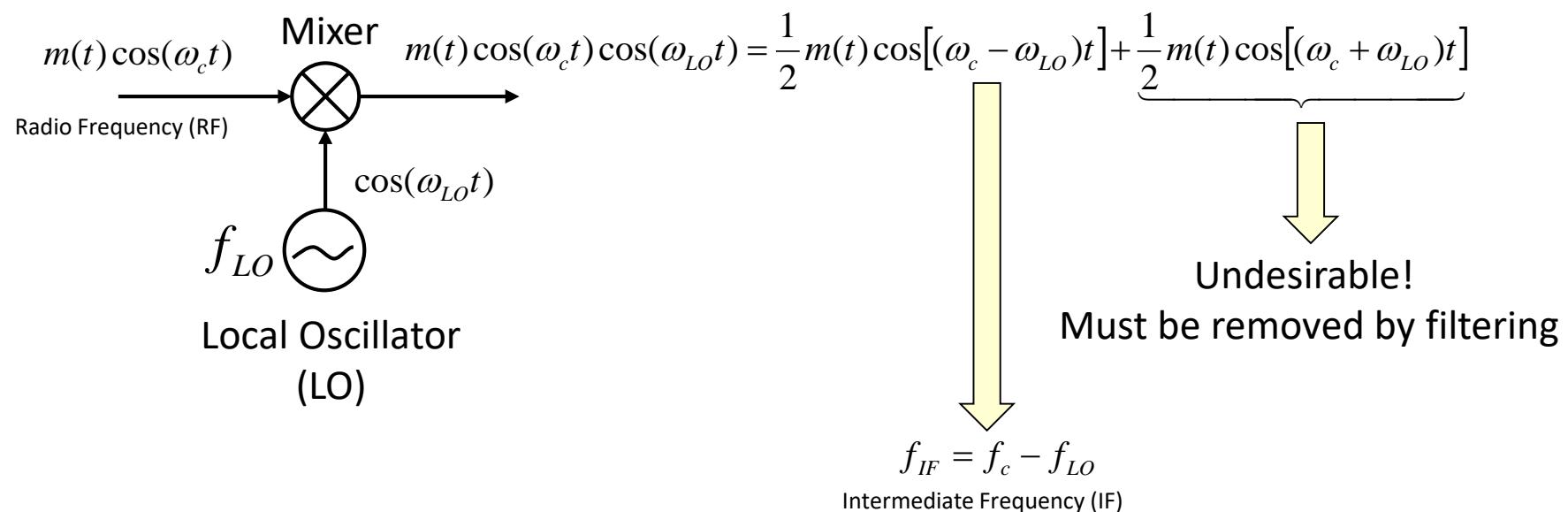


$$\omega_c = 2\pi f_c$$



# Down-conversion

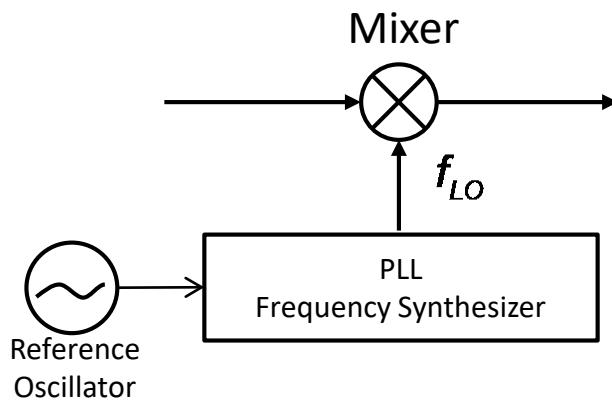
- Similarly, down-conversion can be performed using a **mixer** and a **local oscillator**:



$$\omega_c = 2\pi f_c$$

# Local Oscillator

- The reference signal that we are mixing with is often generated using a local oscillator and a frequency synthesizer:

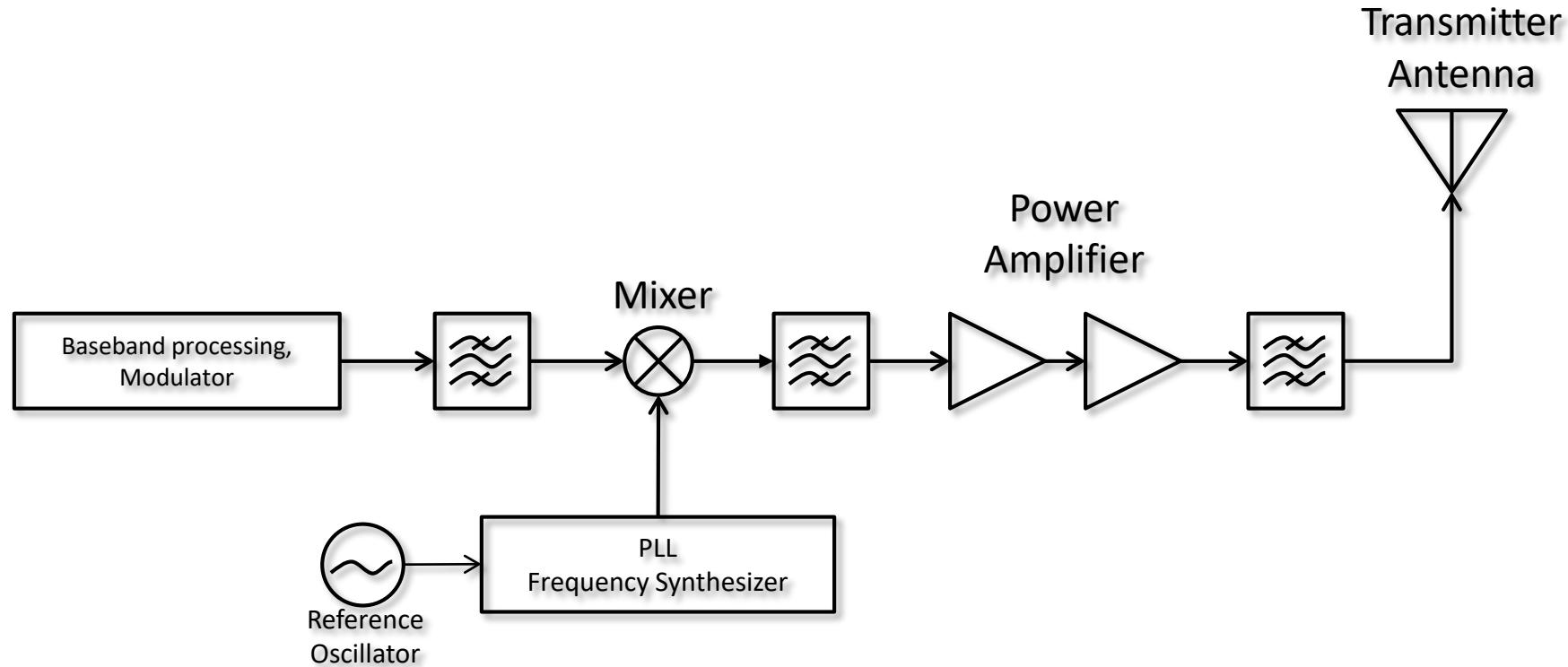


A frequency synthesizer is an electronic system for generating any of a range of frequencies from a single fixed time-base or oscillator.

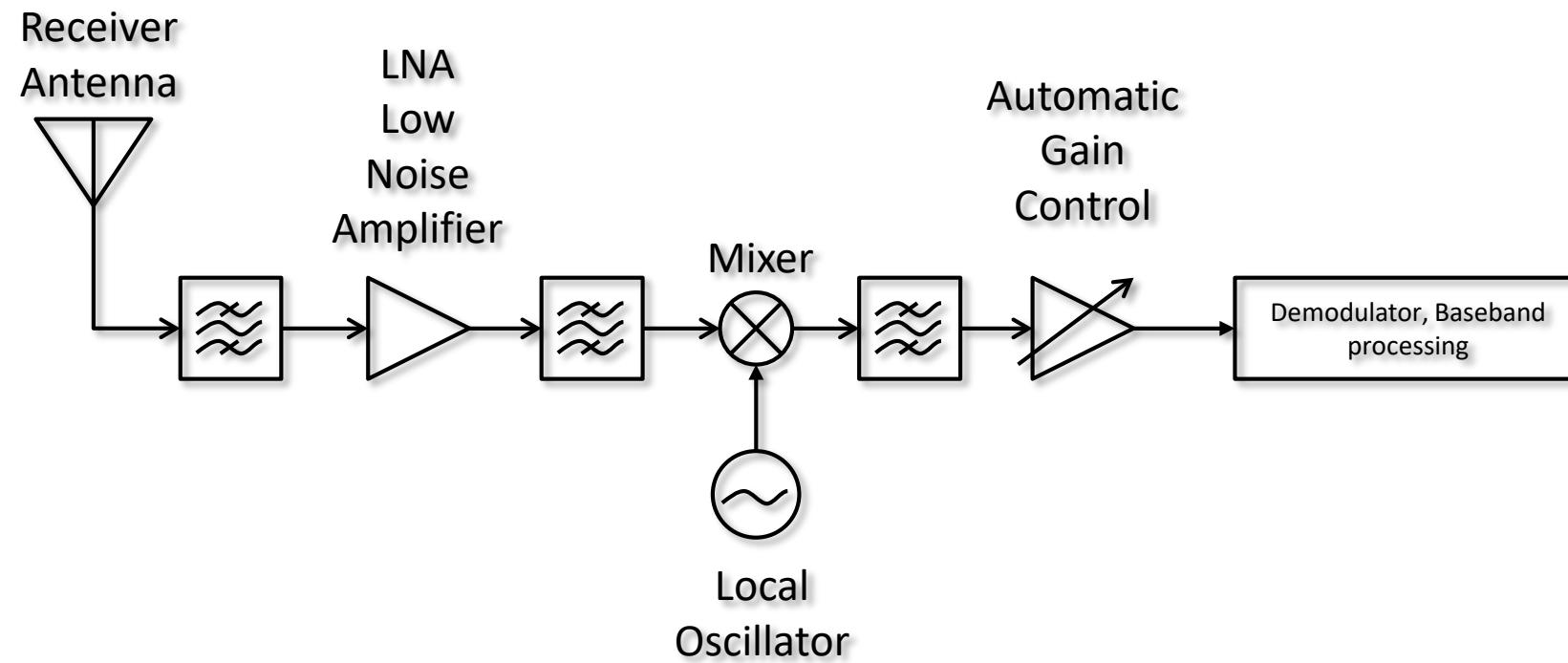
A reference oscillator (or clock) is an important component of a navigation receiver (i.e. GNSS receiver) because it has the most direct impact on the range measurements.

*PLL: Phase Locked Loop – A phase-locked loop or phase lock loop (PLL) is a control system that tries to generate an output signal whose phase is related to the phase of the input "reference" signal.*

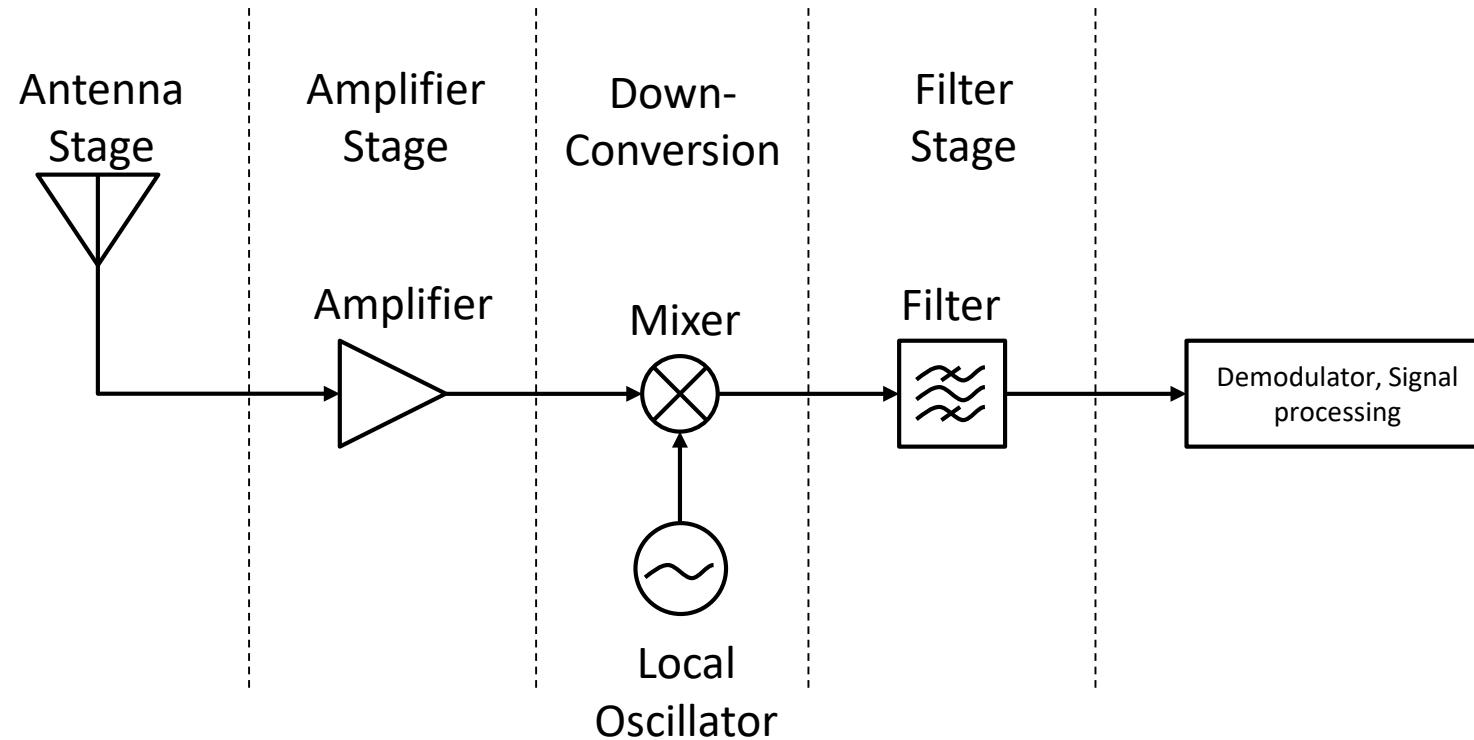
# Transmitter



# Receiver

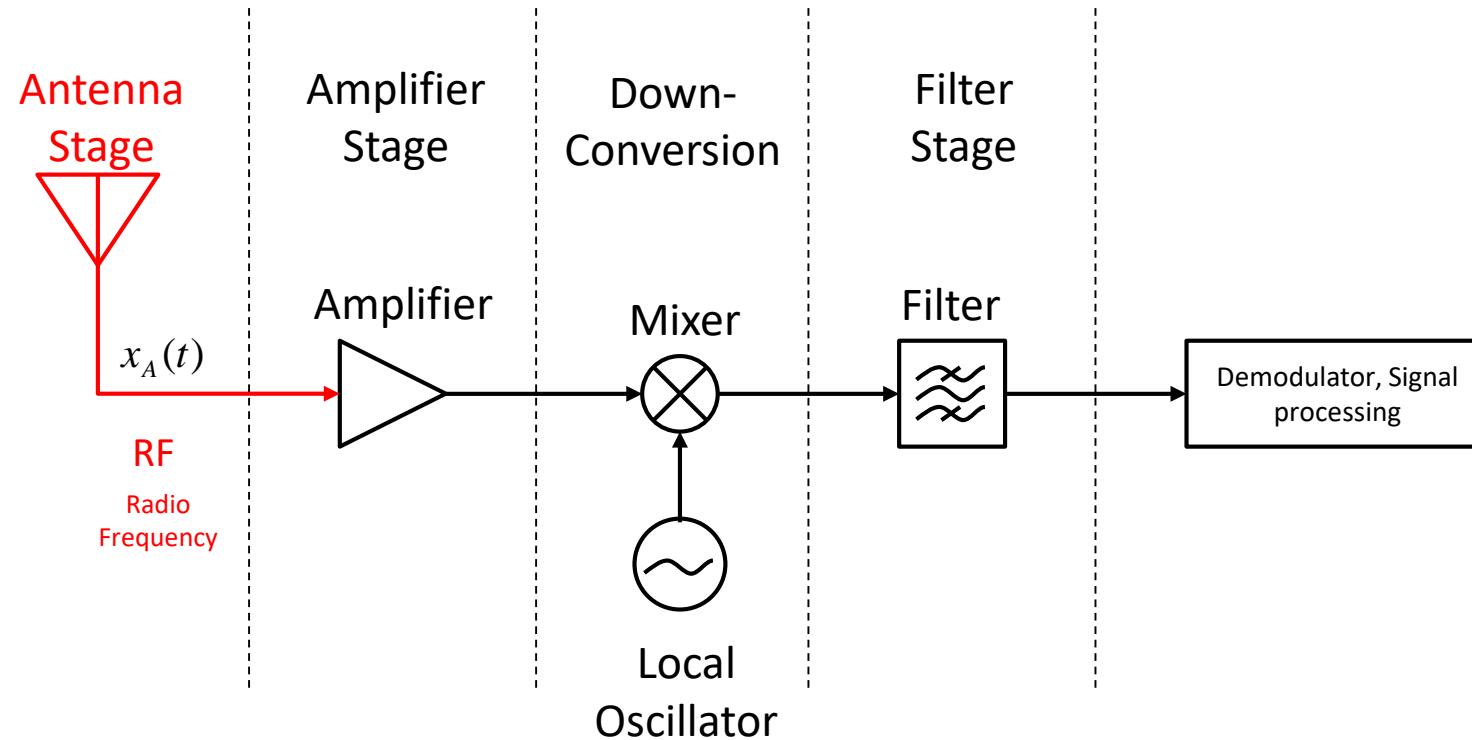


# Superheterodyne Receiver Stages



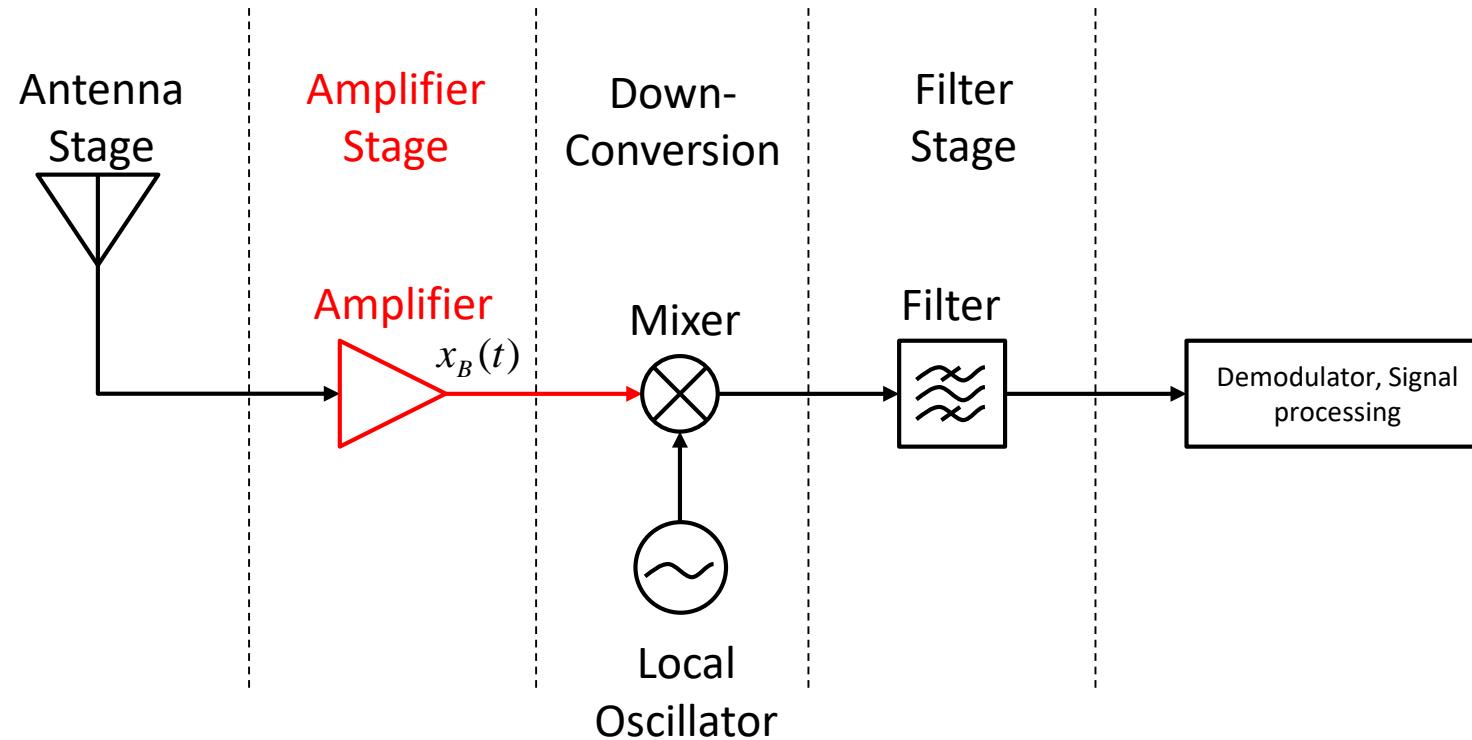
Let's assume that the Signal-in-Space received by the receiver is:  $x(t) = m(t) \cos(2\pi f_c t + \phi_0)$   
(and ignore the noise for now)

# Superheterodyne Receiver Stages



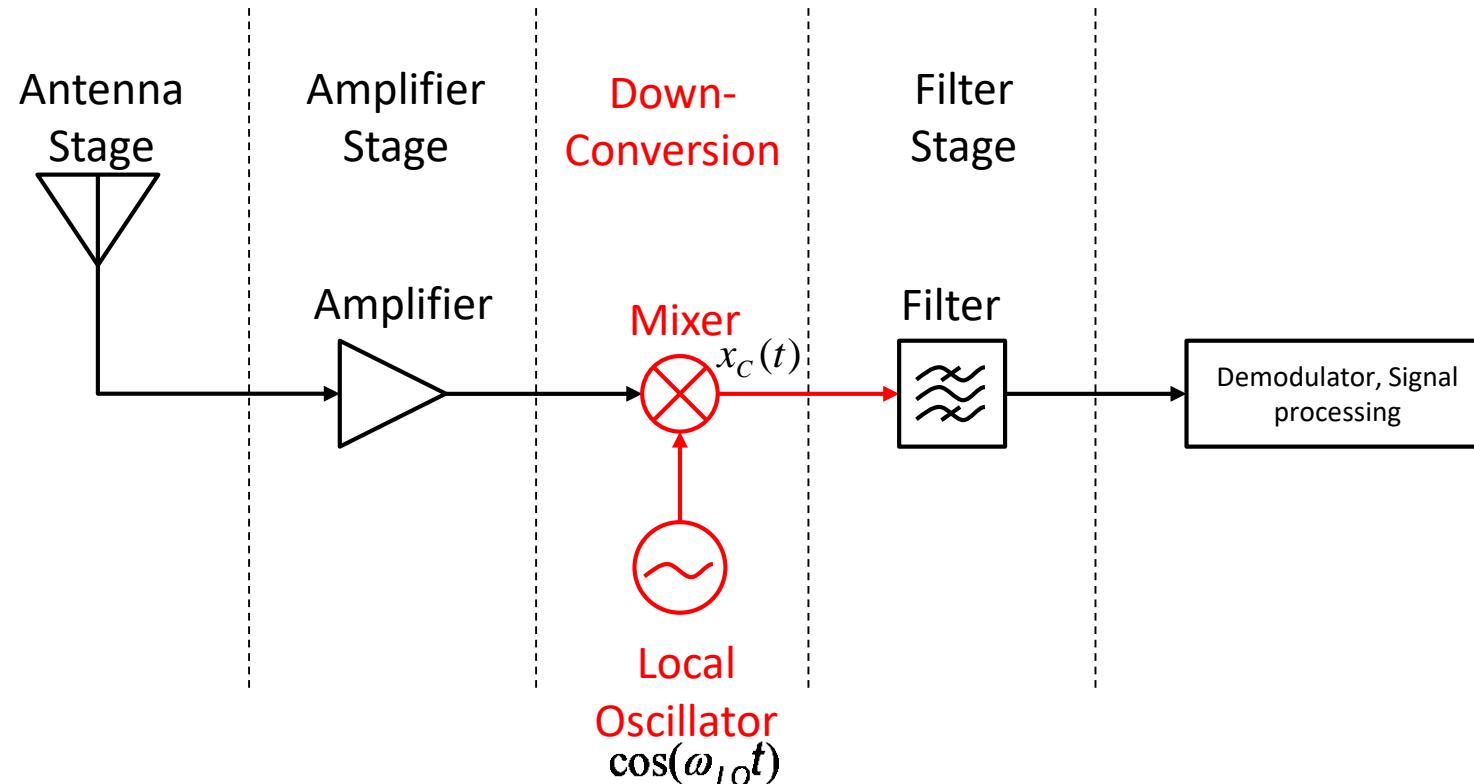
$$x_A(t) = Am(t) \cos(\omega_c t + \phi_0)$$

# Superheterodyne Receiver Stages



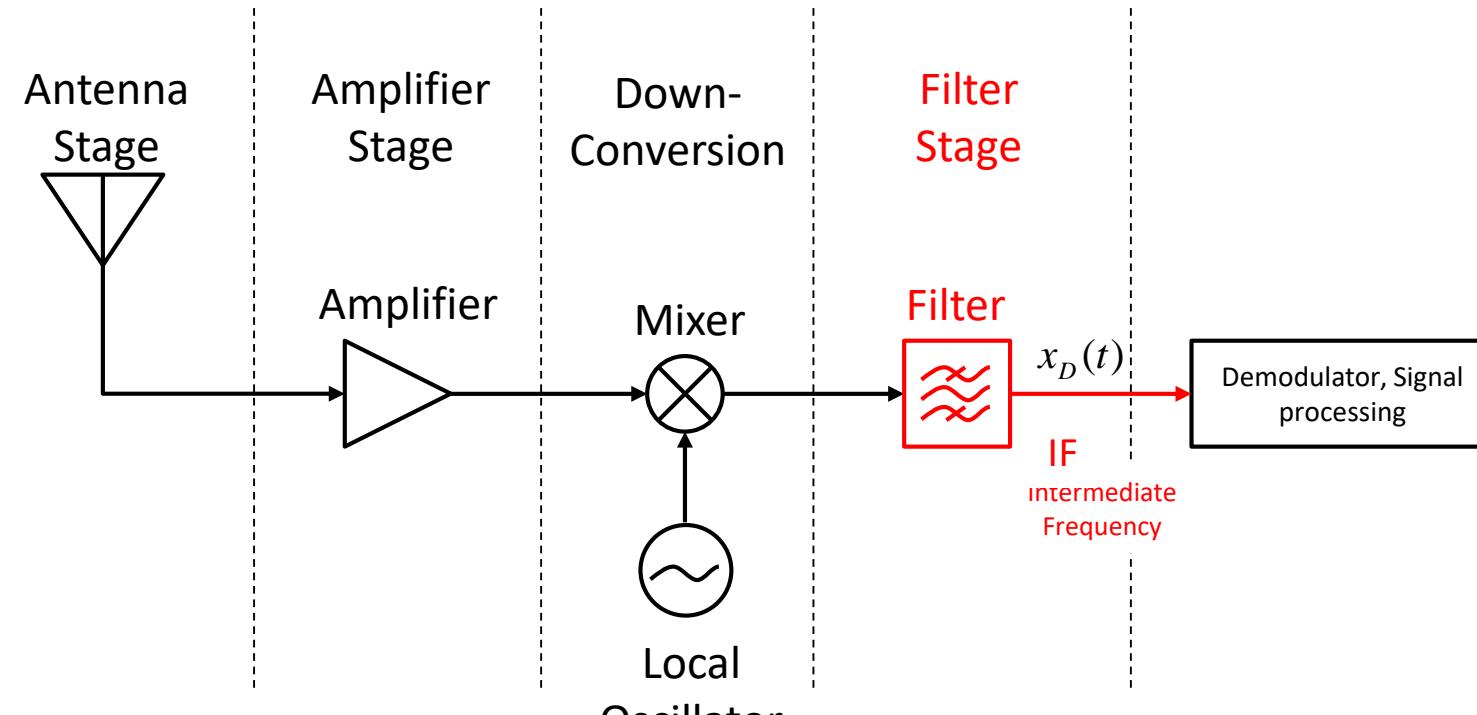
$$x_B(t) = BA m(t) \cos(\omega_c t + \phi_0) = m'(t) \cos(\omega_c t + \phi_0)$$

# Receiver Stages



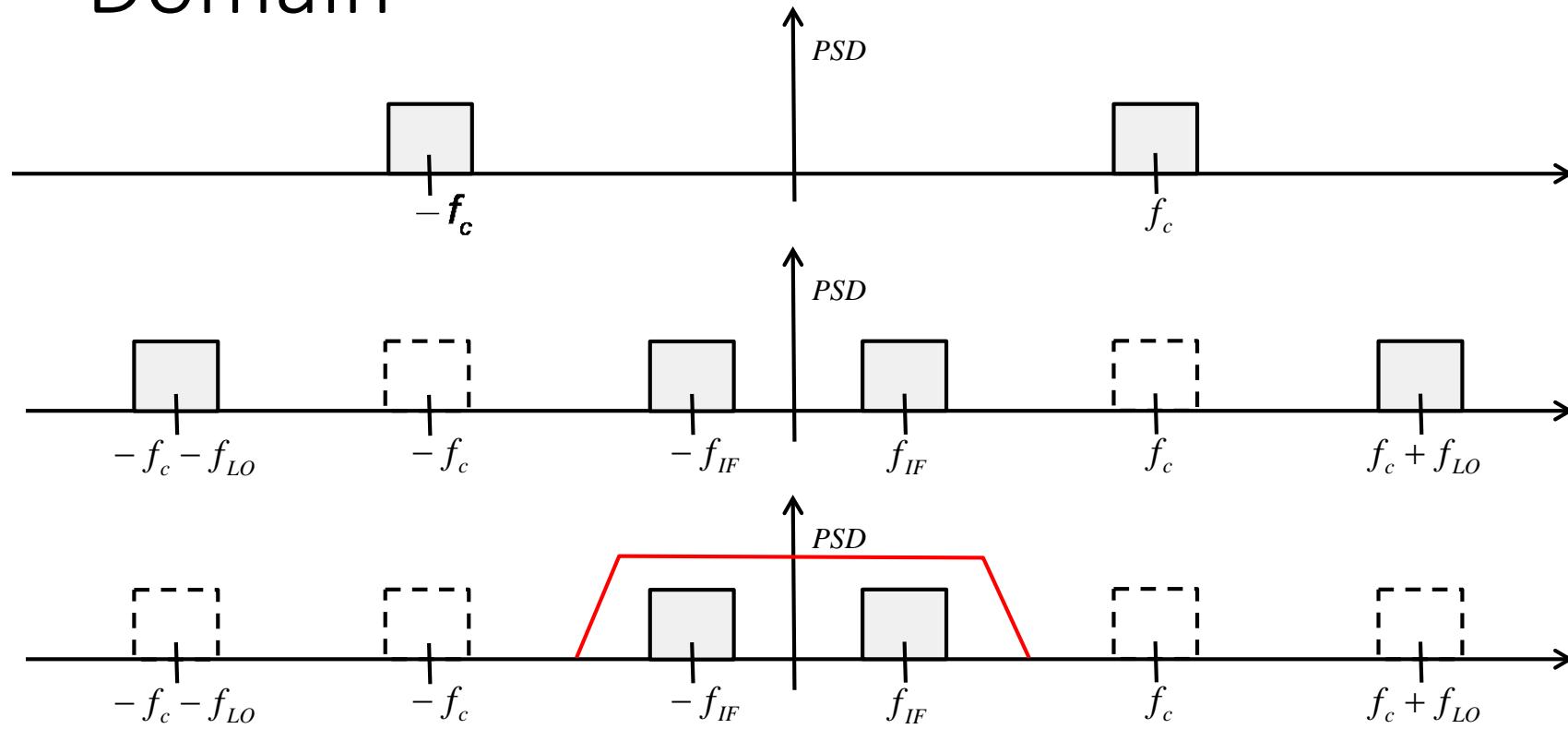
$$x_C(t) = m'(t) \cos(\omega_c t + \phi_0) \cos(\omega_{LO} t) = \frac{1}{2} m'(t) \cos[(\omega_c - \omega_{LO})t + \phi_0] + \frac{1}{2} m'(t) \cos[(\omega_c + \omega_{LO})t + \phi_0]$$

# Superheterodyne Receiver Stages

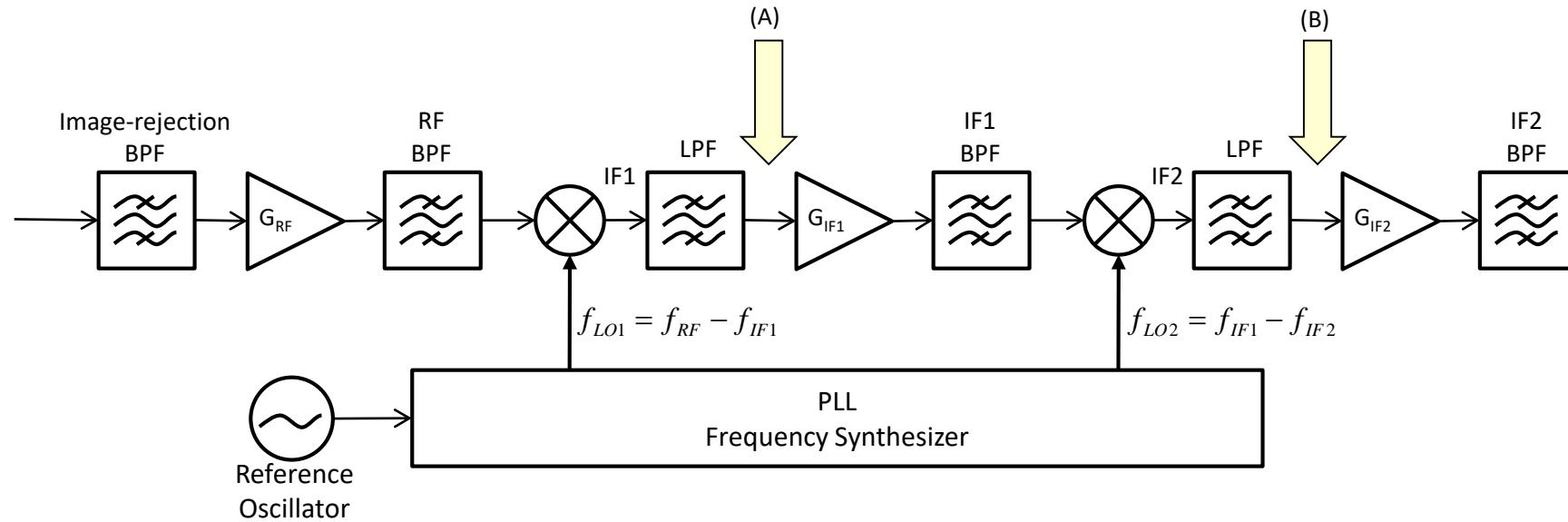


$$x_D(t) = \frac{1}{2} m'(t) \cos[(\omega_c - \omega_{LO})t + \phi_0]$$

# Superheterodyne RX – In Frequency Domain

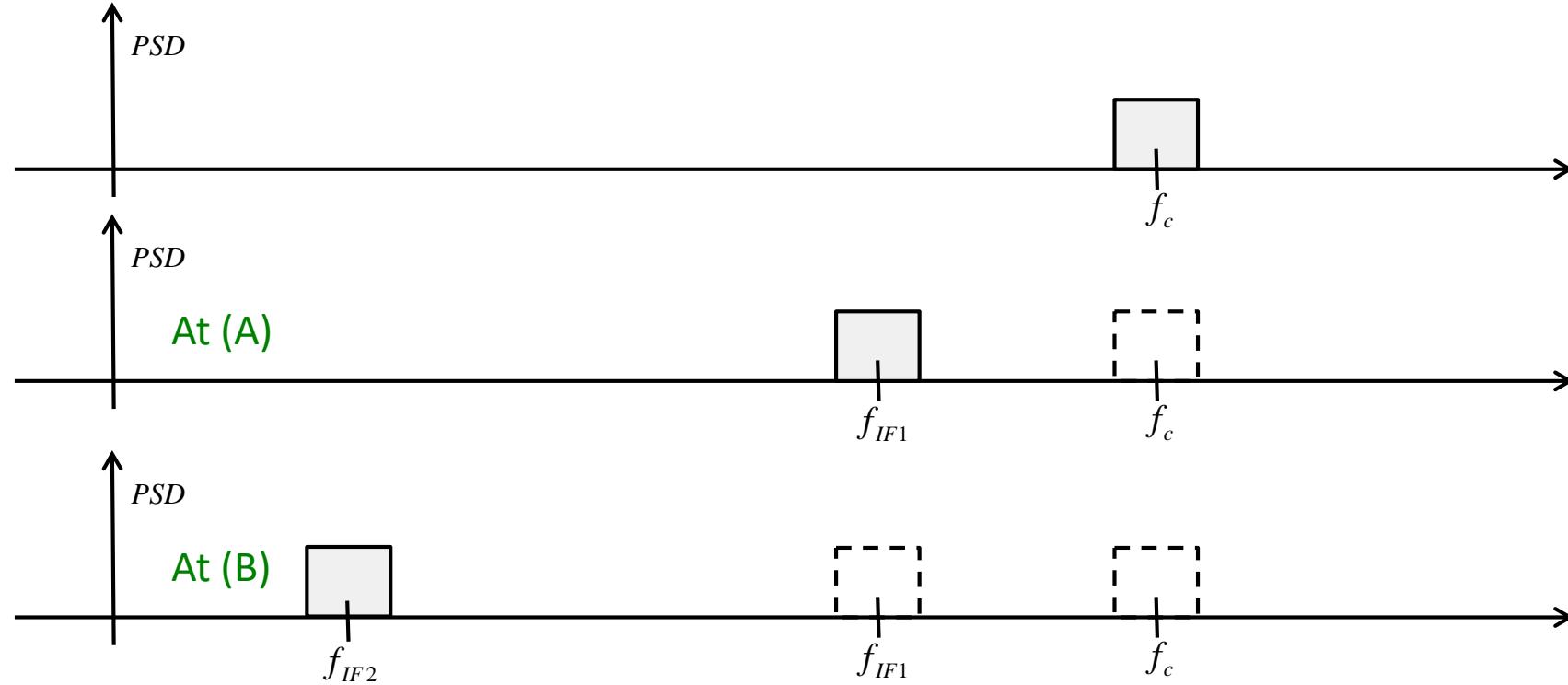


# Multiple Stages of Down-conversion

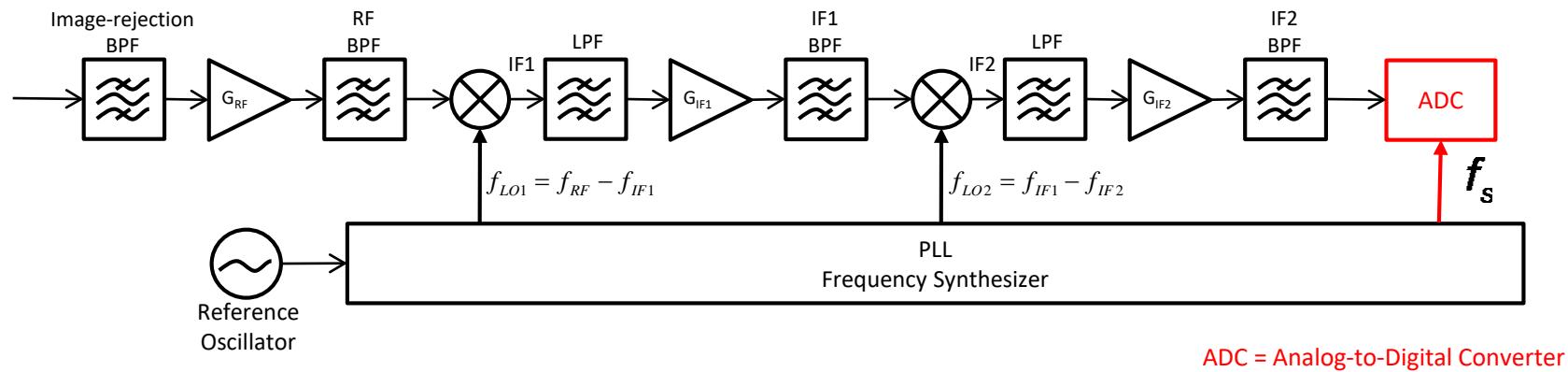


# Multiple Stages of Down-conversion

Look at a single side of the spectrum:



# Digital Receiver



# Tema 2: ANTENES, RADIOENLLAÇOS I PROPAGACIÓ D'ONES ELECTROMAGNÈTIQUES

**Antenes:** Tipologia i paràmetres

Jordi Berenguer i Sau



# Antenna parameters and Basics



## THE ANTENNA FUNCTIONS:

- As a transductor, it transforms an electrical signal into an Electromagnetic wave with an specific space orientation.
- In 2-D Radar Systems, among these functions, it determines the **azimuth angle** of the target.
- In 3-D Radar Systems, it provides the **elevation angle** of the target.

# Antenna parameters

## In Transmission

*The antenna, focus the energy to the target direction.*

- The **Directivity** (D) or the maximum radiation gain.
- The **antenna gain** (G) related with the antenna radiation efficiency.
- The antenna **radiation efficiency** ( $\eta_r$ ), as the losses between the transmitter output power and the radiated power.

## In Reception

*The antenna captures the energy coming from the target.*

- The **physical area** of the antenna:  $A_{\text{phys}}$
- The **effective area** of the antenna,  $A_{\text{eff}}$  which captures the transmitted power density of the electromagnetic wave.
- The **antenna illumination efficiency** ( $\eta_i$ ), or the ratio between the effective and the physical areas of the antenna,

Both roles related through the reciprocity principle



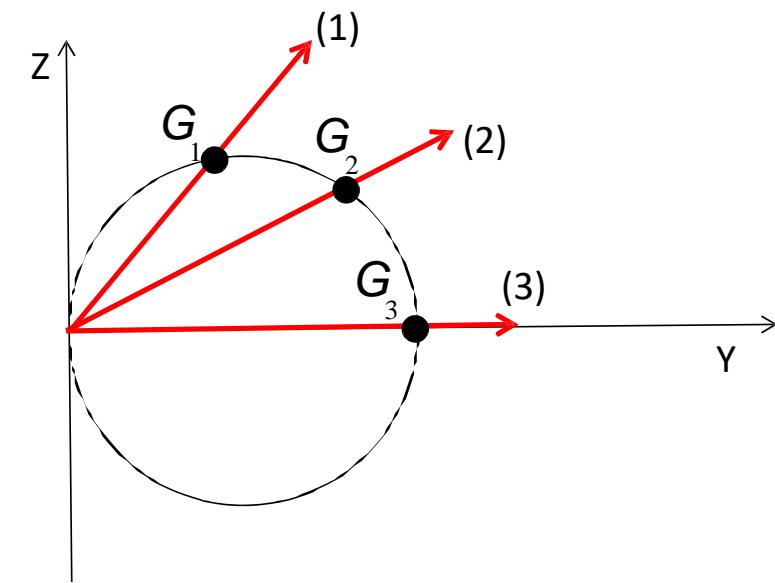
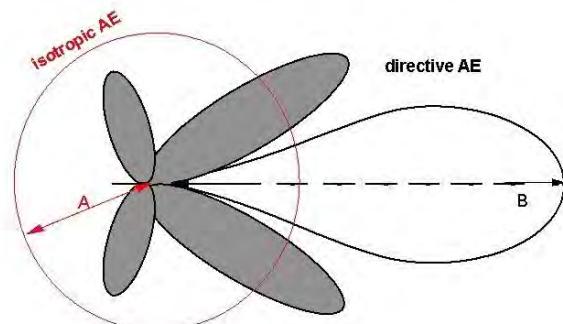
# Antenna parameters and Basics

## Antenna Directivity

The relationship between the power density radiated in one direction and at a distance R, relative to the power density radiated at the same distance from an isotropic antenna.

$$D(\theta, \phi) = \frac{\mathcal{P}(\theta, \phi)}{P_t / 4\pi R^2}$$

θ: azimuth angle  
ϕ: elevation angle



# Antenna parameters and Basics

## Antenna Directivity

If no direction is specified, the Directivity means the power density radiated in the [direction of maximum radiation](#)

$$D = \frac{P_{max}}{P_t / 4\pi R^2}$$

The losses between the transmitter output power and the radiated power are usually computed as the antenna [radiation efficiency](#) ( $\eta_r$ ), as a reduction of the transmitted power.

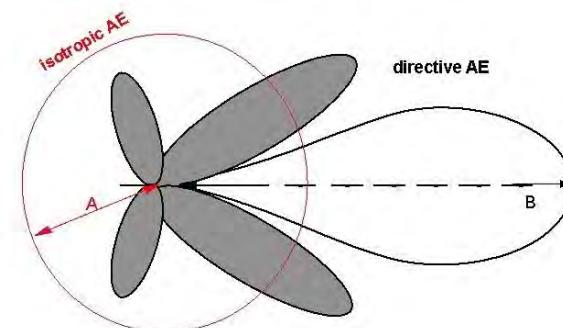


# Antenna parameters and Basics

## Antenna gain:

The relationship between the power density radiated in one direction and at a distance R, relative to the power density radiated at the same distance from an isotropic antenna by the power delivered to the antenna. It takes into account the [radiation efficiency](#)  $\eta_r$ .

$$G(\theta, \phi) = \frac{\mathcal{P}(\theta, \phi)}{P_{delivered}/4\pi R^2} = \frac{P_{radiated}}{P_{delivered}} \cdot \frac{\mathcal{P}(\theta, \phi)}{P_{radiated}/4\pi R^2} = \eta_r \cdot D(\theta, \phi)$$



# Densitat de potència radiada

- La **potència isotòpica radiada equivalent (PIRE)** és el resultat del producte de la potència del transmissor pel guany de l'antena transmissora.

$$\text{PIRE} = P_T \cdot G_T \quad (\text{W})$$

- La **densitat de potència  $\mathcal{P}$** , expressada en **watts/m<sup>2</sup>** es defineix com el quocient entre la potència isotòpica radiada equivalent (PIRE) i  $4\pi$  pel quadrat de la distància a l'antena transmissora des d'on mesurem aquesta densitat de potència. Aquesta densitat **s'atenua** amb el **quadrat de la distància** a l'antena transmissora.

$$\mathcal{P} = \frac{\text{PIRE}}{4\pi \cdot R^2} \quad (\text{W}/\text{m}^2)$$

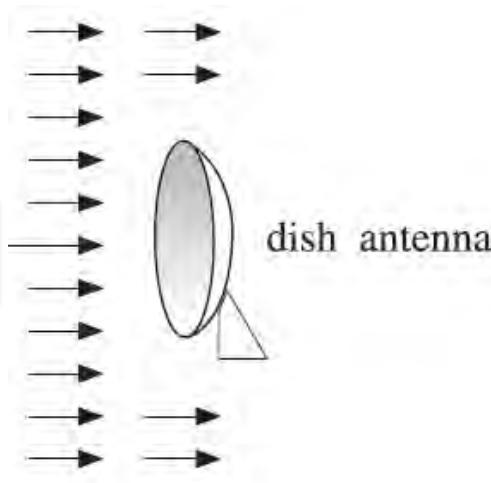
# Antenna parameters and Basics

## Effective Area

Capacity of the antenna to capture energy. Related with its physical dimensions through the **antenna illumination efficiency**  $\eta_i$ :

$$A_{eff}(\theta, \phi) = \eta_i A_{phys}(\theta, \phi)$$

$$\mathcal{P} = \frac{EIRP}{4\pi R^2} \quad (W/m^2)$$



$$P_R = \mathcal{P} \cdot A_{eff} = \frac{EIRP}{4\pi R^2} \cdot A_{eff} = \frac{P_T G_T}{4\pi R^2} \cdot A_{eff} \quad (W)$$

# Antenna parameters and Basics

## RELATION BETWEEN GAIN AND EFFECTIVE AREA

Capacity of the antenna to capture energy. Related with its physical dimensions

$$\frac{D}{A_{eff}} = \frac{4\pi}{\lambda^2}$$

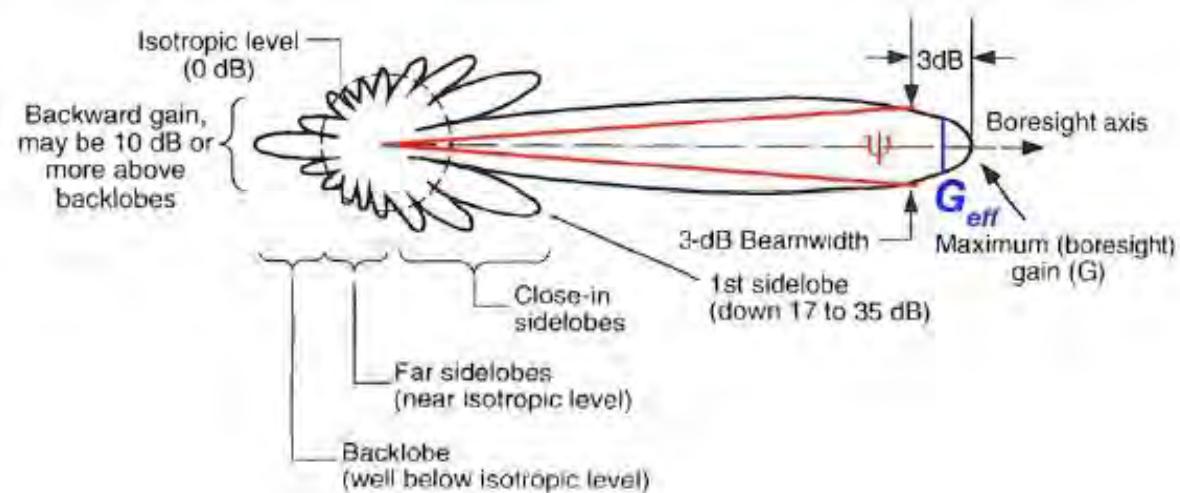
$\lambda$ : Carrier wavelength =  $\frac{c}{f}$

$c$ : speed of light =  $3 \cdot 10^8$  m/s



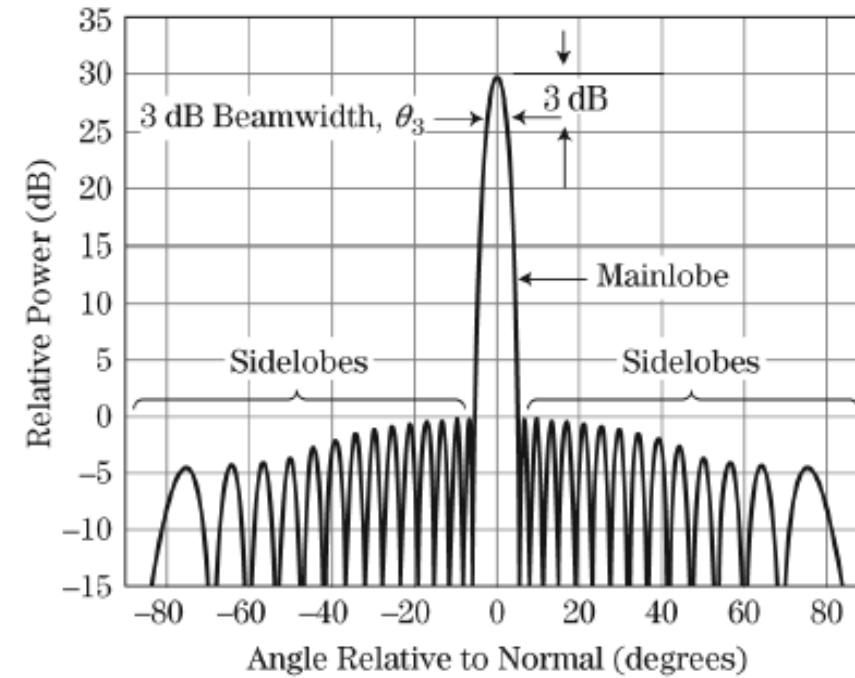
# Antenna parameters and Basics

Diagram of radiation

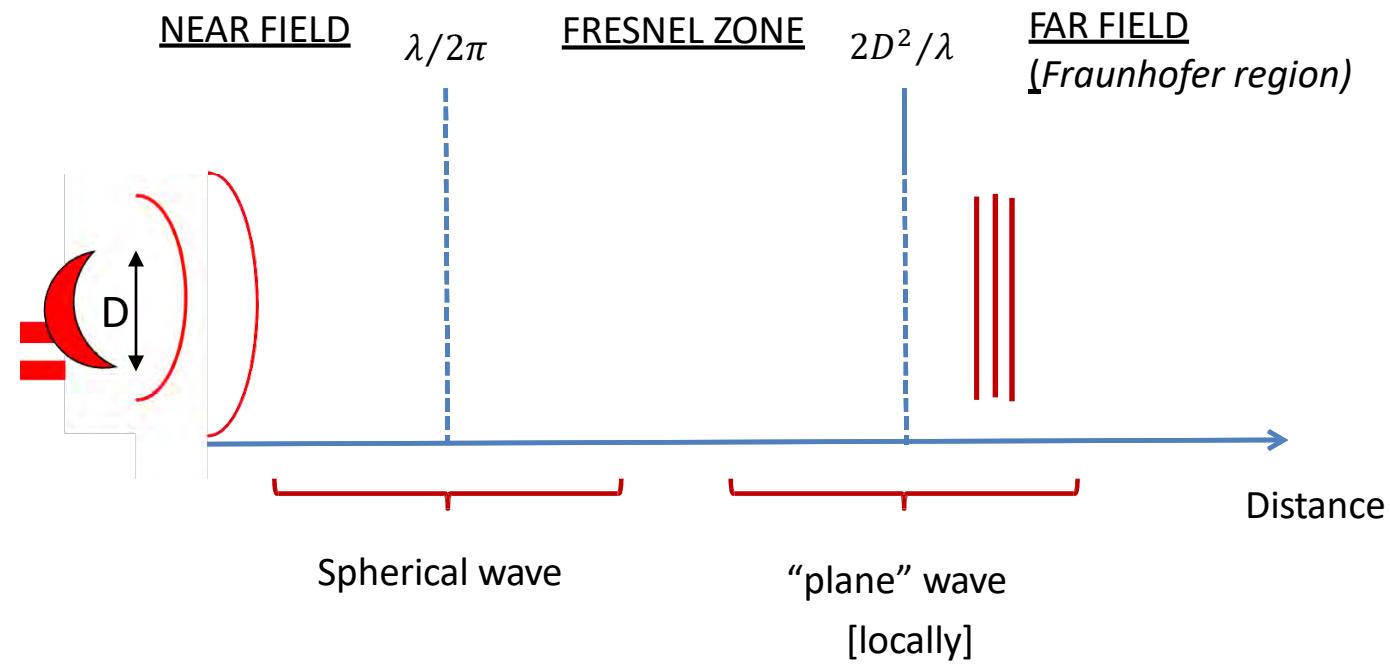


# Antenna parameters and Basics

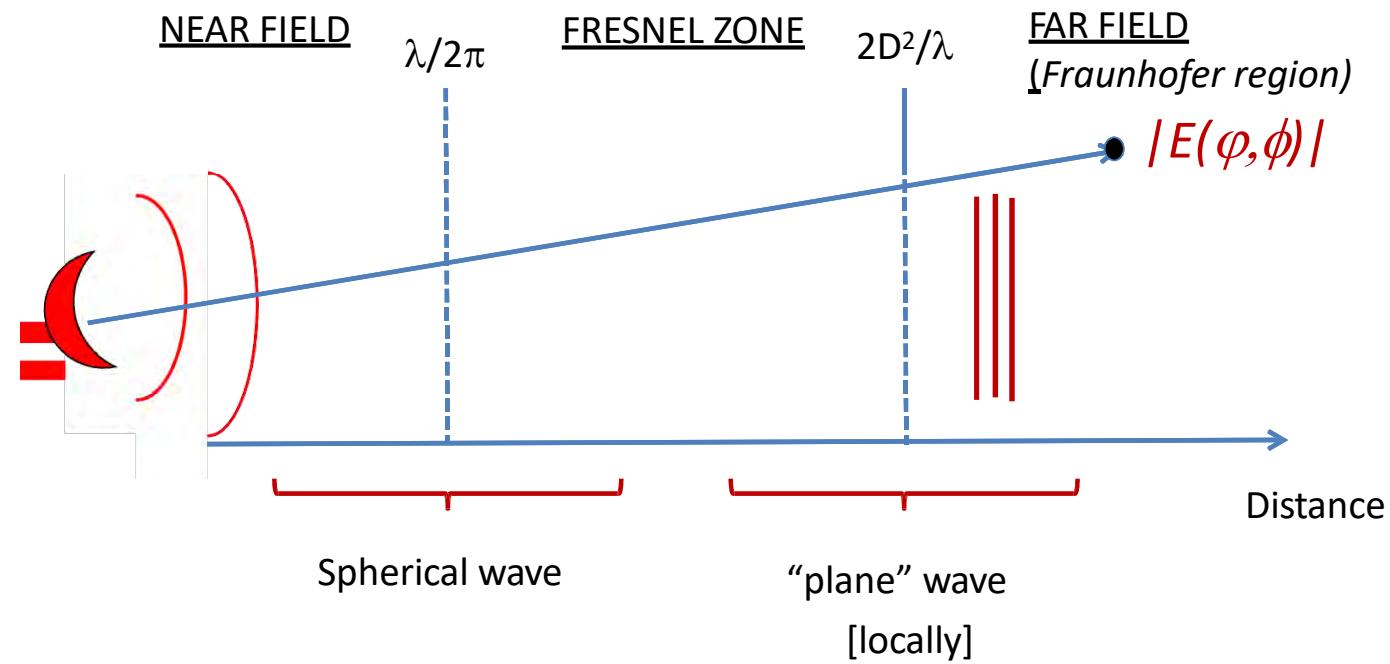
Diagram of radiation



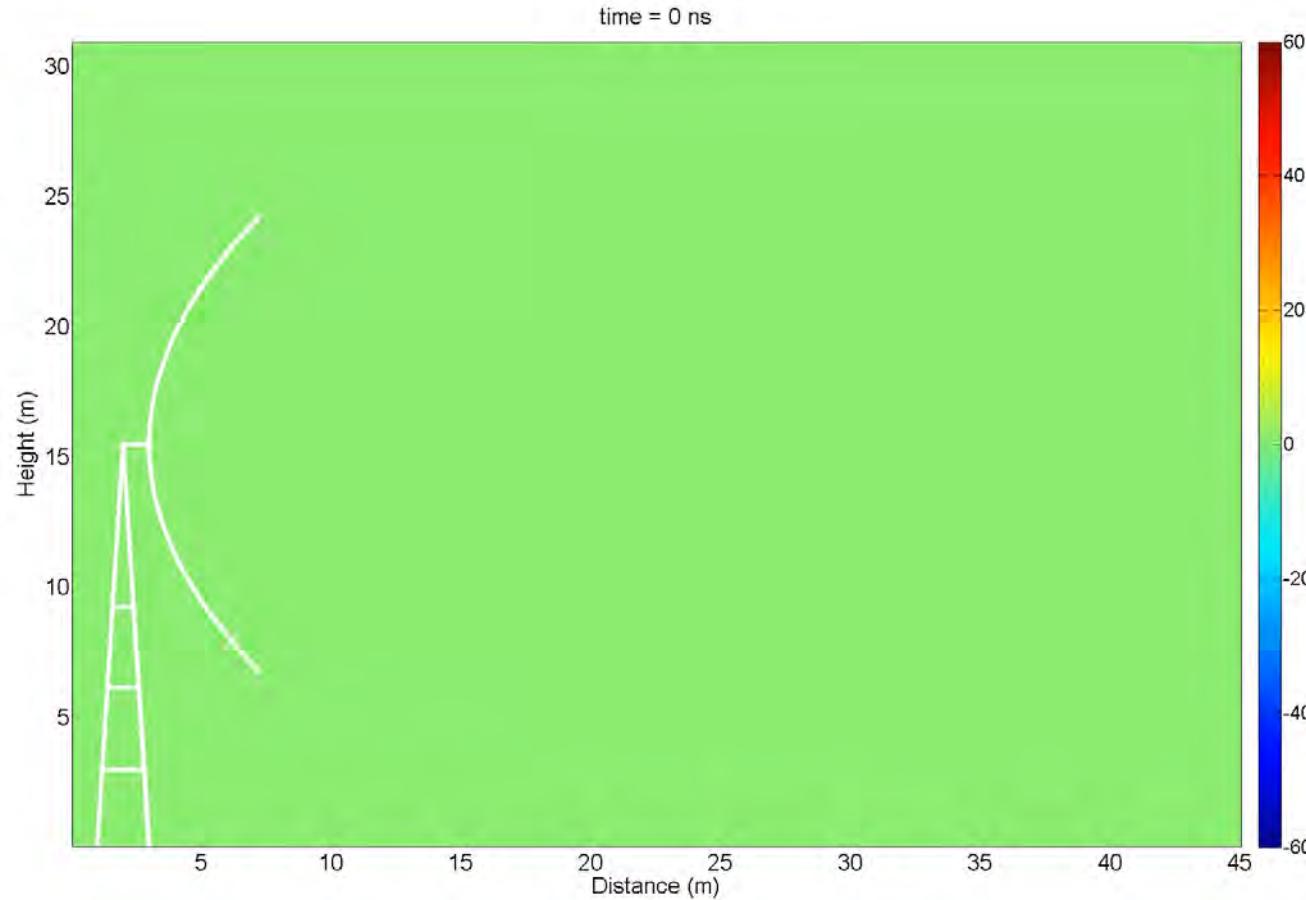
# Antenna parameters and Basics



# Antenna parameters and Basics

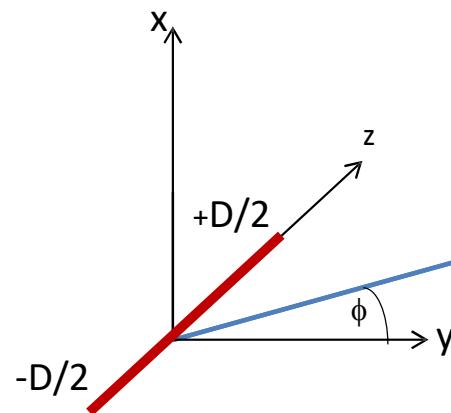


# Generació d'una ona electromagnètica en un reflector parabòlic.



# Antenna radiation pattern and aperture illumination

FAR FIELD RADIATION PATTERN



Inverse Fourier Transform:

$$s(t) = \int_{-\infty}^{+\infty} S(f) e^{j2\pi f t} df$$

$E(\phi)$

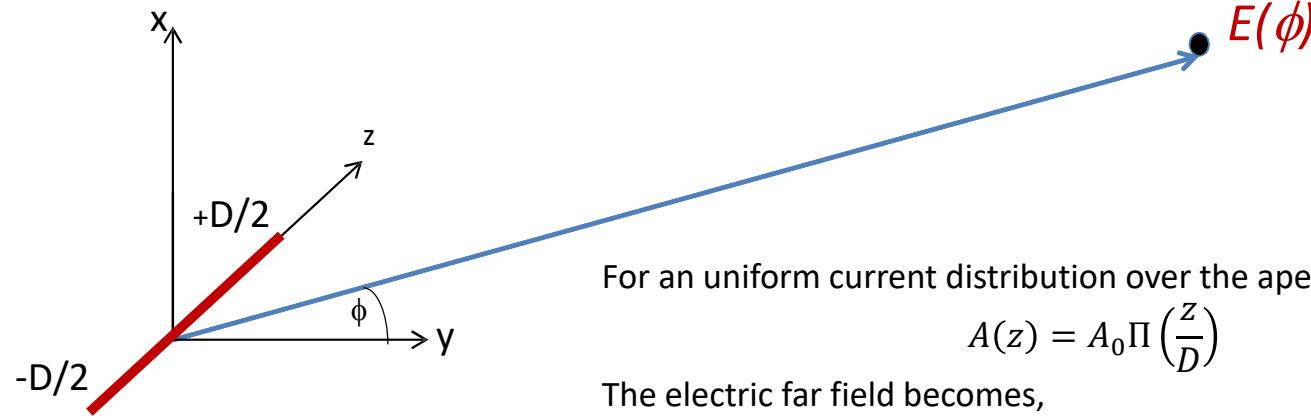
$$E(\phi) = \int_{-D/2}^{+D/2} A(z) e^{j2\pi \frac{z}{\lambda} \sin \phi} dz$$

$A(z)$ : Current distribution along the antenna

The electric far field pattern is the inverse Fourier transform of the aperture illumination.

# Antenna radiation pattern and aperture illumination

FAR FIELD RADIATION PATTERN



For an uniform current distribution over the aperture,

$$A(z) = A_0 \Pi\left(\frac{z}{D}\right)$$

The electric far field becomes,

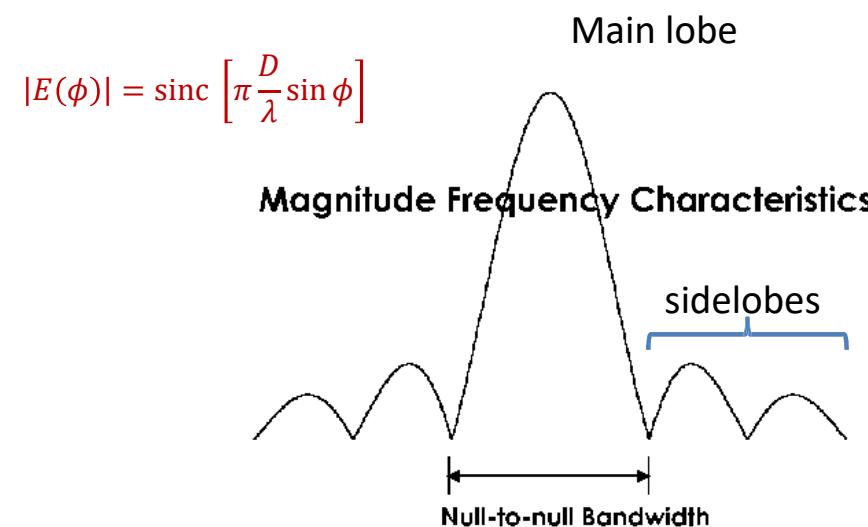
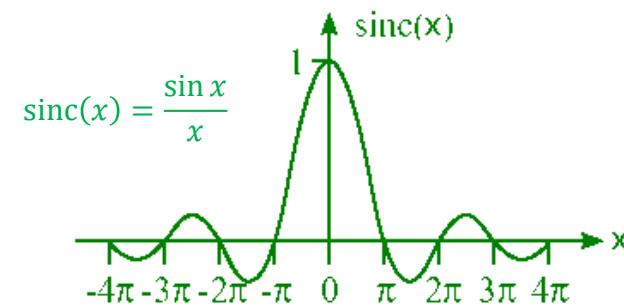
$$E(\phi) = A_0 \int_{-a/2}^{a/2} e^{j2\pi\frac{z}{\lambda} \sin \phi} dz = A_0 D \frac{\sin[\pi(D/\lambda) \sin \phi]}{\pi(D/\lambda) \sin \phi}$$

And after normalizing  $E(0)=1$ , then we obtain:

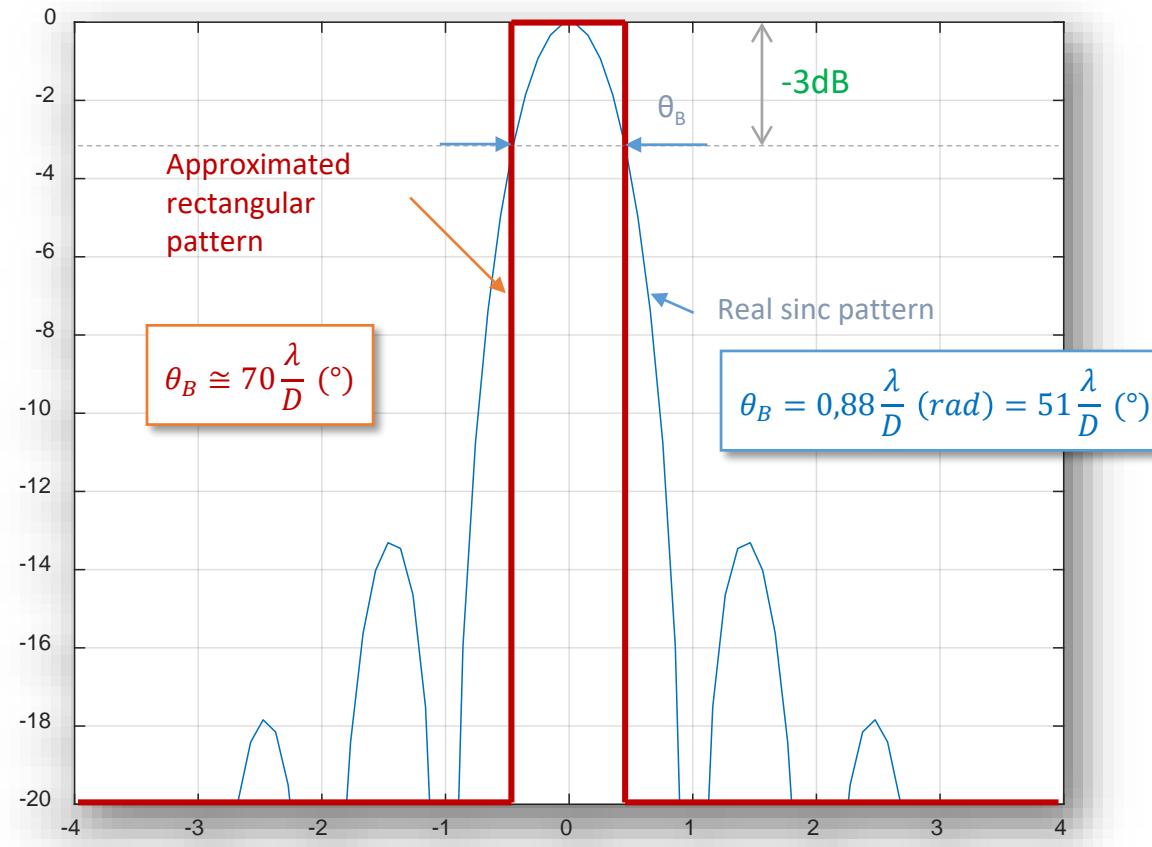
$$E(\phi) = \frac{\sin[\pi(D/\lambda) \sin \phi]}{\pi(D/\lambda) \sin \phi} = \text{sinc}\left[\pi \frac{D}{\lambda} \sin \phi\right]$$

# Antenna radiation pattern and aperture illumination

FAR FIELD RADIATION PATTERN



# Antenna radiation pattern and aperture illumination



# Antenna radiation gain in terms of the beam-width

The antenna gain can be calculated from the antenna beam-widths  $\theta_B$  and  $\phi_B$  by the following approximated equations:

Rectangular beam,  
without sidelobes



$$G \approx \frac{4\pi}{\theta_B \text{ (rad)} \phi_B \text{ (rad)}}$$

Gaussian beam



$$G \approx \frac{\pi^2}{\theta_B \text{ (rad)} \phi_B \text{ (rad)}}$$

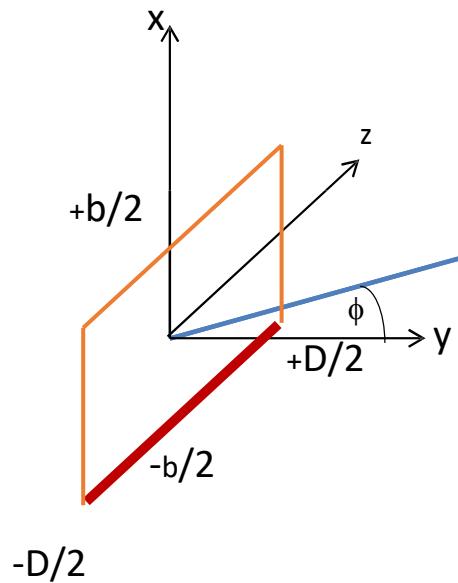
Practical antennas,  
*from Warren Stutzman*



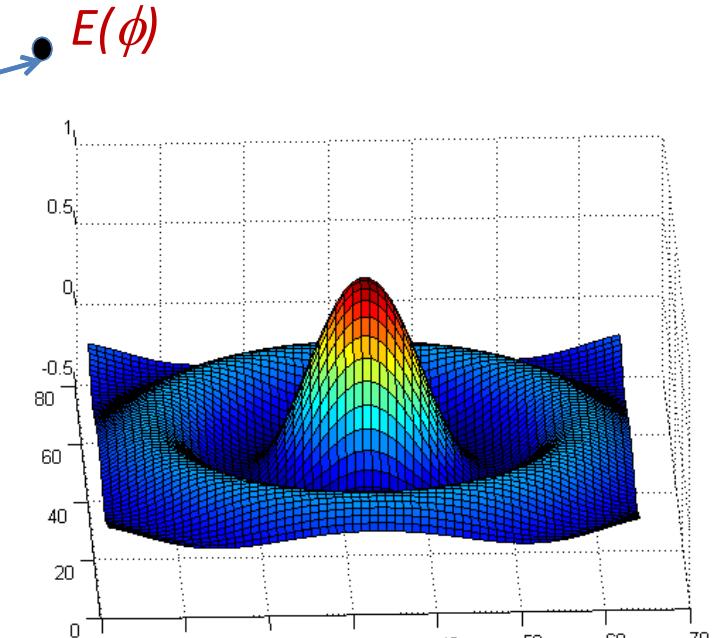
$$G \approx \frac{26000}{\theta_B \text{ (°)} \phi_B \text{ (°)}}$$

# Antenna radiation pattern and aperture illumination

FAR FIELD RADIATION PATTERN



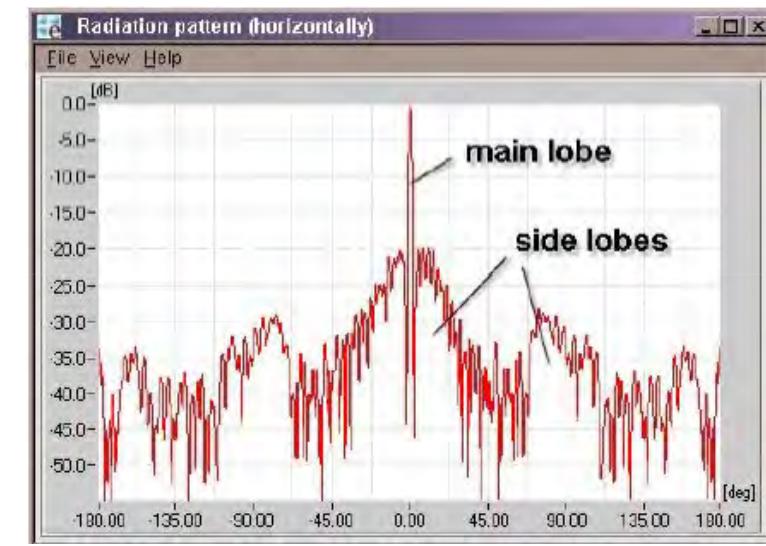
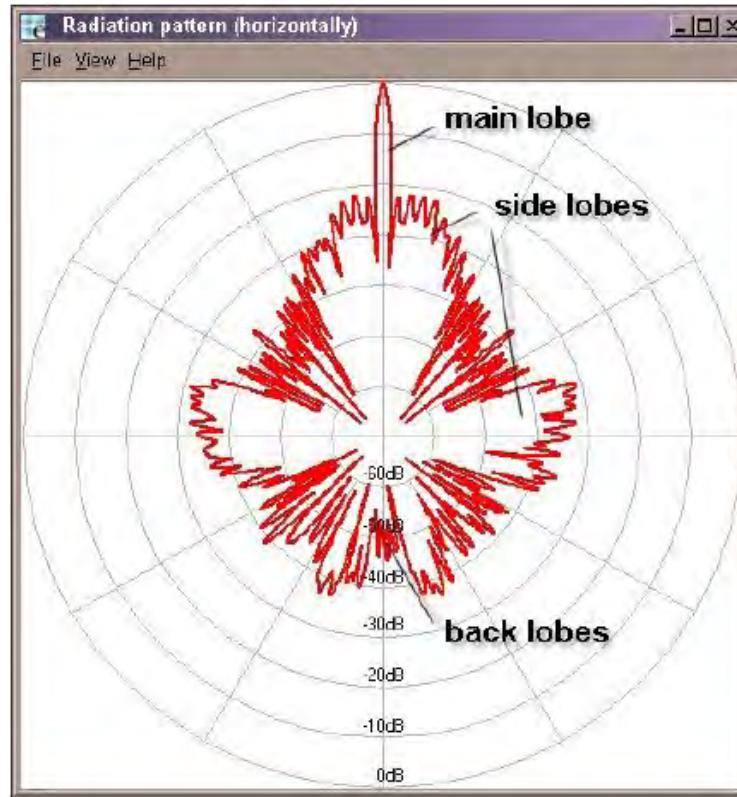
Bidimensional uniform  
aperture illumination



Bidimensional sinc  
radiation pattern

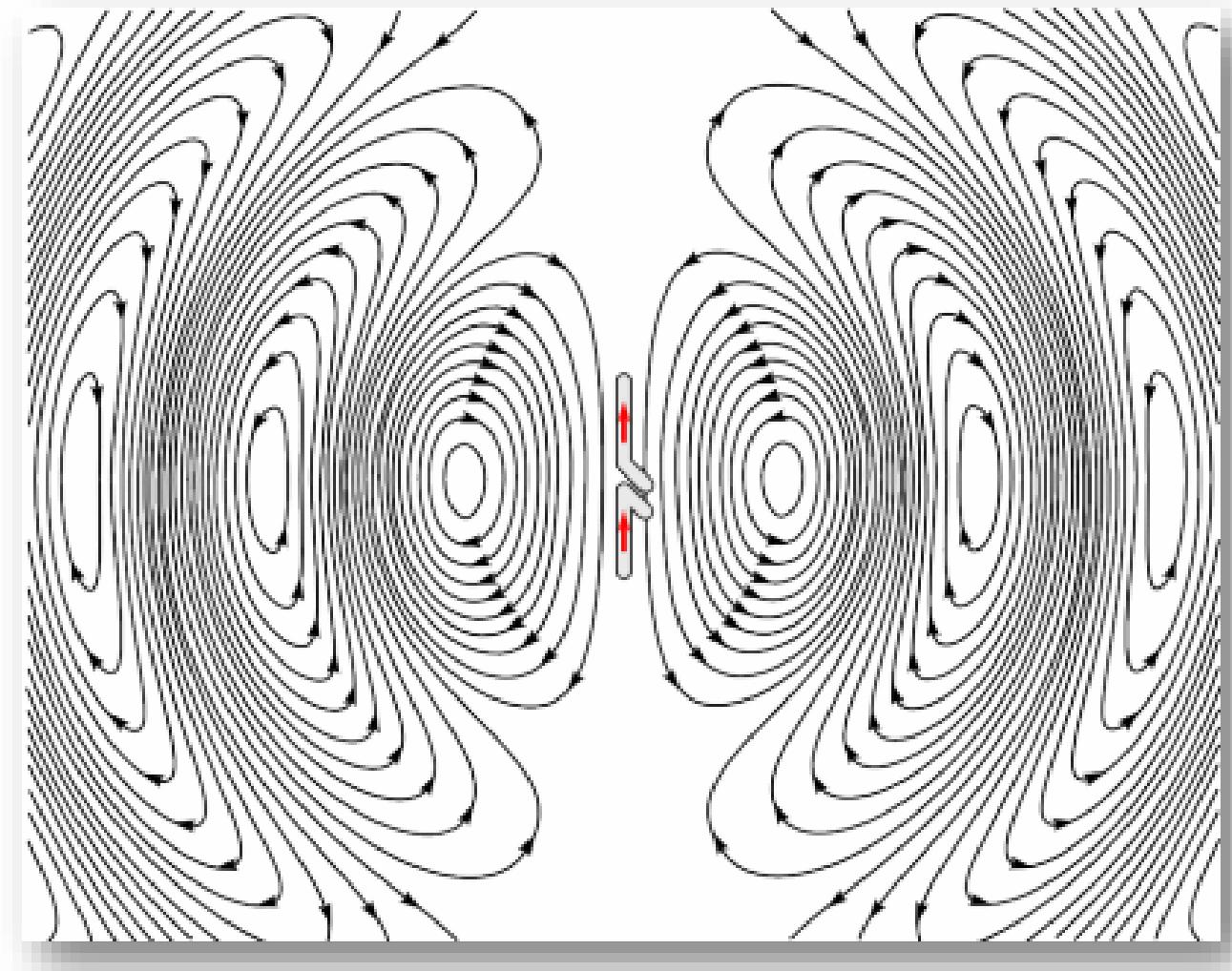
# Antenna radiation pattern and aperture illumination

FAR FIELD RADIATION PATTERN

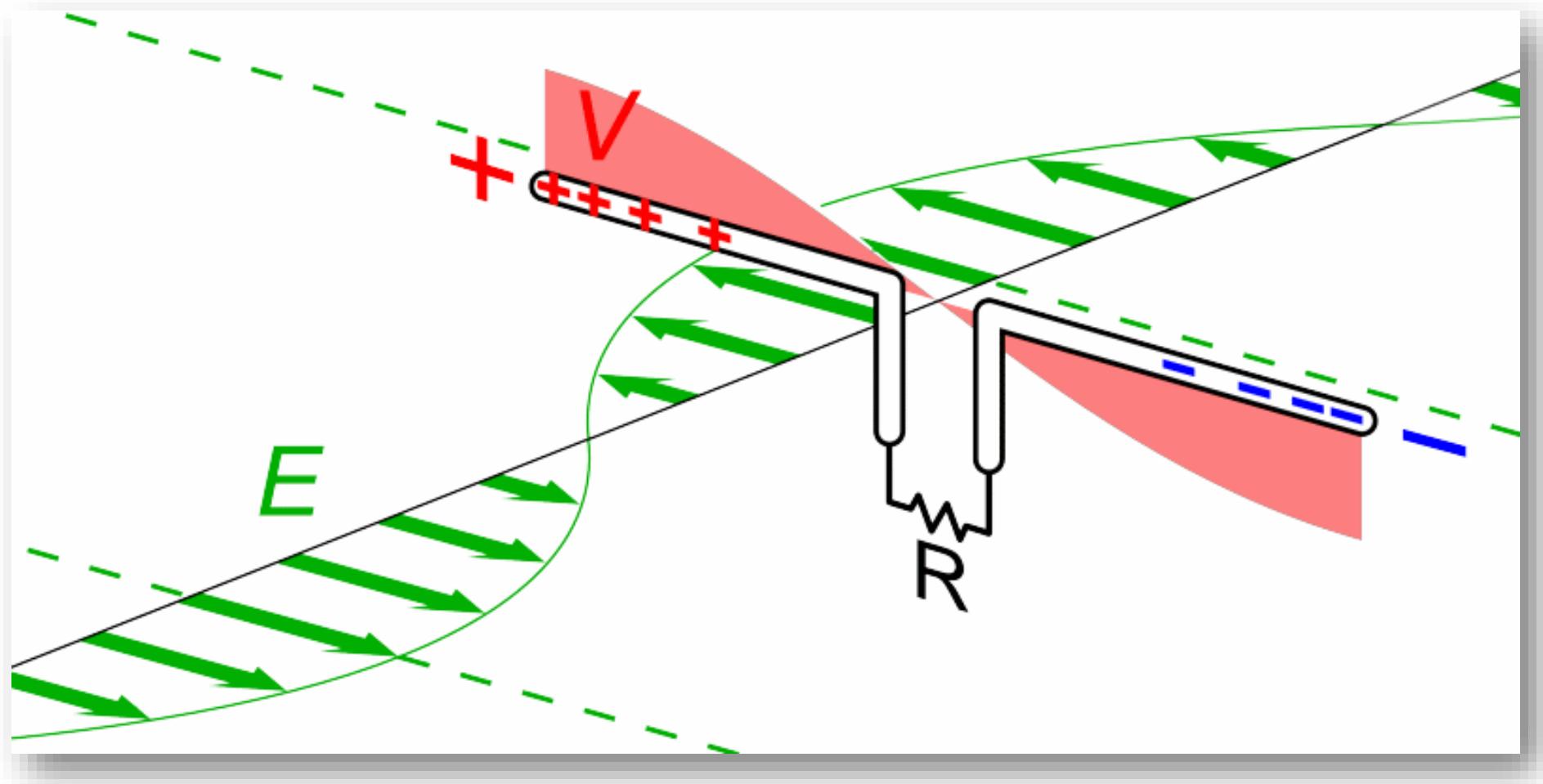


Bidimensional uniform aperture illumination

# Radiació electromagnètica d'una antena dipol



# Captació d'una ona electromagnètica per una antena dipol



# TEMPERATURA D'ANTENA

SOROLL EN ANTENES



UNIVERSITAT POLITÈCNICA DE CATALUNYA

BARCELONATECH

Departament de Teoria del Senyal  
i Comunicacions

# TEMPERATURA D'ANTENA

EN EL MARGE DE 100 kHz A 100 MHz.

Temperatura de soroll d'antena degut al soroll còsmic i al soroll atmosfèric.

Font: Jordan-Balmain, "Ondas electromagnéticas y sistemas radiantes."

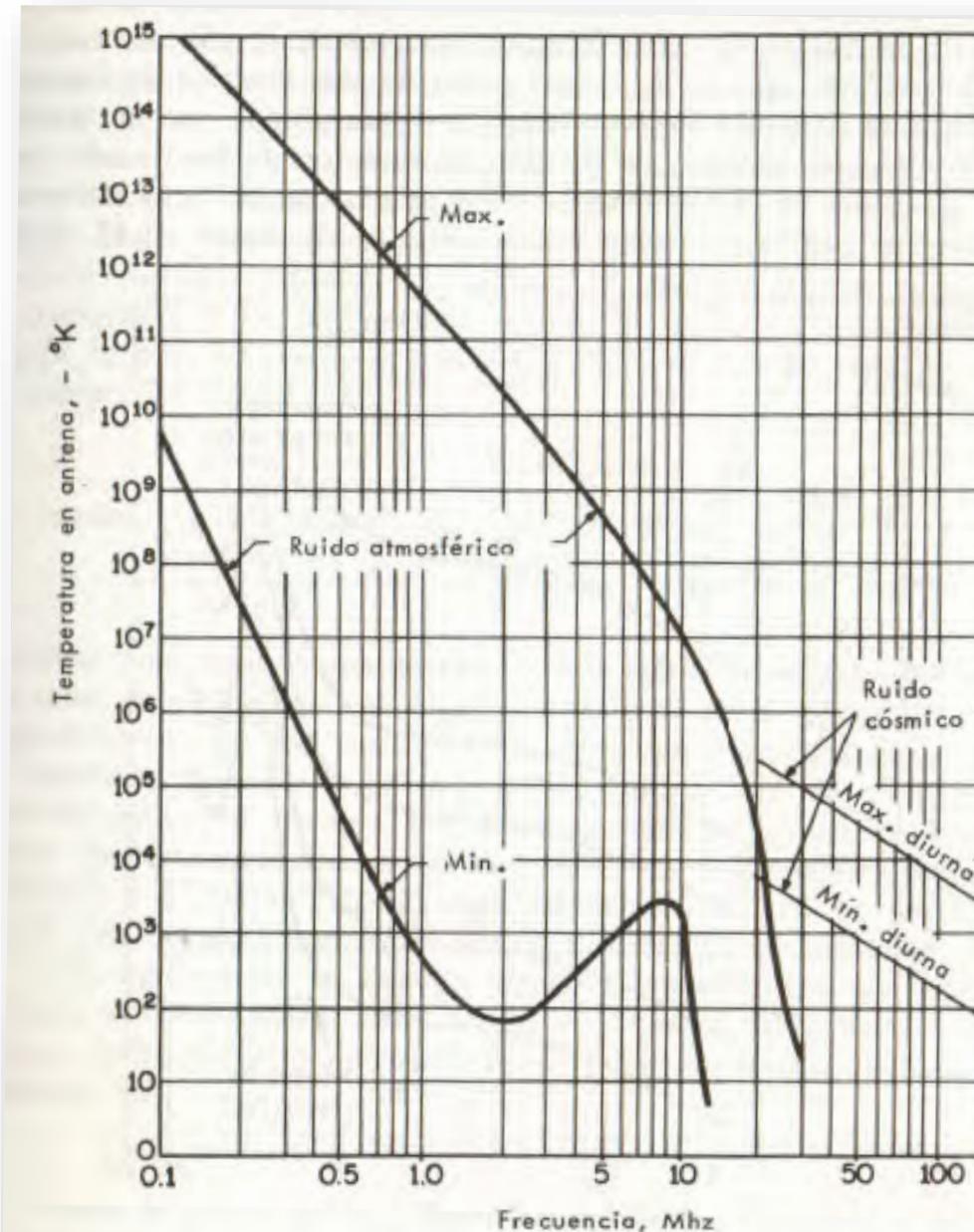


FIG. 11.44. Temperatura de ruido en frecuencias medias y altas (según E. C. Hayden).

# TEMPERATURA D'ANTENA

EN EL MARGE DE 100 MHz A 100 GHz.

Temperatura de soroll d'antena degut al soroll còsmic i a l'absorció d'oxigen, en funció de l'angle d'elevació per antenes apuntant cap a l'espai exterior.

Font: Jordan-Balmain, "Ondas electromagnéticas y sistemas radiantes."



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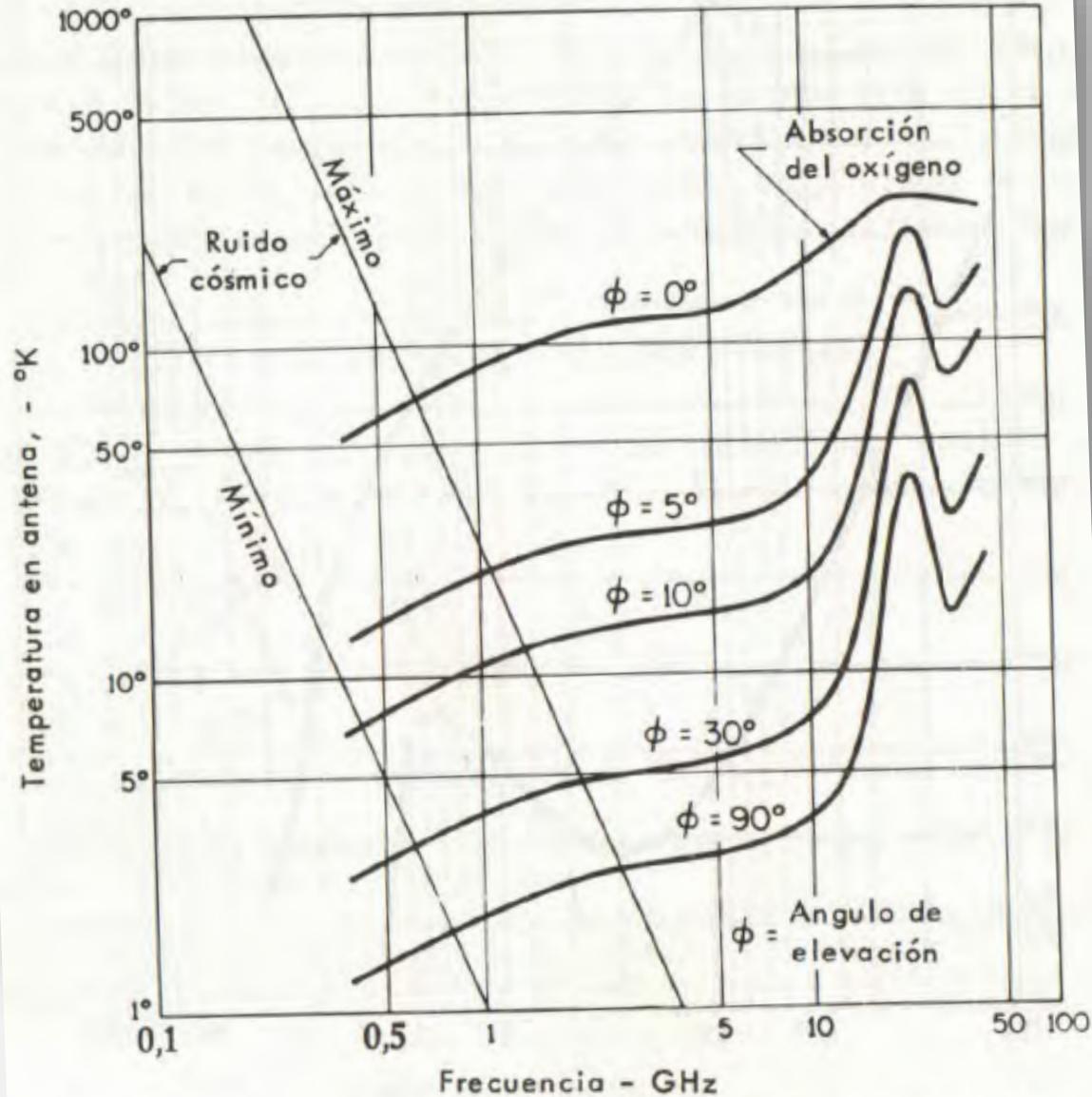
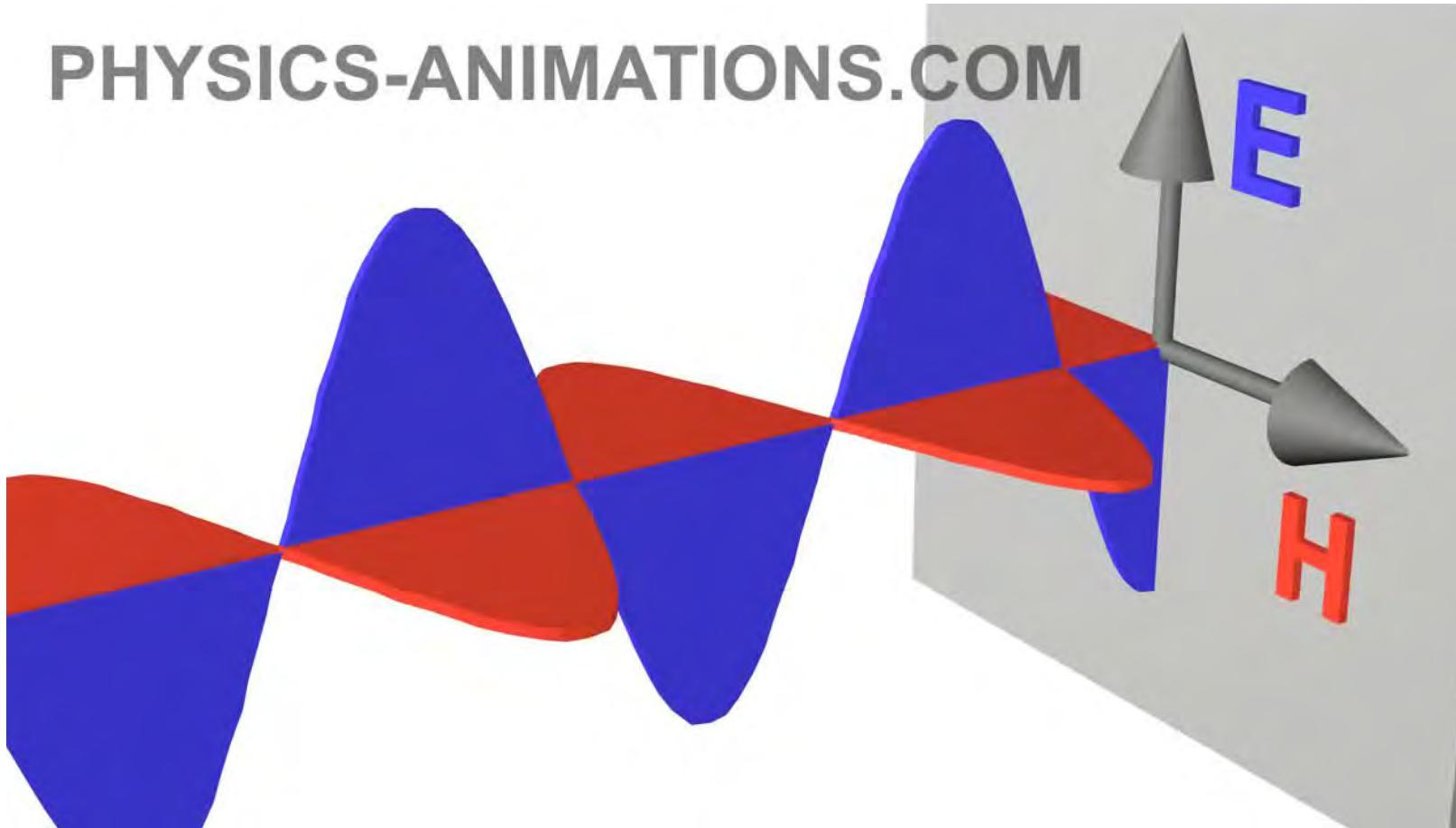


FIG. 11.45. Temperatura de ruido en frecuencias de microondas (Pierce y Kompfner, según D. C. Hogg).

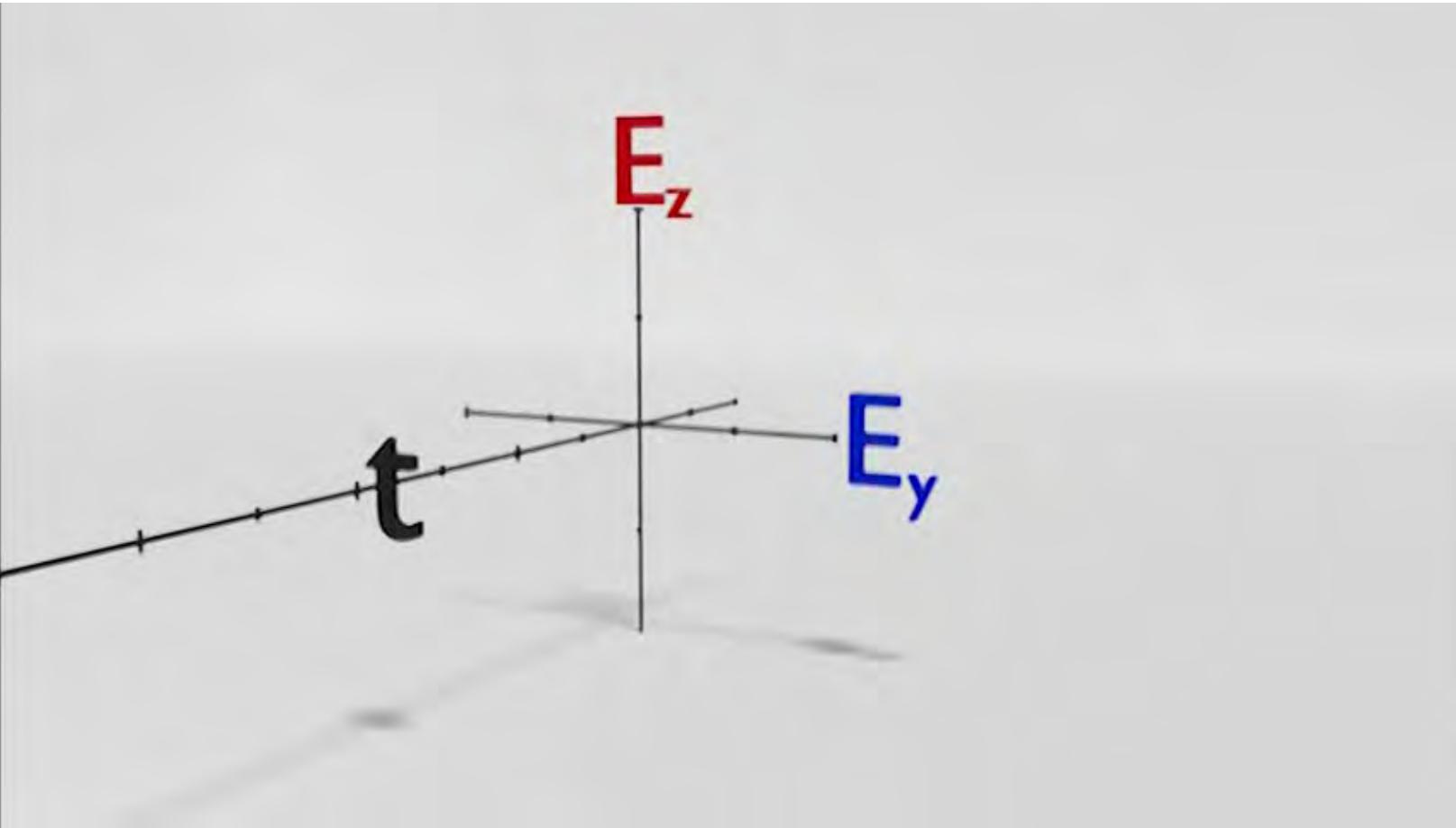
# Polarització



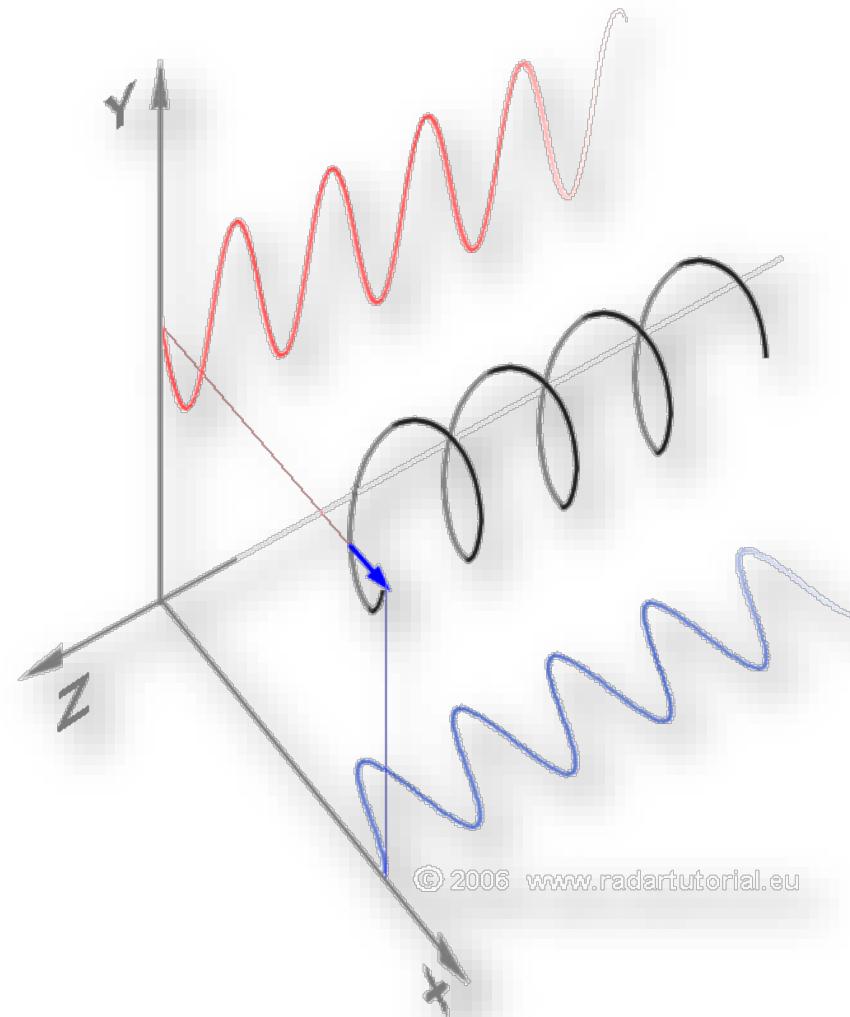
# Ona electromagnètica plana



# Polarització d'ones planes

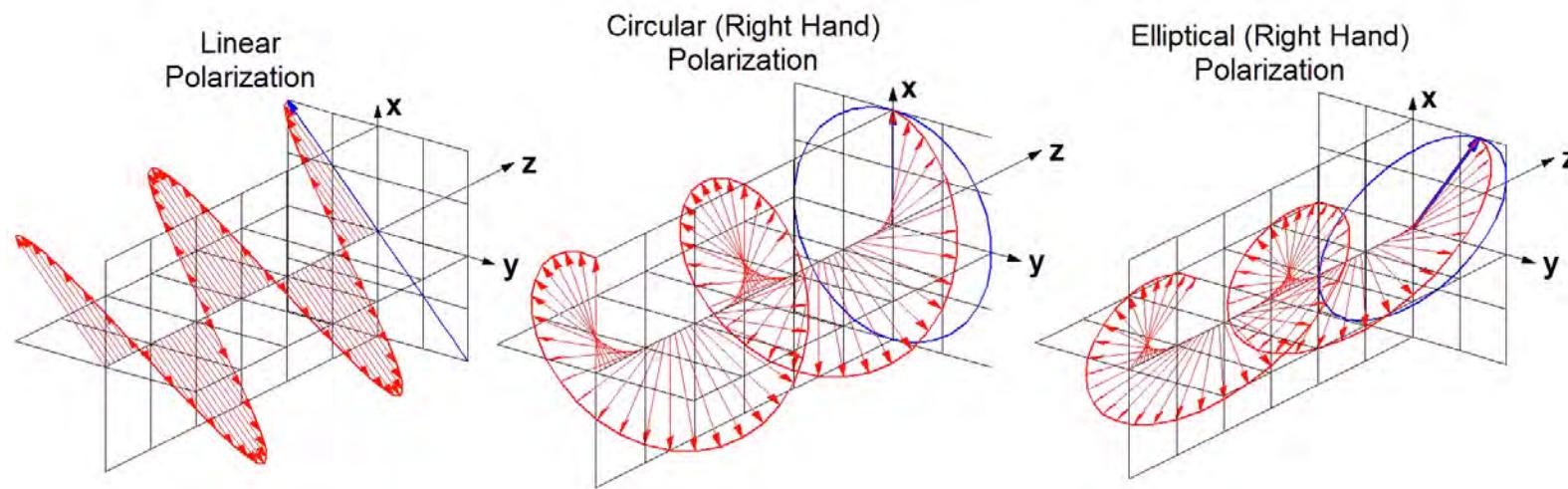


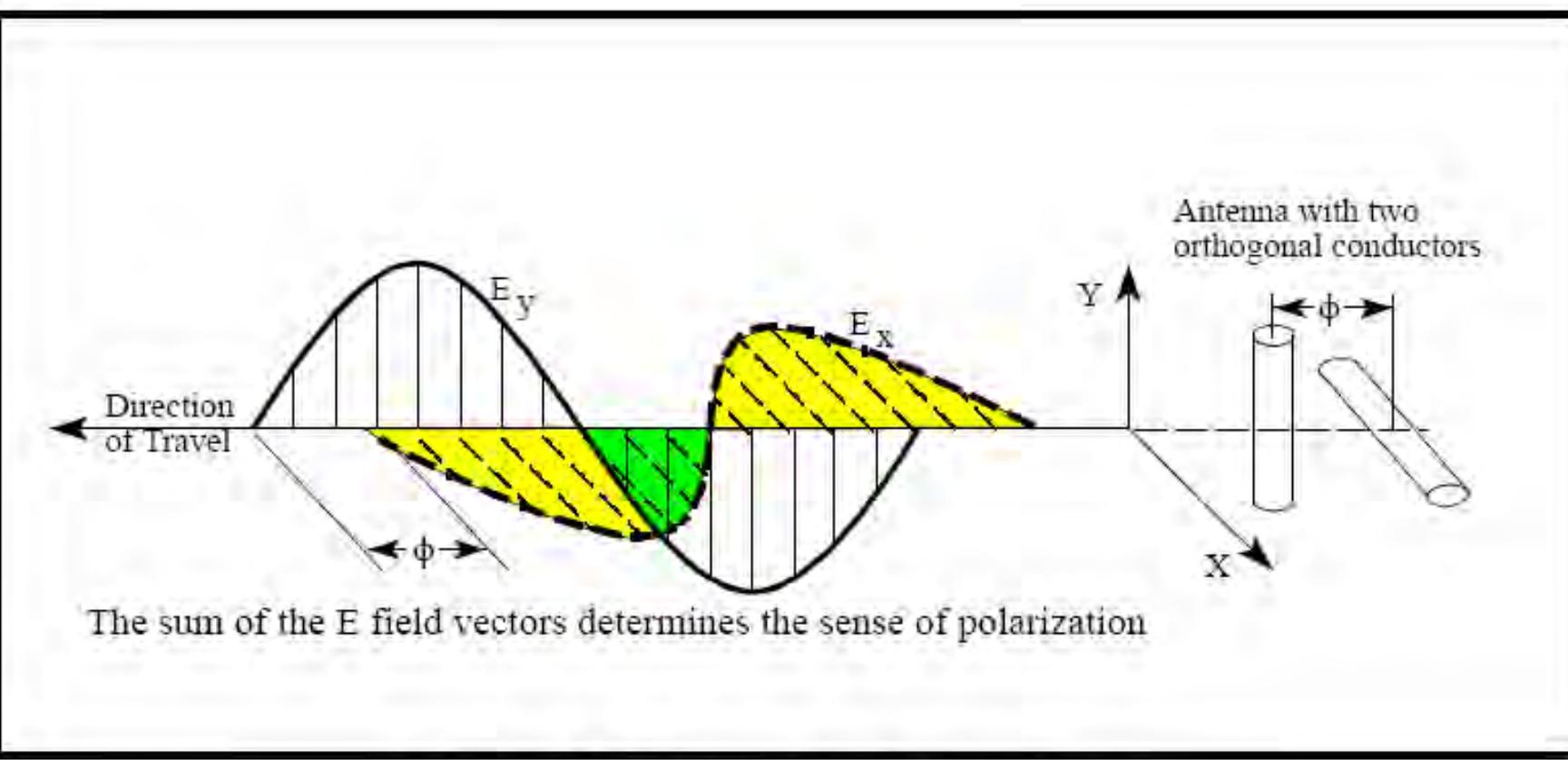
# Polarització circular d'ones planes



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# Polarització lineal, circular i el·líptica





**Figure 1.** Polarization Coordinates

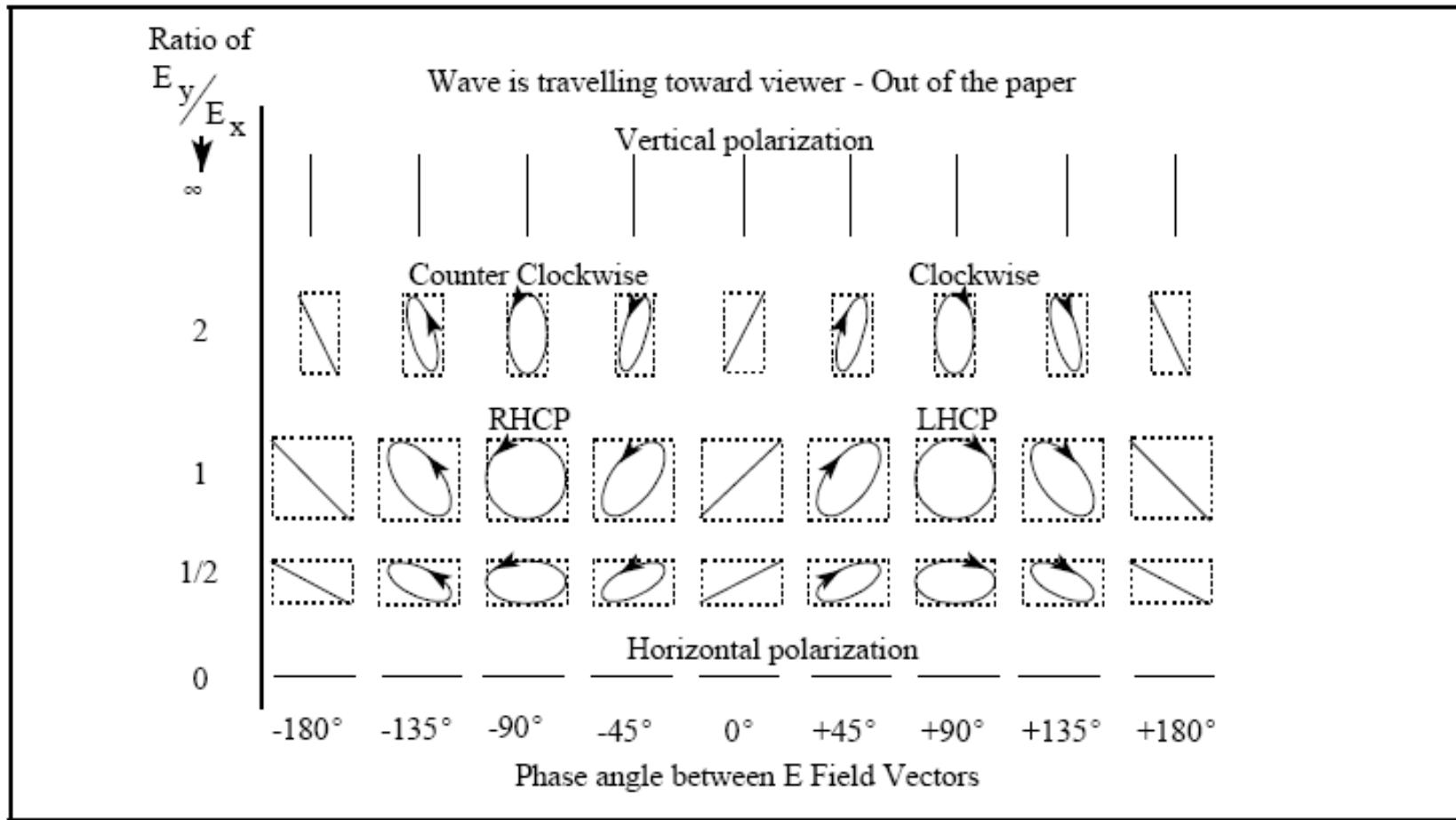
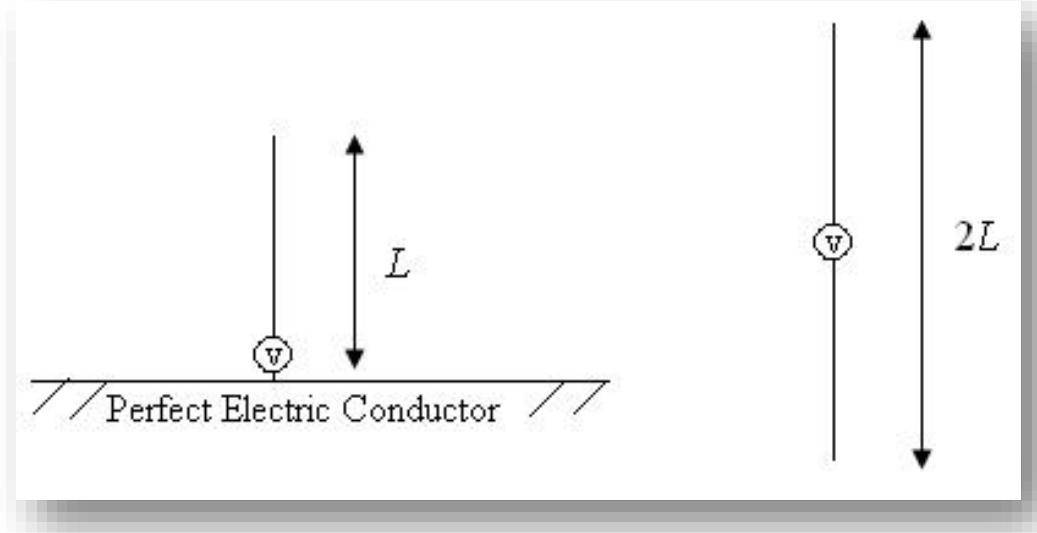


Figure 2. Polarization as a Function of  $E_y/E_x$  and Phase angle



# Antenes de fil

# Diagrama de radiació en funció de la llargada del dipol en termes de $\lambda$

	$H = \lambda/4$	$\Delta\theta_{-3dB} = 78^\circ$	$R_p = 73 \Omega$
	$H = 3\lambda/8$	$\Delta\theta_{-3dB} = 64^\circ$	$R_p = 360 \Omega$
	$H = \lambda/2$	$\Delta\theta_{-3dB} = 48^\circ$	$R_p = \infty \Omega$
	$H = 5\lambda/8$	$\Delta\theta_{-3dB} = 33^\circ$	$R_p = 210 \Omega$
	$H = 3\lambda/4$	$\Delta\theta_{-3dB} = 33^\circ$	$R_p = 99,5 \Omega$
	$H = \lambda$	$\Delta\theta_{-3dB} = 27^\circ$	$R_p = \infty \Omega$
		$\theta_{max} = 43^\circ$	$D = 2,17$
		$\theta_{max} = 57^\circ$	$D = 2,52$

Tabla 4.1 Parámetros de dipolos de diferentes longitudes

# Antenes d'escletxa

(Antenas de Ranura) (Slotted antennas)



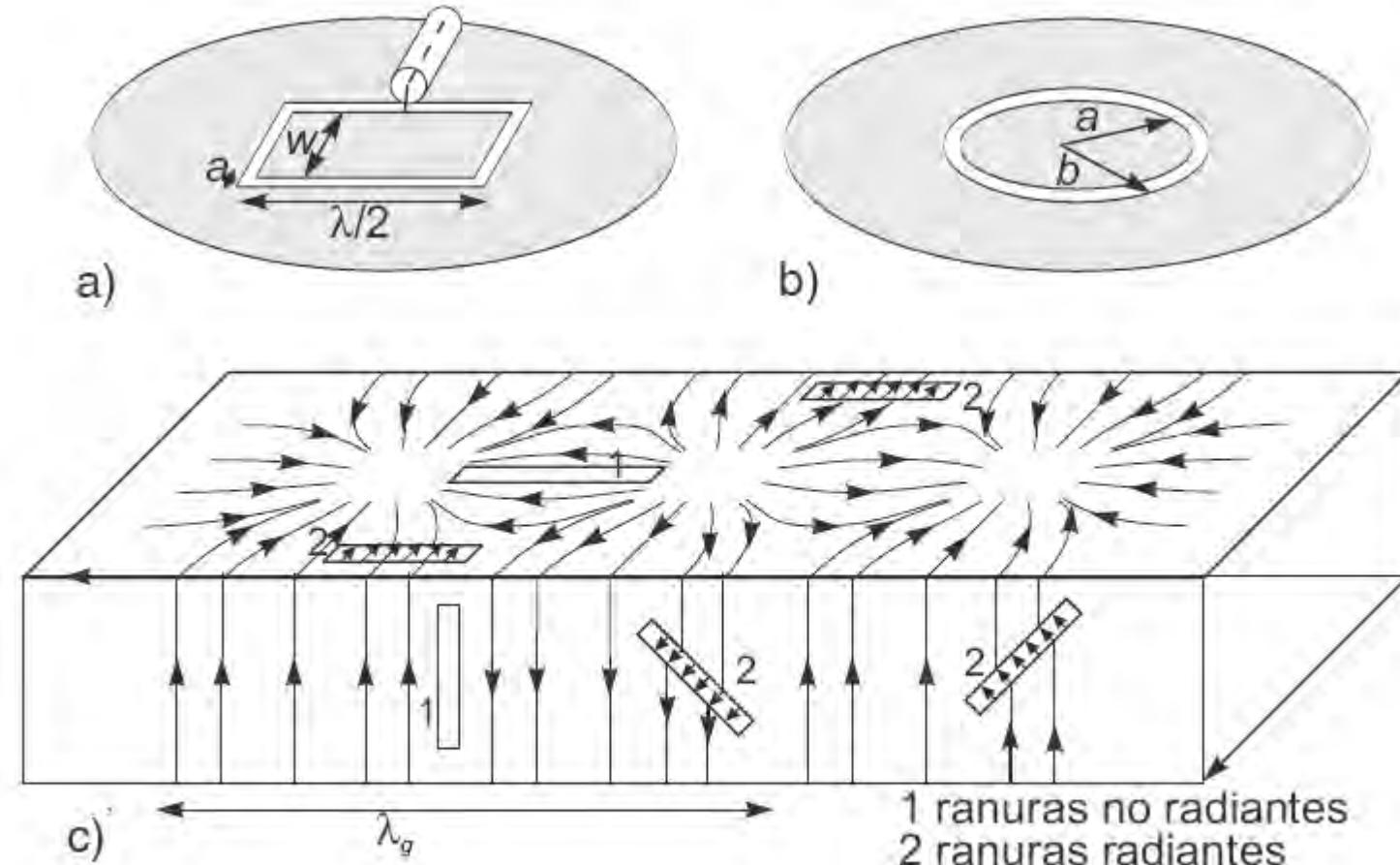
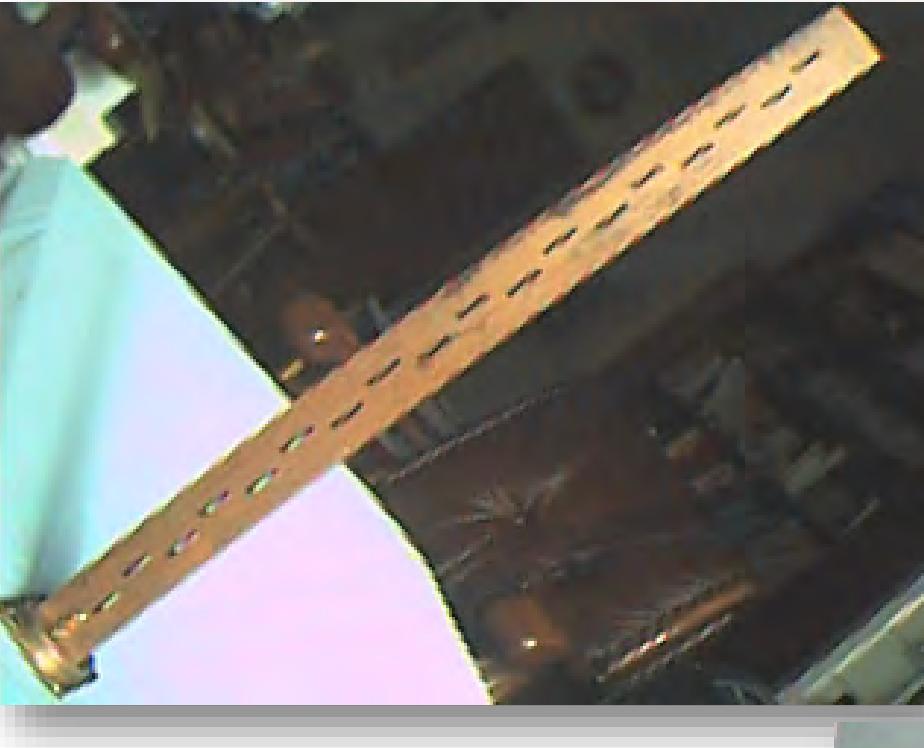


Fig. 6.21 Realizaciones habituales con ranuras: a) ranura doblada, b) coaxial abierto en un plano conductor y c) guía rectangular ranurada



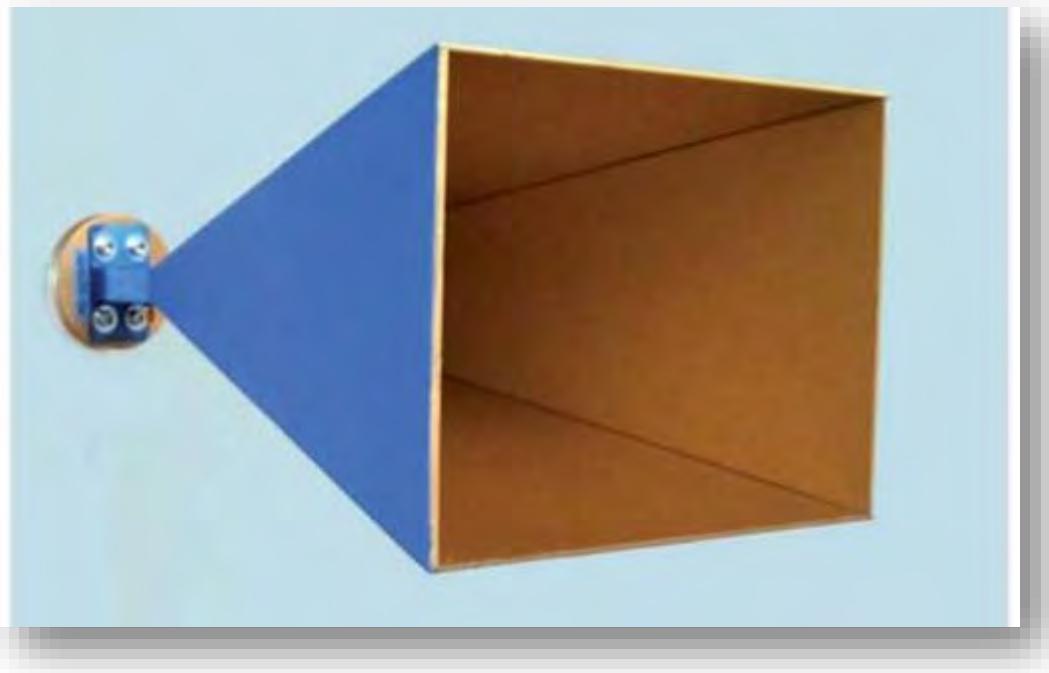


**Radar Sensors**

The NavNet 3D radar processor is incorporated into a Radome antenna or a gearbox for an open antenna. Simply plug in Ethernet and power cable connectors, and you will have a digital radar sensor within your NavNet 3D network. The IP address is automatically assigned to the radar sensor upon plugged into the network, facilitating real Plug and Play installation.

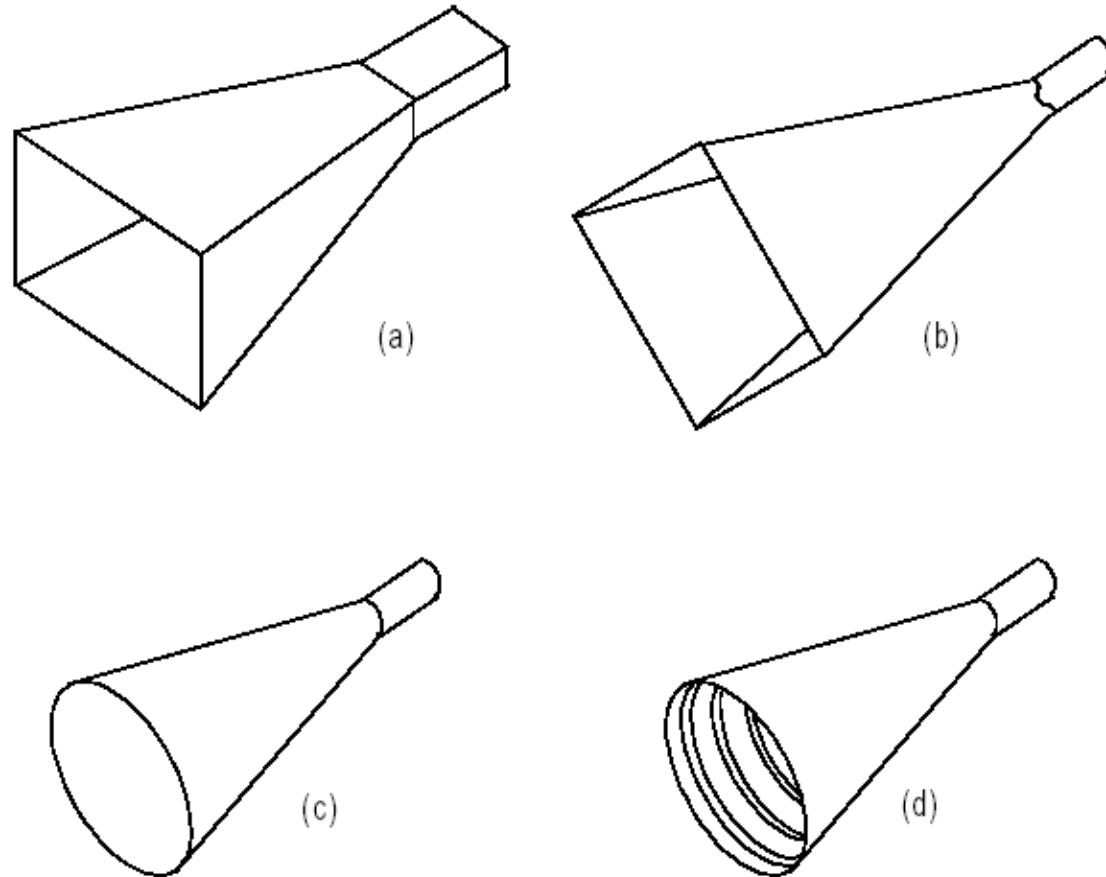
**NavNet 3D Radar Sensor Options**

	DRS2D	DRS4D	DRS4A	DRS6A	DRS12A	DRS25A
<b>Output Power</b>	2.2 kW	4 kW	4 kW	6 kW	12 kW	25 kW
<b>Size</b>	19 inch	24 inch	3.5 ft	4 ft	4 ft/6 ft	4 ft/6 ft
<b>Antenna Type</b>	Radome	Radome	Open	Open	Open	Open
<b>Beam Width</b>	Horizontal Vertical	5.2° 25°	4.0° 25°	2.3° 22°	1.9° 22°	1.9°/1.4° 22°/22°
<b>Max. Range</b>	24 nm	36 nm	48 nm	64 nm	72 nm	96 nm
<b>48 rpm Capability</b>	●	●	●	●	●	●



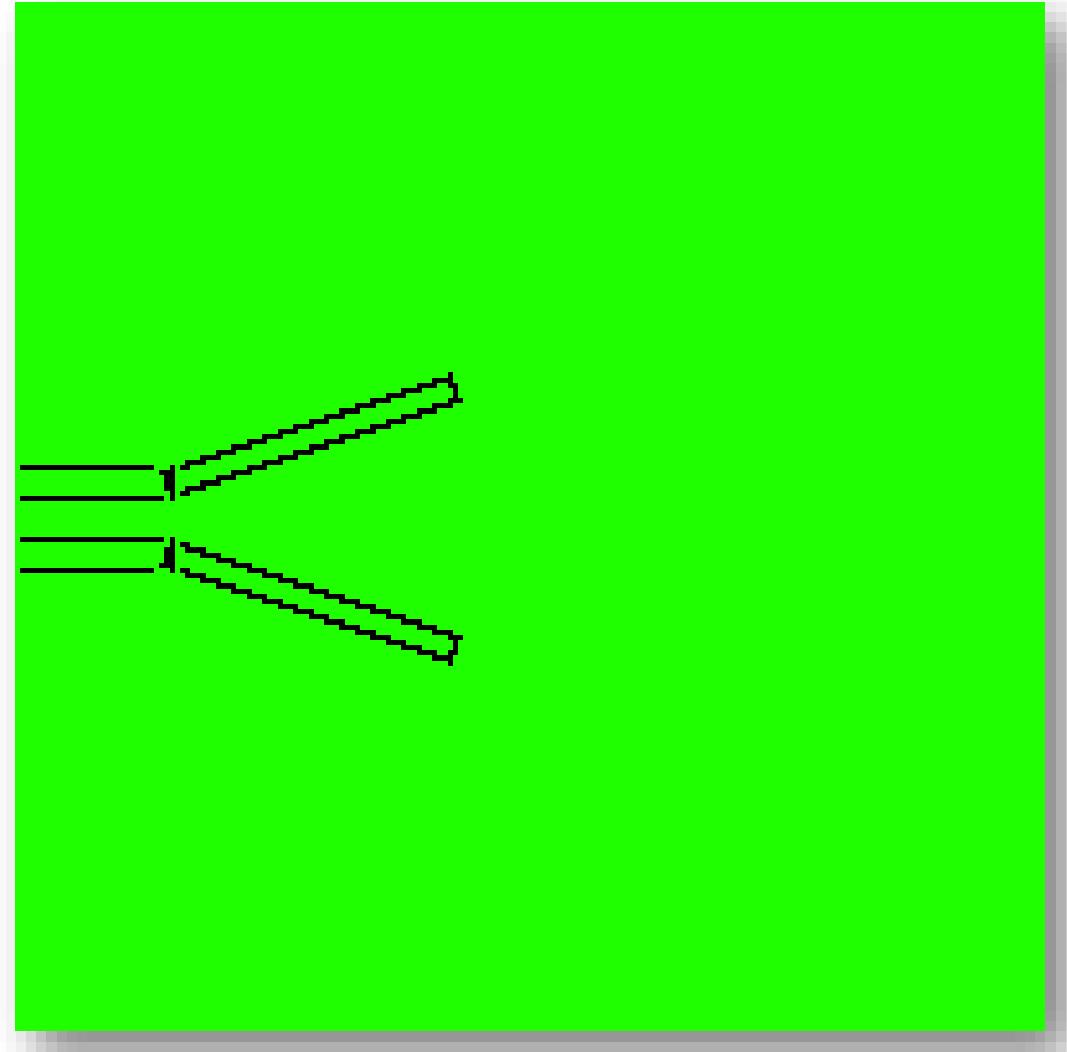
# Antenes d'obertura

# Antenes de botzina



**Figure A59** Common types of horn antennas: (a) pyramidal horn; (b) diagonal horn; (c) conical horn; (d) corrugated horn (after Currie, 1987, Fig. 12.12, p. 539).

# Antenes de botzina en transmissió



# Antenes de reflector

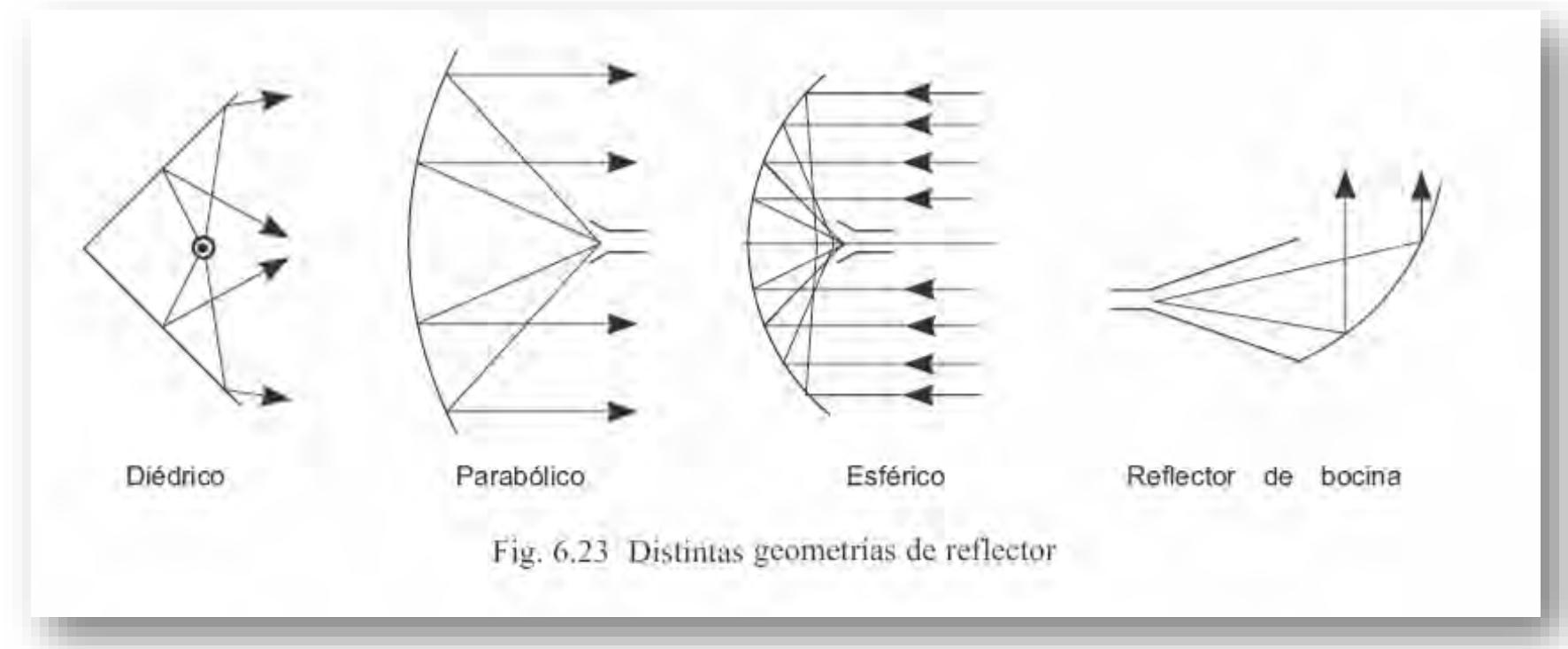
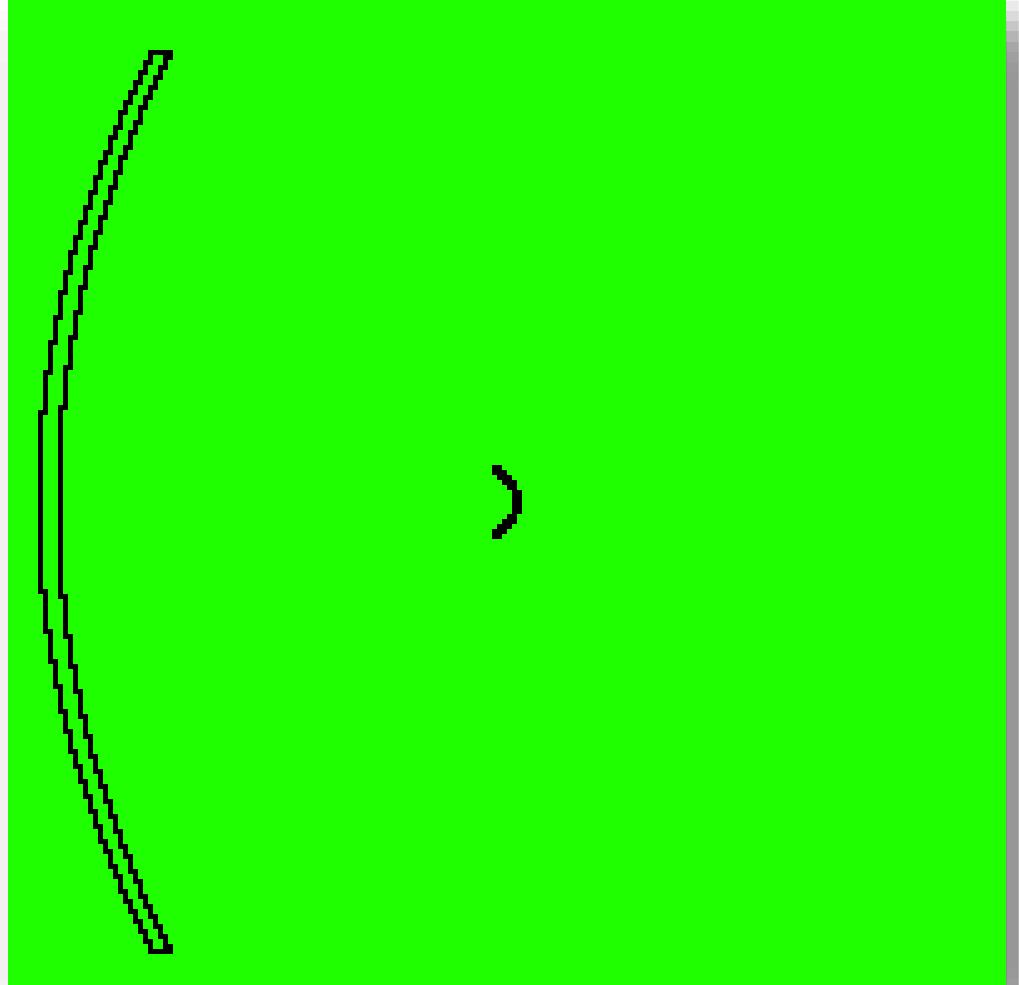
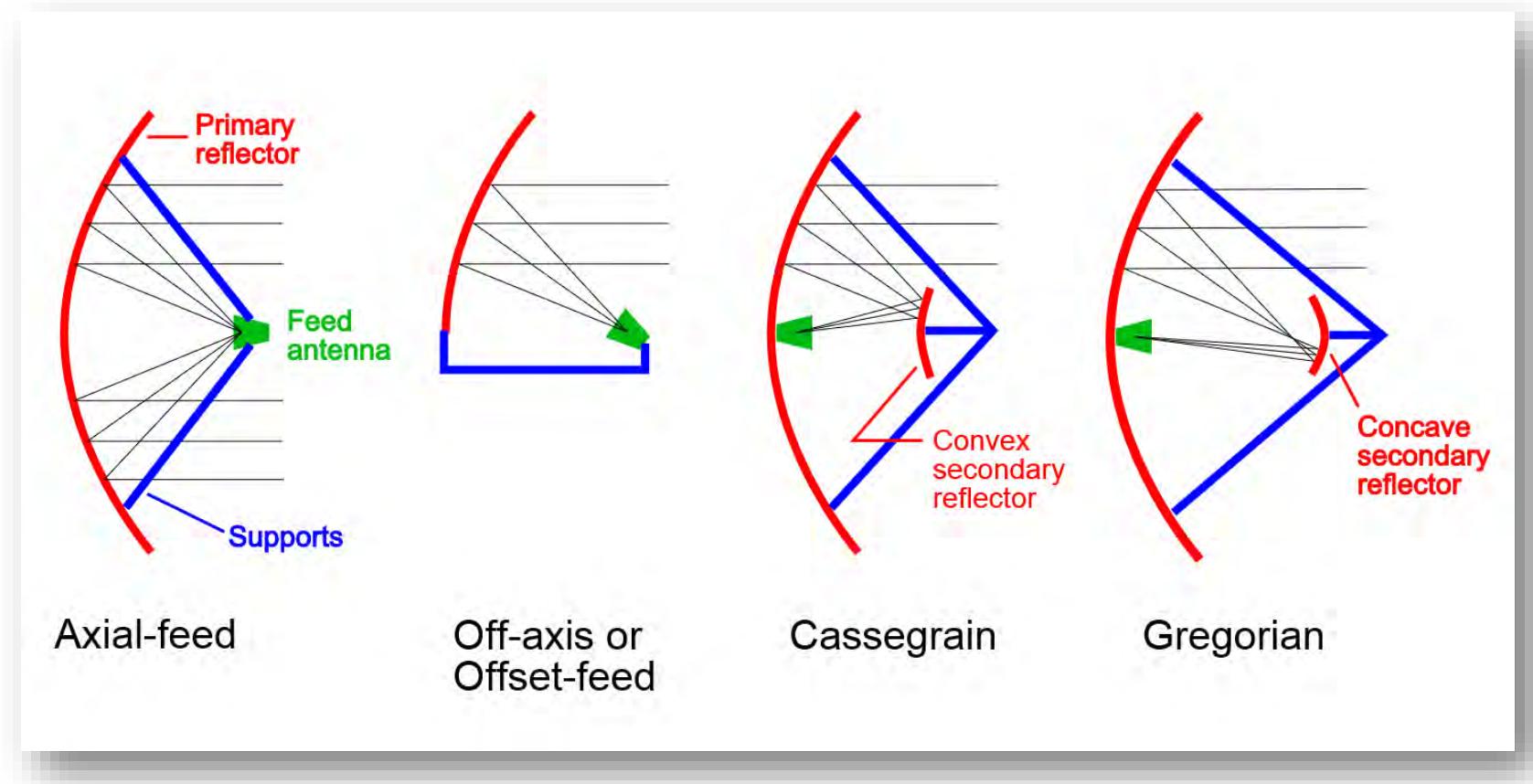


Fig. 6.23 Distintas geometrías de reflector

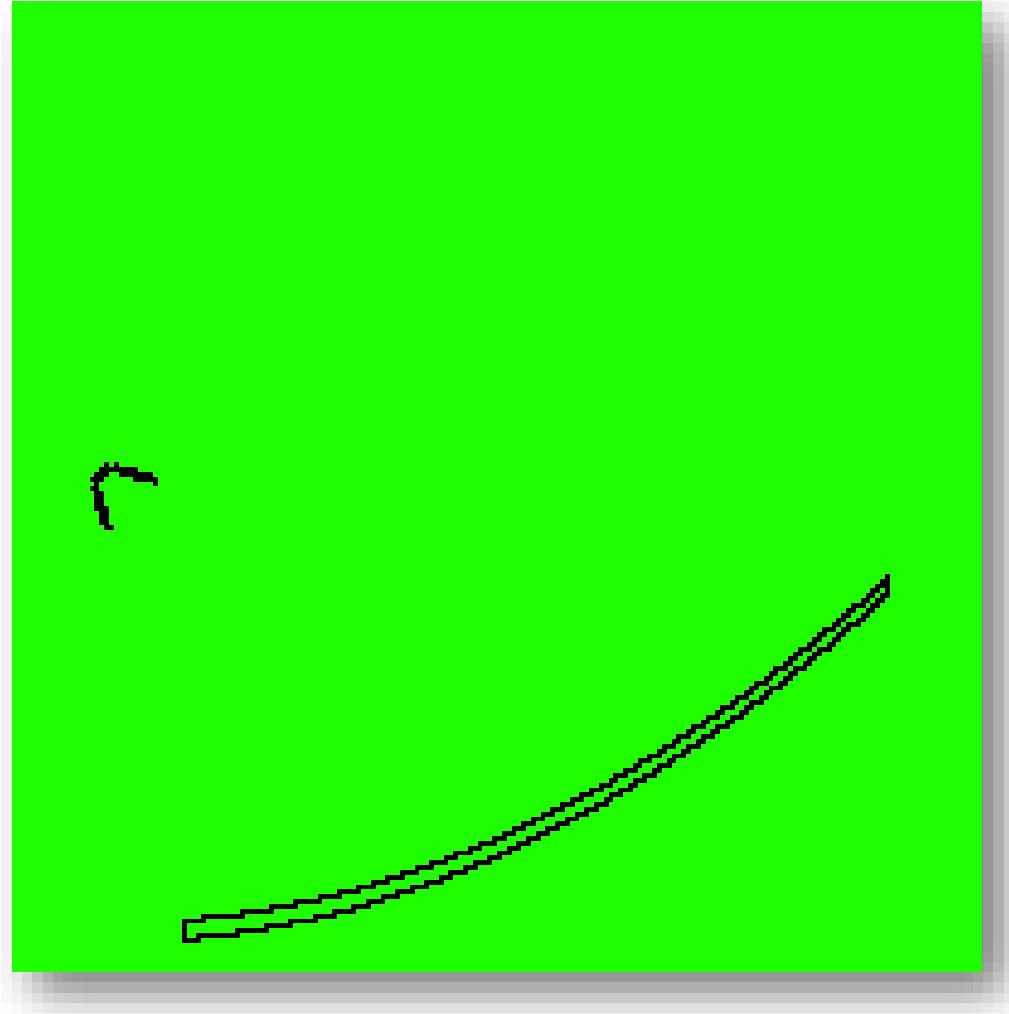
# Antena parabòlica en transmissió



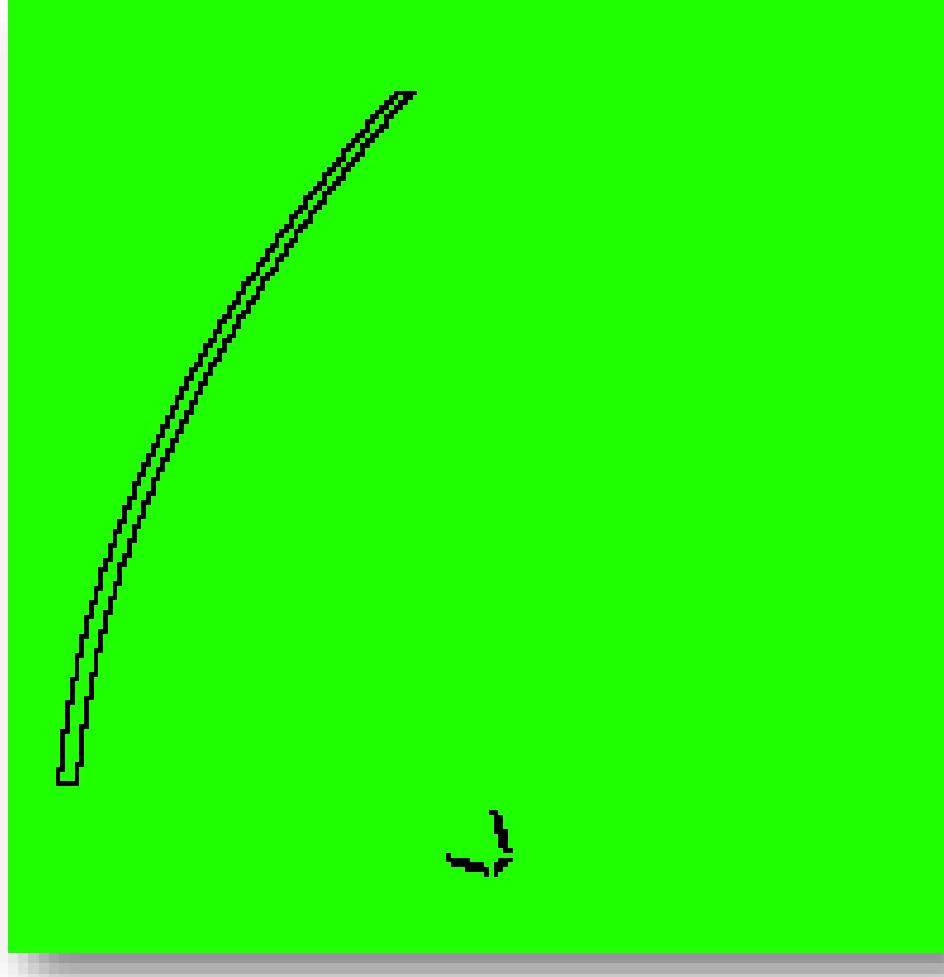
# Tipus de reflectors parabòlics



# Antena parabòlica offset en transmissió



# Antena parabòlica offset en recepció



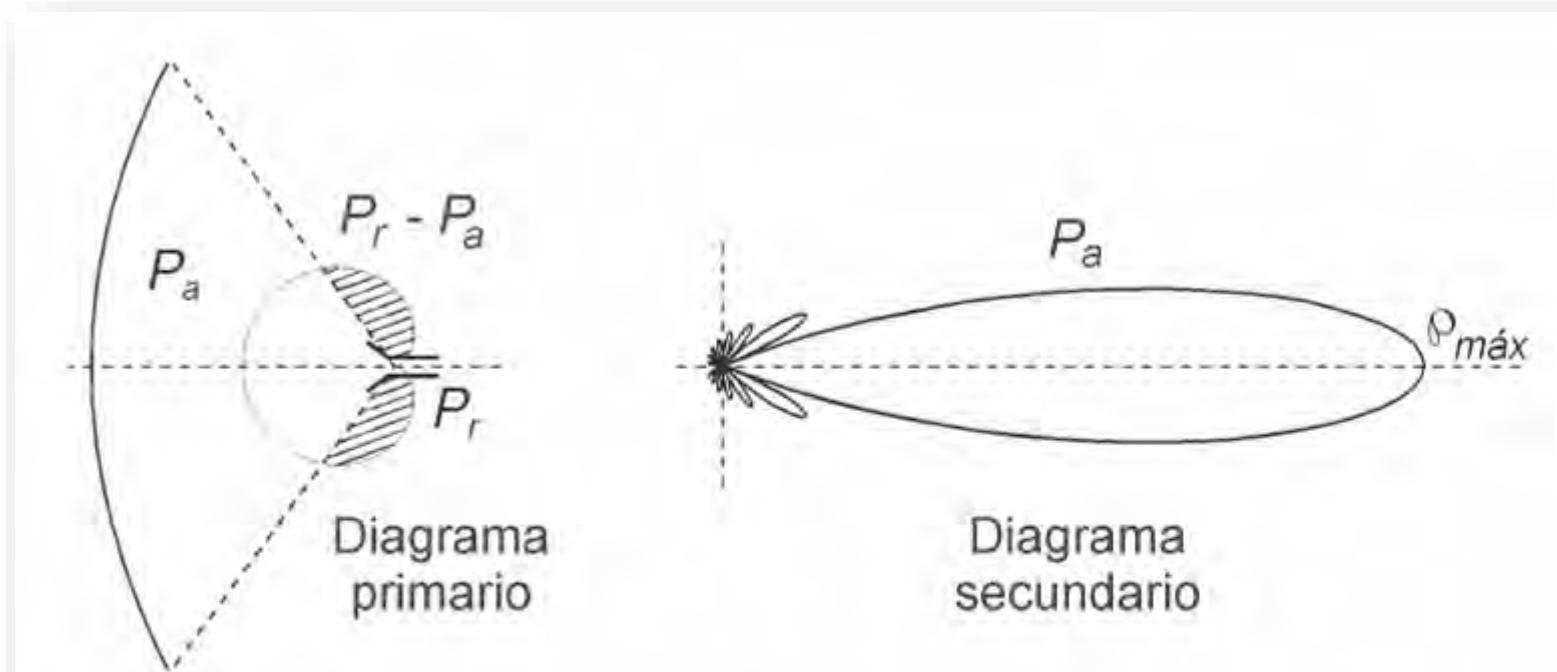


Fig. 6.40 Balance de potencias en un reflector parabólico

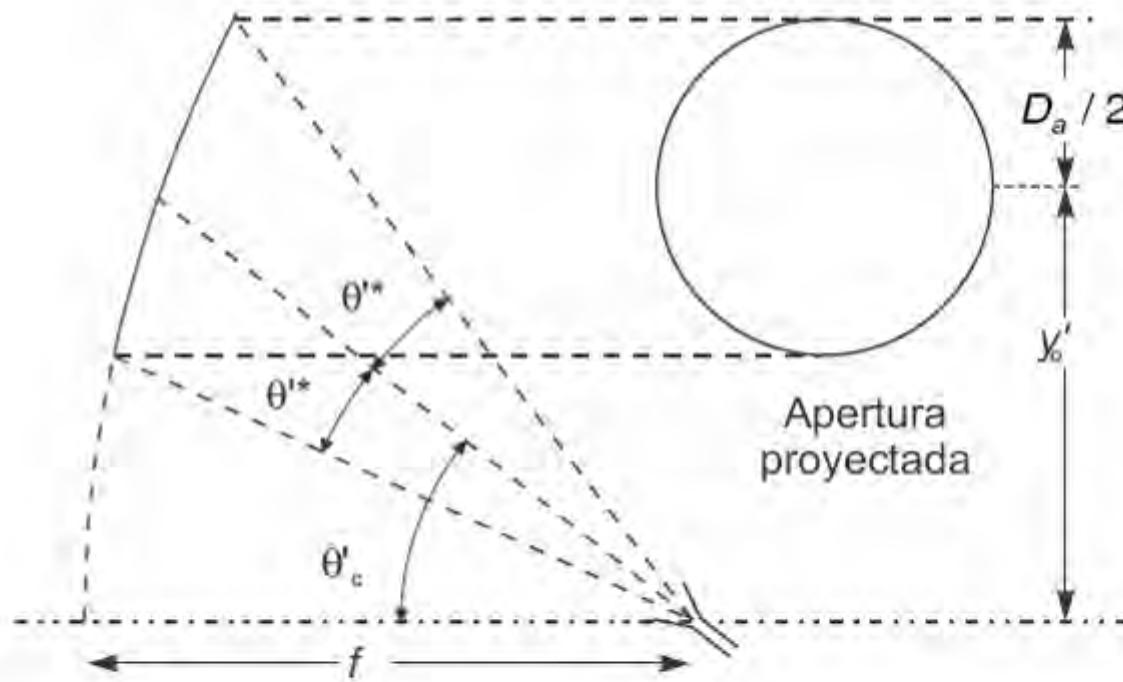


Fig. 6.50 Geometría de reflector asimétrico (*offset*)

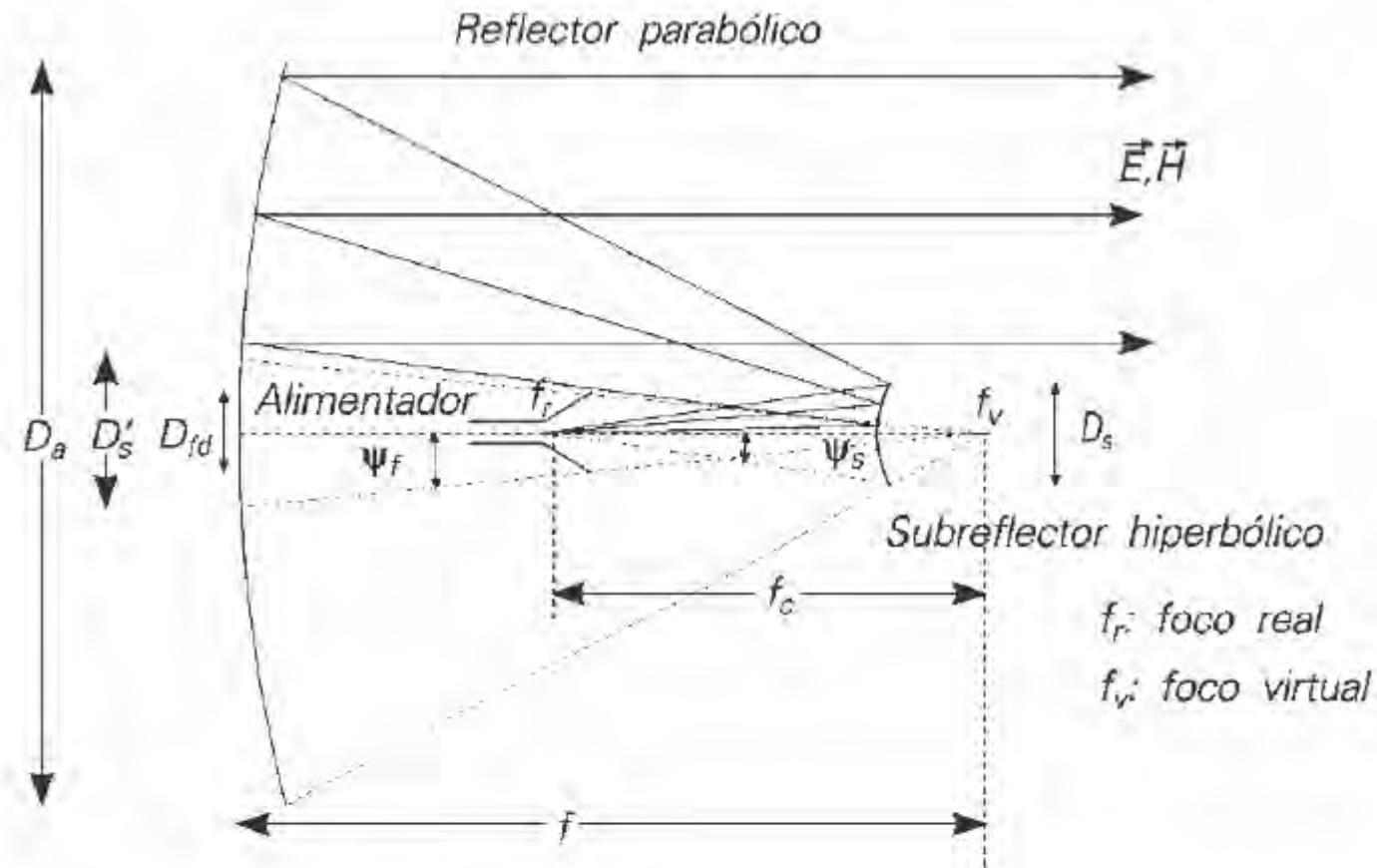
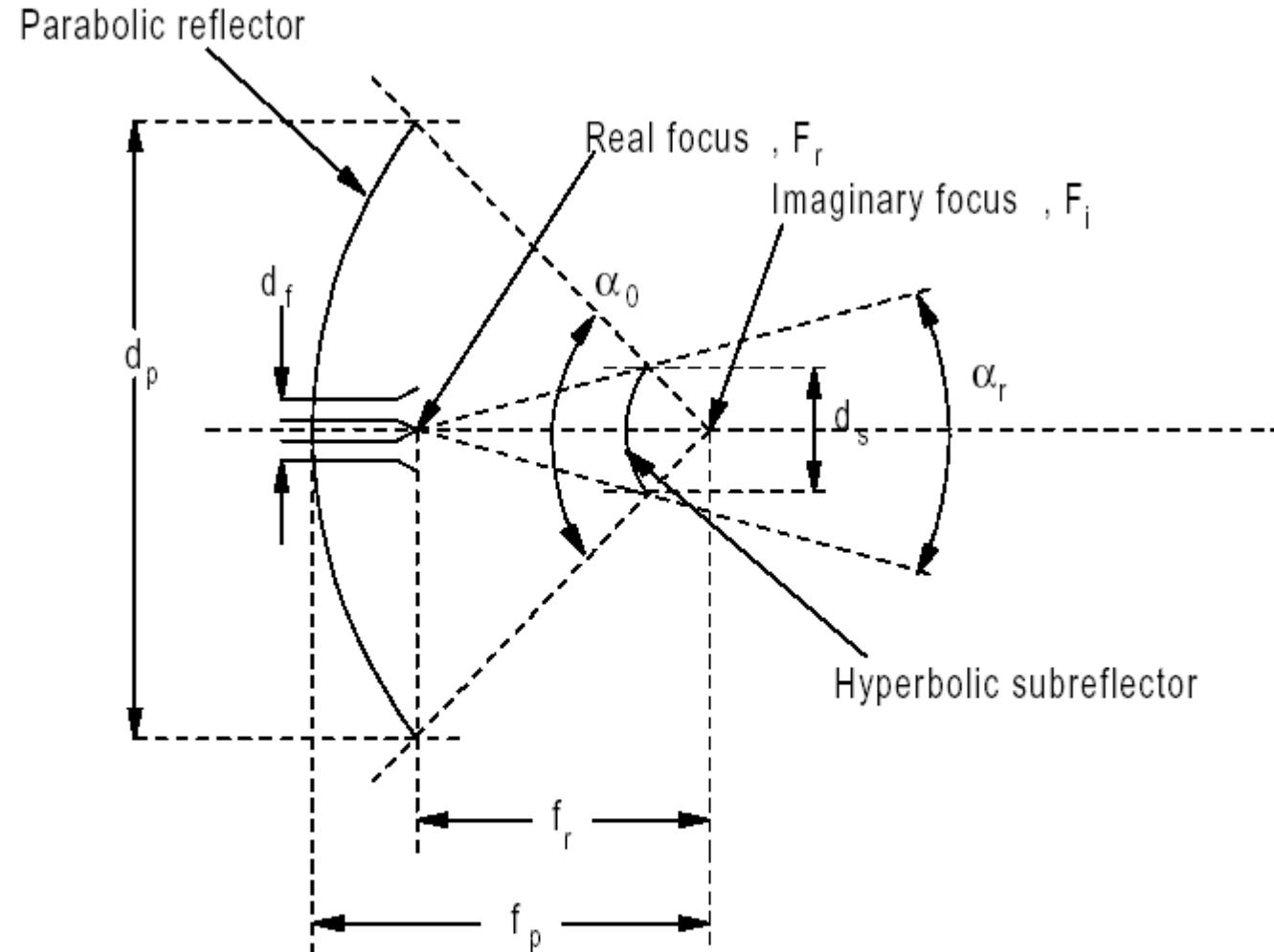
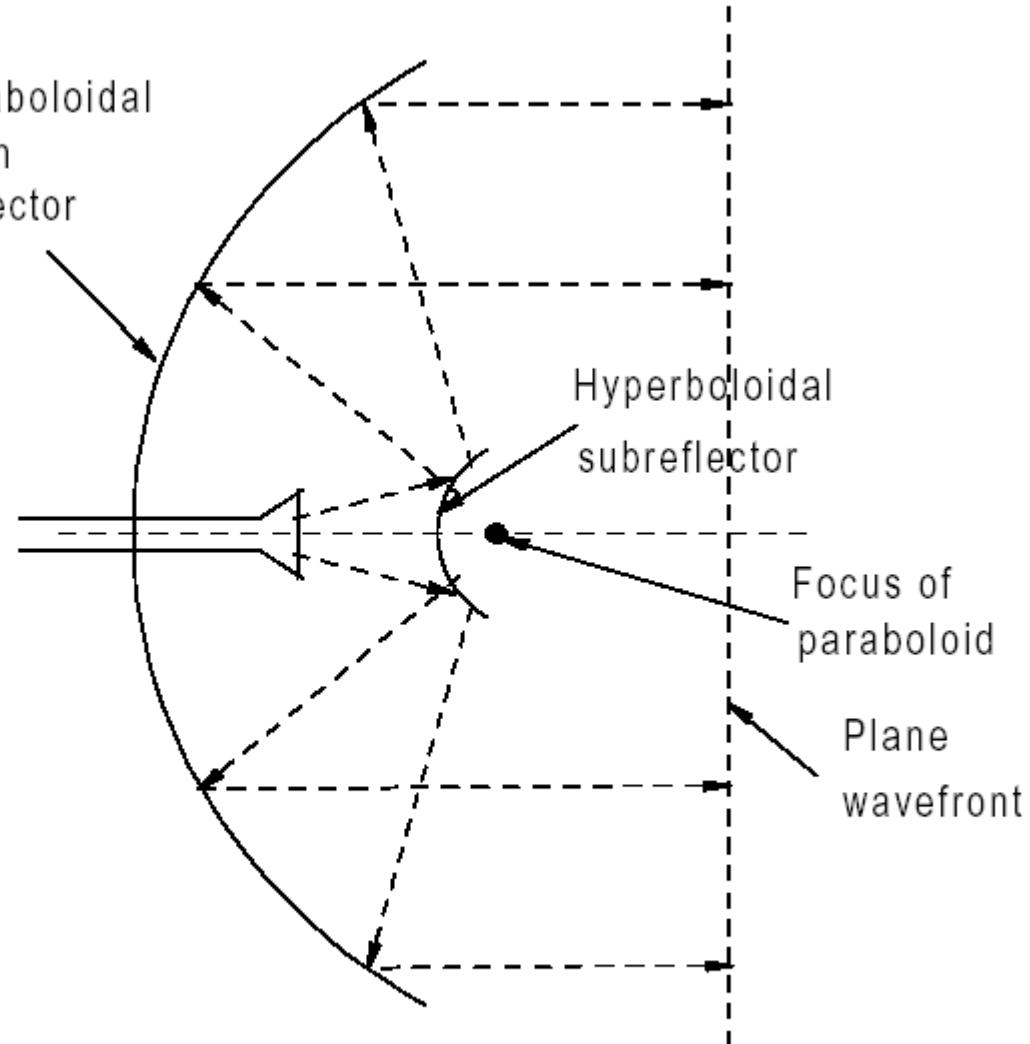


Fig. 6.51 Geometría de un reflector Cassegrain

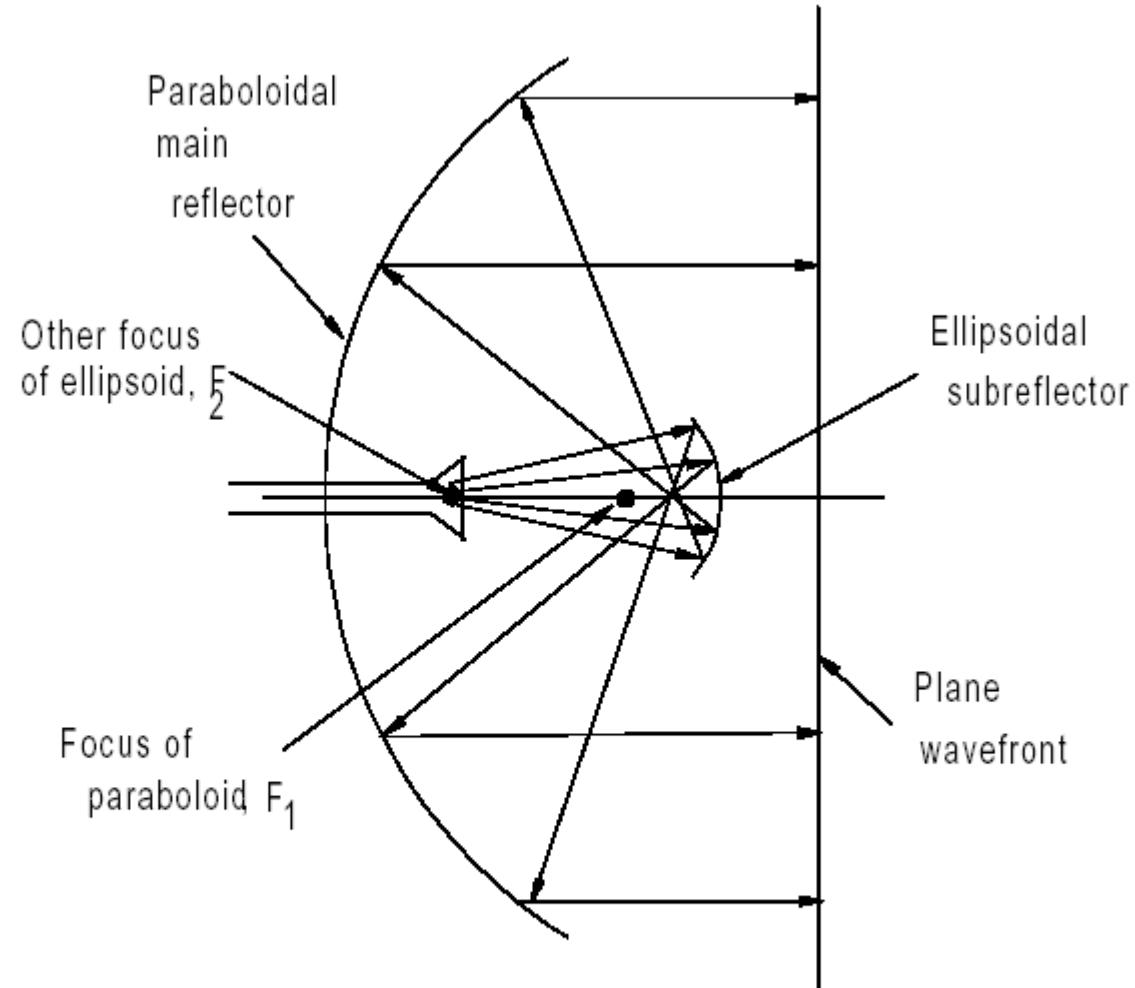


**Figure A50** Cassegrainian reflector antenna. (after Leonov, 1986, Fig. 2.3, p. 15).

Ref.: Johnston (1979), p. 58.



**Figure A56** Geometry of the Cassegrainian dual-reflector antenna.



**Figure A57** Dual-reflector Gregorian antenna.

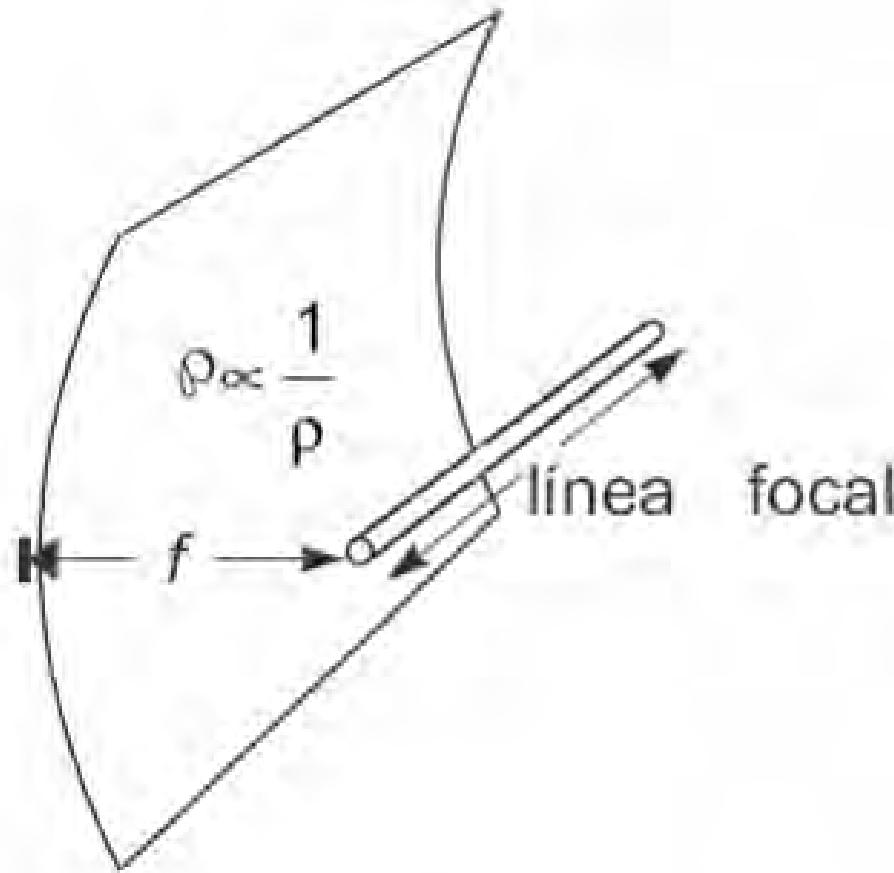


Fig. 6.53 Reflector parabólico cilíndrico

# Diagrams de radiació

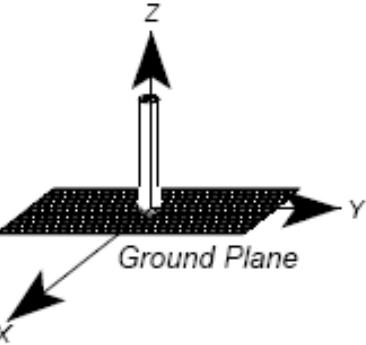
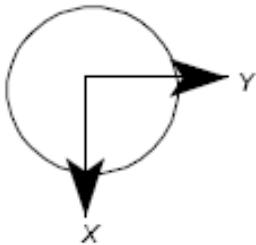
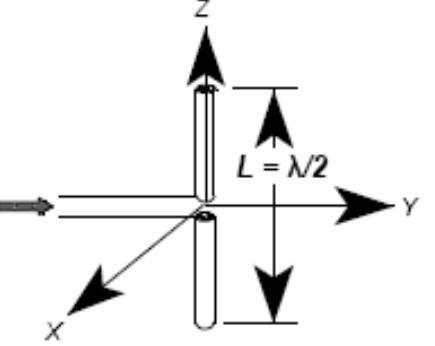
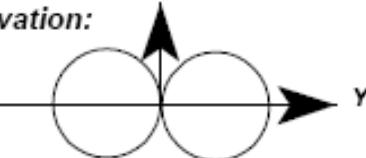
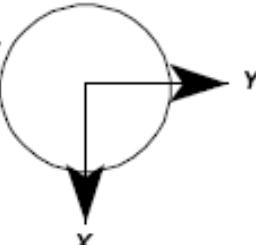
Antenna Type	Radiation Pattern	Characteristics
<b>MONPOLE</b> 	<i>Elevation:</i>  <i>Azimuth:</i> 	<p><b>Polarization:</b> Linear Vertical as shown</p> <p><b>Typical Half-Power Beamwidth:</b> 45 deg x 360 deg</p> <p><b>Typical Gain:</b> 2-6 dB at best</p> <p><b>Bandwidth:</b> 10% or 1.1:1</p> <p><b>Frequency Limit</b> Lower: None Upper: None</p> <p><b>Remarks:</b> Polarization changes to horizontal if rotated to horizontal</p>
<b>N/2 DIPOLE</b> 	<i>Elevation:</i>  <i>Azimuth:</i> 	<p><b>Polarization:</b> Linear Vertical as shown</p> <p><b>Typical Half-Power Beamwidth:</b> 80 deg x 360 deg</p> <p><b>Typical Gain:</b> 2 dB</p> <p><b>Bandwidth:</b> 10% or 1.1:1</p> <p><b>Frequency Limit</b> Lower: None Upper: 8 GHz (practical limit)</p> <p><b>Remarks:</b> Pattern and lobing changes significantly with <math>L/f</math>. Used as a gain reference &lt; 2 GHz.</p>

Figure 1

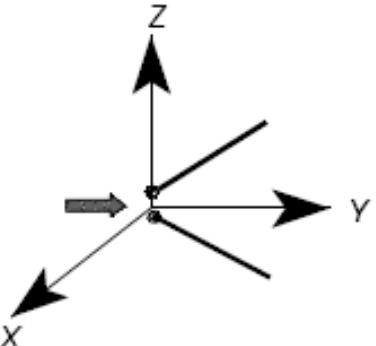
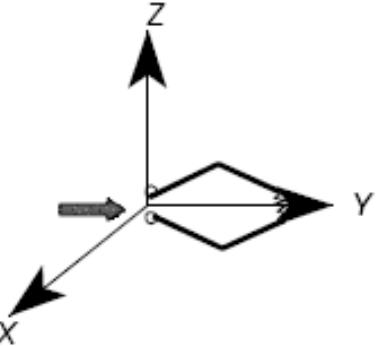
Antenna Type	Radiation Pattern	Characteristics
<p>VEE</p> 	<p>Elevation &amp; Azimuth:</p> 	<p><b>Polarization:</b> Linear Vertical as shown</p> <p><b>Typical Half-Power Beamwidth:</b> 60 deg x 60 deg</p> <p><b>Typical Gain:</b> 2 to 7 dB</p> <p><b>Bandwidth:</b> "Broadband"</p> <p><b>Frequency Limit</b> Lower: 3 MHz Upper: 500 MHz (practical limits)</p> <p><b>Remarks:</b> 24KHz versions are known to exist. Terminations may be used to reduce backlobes.</p>
<p>RHOMBIC</p> 	<p>Elevation &amp; Azimuth:</p> 	<p><b>Polarization:</b> Linear Vertical as shown</p> <p><b>Typical Half-Power Beamwidth:</b> 60 deg x 60 deg</p> <p><b>Typical Gain:</b> 3 dB</p> <p><b>Bandwidth:</b> "Broadband"</p> <p><b>Frequency Limit</b> Lower: 3 MHz Upper: 500 MHz</p> <p><b>Remarks:</b> Termination resistance used to reduce backlobes.</p>

Figure 2

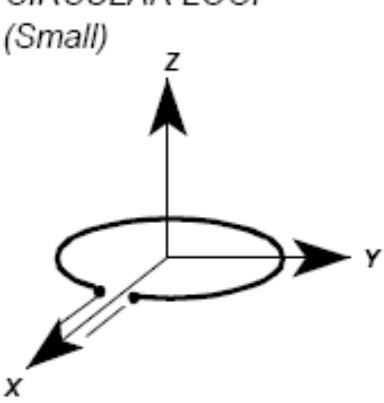
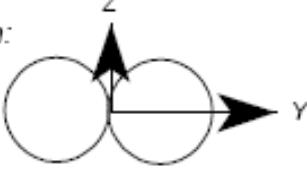
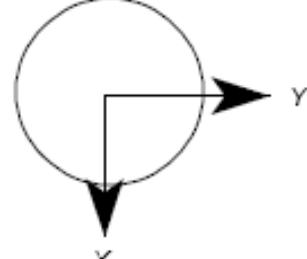
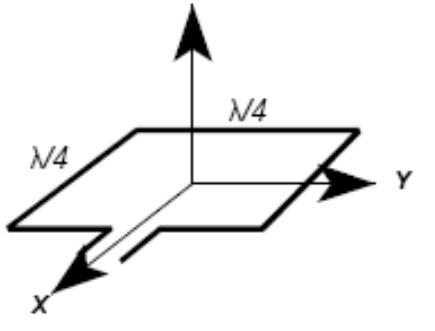
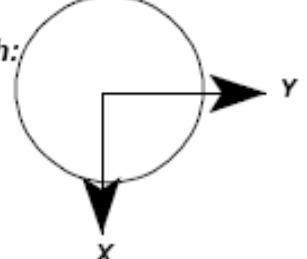
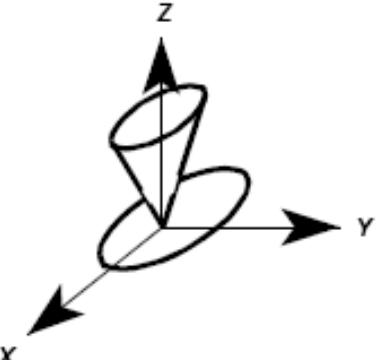
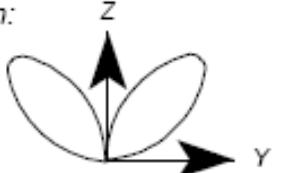
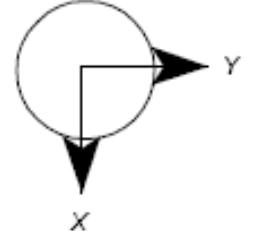
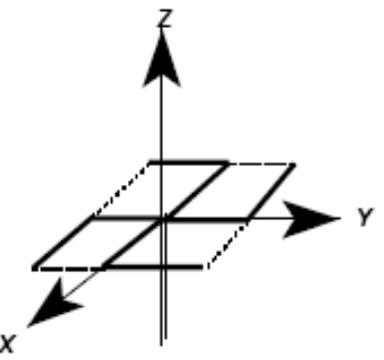
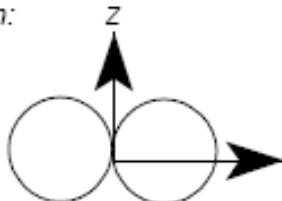
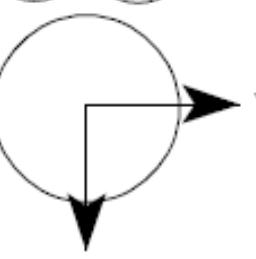
<i>Antenna Type</i>	<i>Radiation Pattern</i>	<i>Characteristics</i>
<p><i>CIRCULAR LOOP (Small)</i></p> 	<p><i>Elevation:</i></p>  <p><i>Azimuth:</i></p> 	<p><i>Polarization:</i> Linear Horizontal as shown</p> <p><i>Typical Half-Power Beamwidth:</i> 80 deg x 360 deg</p> <p><i>Typical Gain:</i> -2 to 2 dB</p> <p><i>Bandwidth:</i> 10% or 1.1:1</p> <p><i>Frequency Limit:</i> Lower: 50 MHz Upper: 1 GHz</p>
<p><i>SQUARE LOOP (Small) z</i></p> 	<p><i>Elevation:</i></p>  <p><i>Azimuth:</i></p> 	<p><i>Polarization:</i> Linear Horizontal as shown</p> <p><i>Typical Half-Power Beamwidth:</i> 100 deg x 360 deg</p> <p><i>Typical Gain:</i> 1-3 dB</p> <p><i>Bandwidth:</i> 10% or 1.1:1</p> <p><i>Frequency Limit:</i> Lower: 50 MHz Upper: 1 GHz</p>

Figure 3

Antenna Type	Radiation Pattern	Characteristics
<b>DISCONE</b> 	<i>Elevation:</i>  <i>Azimuth:</i> 	<i>Polarization:</i> Linear Vertical as shown <i>Typical Half-Power Beamwidth:</i> 20-80 deg x 360 deg <i>Typical Gain:</i> 0-4 dB <i>Bandwidth:</i> 100% or 3:1 <i>Frequency Limit:</i> Lower: 30 MHz Upper: 3 GHz
<b>ALFORD LOOP</b> 	<i>Elevation:</i>  <i>Azimuth:</i> 	<i>Polarization:</i> Linear Horizontal as shown <i>Typical Half-Power Beamwidth:</i> 80 deg x 360 deg <i>Typical Gain:</i> -1 dB <i>Bandwidth:</i> 67% or 2:1 <i>Frequency Limit:</i> Lower: 100 MHz Upper: 12 GHz

*Figure 4*

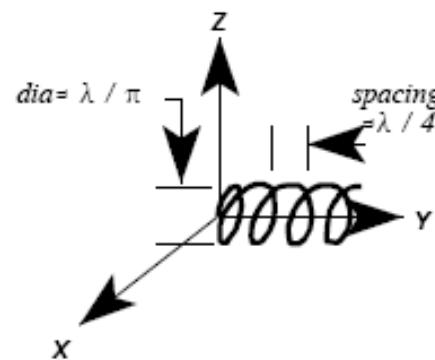
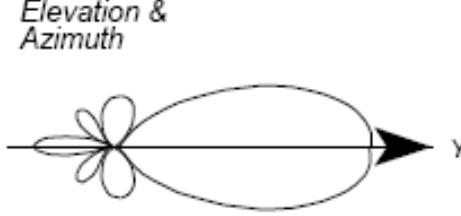
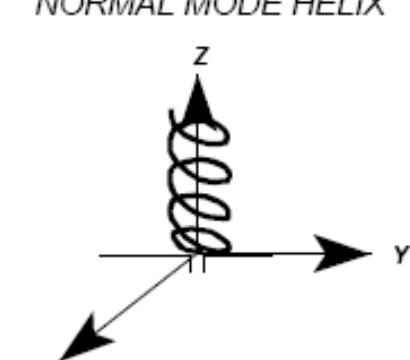
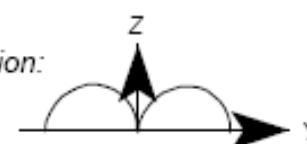
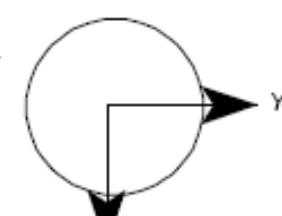
Antenna Type	Radiation Pattern	Characteristics
<b>AXIAL MODE HELIX</b> 	<i>Elevation &amp; Azimuth</i> 	<p><b>Polarization:</b> Circular Left hand as shown</p> <p><b>Typical Half-Power Beamwidth:</b> 50 deg x 50 deg</p> <p><b>Typical Gain:</b> 10 dB</p> <p><b>Bandwidth:</b> 52% or 1.7:1</p> <p><b>Frequency Limit</b> Lower: 100 MHz Upper: 3 GHz</p> <p><b>Remarks:</b> Number of loops &gt;3</p>
<b>NORMAL MODE HELIX</b> 	<i>Elevation:</i>  <i>Azimuth:</i> 	<p><b>Polarization:</b> Circular - with an ideal pitch to diameter ratio.</p> <p><b>Typical Half-Power Beamwidth:</b> 60 deg x 360 deg</p> <p><b>Typical Gain:</b> 0 dB</p> <p><b>Bandwidth:</b> 5% or 1.05:1</p> <p><b>Frequency Limit</b> Lower: 100 MHz Upper: 3 GHz</p>

Figure 5

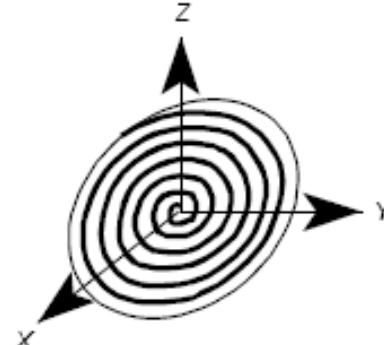
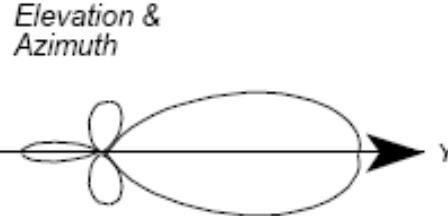
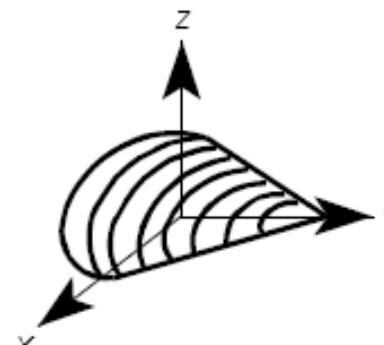
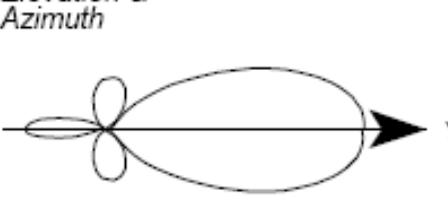
Antenna Type	Radiation Pattern	Characteristics
<b>CAVITY BACKED SPIRAL (Flat Helix)</b> 		<p><b>Polarization:</b> Circular Left hand as shown</p> <p><b>Typical Half-Power Beamwidth:</b> 60 deg x 90 deg</p> <p><b>Typical Gain:</b> 2-4 dB</p> <p><b>Bandwidth:</b> 160% or 9:1</p> <p><b>Frequency Limit:</b> Lower: 500 MHz Upper: 18 GHz</p>
<b>CONICAL SPIRAL</b> 		<p><b>Polarization:</b> Circular Left hand as shown</p> <p><b>Typical Half-Power Beamwidth:</b> 60 deg x 60 deg</p> <p><b>Typical Gain:</b> 5-8 dB</p> <p><b>Bandwidth:</b> 120% or 4:1</p> <p><b>Frequency Limit:</b> Lower: 50 MHz Upper: 18 GHz</p>

Figure 6

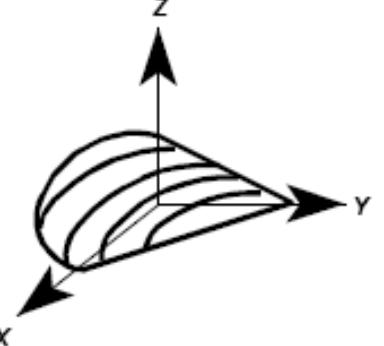
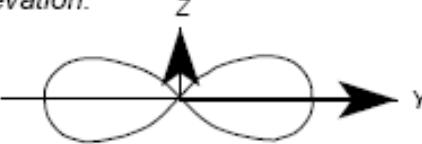
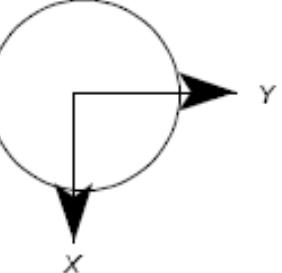
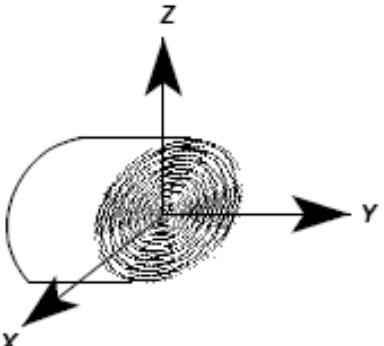
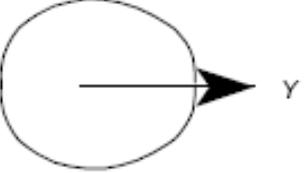
Antenna Type	Radiation Pattern	Characteristics
<b>4 ARM CONICAL SPIRAL</b> 	<i>Elevation:</i>  <i>Azimuth:</i> 	<i>Polarization:</i> Circular Left hand as shown  <i>Typical Half-Power Beamwidth:</i> 50 deg x 360 deg  <i>Typical Gain:</i> 0 dB  <i>Bandwidth:</i> 120% or 4:1  <i>Frequency Limit:</i> Lower: 500 MHz Upper: 18 GHz
<b>DUAL POLARIZED SINUOUS</b> 	<i>Elevation &amp; Azimuth</i> 	<i>Polarization:</i> Dual vertical or horizontal or dual Circular right hand or left hand with hybrid  <i>Typical Half-Power Beamwidth:</i> 75 deg x 75 deg  <i>Typical Gain:</i> 2 dB  <i>Bandwidth:</i> 163% or 10:1  <i>Frequency Limit:</i> Lower: 500 MHz Upper: 18 GHz

Figure 7

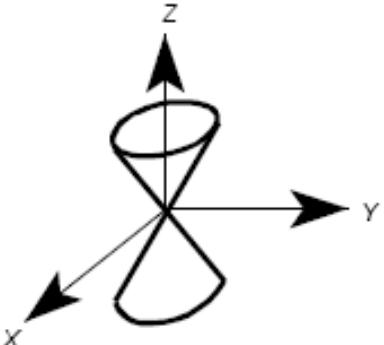
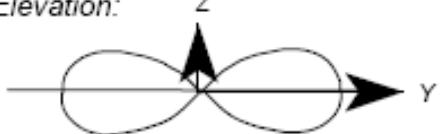
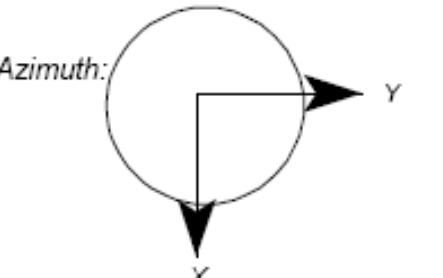
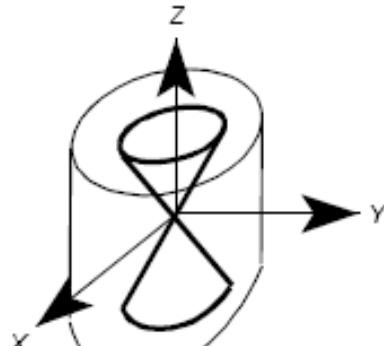
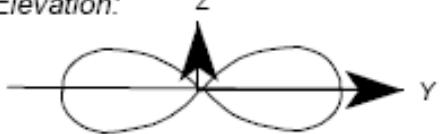
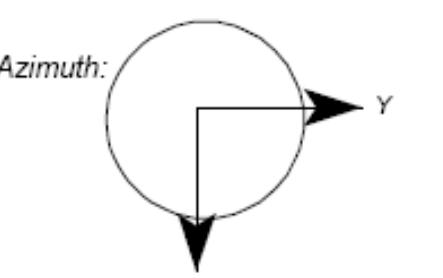
Antenna Type	Radiation Pattern	Characteristics
<b>BICONICAL</b> 	<i>Elevation:</i>  <i>Azimuth:</i> 	<i>Polarization:</i> Linear, Vertical as shown <i>Typical Half-Power Beamwidth:</i> 20-100 deg x 360 deg <i>Typical Gain:</i> 0-4 dB <i>Bandwidth:</i> 120% or 4:1 <i>Frequency Limit:</i> Lower: 500 MHz Upper: 40 GHz
<b>BICONICAL W/POLARIZER</b> 	<i>Elevation:</i>  <i>Azimuth:</i> 	<i>Polarization:</i> Circular, Direction depends on polarization <i>Typical Half-Power Beamwidth:</i> 20-100 deg x 360 deg <i>Typical Gain:</i> -3 to 1 dB <i>Bandwidth:</i> 100% or 3:1 <i>Frequency Limit:</i> Lower: 2 GHz Upper: 18 GHz

Figure 8

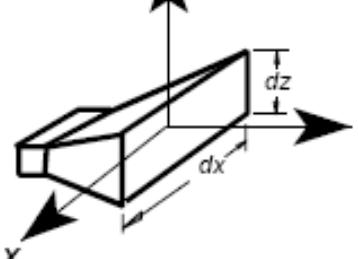
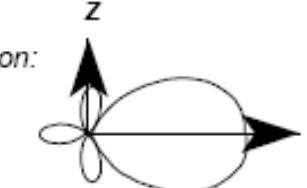
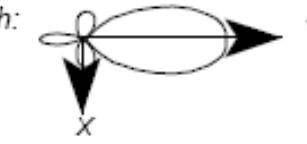
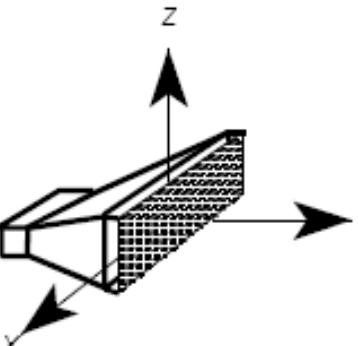
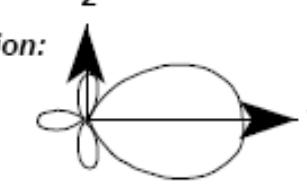
Antenna Type	Radiation Pattern	Characteristics
<b>HORN</b> 	<i>Elevation:</i>  $3\text{ dB beamwidth} = 56 \lambda^\circ / dz$  <i>Azimuth:</i>  $3\text{ dB beamwidth} = 70 \lambda^\circ / dx$	<p><b>Polarization:</b> Linear</p> <p><b>Typical Half-Power Beamwidth:</b> 40 deg x 40 deg</p> <p><b>Typical Gain:</b> 5 to 20 dB</p> <p><b>Bandwidth:</b> If ridged: 120% or 4:1 If not ridged: 67% or 2:1</p> <p><b>Frequency Limit:</b> Lower: 50 MHz Upper: 40 GHz</p>
<b>HORN W / POLARIZER</b> 	<i>Elevation:</i>   <i>Azimuth:</i> 	<p><b>Polarization:</b> Circular, Depends on polarizer</p> <p><b>Typical Half-Power Beamwidth:</b> 40 deg x 40 deg</p> <p><b>Typical Gain:</b> 5 to 10 dB</p> <p><b>Bandwidth:</b> 60% or 2:1</p> <p><b>Frequency Limit:</b> Lower: 2 GHz Upper: 18 GHz</p>

Figure 9

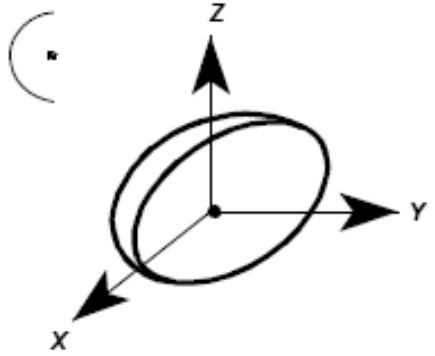
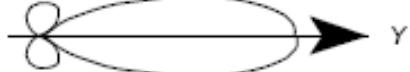
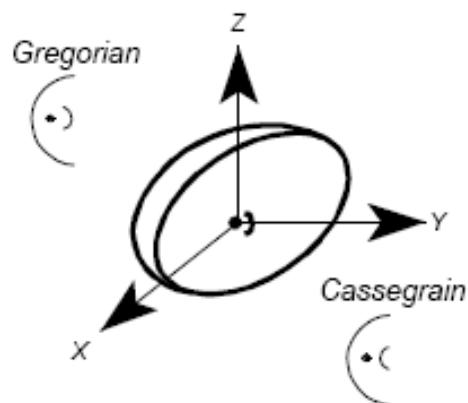
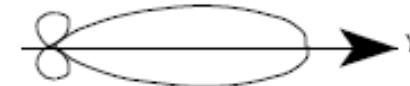
Antenna Type	Radiation Pattern	Characteristics
<b>PARABOLIC (Prime)</b> 	<i>Elevation &amp; Azimuth</i> 	<p><b>Polarization:</b> Takes polarization of feed</p> <p><b>Typical Half-Power Beamwidth:</b> 1 to 10 deg</p> <p><b>Typical Gain:</b> 20 to 30 dB</p> <p><b>Bandwidth:</b> 33% or 1.4:1 limited mostly by feed</p> <p><b>Frequency Limit:</b> Lower: 400 MHz Upper: 13+ GHz</p>
<b>PARABOLIC</b> 	<i>Elevation &amp; Azimuth</i> 	<p><b>Polarization:</b> Takes polarization of feed</p> <p><b>Typical Half-Power Beamwidth:</b> 1 to 10 deg</p> <p><b>Typical Gain:</b> 20 to 30 dB</p> <p><b>Bandwidth:</b> 33% or 1.4:1</p> <p><b>Frequency Limit:</b> Lower: 400 MHz Upper: 13+ GHz</p>

Figure 10

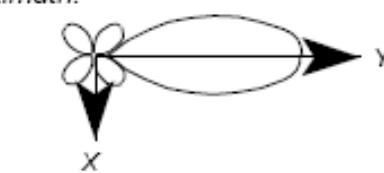
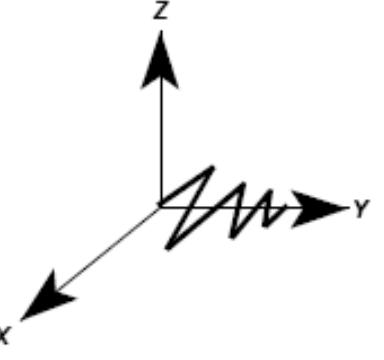
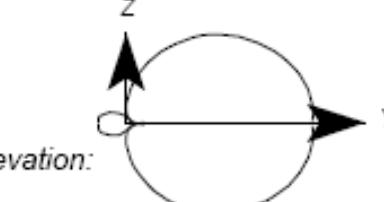
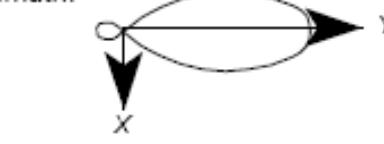
Antenna Type	Radiation Pattern	Characteristics
<b>YAGI</b> 	 <i>Elevation:</i>  <i>Azimuth:</i>	<p><b>Polarization:</b> Linear Horizontal as shown</p> <p><b>Typical Half-Power Beamwidth:</b> 50 deg X 50 deg</p> <p><b>Typical Gain:</b> 5 to 15 dB</p> <p><b>Bandwidth:</b> 5% or 1.05:1</p> <p><b>Frequency Limit:</b> Lower: 50 MHz Upper: 2 GHz</p>
<b>LOG PERIODIC</b> 	 <i>Elevation:</i>  <i>Azimuth:</i>	<p><b>Polarization:</b> Linear</p> <p><b>Typical Half-Power Beamwidth:</b> 60 deg x 80 deg</p> <p><b>Typical Gain:</b> 6 to 8 dB</p> <p><b>Bandwidth:</b> 163% or 10:1</p> <p><b>Frequency Limit:</b> Lower: 3 MHz Upper: 18 GHz</p> <p><b>Remarks:</b> This array may be formed with many shapes including dipoles or toothed arrays.</p>

Figure 11

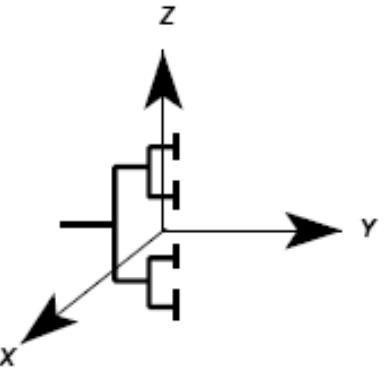
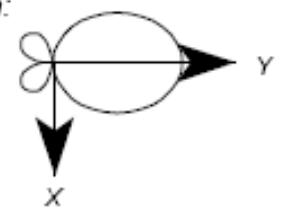
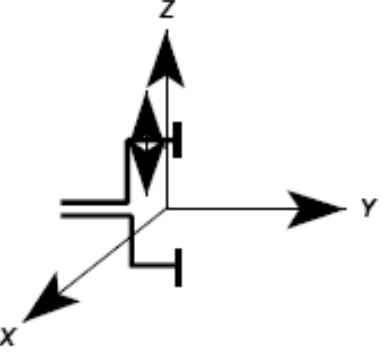
Antenna Type	Radiation Pattern	Characteristics
<b>LINEAR DIPOLE ARRAY</b> (Corporate Feed)	 <p>Elevation:  </p> <p>Azimuth:  </p>	<p><b>Polarization:</b> Element dependent            Vertical as shown</p> <p><b>Typical Half-Power Beamwidth:</b>            Related to gain</p> <p><b>Typical Gain:</b> Dependent on number of elements</p> <p><b>Bandwidth:</b> Narrow</p> <p><b>Frequency Limit:</b>            Lower: 10 MHz            Upper: 10 GHz</p>
<b>APERTURE SYNTHESIS</b>	 <p><i>Elevation &amp; Azimuth</i>  </p>	<p>All characteristics dependent on elements</p> <p><b>Remarks:</b> Excellent side-looking, ground mapping where the aircraft is a moving linear element.</p>

Figure 12

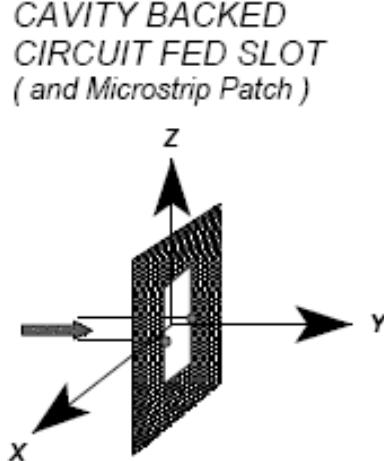
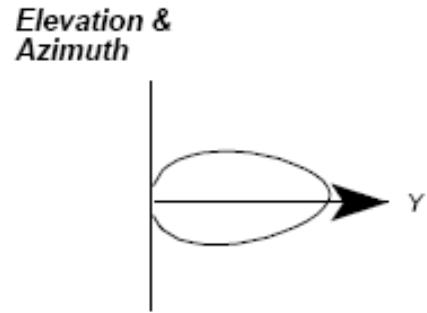
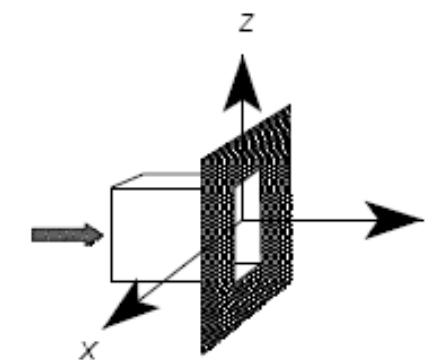
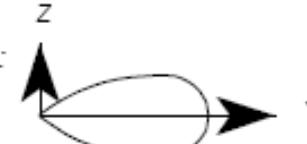
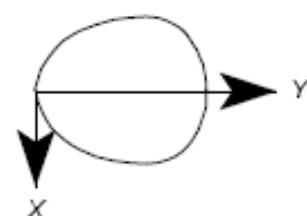
Antenna Type	Radiation Pattern	Characteristics
<b>CAVITY BACKED CIRCUIT FED SLOT (and Microstrip Patch)</b> 	<i>Elevation &amp; Azimuth</i> 	<p><b>Polarization:</b> Linear, vertical as shown</p> <p><b>Typical Half-Power Beamwidth:</b> 80 deg x 80 deg</p> <p><b>Typical Gain:</b> 6 dB</p> <p><b>Bandwidth:</b> Narrow</p> <p><b>Frequency Limit:</b> Lower: 50 MHz Upper: 18 GHz</p> <p><b>Remarks:</b> The feed line is sometimes separated from the radiator by a dielectric &amp; uses capacitive coupling. Large conformal phased arrays can be made this way.</p>
<b>GUIDE FED SLOT</b> 	<i>Elevation:</i>  <i>Azimuth:</i> 	<p><b>Polarization:</b> Linear,</p> <p><b>Typical Half-Power Beamwidth</b> Elevation: 45-50° Azimuth: 80°</p> <p><b>Typical Gain:</b> 0 dB</p> <p><b>Bandwidth:</b> Narrow</p> <p><b>Frequency Limit:</b> Lower: 2 GHz Upper: 40 GHz</p> <p><b>Remarks:</b> Open RF Waveguide</p>

Figure 13

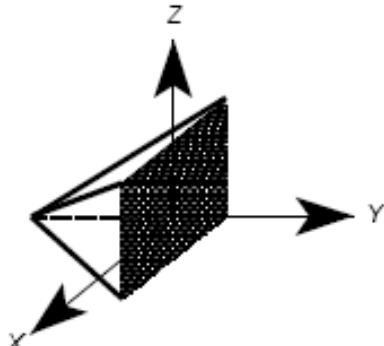
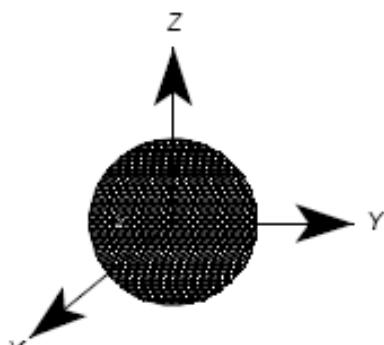
Antenna Type	Radiation Pattern	Characteristics
<b>CORNER REFLECTOR</b> 	<i>Elevation: (Z-Y)</i> <i>Azimuth: (X-Y)</i> <i>Dependent upon feed emitter</i>	<i>Polarization:</i> <i>Feed dependent</i>  <i>Typical Half-Power Beamwidth:</i> <i>40 deg x variable</i>  <i>Typical Gain:</i> 10 dB above feed  <i>Bandwidth:</i> Narrow  <i>Frequency Limit:</i> <i>Lower: 1 GHz</i> <i>Upper: 40 GHz</i>  <i>Remarks:</i> Typically fed with a dipole or colinear array.
<b>LUNEBURG LENS</b> <i>Also "LUNEBERG"</i> 	<i>Elevation &amp; Azimuth</i> 	<i>Polarization:</i> <i>Feed dependent</i>  <i>Typical Half-Power Beamwidth:</i> <i>System dependent</i>  <i>Typical Gain:</i> System dependent  <i>Bandwidth:</i> Narrow  <i>Frequency Limit:</i> <i>Lower: 1 GHz</i> <i>Upper: 40 GHz</i>  <i>Remarks:</i> Variable index dielectric sphere.

Figure 14

# Antenes comercials



Antenas de tipo monopolo plegado diseñadas para un mejor aprovechamiento de la emisión con un ángulo de radiación bajo.

- Incorporan un plano de tierra totalmente horizontal, obteniéndose gran estabilidad en la respuesta eléctrica.



Folded monopole base station type antenna. These references feature a lowered radiation pattern.

They incorporate a fully horizontal ground plane thus obtaining higher stable electrical response.



- Antenas do tipo monopolo desenhadas para um melhor aproveitamento da emissão com um angulo de radiação baixo.

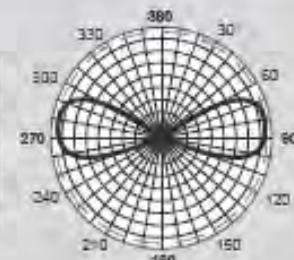
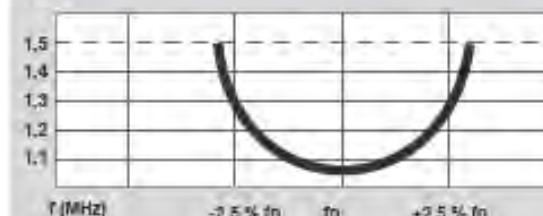
- Incorporam um plano de terra totalmente horizontal, obtendo-se grande estabilidade de resposta eléctrica.



#### CARACTERÍSTICAS TÉCNICAS/ TECHNICAL SPECIFICATIONS

Referencia/ Reference	6522	6591	6571
Frecuencia/frequency (MHz)	66-88	86-142	142-235
Ganancia/ Gain (dBi)	2,1	2,1	2,1
Ancho de banda /Bandwidth (MHz)	3	4	5
Potencia máxima/Max power (Weff)	2500	2000	1500
Impedancia / Impedance (Ω)		50	
Longitud radiante/Rad. length (mm)	1150	775	425
Long. elem. rad./Rad. elem.length (mm)	1050	840	505
Ø mástil /Mast Ø (mm)	40	40	40
Peso / Weight (grs)	2000	1600	1300

R.O.E





## DM C50-17 VHF ANTENNA

The DM C50-17 Series VHF Communication Antennas have incorporated design improvements to enhance corona threshold, corrosion protection, and drag characteristics.

The DM C50-17 Series provides the lightest weight and strongest blade antenna at lower cost for current use on commercial jet aircraft.

In addition to its low initial price, further cost reductions are realized due to the weight and drag reduction of the antenna. The fuel saving per shipset is calculated to be 160.5 gallons per aircraft per year.

The DM C50-17 antenna has been selected as original equipment for the Boeing 757 and 767, and 777 aircraft. Other models in the DM C50-17 Series can also be used on Boeing 707, 727, 737, 747; Douglas DC-8, DC-9, and DC-10; Aerospatiale A300 Series; and other commercial aircraft. Many of the DM C50-17 Series are interchangeable with other types of antennas presently in use.

### SPECIFICATIONS

#### ELECTRICAL

Frequency Range	116 – 156 MHz
VSWR	2.0:1
Power	1 KW CW
Impedance	50 Ohms
Polarization	Vertical
Radiation Pattern	Omnidirectional (Equivalent to a vertical stub)



### DESCRIPTION:

The VHF coaxial dipole is a vertically polarized omnidirectional antenna suitable for civil aviation and for mobile and semi stationary applications specially on ships.

This antenna has a high suppression of current flow on the outside cables.

### SPECIAL FEATURES:

- Broadband: 118 ÷ 137 MHz
- Nr. input: 1
- Omnidirectional radiation
- High power: 100 W
- Protected against lightning
- Very rugged construction

### Electrical Specifications

Frequency Band (MHz)	118 ÷ 137
Impedance ( $\Omega$ )	50
VSWR	< 1.5
Polarization	linear vertical
Gain (dBi)	2
Pattern	
Horizontal Plane	omni $\pm$ 0.5 dB
Vertical Plane (degree)	80 $\pm$ 5
Continuous Max Power (W)	100
Op. Temp. Range (°C)	- 40 ÷ 70
Lightning Protection	DC grounded

### Mechanical Specifications

Connector	Nf
Dimensions (mm)	
Length	780
Radome diameter	$\varnothing$ 40
Colour	RAL 7035 (grey)
Weight (Kg)	2.5
Wind load @ 150 Km/h (N)	23
Radome	Fiberglass
Mounting	on pole $\varnothing$ 40÷60 mm

6'High Performance Pathfinder  
10KW Open Array Antenna.  
Includes Pathfinder series  
compatible interconnect cable,



Product Number: T52014

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### General Specifications

**Approvals** CE - conforms to 89/336/EEC (EMC), EN60945,1997  
FCC - conforms to Part 80 (47CFR) and Part 2 (47CFR)

**Dimensions: Array** 1829 mm(72in) length

**Dimensions:  
Pedestal** 427 x 296 x 406mm (16.8 x 10.5 x 16in)

**Environmental** Waterproof to CFR46  
Temperature range: -10<sup>0</sup> to +55<sup>0</sup>C  
Humidity limit: up to 95% at 35<sup>0</sup>C  
Maximum wind speed for satisfactory operation:  
100Kts

**Input voltage** 20- 44 V DC (from display unit)  
A 12Volt to 24Volt rectifier is required for vessels  
equipped with 12volt DC systems

**Maximum Range  
Scale** 72 nm

**Power  
consumption** 11 W Standby  
80 W Typical operation in light winds  
117 W Max. operation in 50 Kt winds  
179 W Max. operation in 100Kt winds

**Weight: Array** 6kg(13.2lbs)

**Weight: Pedestal** 24kg(53lbs)

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[C-Series](#)  
[E-Series](#)  
[Raymarine H6](#)  
[Marine Radar](#)  
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[Open Array Antennas](#)  
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**Radome Antennas**

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Compact 18" High Performance Pathfinder 2kW Radome Antenna



Product Number: M92650-S

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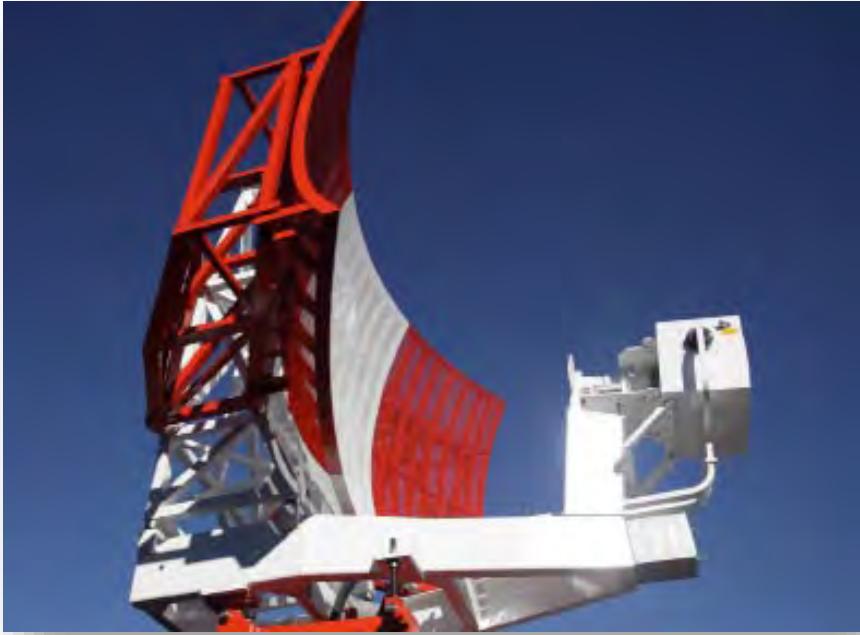
**General Specifications**

<b>Antenna Type</b>	Radome incorporating patch antenna
<b>Approvals</b>	CE - conforms to 89/336/EEC (EMC), EN60945:1997 FCC - conforms to Part 80 (47CFR) and Part 2 (47CFR)
<b>Dimensions</b>	468mm x 227mm (18.4" x 8.9")
<b>Environmental</b>	Waterproof to CFR46 Temperature range: -10° to +55°C Humidity limit: up to 95% at 35°C Maximum wind speed for satisfactory operation: 100Kts
<b>Horizontal Beamwidth</b>	5.2°
<b>Input Voltage</b>	10.7 - 32 VDC
<b>Maximum Range Scale</b>	24 nm
<b>Maximum Wind Load</b>	100 kts
<b>Operating Temperature</b>	-10°C to +55°C. Humidity limit: Up to 95% at 35°C
<b>Power Consumption</b>	9W standby, 28W transmit
<b>Rotation Speed</b>	24 rpm
<b>Vertical Beamwidth</b>	25°
<b>Weight</b>	6.5kg (14.3 lbs)





15 *S600 series modular radar*





# AIRBUS 320

Antenes



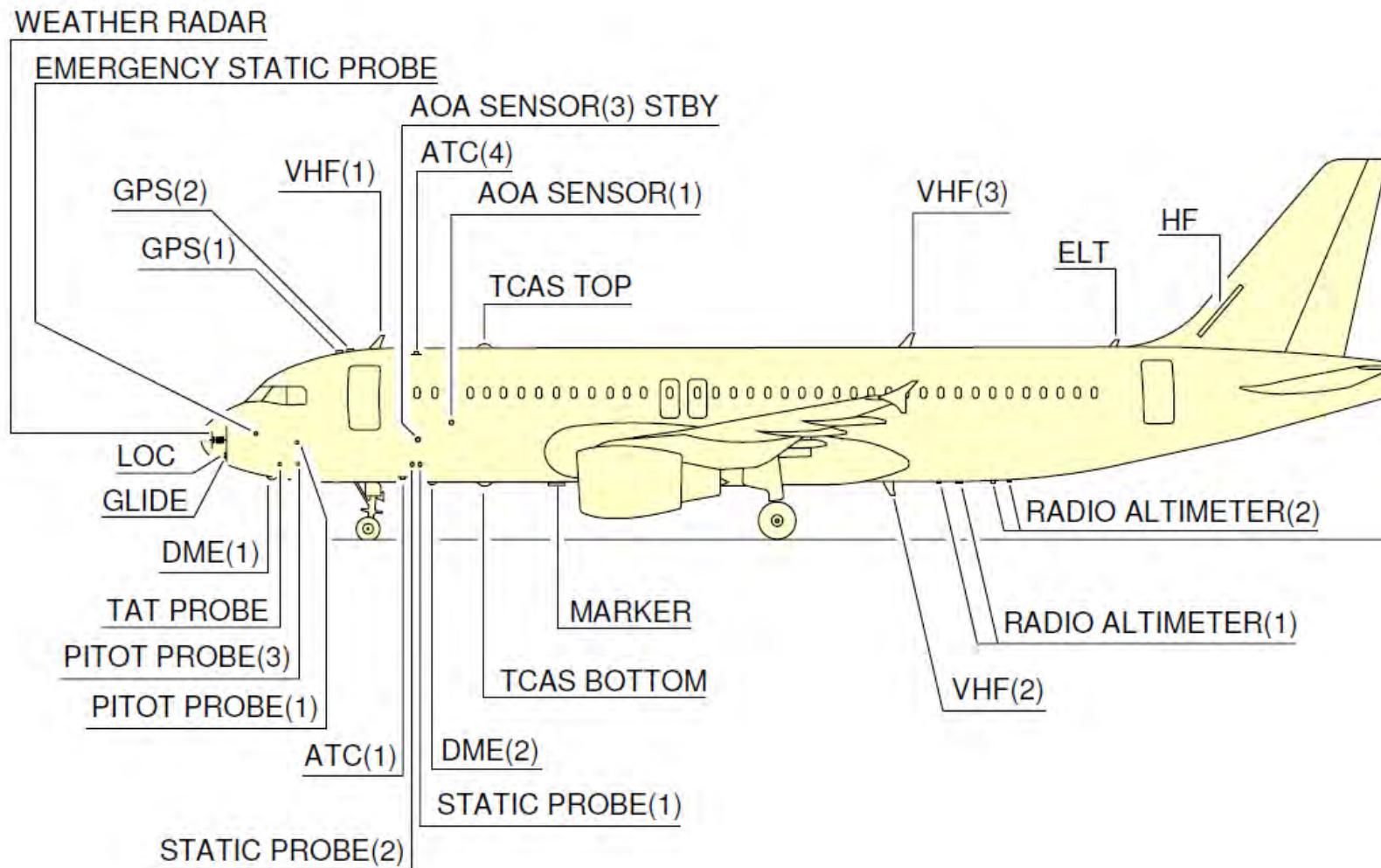
A320/A320NEO

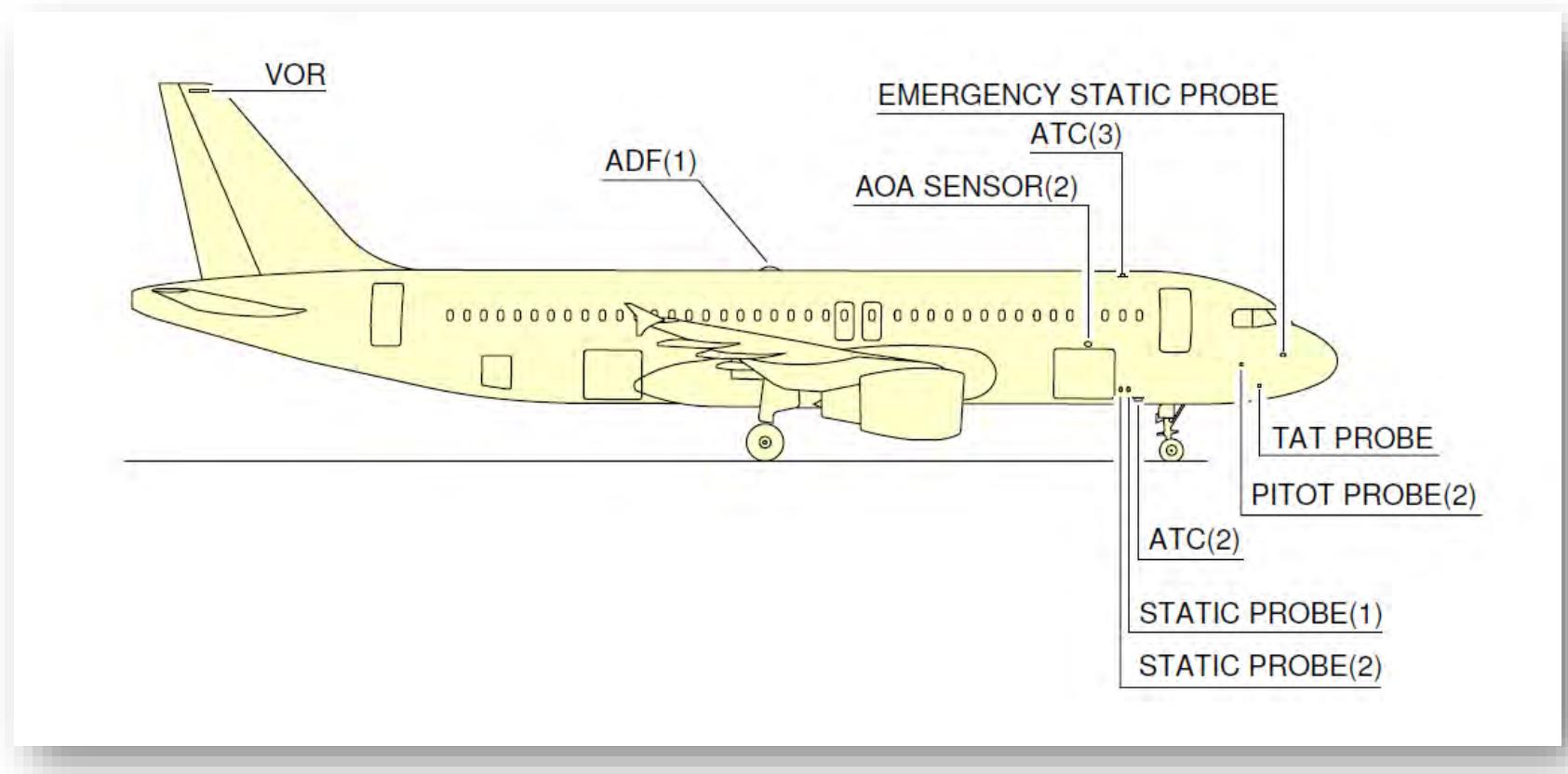


UNIVERSITAT POLITÈCNICA DE CATALUNYA

BARCELONATECH

Departament de Teoria del Senyal  
i Comunicacions





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# Tema 2: ANTENES, RADIOENLLAÇOS I PROPAGACIÓ D'ONES ELECTROMAGNÈTIQUES

Mecanismes de propagació radioelèctrica.

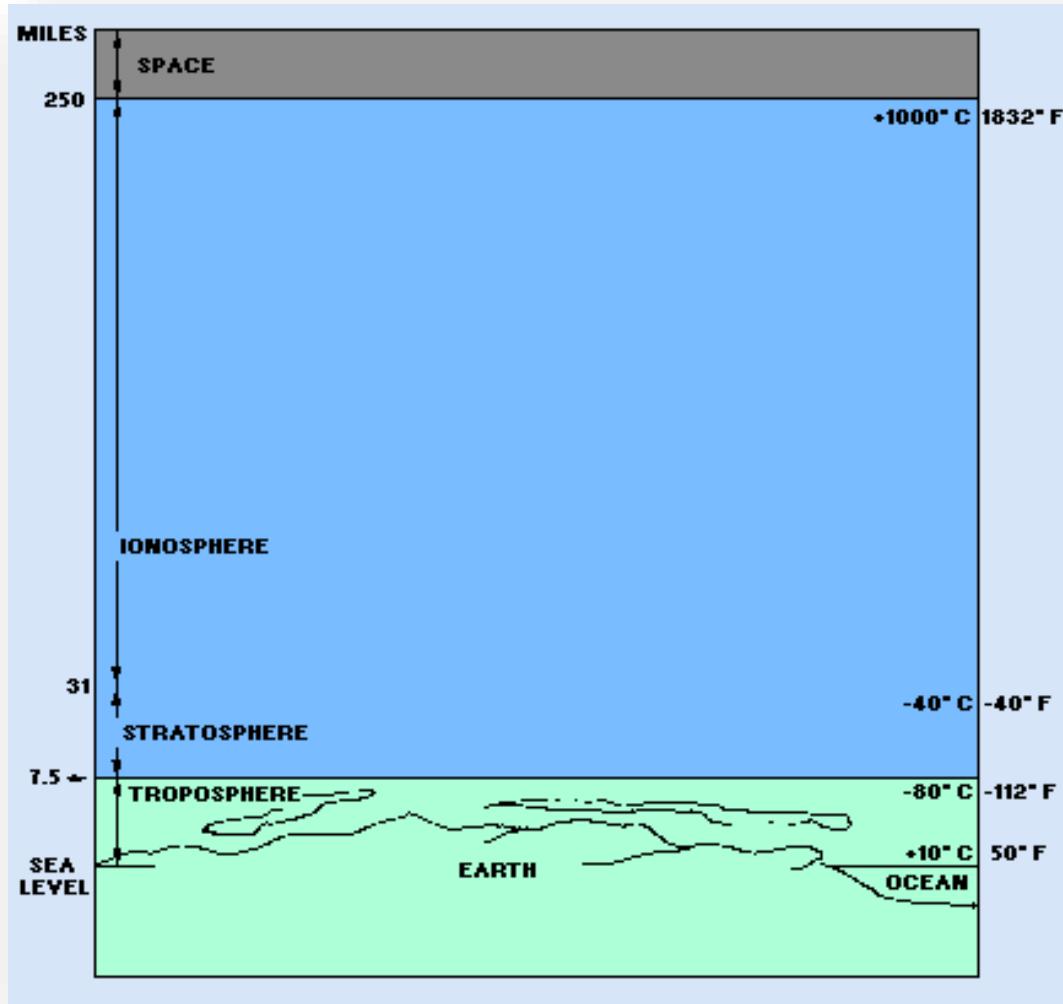
Jordi Berenguer i Sau



# Mecanismes de propagació radioelèctrica

- La propagació d'ones electromagnètiques a l'espai lliure, és a dir, la radiació, es produeix de diverses formes en funció de la banda de freqüències d'emissió.
- La regulació dels serveis de telecomunicació i l'assignació de freqüències que realitza la UIT es basen en el bon aprofitament dels mecanismes de propagació de les ones electromagnètiques i també de les necessitats d'amplada de banda de transmissió dels diferents serveis.
- A continuació descriurem de forma qualitativa els principals mecanismes de propagació radioelèctrica en funció de la freqüència, suposant que l'ona ja ha estat generada per una antena adequada per a la seva transmissió.

# Propagació radioelèctrica



## TROPOSFERA

Es la part de l'atmosfera que s'estén des de la superfície de la terra fins a una altura d'uns 6 km en els pols nord i sud, i sobre uns 18 km a l'equador.

És on es produeixen els fenòmens atmosfèrics. La temperatura decreix ràpidament amb l'altitud, i es produeixen canvis en la seva densitat i pressió que influeixen en la propagació.

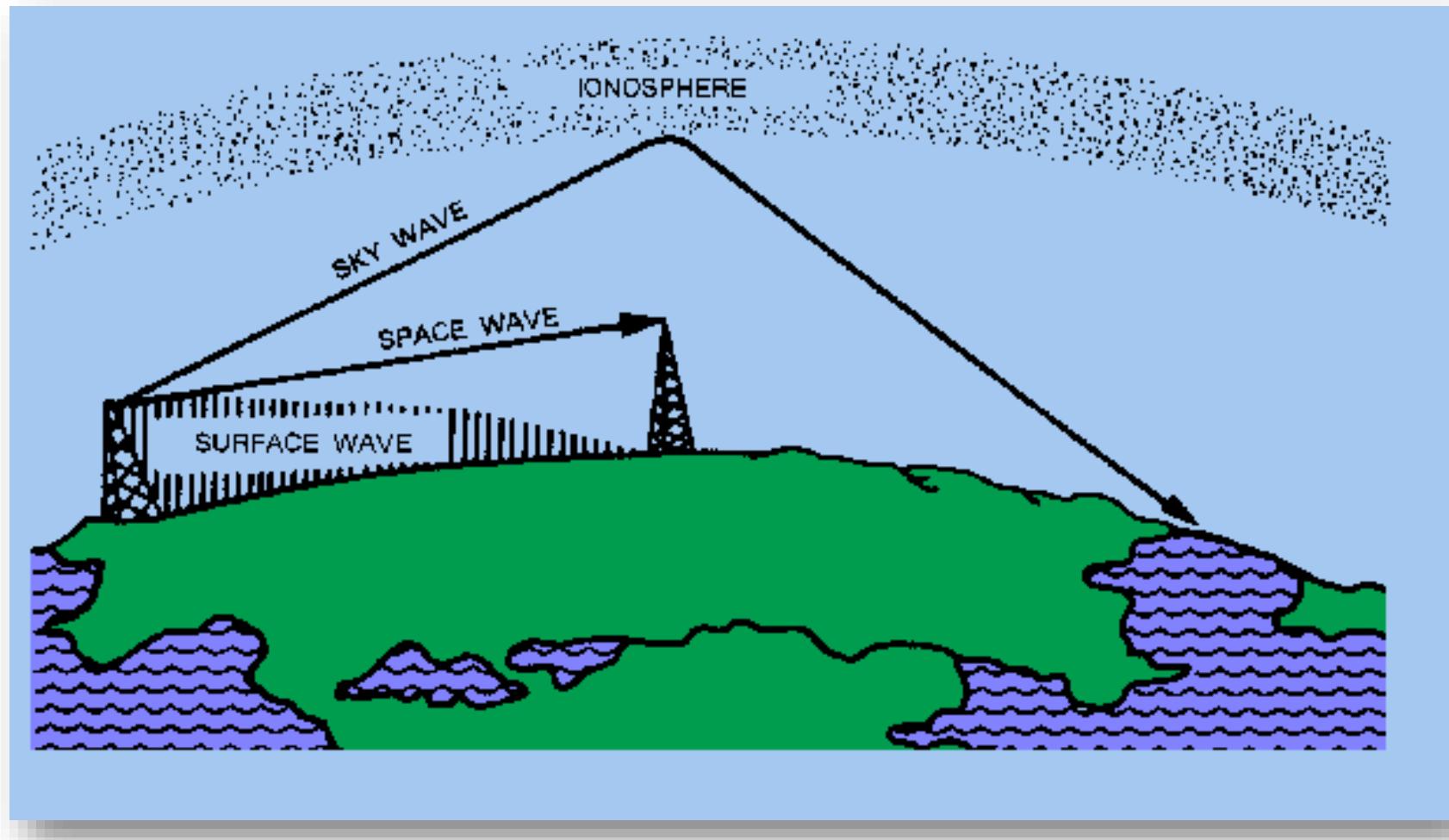
## ESTRATOSFERA

Situada entre la ionosfera i la troposfera, té una temperatura constant amb poca presència de vapor d'aigua. Té poca incidència en la propagació radioelèctrica degut a la seva estabilitat tèrmica.

## IONOSFERA

Es situa entre uns 50 km i 402 km de la superfície de la terra. Conté quatre capes amb ions carregats elèctricament (plasma), que permeten la propagació a gran distància.

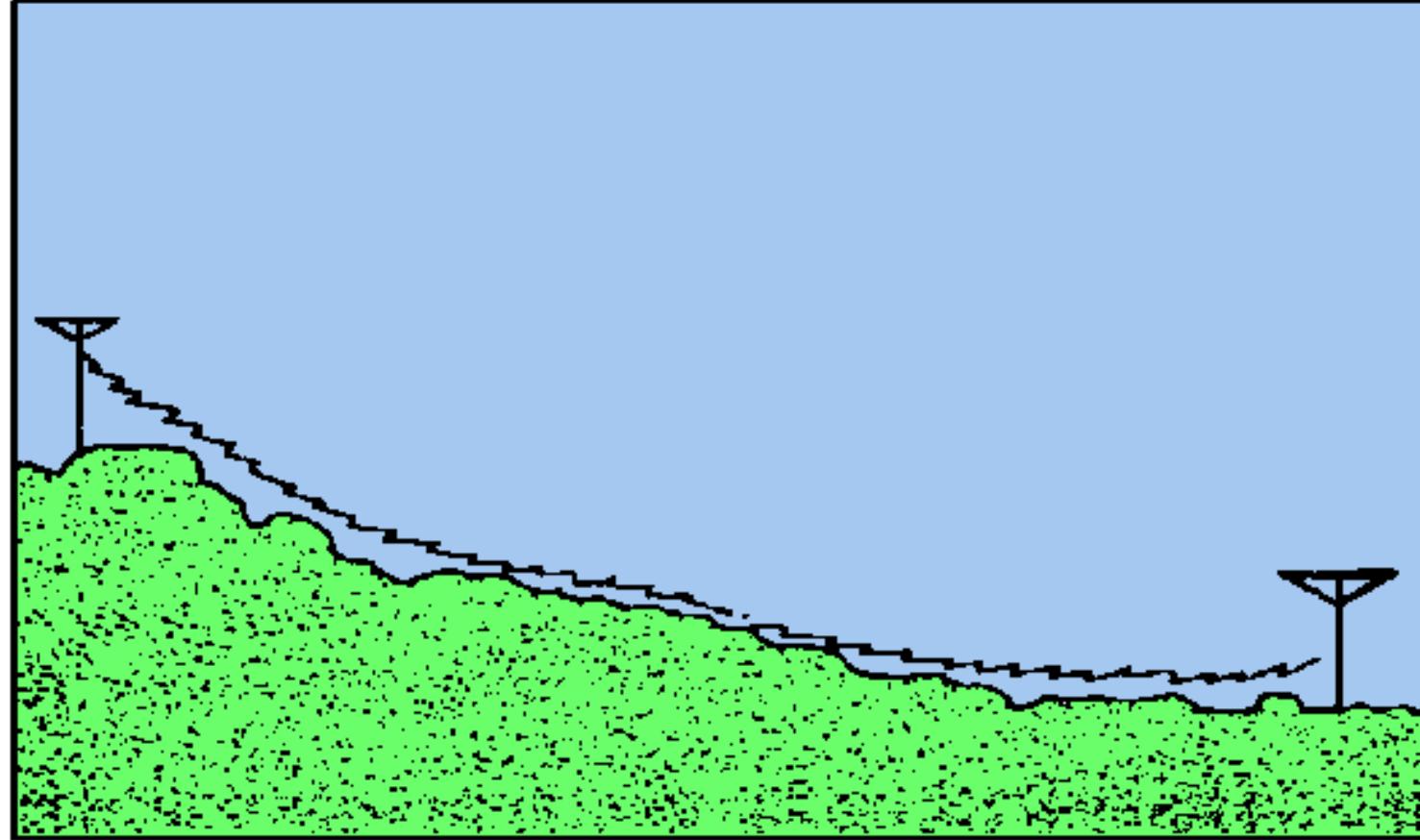
# Mecanismes de propagació



# Ones quilomètriques (LF) - 30 kHz a 300 kHz

- En aquest marge de freqüències la propagació es realitza per difracció de l'ona electromagnètica sobre la superfície de la Terra, sent pràcticament independent del tipus de terra i dels obstacles que troba.
- A grans distàncies, la capa D de la ionosfera en pot afavorir la propagació.
- Aquest mecanisme de propagació és d'especial interès en la telegrafia intercontinental de baixa velocitat, els senyals horaris i els sistemes de radionavegació.
- Penetren alguns metres per sota la superfície del mar, fet que els dóna utilitat en les comunicacions amb submarins.
- Requereixen antenes de grans dimensions, a més d'una gran potència d'emissió.

# Propagació per ona de superfície

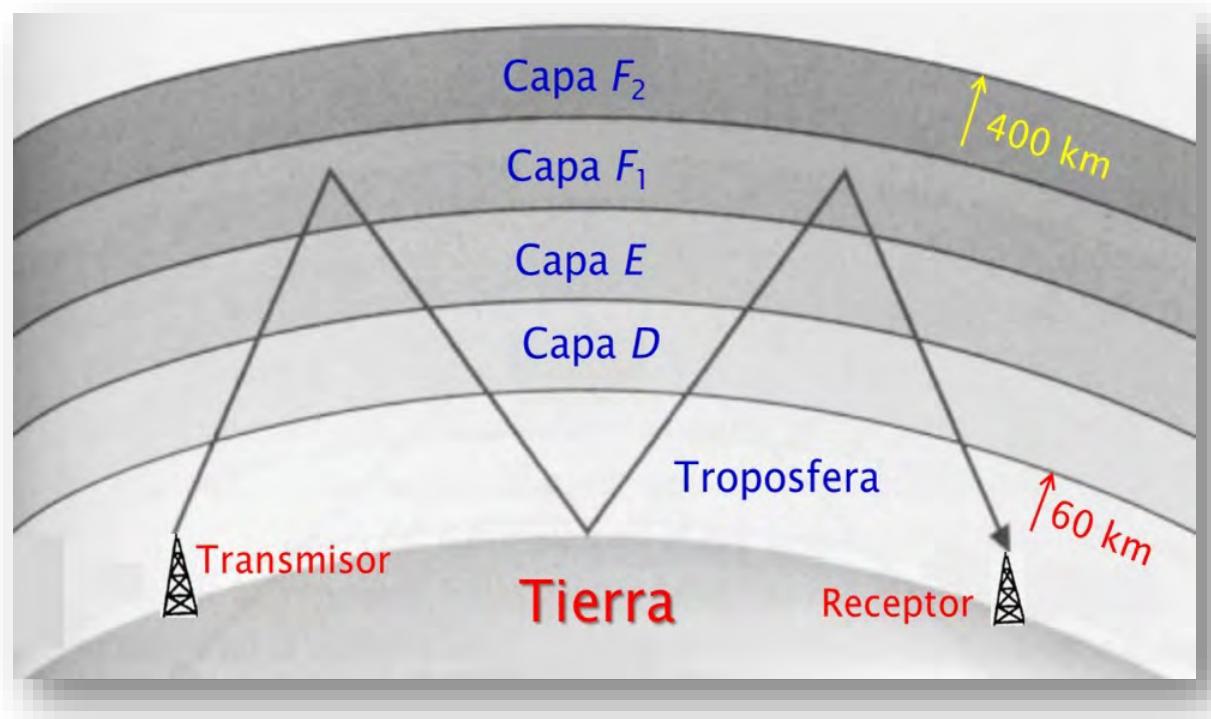


# Ones hectomètriques (MF) - 300 kHz - 3 MHz

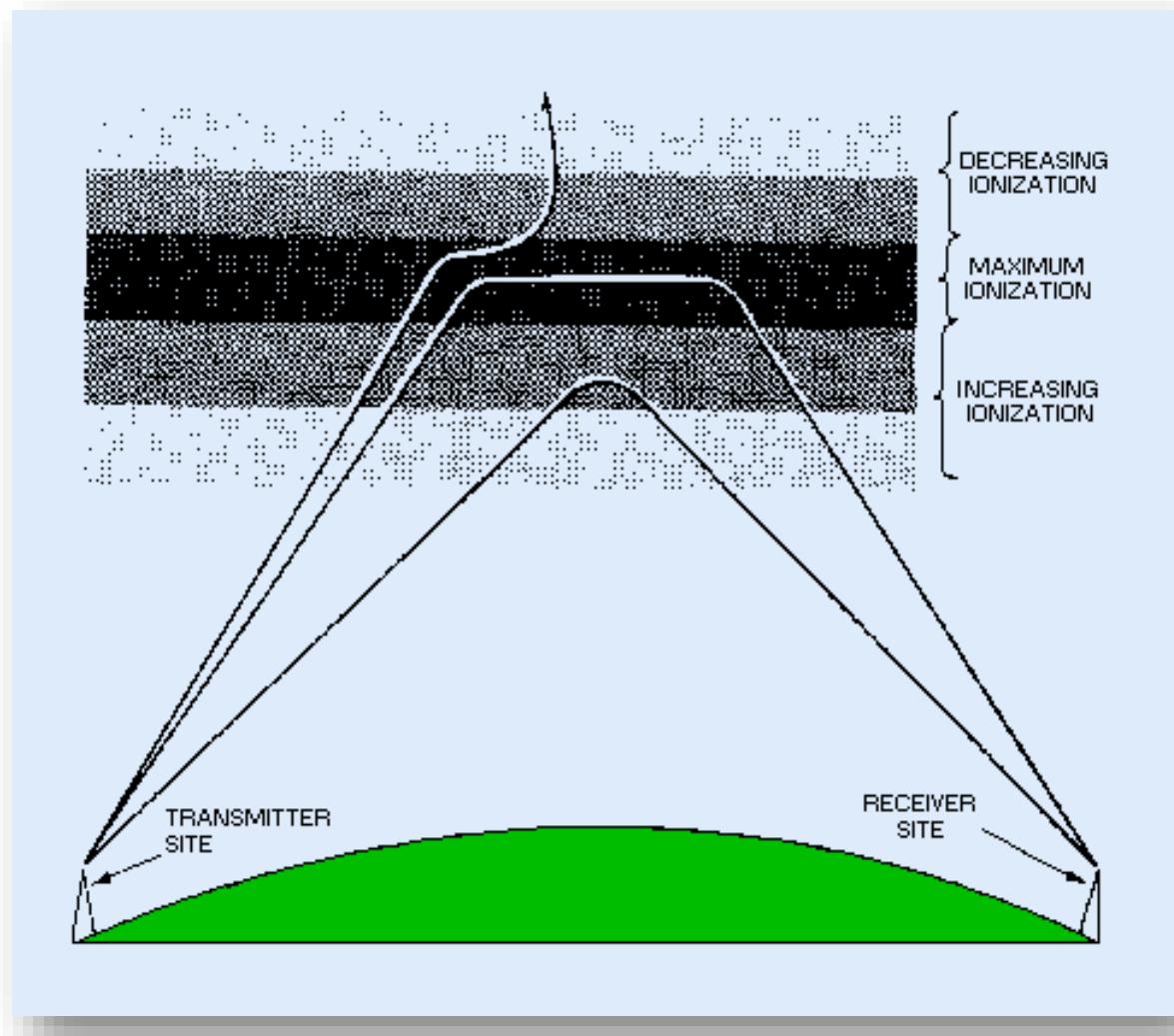
- En aquest marge de freqüències la propagació per ona terrestre difractada és més dificultosa.
- Es propaga millor sobre la superfície del mar que sobre la terra.
- La propagació més important es realitza mitjançant la reflexió en la capa E de la ionosfera, encara que és molt inestable; de nit la propagació augmenta.
- Aquest mecanisme és el que utilitza la radiodifusió sonora en AM en la zona baixa de la banda; la part superior de la banda s'empra en comunicacions marines, atesa la bona propagació que presenta sobre la superfície del mar, sense necessitat d'haver de fer servir antenes molt grans.

# Ones decamètriques (HF) - 3 MHz - 30 MHz

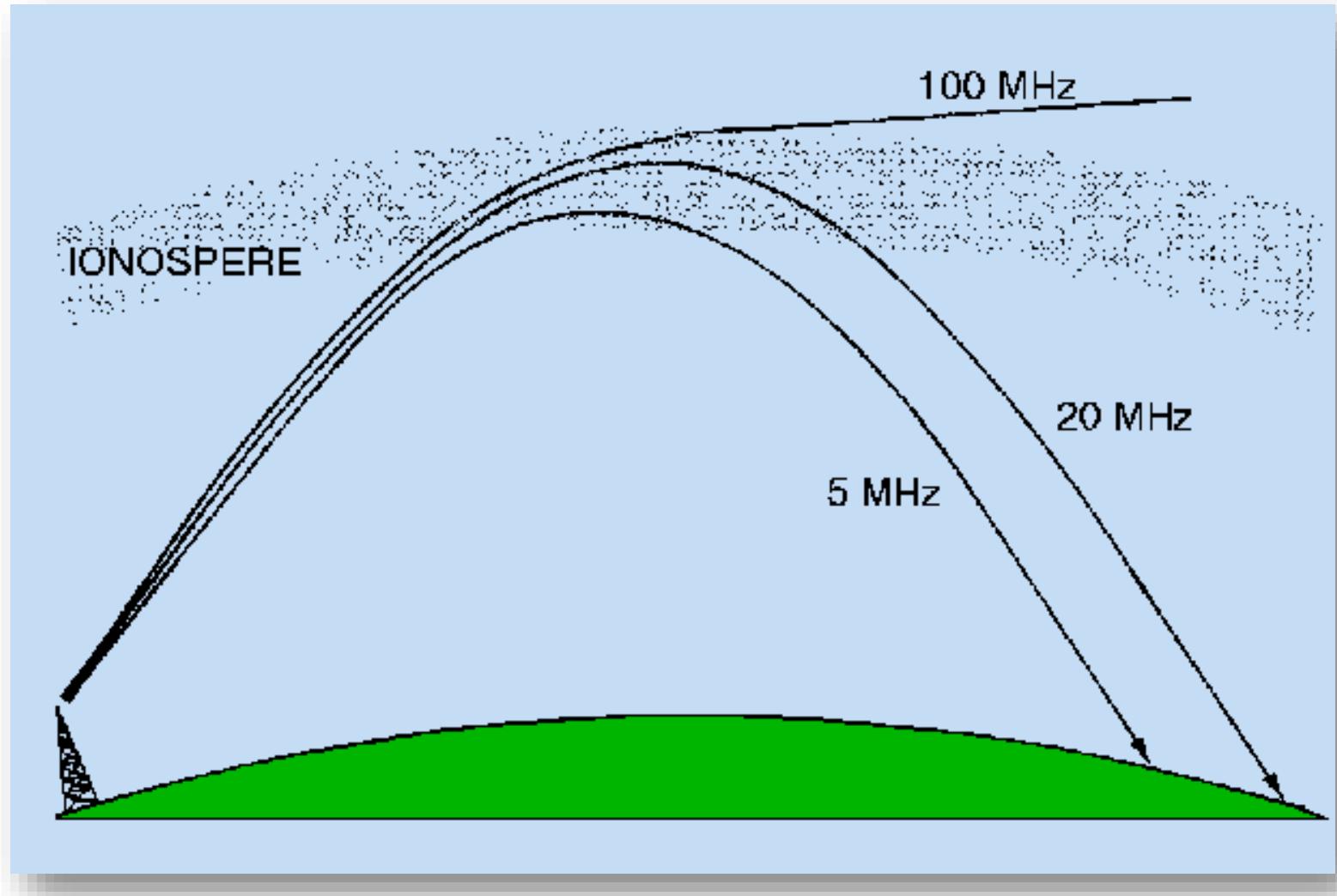
- També conegeudes com a ones curtes, utilitzen la **reflexió ionosfèrica** per transmetre a grans distàncies (**capa F2**); les capes D i E produueixen una certa absorció del senyal.
- A causa de la variació de les capes de la ionosfera en funció de si és de nit o de dia, **els enllaços s'estableixen segons la freqüència i l' hora del dia.**



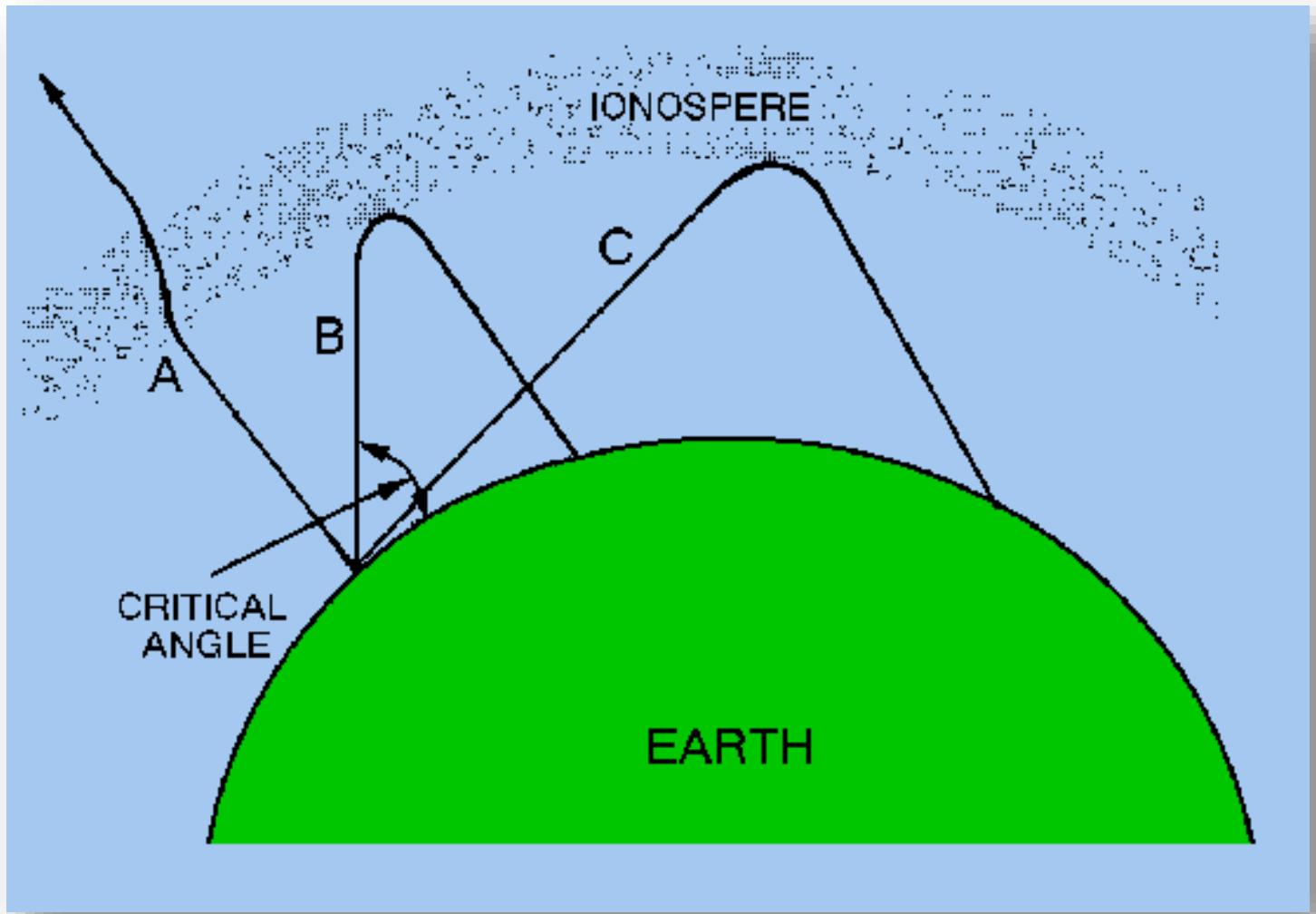
# Reflexió ionosfèrica



# Reflexió ionosfèrica



# Reflexió ionosfèrica



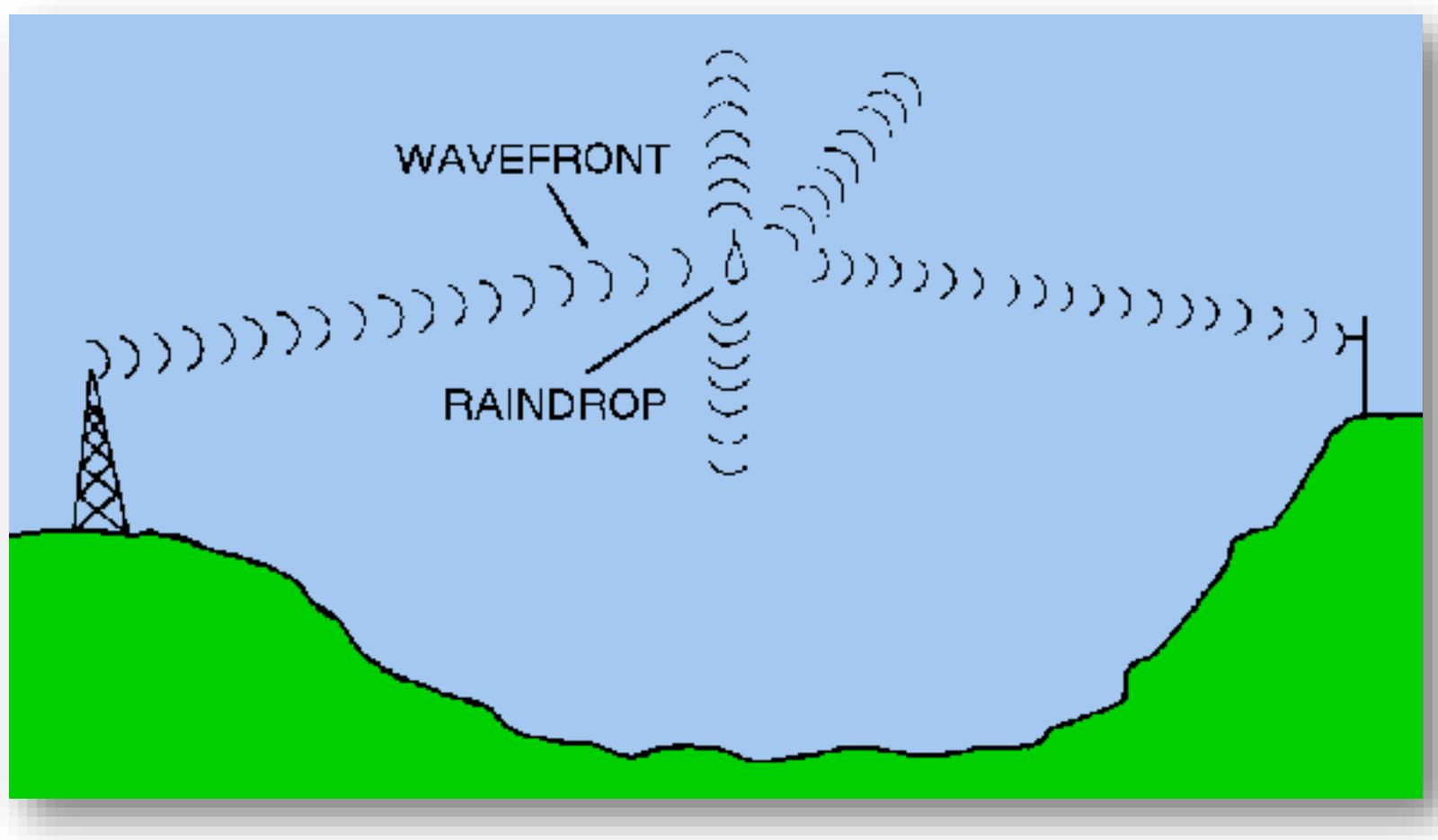
# Ones mètriques (VHF) - 30 MHz – 300 MHz

- En aquest marge de freqüències la propagació es realitza per visió directa (*Línia de vista*) (*Line of sight: LOS*), o també per difracció al voltant de l'esfera terrestre o de diferents obstacles.
- S'utilitza en enllaços de comunicacions mòbils i, s'havia utilitzat fins l'any 2000 en radiodifusió de TV (banda I).

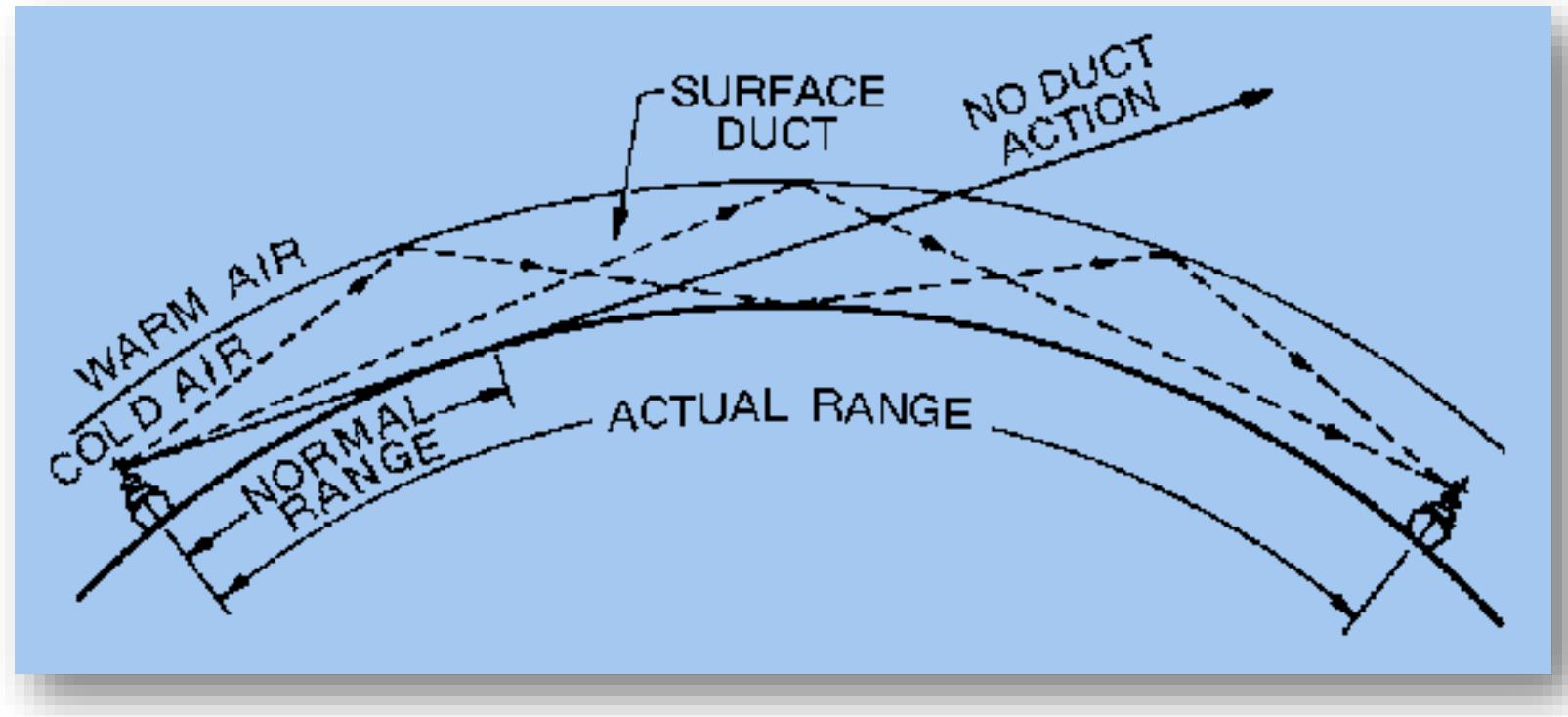
# Ones decimètriques (UHF) - 300 MHz – 3 GHz

- La propagació per difracció no és gaire important; es realitza bàsicament per visió directa o també per difusió troposfèrica més enllà de l'horitzó.
- Aquest últim mecanisme és el que permet a l'estiu poder captar esporàdicament algunes emissions de TV procedents de països europeus costaners.

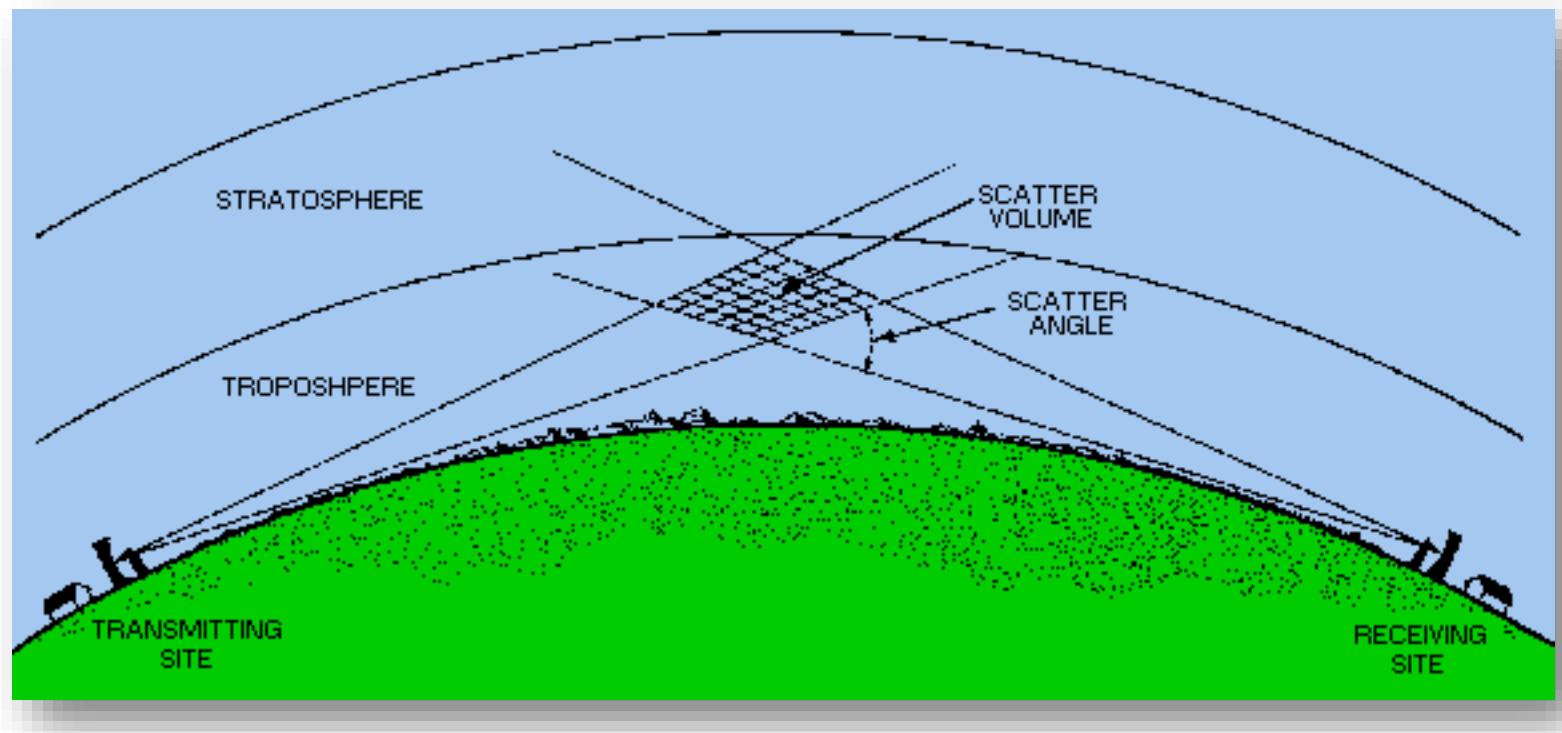
# Dispersió atmosfèrica



# Propagació per conductes troposfèrics



# Dispersió troposfèrica (scattering)



# Ones centimètriques (SHF)

## 3 GHz – 30 GHz

- La propagació només es pot fer per visió directa.
- L'**atenuació** produïda per la **pluja** té un efecte important en freqüències superiors a **10 GHz**.

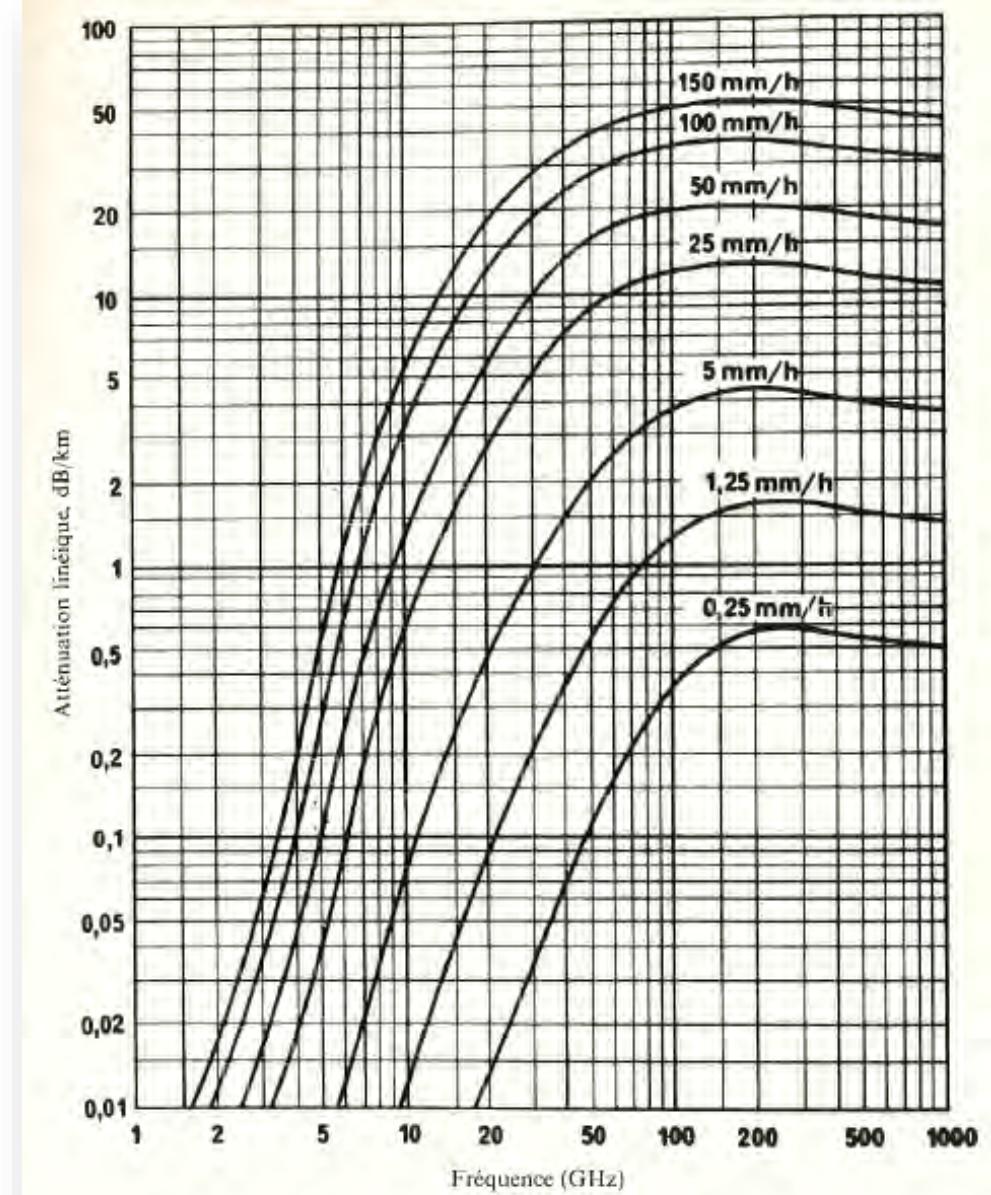


Fig. 5.5. Atténuation linéaire due à la pluie.  
Distribution des dimensions des gouttes de pluie (Law et Parsons).

# Ones mil·limètriques (EHF)

## 30 GHz – 300 GHz

- La propagació també és exclusivament per visió directa, encara que limitada per la forta atenuació que introduceix **l'absorció atmosfèrica de l'oxigen i del vapor d'aigua.**

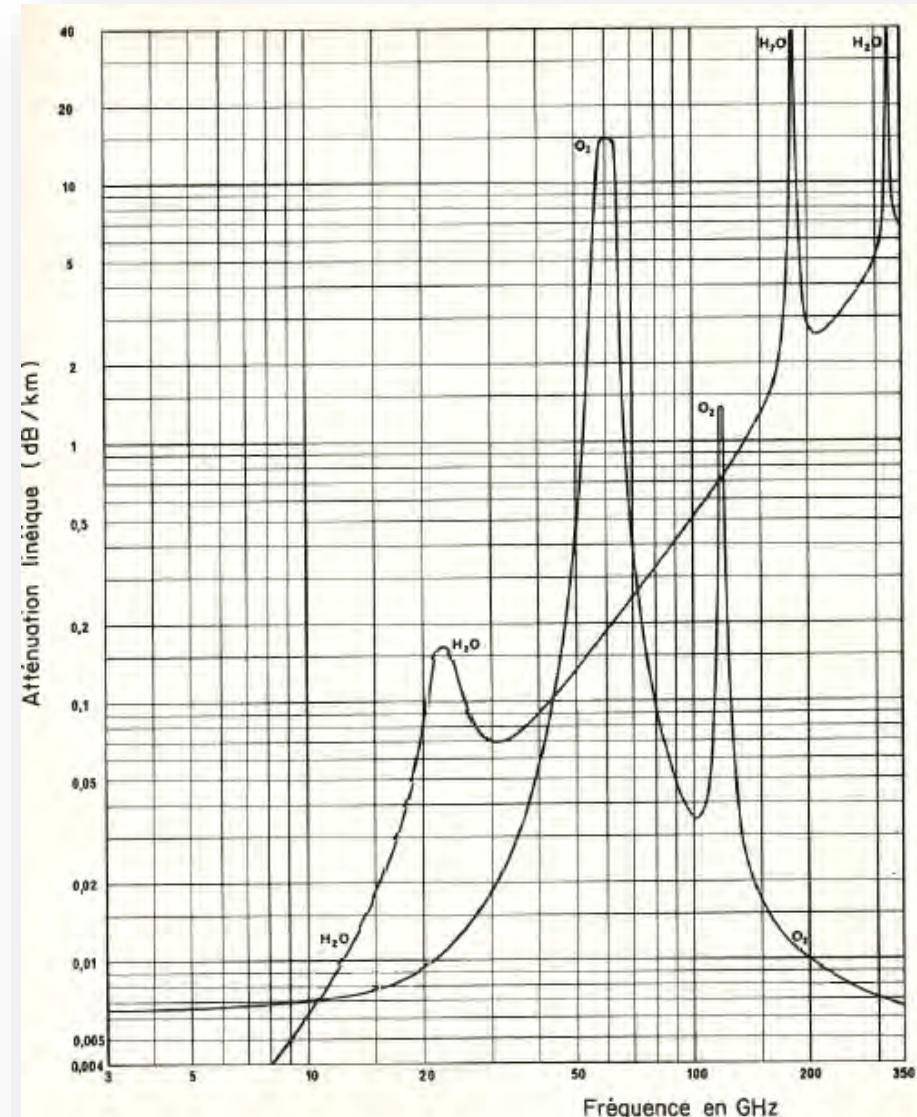
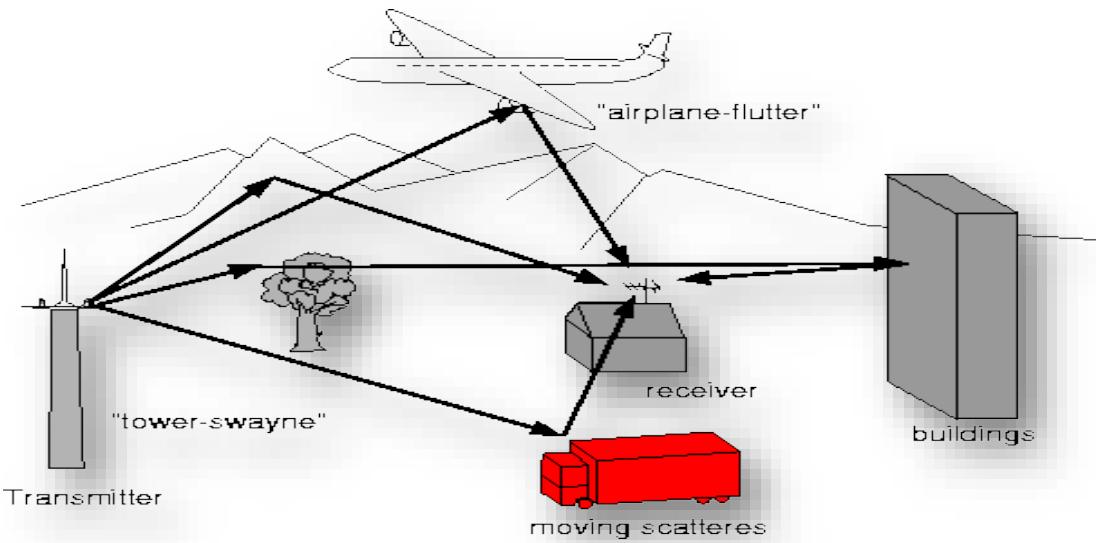


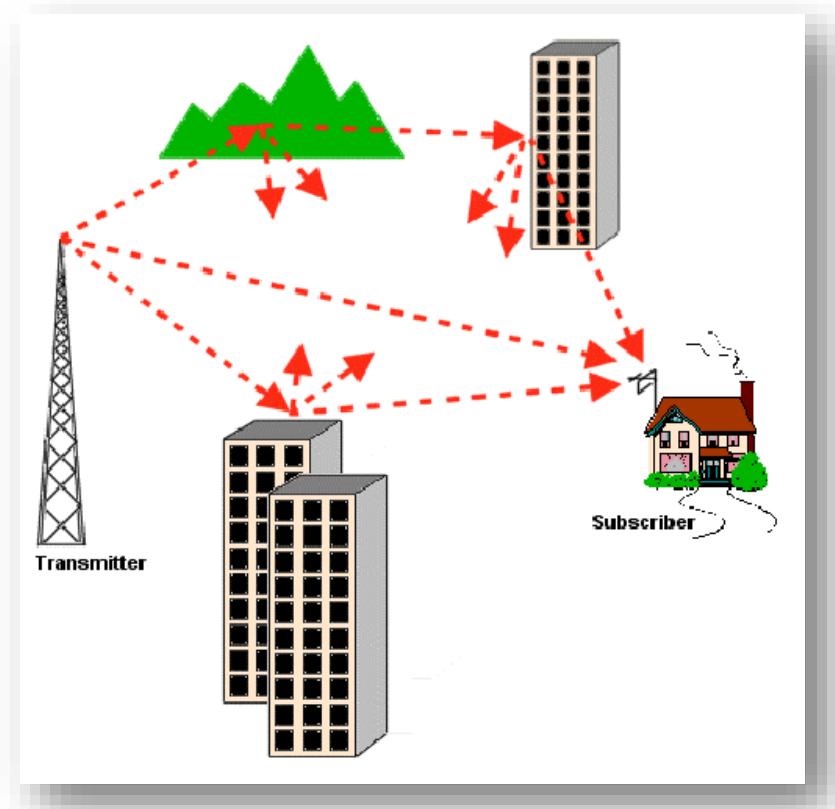
Fig. 5.1. Atténuation par les gaz de l'atmosphère.  
Pression : 1 013,6 mbar.  
Température : 20°.  
Vapeur d'eau : 7,5 g/m<sup>3</sup>.

# Fading (multipath)



La propagació multicamí pot provocar **interferència destructiva** en el receptor si la diferència de fase entre el senyal directe i el senyal reflectit és de l'ordre de  $180^\circ$ .

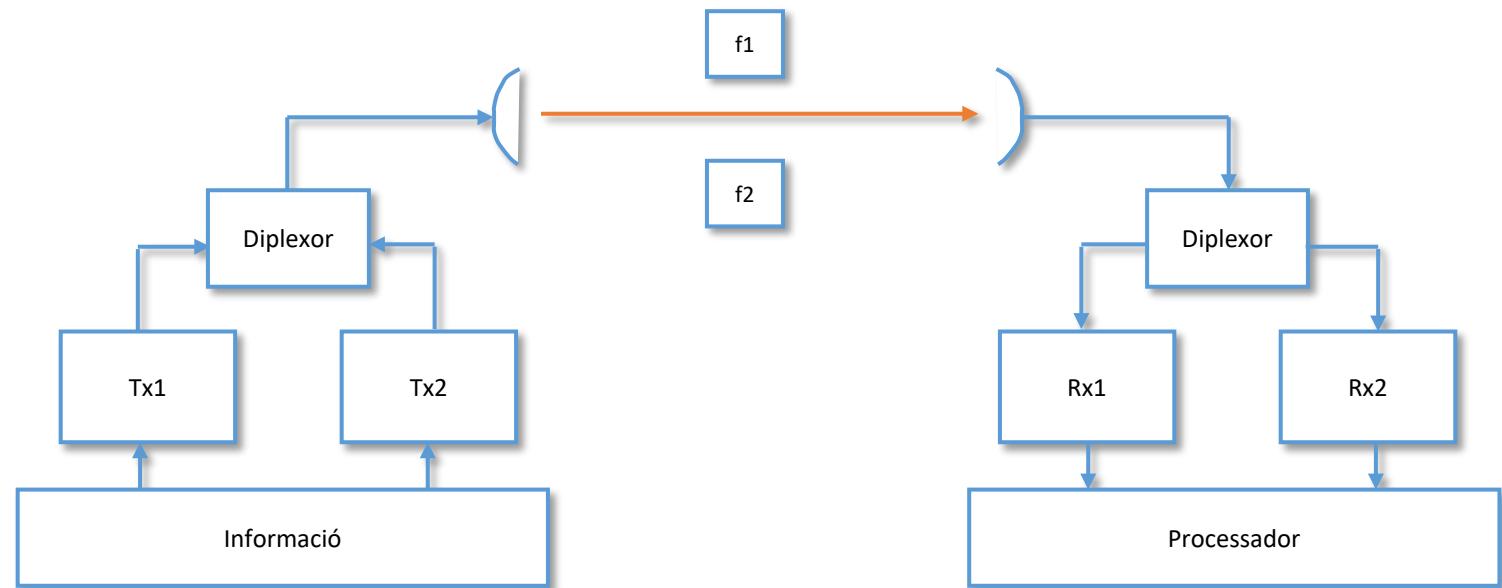
El resultat és l'efecte d'**esvaïment** de l'enllaç (**fading**).



# Solucions al “fading”

## Diversitat en freqüència:

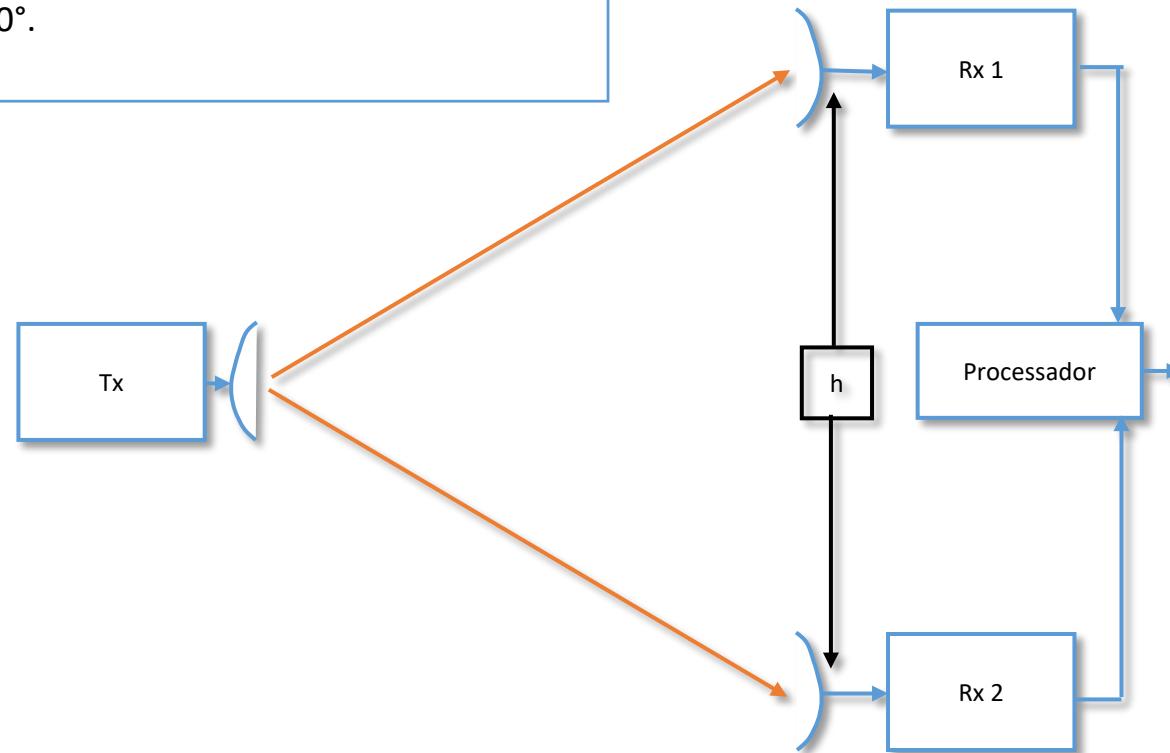
Utilitzar dues freqüències properes (**duplicar l'ús de l'espectre radioelèctric**, amb dos emissors i dos receptors), per garantir que la diferència de fase amb que els senyals arriben a cada receptor sigui com a mínim diferent de  $180^\circ$  en un d'ells.



# Solucions al “fading”

## Diversitat en espai:

Utilitzar **dues antenes receptors** separades un múltiple de  $\lambda/2$ , per garantir que la diferència de fase amb que els senyals reflectits arriben a cada antena presentin una diferencia de fase de  $180^\circ$ .



# Solucions al “fading”

## Evitar obstacles dins de la primera zona de Fresnel:

Els radis de les zones de Fresnel es calculen a partir de la següent expressió:

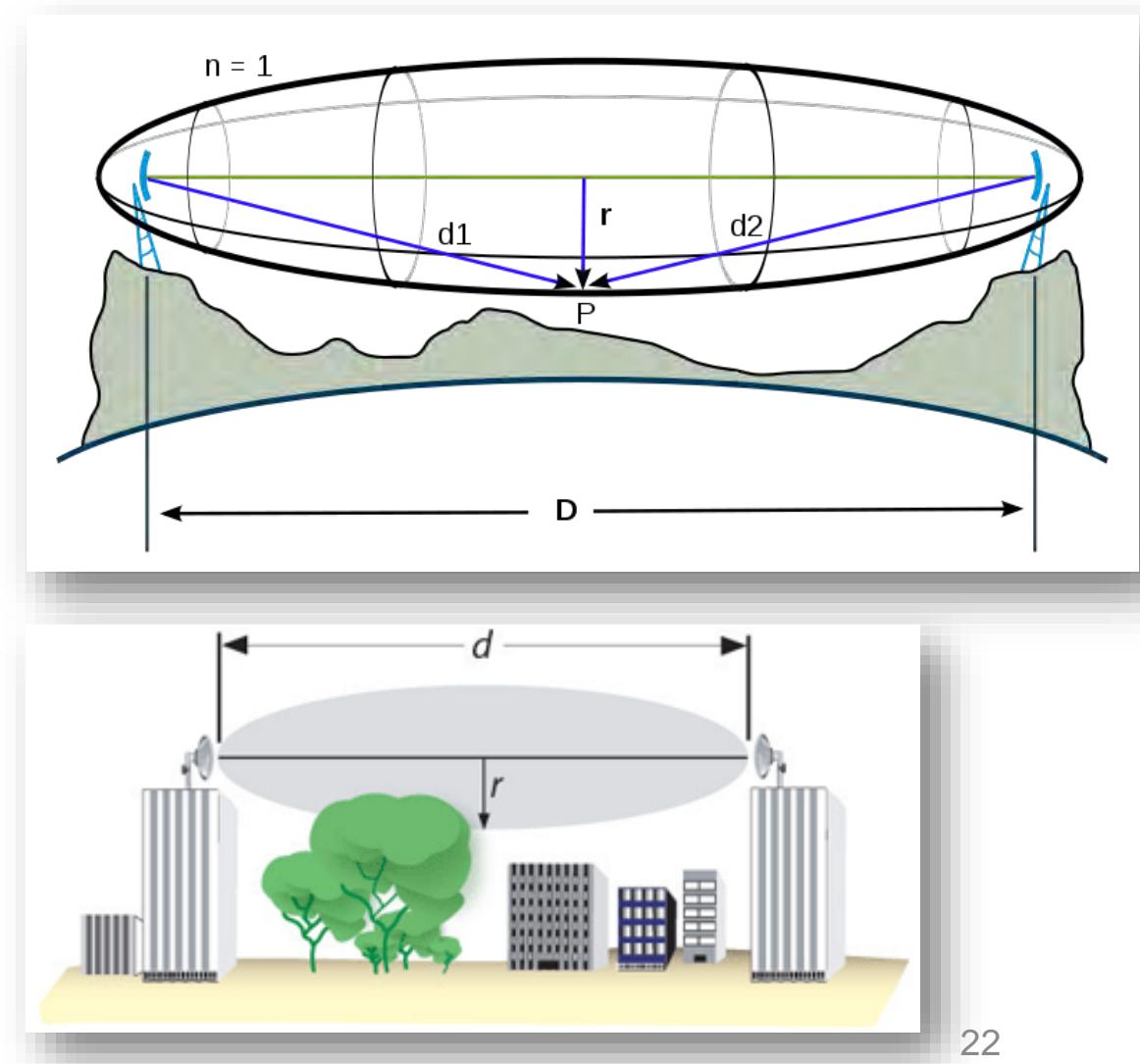
$$r_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}}$$

Qualsevol trajectòria que estigui dins de la primera zona de Fresnel de radi:

$$r_1 = \sqrt{\frac{\lambda d_1 d_2}{d_1 + d_2}}$$

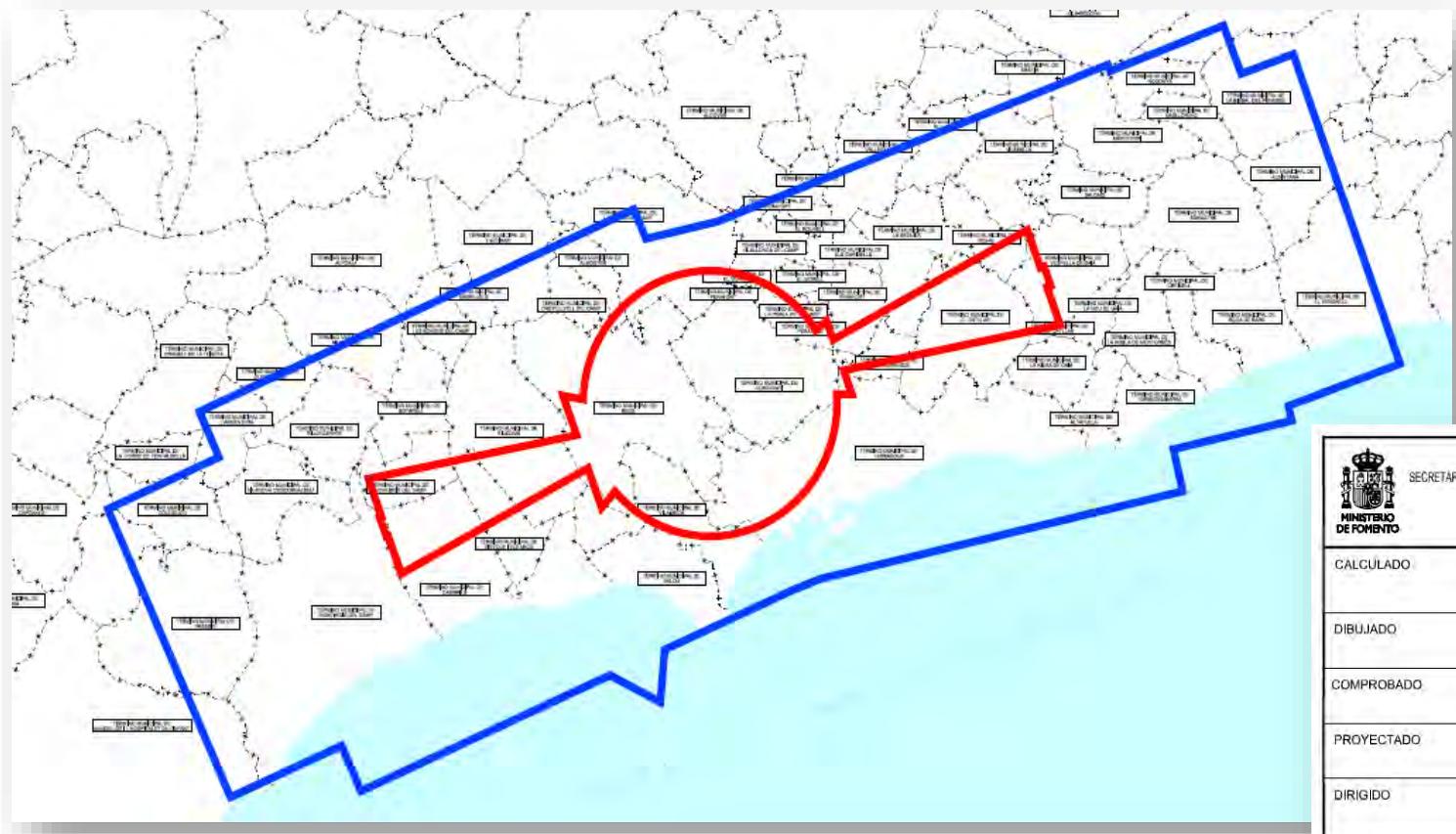
pot arribar amb un desfasament de 180°.

Per tant **s'ha d'evitar**, ajustant l'altura de les antenes, **que cap obstacle quedí dins de la primera zona de Fresnel**.



# Solucions al “fading”

## Cas aeronàutic: Servituds Radioelèctriques



AEROPUERTO DE REUS  
SERVIDUMBRES AERONÁUTICAS

PLANOS DE SERVIDUMBRES DE AERÓDROMO Y  
RADIOELÉCTRICAS

SECRETARÍA DE ESTADO DE TRANSPORTES MINISTERIO DE FOMENTO	Aena Aeropuertos Españoles y Navegación Aérea				
CALCULADO	DIRECCIÓN DE PLANIFICACIÓN DE INFRAESTRUCTURAS DIRECCIÓN DE NAVEGACIÓN AÉREA				
DIBUJADO					
COMPROBADO	AEROPUERTO DE REUS PROPIUESTA DE MODIFICACIÓN DE SERVIDUMBRES AERONÁUTICAS				
PROYECTADO					
DIRIGIDO	TÉRMINOS MUNICIPALES AFECTADOS POR LAS SERVIDUMBRES				
HOJA N° 1	PLANO N° 1	EDICIÓN V.2	FECHA Enero 2009	ESCALA 1:100.000 (A1)	SUSTITUYE Á

# Decreto 584/1972, de 24 de febrero, de servidumbres aeronáuticas.

## *CAPÍTULO II. Servidumbres de las instalaciones radioeléctricas aeronáuticas*

### **Artículo 14.**

A los fines de este Decreto se considera que las perturbaciones radioeléctricas sufridas en la normal utilización de una instalación radioeléctrica aeronáutica se hallan producidas por:

- a) Absorciones y/o reflexiones de las ondas electromagnéticas radiadas o recibidas por la instalación.
- b) Otras radiaciones ajenas a la misma.

### **Artículo 15.**

Al objeto de reducir las perturbaciones definidas en el artículo decimocuarto, a), se imponen las servidumbres siguientes:

- a) Zona de limitación de alturas.—En esta zona se prohíbe que ningún elemento sobre el terreno sobrepase en altura la superficie de limitación de alturas correspondientes.
- b) Zona de seguridad.—En esta zona se prohíbe cualquier construcción o modificación temporal o permanente de la constitución del terreno, de su superficie o de los elementos que sobre ella se encuentren, sin previo consentimiento del Ministerio del Aire.

### **Artículo 16.**

Al objeto de reducir las perturbaciones definidas en el artículo decimocuarto, b), se imponen las servidumbres siguientes:

- a) Dentro de la zona de limitación de alturas será necesario el consentimiento previos del Ministerio del Aire para la instalación fija o móvil de todo tipo de emisor radioeléctrico, aun cuando cumpla con las condiciones de la Unión Internacional de Telecomunicaciones, así como cualquier dispositivo que pueda dar origen a radiaciones electromagnéticas perturbadoras del normal funcionamiento de la instalación radioeléctrica aeronáutica.
- b) Si una vez instalado el emisor o dispositivo, a que se refiere el apartado a) de este artículo, se localizaran en él fuentes perturbadoras del normal funcionamiento de la instalación radioeléctrica aeronáutica, el Ministerio del Aire lo notificará al propietario, quien vendrá obligado, a sus expensas, a reducir los efectos perturbadores a límites aceptables para dicho Ministerio, o a eliminarlo si fuera necesario y en el plazo que éste señale.

*Ministerio del Aire «BOE» núm. 69, de 21 de marzo de 1972*

*Referencia: BOE-A-1972-426*

*TEXTO CONSOLIDADO Última modificación: 17 de mayo de 2013*



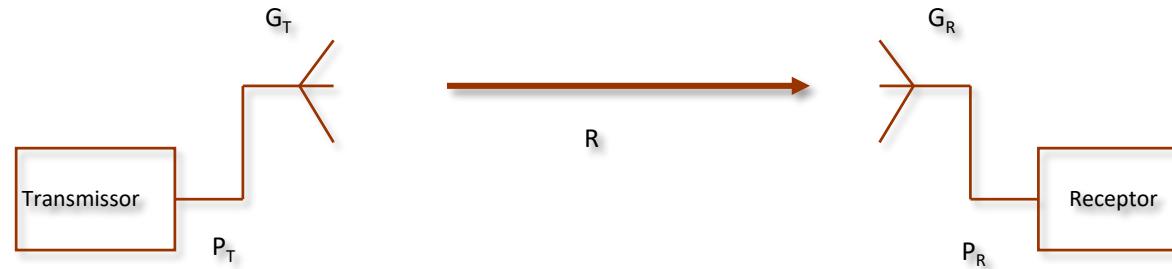
# Tema 2: ANTENES, RADIOENLLAÇOS I PROPAGACIÓ D'ONES ELECTROMAGNÈTIQUES

**Radioenllaços:** Procediment de disseny

Jordi Berenguer i Sau



# Equació de transmissió



- Un sistema de comunicacions radioelèctric es regeix per una lleia fonamental que és el que es coneix com a **equació de transmissió**.

$$P_R = \frac{P_T G_T}{4\pi R^2} \cdot G_R \cdot \frac{\lambda^2}{4\pi} = P_T \cdot G_T \cdot G_R \left( \frac{\lambda}{4\pi R} \right)^2 = PIRE \cdot G_R \cdot \left( \frac{\lambda}{4\pi R} \right)^2 = PIRE \cdot G_R \cdot FSL \quad (W)$$

- Es defineix l'atenuació per propagació en espai lliure, "**Free Space Loss: FSL**", com:

$$FSL = \left( \frac{\lambda}{4\pi R} \right)^2$$

$$FSL(dB) = 10 \cdot \log \left( \frac{\lambda}{4\pi R} \right)^2$$

# Càlcul de l'enllaç

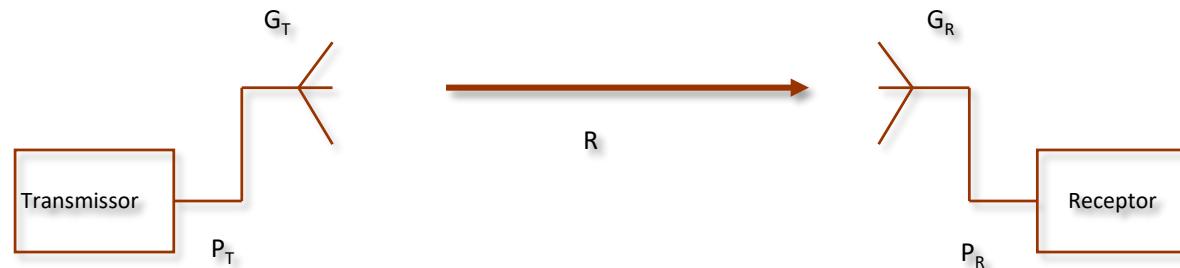
Punt de partida: Aplicació de l'equació de transmissió.

$$P_R = PIRE \cdot G_R \left( \frac{\lambda}{4\pi R} \right)^2$$

Afegint les possibles pèrdues per:

- Atenuació per la pluja:  $L_r$
- Desapuntament de les antenes:  $L_a$
- Desacoblament en polarització:  $L_p$
- Desadaptació d'impedàncies:  $L_m$

$$P_R = PIRE \cdot G_R \left( \frac{\lambda}{4\pi R} \right)^2 \cdot L_r \cdot L_a \cdot L_p \cdot L_m$$



# Càlcul de l'enllaç

**Càlcul de la distància màxima de l'enllaç per efecte de la curvatura de la terra.**

L'horitzó radioelèctric és aproximadament 4/3 més gran que l'horitzó òptic, degut als efectes de difracció de la troposfera.

Per una antena d'altura  $h$  sobre la superfície de la terra, el seu horitzó òptic és:

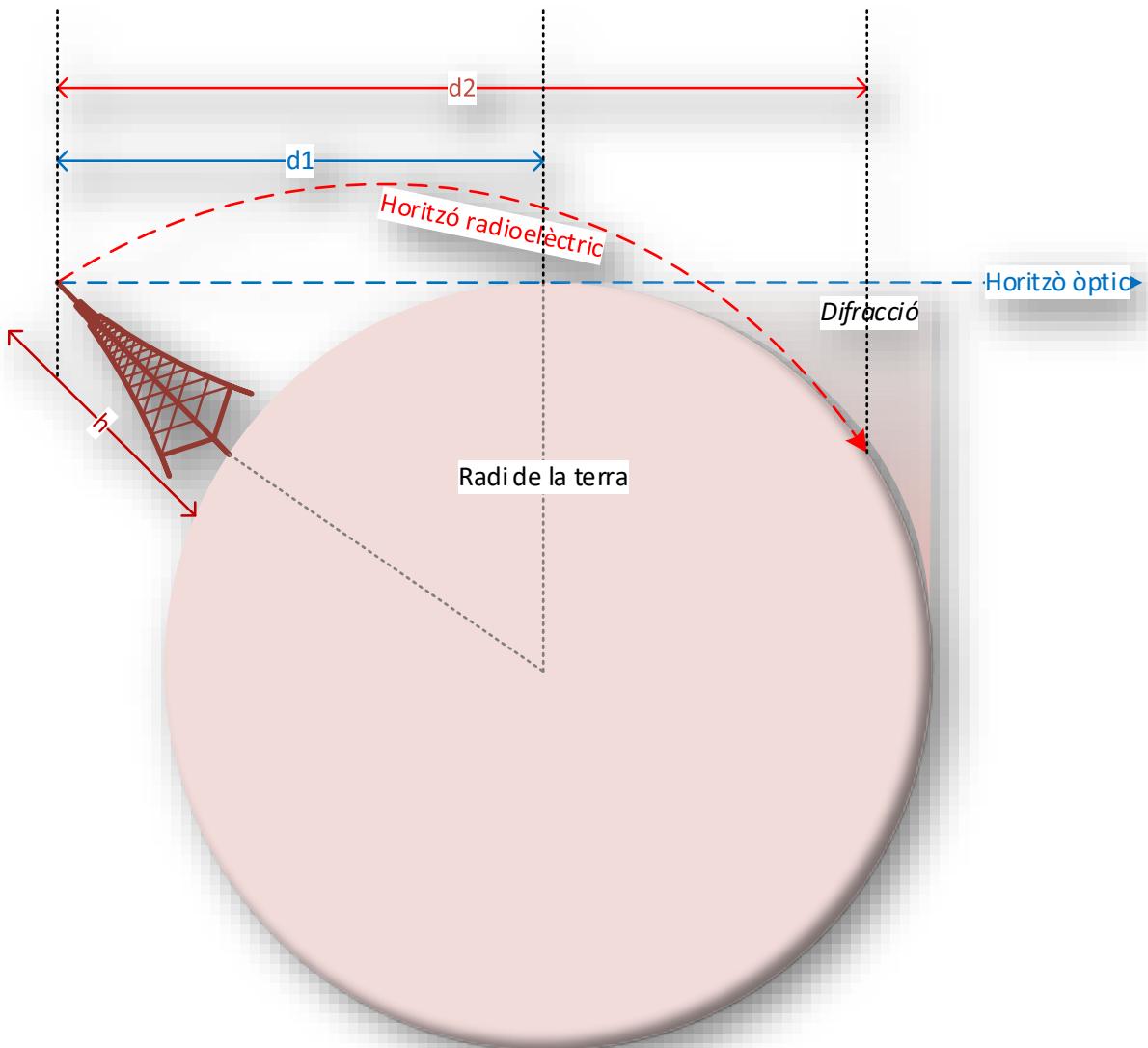
$$d_1(\text{km}) = \sqrt{12,74 \cdot h(\text{m})}$$

Per una antena d'altura  $h$  sobre la superfície de la terra, el seu horitzó radioelèctric és:

$$d_2(\text{km}) = \sqrt{17 \cdot h(\text{m})}$$

Per dues antenes d'altura  $h_1$  i  $h_2$  sobre la superfície de la terra, la distància màxima en la que es podrà produir l'enllaç radioelèctric serà:

$$d(\text{km}) = \sqrt{17 \cdot h_1(\text{m})} + \sqrt{17 \cdot h_2(\text{m})}$$

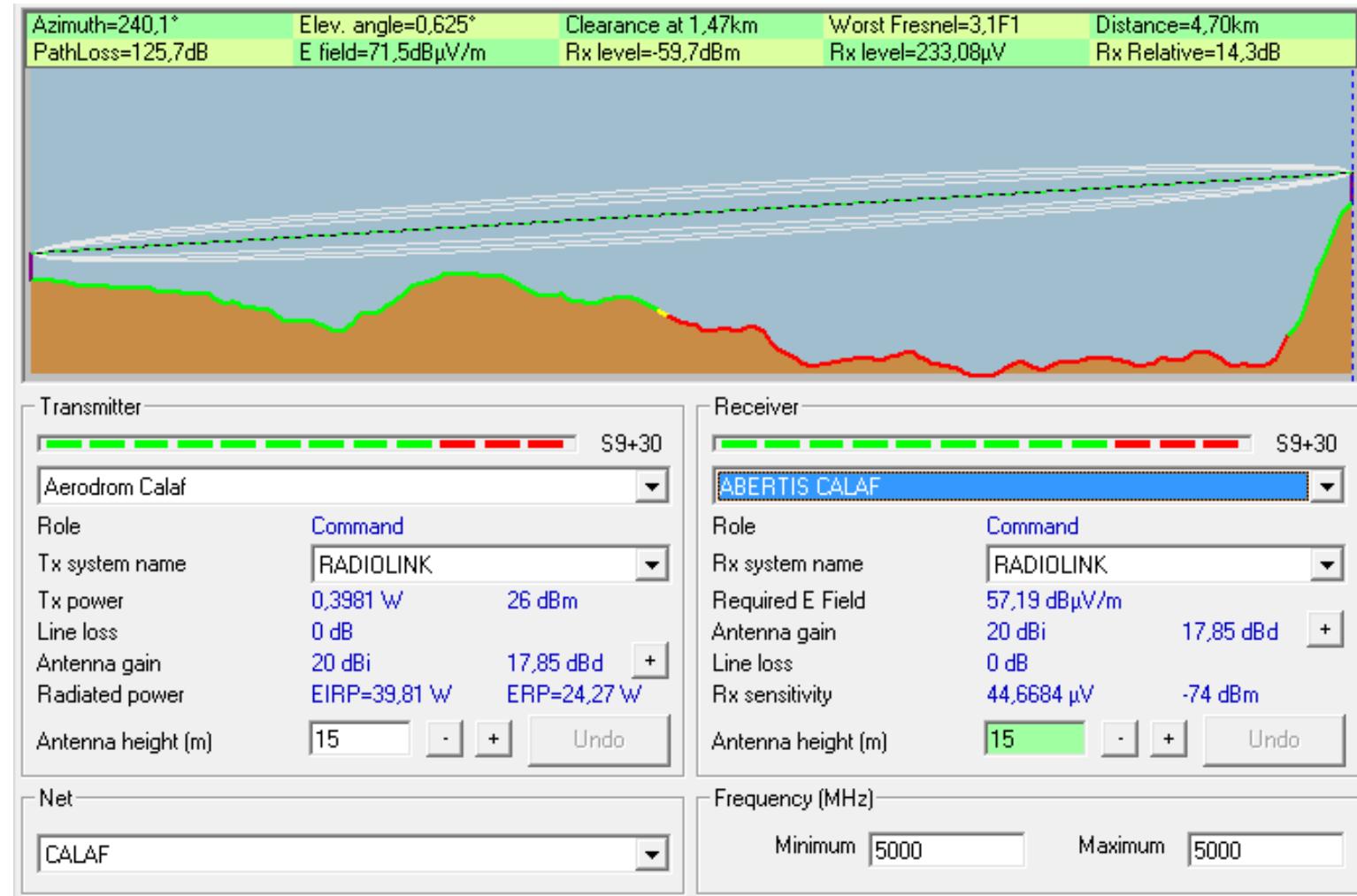


# Càlcul de l'enllaç

Realitzar un aixecament topogràfic i ajustar l'altura de les antenes per evitar obstacles dins de la primera zona de Fresnel.

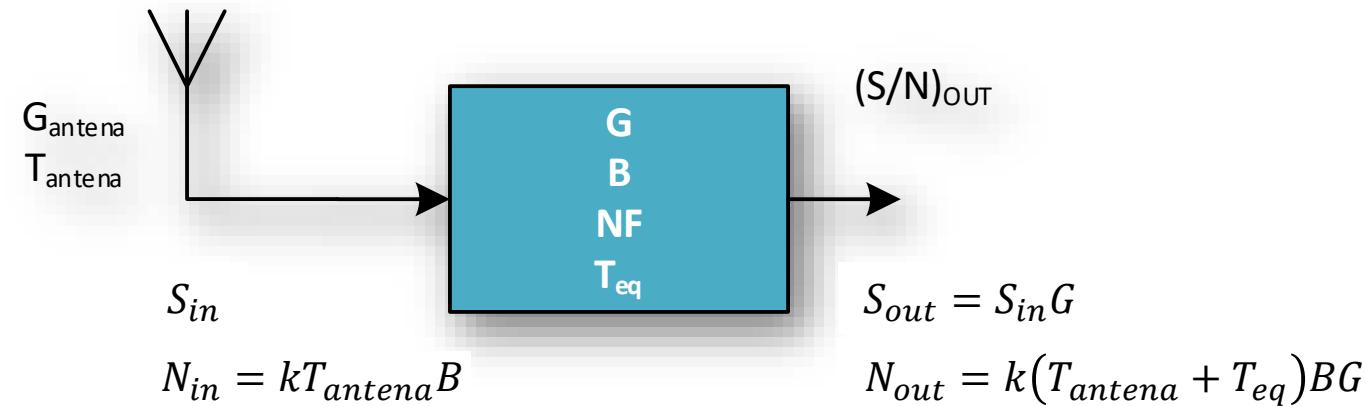
$$r_1 = \sqrt{\frac{\lambda d_1 d_2}{d_1 + d_2}}$$

Programa freeware Radio Mobile:  
<http://www.cplus.org/rmw/english1.html>



# Càlcul de l'enllaç

Fer els càlculs pertinents de la relació senyal soroll ( $S/N$ ) i potència mínima del senyal obtinguts en el receptor



$$(S/N)_{out} = \frac{(S/N)_{in}}{\left(1 + \frac{T_{eq}}{T_{antenna}}\right)} = \frac{(S/N)_{in}}{\left(1 + \frac{T_0}{T_{antenna}}(F - 1)\right)}$$

# Marge de l'enllaç

És la diferència entre la relació senyal-soroll mínima que precisa el receptor, i la que realment li arriba.

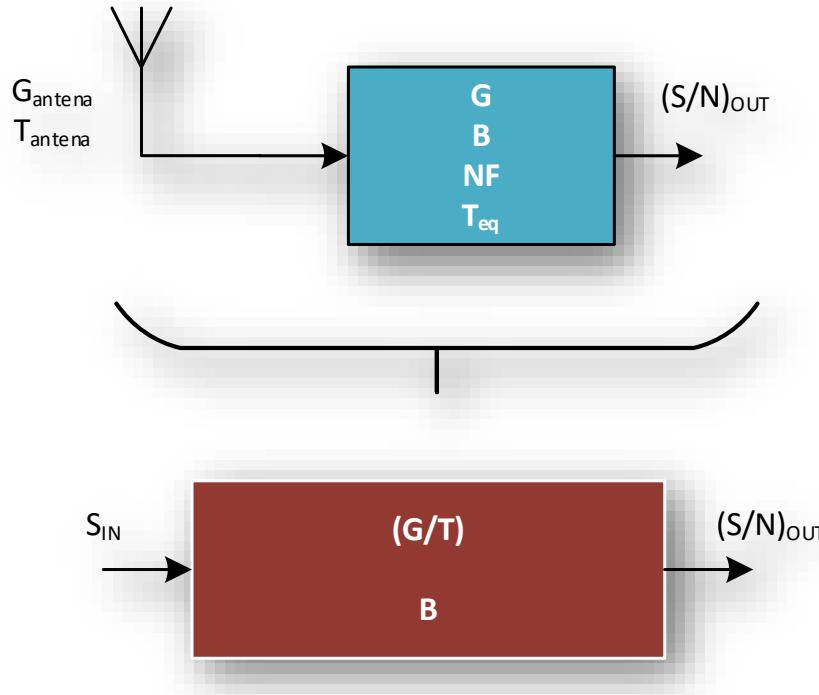
$$M(dB) = (S/N)_{obtinguda}(dB) - (S/N)_{requerida}(dB)$$

És una manera d'indicar l'atenuació màxima que podrà experimentar el radioenllaç sense que es talli la comunicació.

Com més gran sigui el marge de l'enllaç, més robusta serà la connexió.



# Factor de mèrit del receptor ( $G/T$ )



Consisteix en la relació entre el **guany de l'antena receptora respecte de la temperatura equivalent de soroll total del receptor** (antena+receptor).

S'obté a partir del càlcul de la relació senyal-soroll obtinguda en el receptor mitjançant l'equació de transmissió.

$$(S/N)_{OUT} = \frac{P_R}{N} = \frac{PIRE \cdot G_R \cdot \left(\frac{\lambda}{4\pi R}\right)^2 \cdot L_T}{k \cdot (T_a + T_{eq}) \cdot B} = \frac{PIRE}{k \cdot B} \cdot L_T \cdot \left(\frac{\lambda}{4\pi R}\right)^2 \cdot \left(\frac{G_R}{T}\right)$$

$$(S/N)_{OUT}(dB) = PIRE(dBW) + FSL(dB) - L_T(dB) + 228,6(dBW/HzK) - 10\log(B) + \left(\frac{G_R}{T}\right)(dB/K)$$

$$\left(\frac{G_R}{T}\right) = \frac{G_R}{T_a + T_{eq}}$$

# Conclusió

- El càlcul d'un radioenllaç es realitza en base a:
  - La geometria i el perfil topogràfic de l'enllaç.
  - Els mecanismes de propagació radioelèctrica que són funció de la banda de freqüències utilitzada.
  - La consideració dels efectes de propagació multicamí, i la seva minimització mitjançant diversitat en freqüència i/o espai, o d'altres sistemes o tècniques de modulació.
  - La consideració dels efectes de la troposfera i la ionosfera en la propagació dels senyals radioelèctrics.
  - Els paràmetres de mèrit del transmissor (PIRE i distorsió) i del receptor (G/T).

# Satèl·lits de comunicacions

Radioenllaços

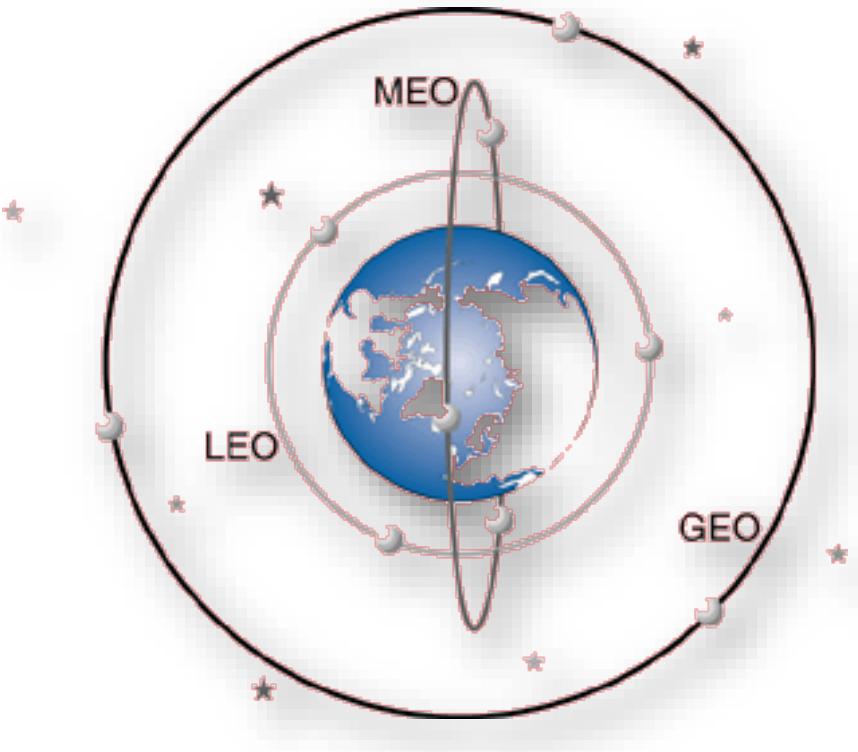


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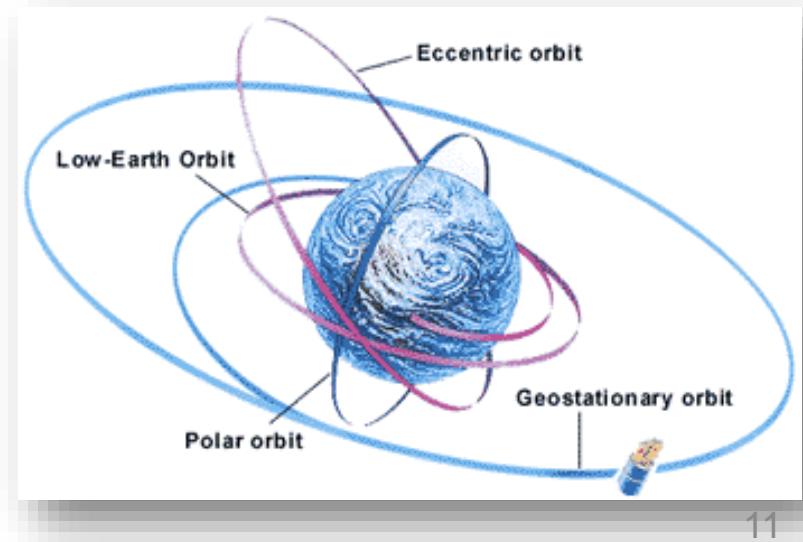
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# Tipus d'òrbites

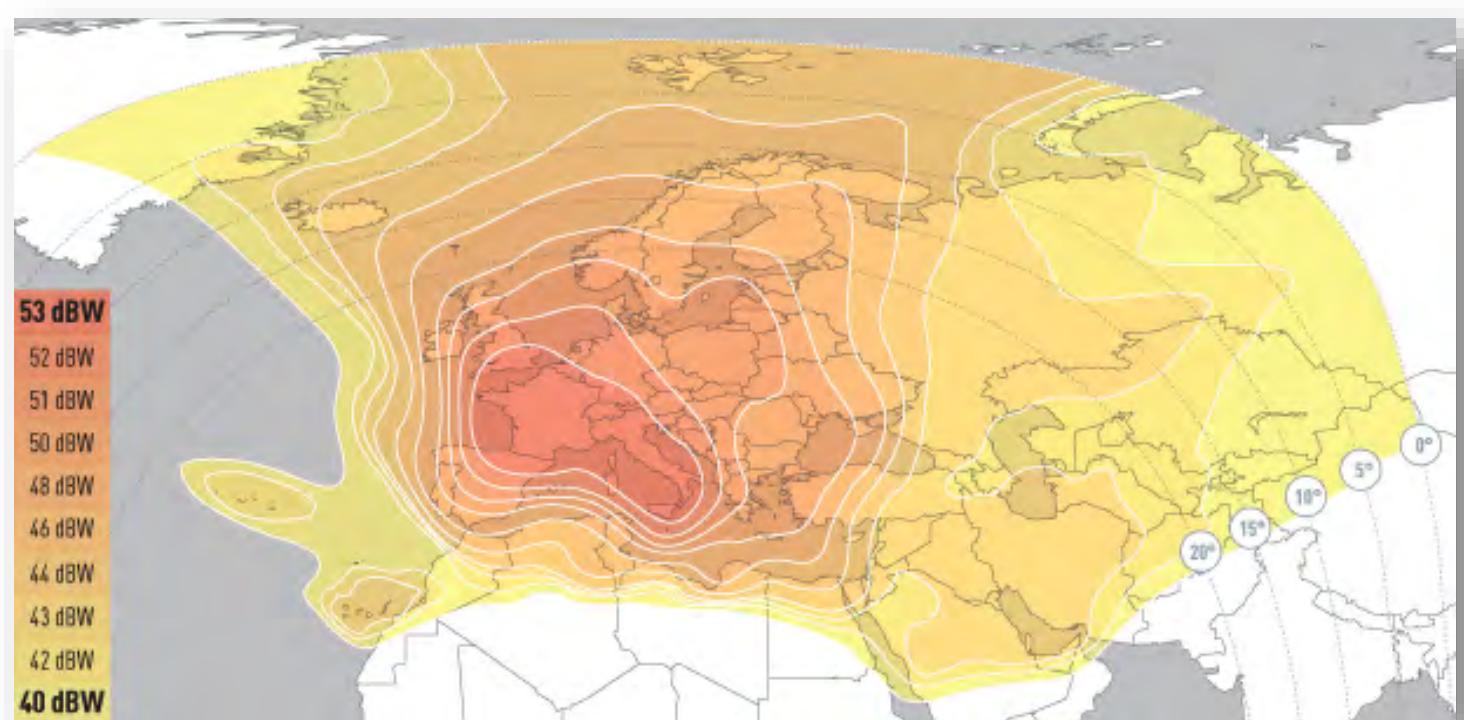


Orbit Distance	Miles	km	1-way Delay
Low Earth Orbit (LEO)	100-500	160 - 1,400	50 ms
Medium Earth Orbit (MEO)	6,000 - 12,000	10 -15,000	100 ms
Geostationary Earth Orbit (GEO)	~22,300	36,000	250 ms
High Earth Orbit (HEO)	Above 22,300	Faster than 36,000	300 ms or more



# Satèl·lits geoestacionaris

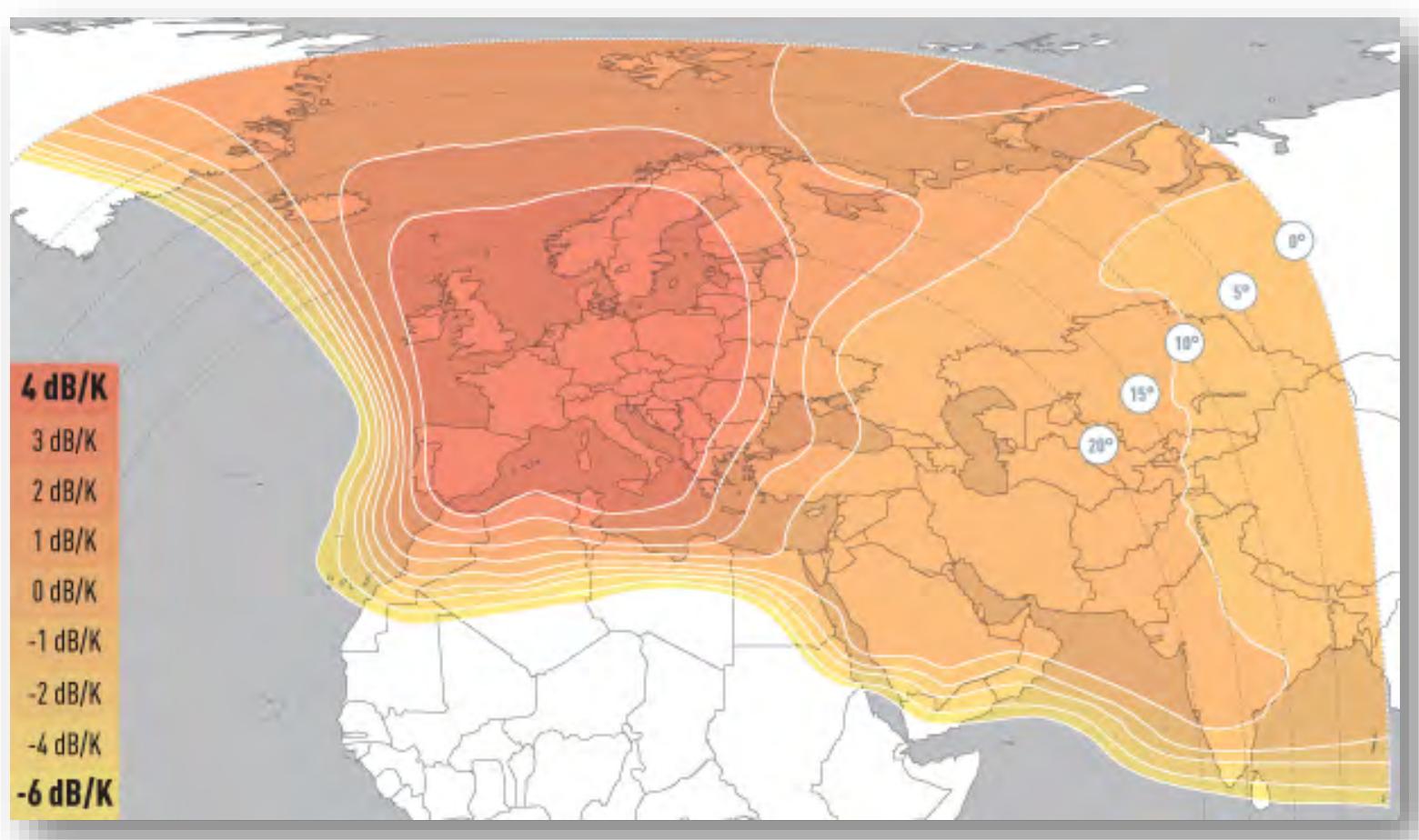
- Ubicats a **36.000 km** de distància sobre l'equador.
- Els angles d'apuntament de les antenes es calculen a partir de les coordenades terrestres i de la latitud del satèl·lit.  
[http://www.satlex.de/en/azel\\_calc.html](http://www.satlex.de/en/azel_calc.html)
- En transmissió, la cobertura es determina per la petjada de **PIRE** emesa des del satèl·lit en dBW.



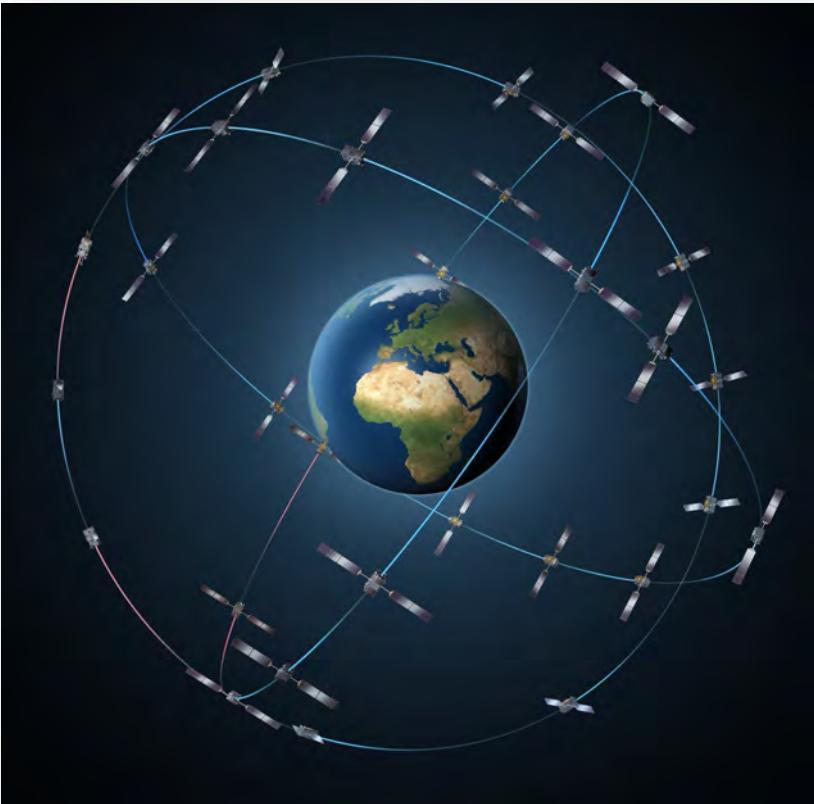
Eutelsat Hotbird 13B at 13°E, at Ku Band

# Satèl·lits geoestacionaris

- En recepció, la cobertura es determina per la petjada de **(G/T)** del satèl·lit.

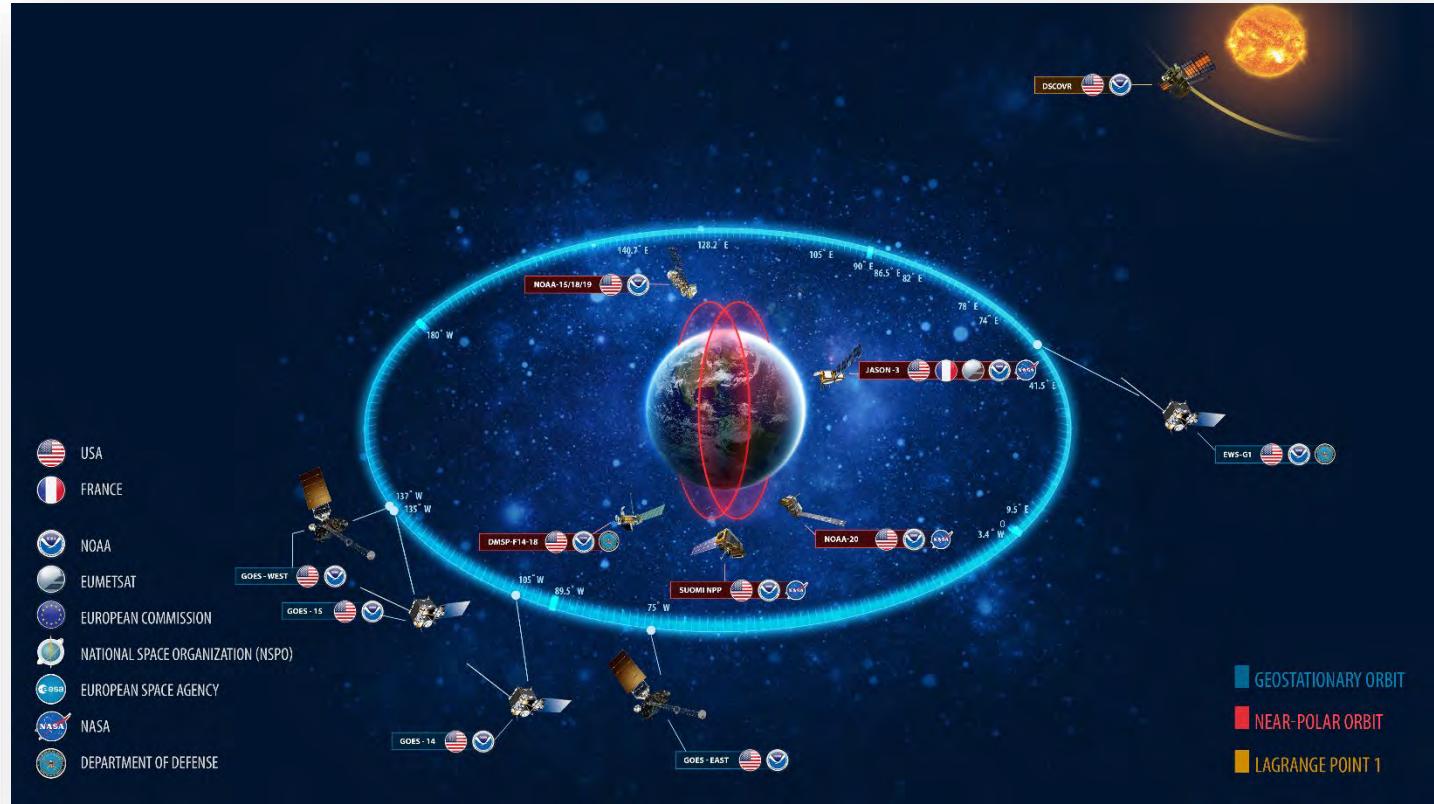


# Satèl·lits MEO



Constel·lació del Galileo - ESA

# Satèl·lits d'òrbita polar (LEO)

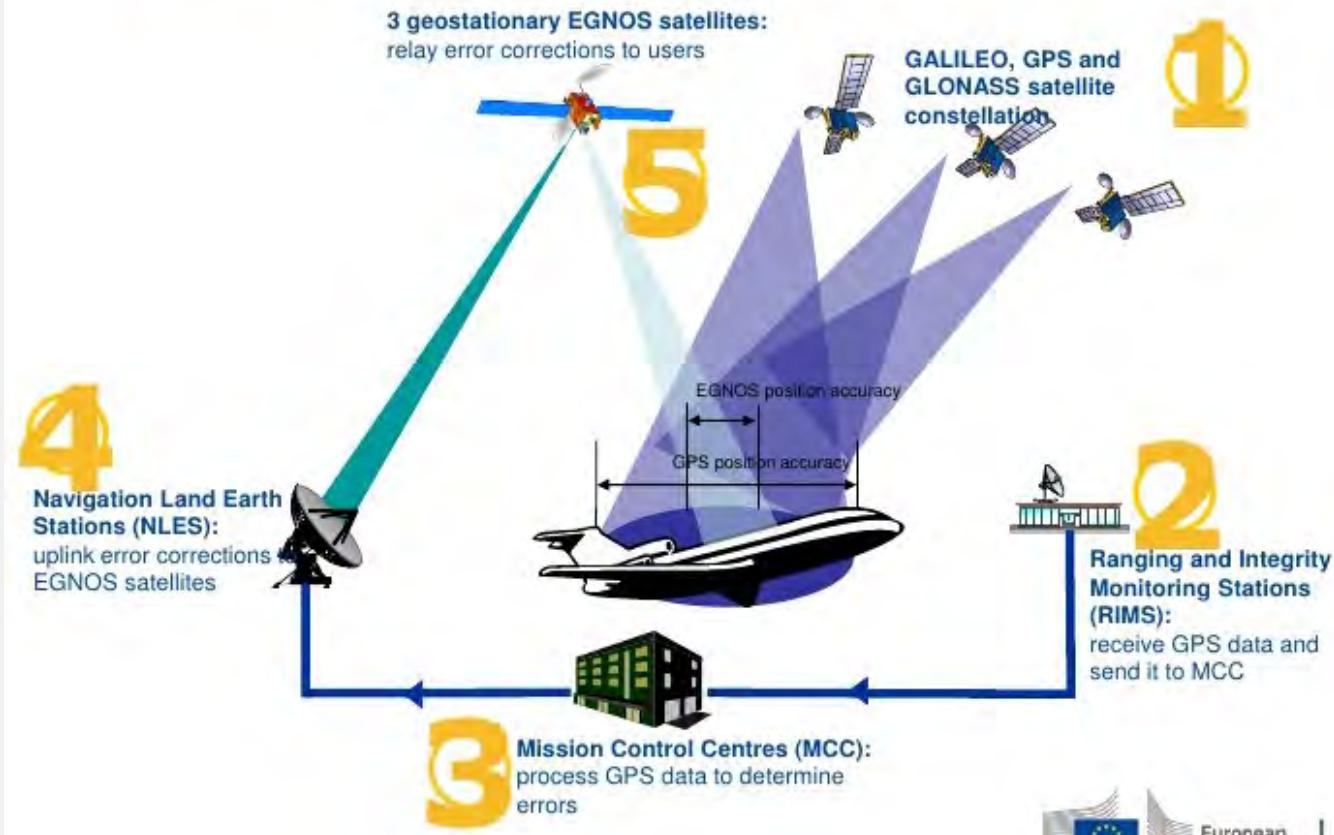


Constel·lació satèl·lits meteorològics NOAA

# Sistema EGNOS d'augmentació

Les dades rebudes dels satèl·lits d'òrbita polar dels sistemes de navegació per satèl·lit, són corregides per augmentar la precisió, i es radio-difonen mitjançant satèl·lits d'òrbita geoestacionària per tal de que els usuaris puguin fer les correccions adients i millorar la precisió en la seva ubicació.

## EGNOS improves GPS over Europe



# Tema 3: SISTEMES DE MODULACIONS ANALÒGIQUES I DIGITALS

Jordi Berenguer  
Setembre 2021



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# LA MODULACIÓ

- A l' hora d'establir un sistema de comunicació, un cop seleccionat el mitjà de transmissió més idoni, s'ha de realitzar el procés d'adequació del senyal d'informació en aquest medi, ja que la majoria dels senyals no poden ser enviats de manera directa.
- La forma de fer-ho és seleccionant una **ona portadora** amb una freqüència tal que s'adapti bé al **mitjà de transmissió i al mecanisme de propagació** que porta associat, i després alterar algun dels seus paràmetres en funció del senyal d'informació, procés que es coneix amb el nom de ***modulació***.
- La **modulació** es defineix com **l'alteració sistemàtica d'una ona portadora d'acord amb el missatge o el senyal modulador**.

# Modulacions: tipus

- Podem distingir entre la **modulació d'ona contínua** i la **modulació de trens de polsos**.
  - En la primera **la portadora és una forma d'ona sinusoïdal**, de la qual es modifiquen alguns dels tres paràmetres fonamentals: *l'amplitud, la freqüència o la fase*, en funció del senyal que s'ha de transmetre; exemples d'això els trobem en la majoria dels sistemes de radiodifusió.
  - En la segona es tracta d'un sistema digital en el qual, partint d'un tren periòdic de polsos, s'hi **modulen la freqüència, l'amplitud o la fase de forma discreta**; exemples d'això els trobem en els radioenllaços digitals, els sistemes radar, etc.
- En definitiva, qualsevol procés de modulació equival a **traslladar l'espectre de banda base de la informació cap a l'entorn d'una freqüència sensiblement més alta, que és la que anomenem portadora**.

# Perquè modular?

- Encara que l'objectiu fonamental de la modulació és adequar el senyal al mitjà de transmissió, podem trobar d'altres motius que ho aconsellen, com ara aquests:
  - **modulació per facilitar la radiació:** és evident que, si volguéssim radiar directament el senyal d'àudio obtingut en un micròfon, hauríem d'emprar **antenes** que tinguessin unes **dimensions comparables a la longitud d'ona** del senyal, la qual cosa ens portaria a dimensions de l'ordre de 30 km!. És evident, doncs, que és molt més fàcil radiar, per exemple, a 100 MHz ( $\lambda/2=1,5\text{m}$ ), on podem utilitzar antenes de dimensions més raonables, que no pas a 10 kHz ( $\lambda/2=15\text{ km}$ ).
  - **modulació per reducció de soroll i interferències:** el fet de modular provoca un desplaçament de l'espectre del senyal, fet que es potaprofitar per situar-lo en una zona on la presència de senyals interferents sigui petita.
  - **modulació per assignació de l'espectre radioelèctric:** és evident que si es volen transmetre diversos senyals pel mateix mitjà, per exemple l'espai lliure, serà necessari, per tal d'evitar interferències i superposicions que cadascun dels senyals empri freqüències diferents; això s'aconseguirà modulant els senyals amb portadores diferents d'acord amb l'assignació de freqüències efectuada pels organismes competents (UIT i OACI).

# Modulacions analògiques



# MODULACIÓNS LINEALS

Modulacions d'amplitud



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# Modulació d'amplitud (AM) amb portadora

- Es caracteritza perquè l'envolupant del senyal portador és idèntica al senyal d'informació o modulador.
- L'expressió temporal d'un senyal modulat en amplitud amb portadora és la següent:

$$x_{AM}(t) = A_c [1 + m \cdot x_m(t)] \cos(\omega_c t + \varphi)$$

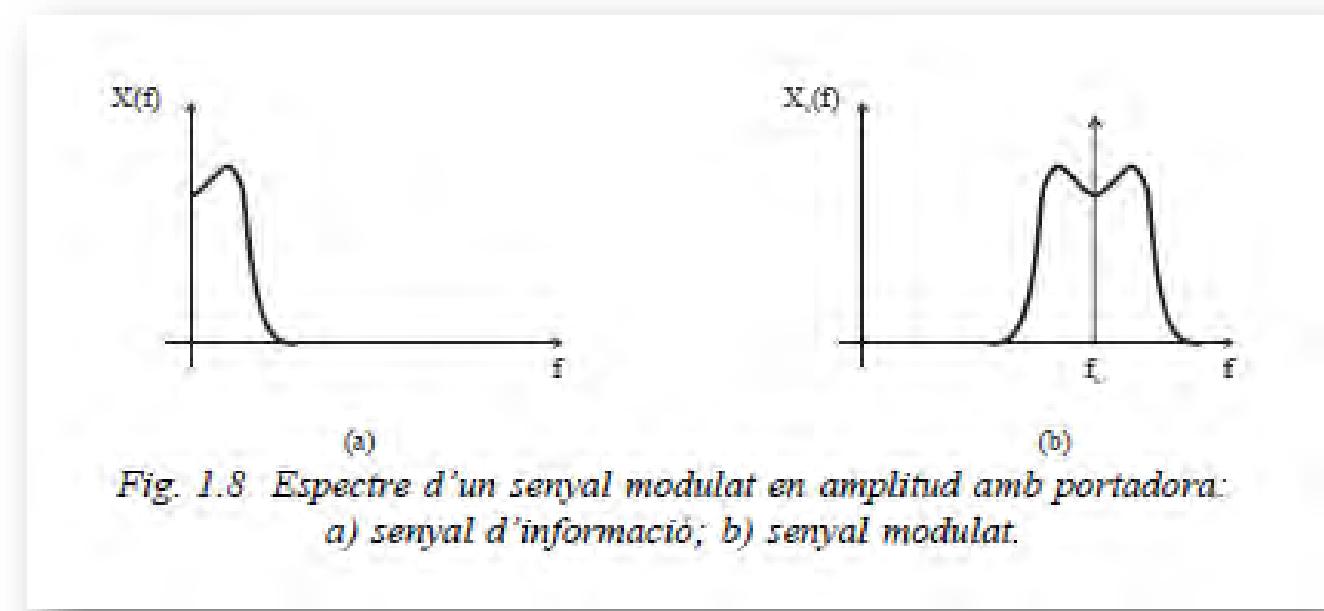
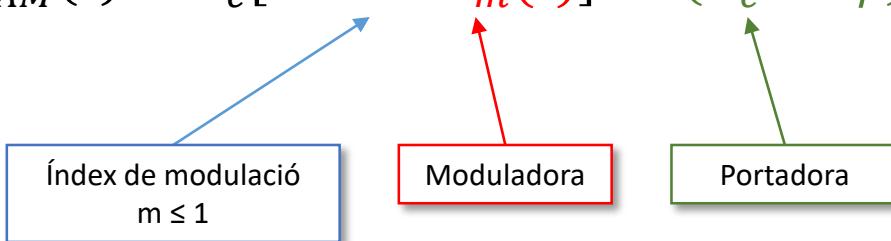
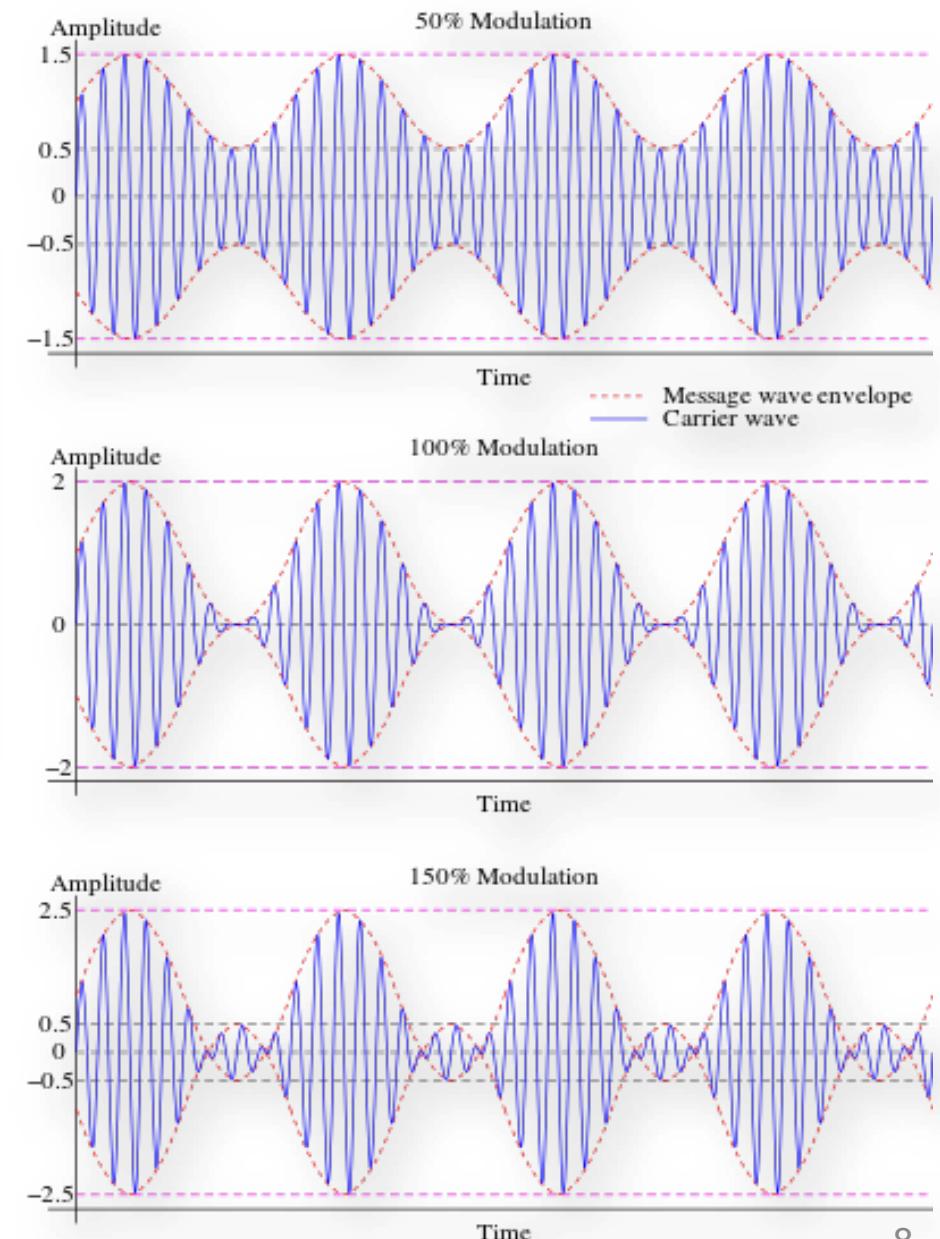
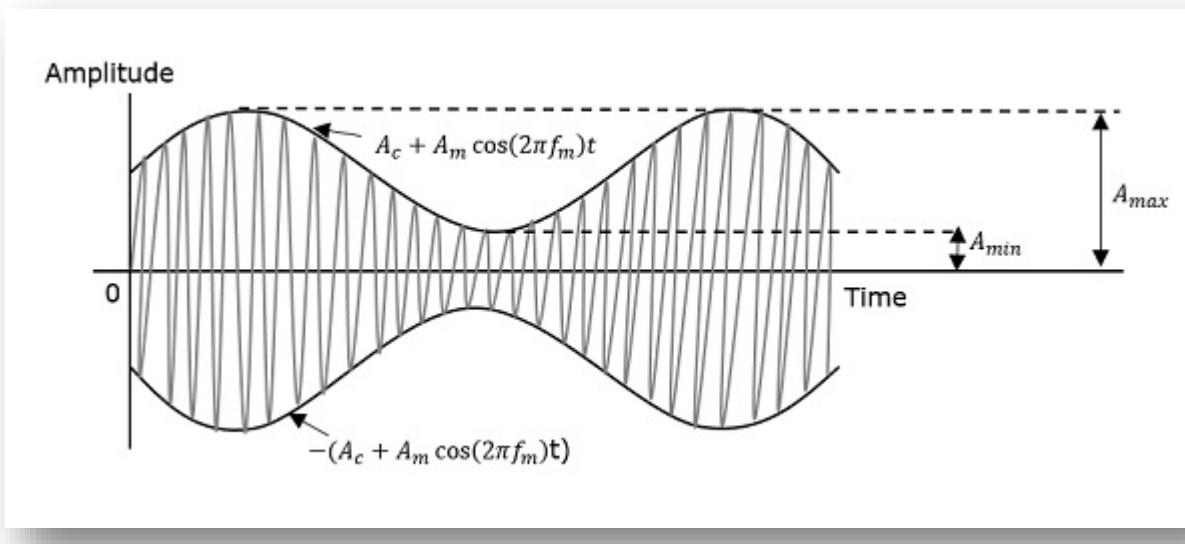


Fig. 1.8. Espectre d'un senyal modulat en amplitud amb portadora:  
a) senyal d'informació; b) senyal modulat.

L'AMPLADA DE BANDA DE TRANSMISIÓ DEL SENYAL MODULAT ( $2B$ ) ÉS EL DOBLE DEL SENYAL EN BANDA BASE ( $B$ ).

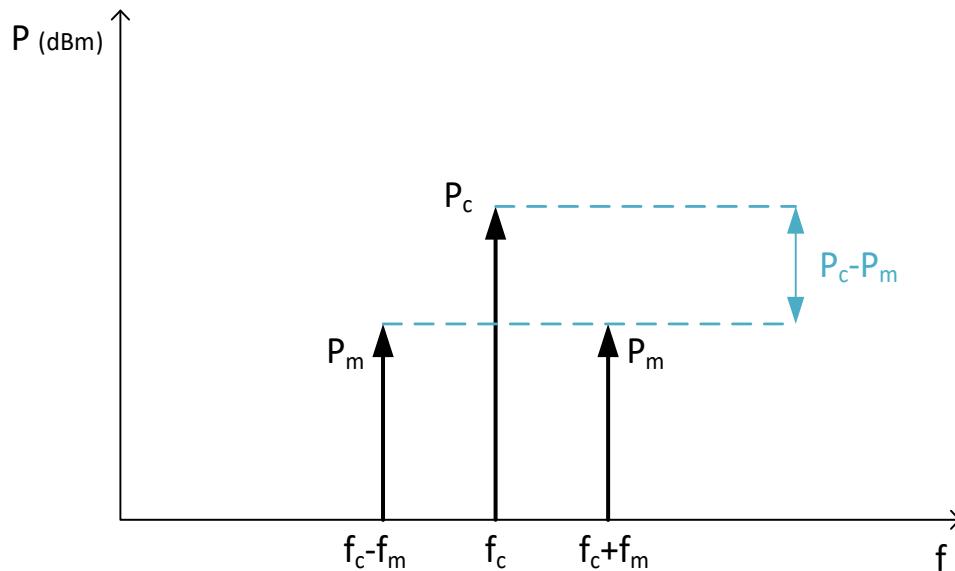
# AM amb portadora Modulació sinusoidal



Índex de modulació:

$$m = \frac{A_{\max} - A_{\min}}{A_{\max} + A_{\min}}$$

# Espectre d'una AM amb portadora



$$P_c(dBm) = 20 \log(A_c);$$

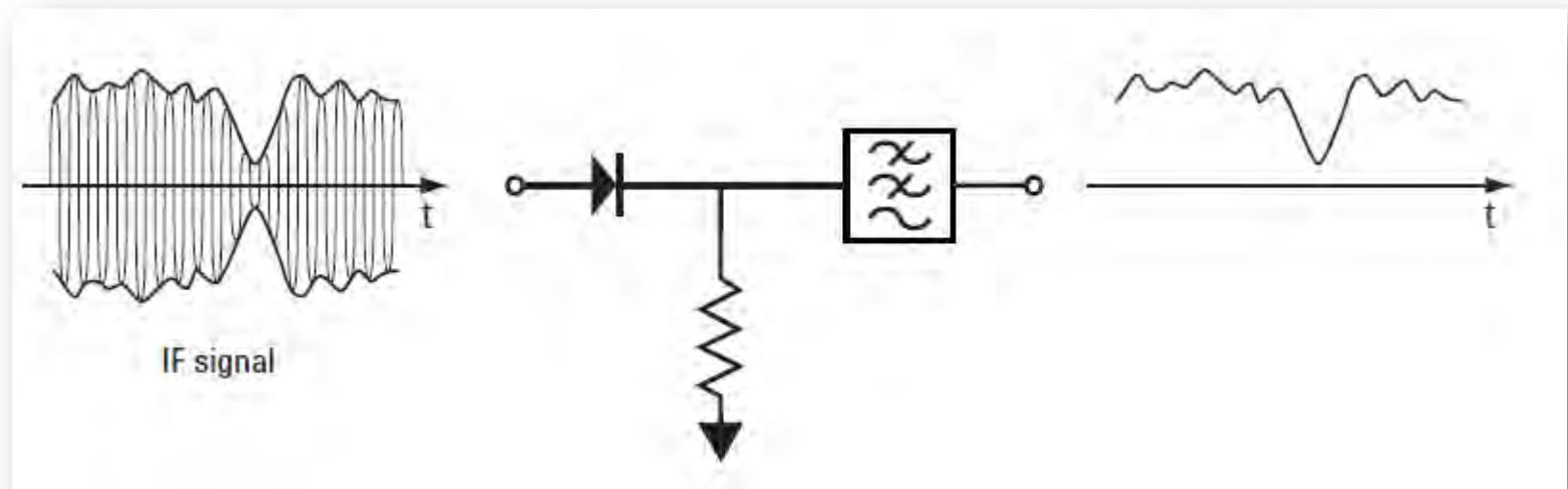
$$P_m(dBm) = 20 \log\left(A_c \frac{m}{2}\right)$$

$$P_c(dBm) - P_m(dBm) = -20 \log\left(\frac{m}{2}\right) = 6 dB - 20 \log(m)$$

$$m = 10^{\left(\frac{6 dB - (P_c(dBm) - P_m(dBm))}{20}\right)}$$

# Característiques de l'AM

- Un dels avantatges que implica la utilització d'aquest tipus de modulació és que el **receptor pot ser extremadament senzill**; per detectar el senyal n'hi ha prou a disposar d'un **detector d'envolupant**, és a dir, un circuit format per un díode i una xarxa RC.



# Característiques de l'AM

- Ara bé, l'inconvenient que presenta aquest tipus de modulació és que almenys **el 50 % de la potència transmesa és a la portadora** i la resta es distribueix en les bandes laterals; això vol dir que es fa un **mal aprofitament de l'energia radiada** a canvi d'una **gran senzillesa en el receptor**.
- A més, en tots els sistemes AM la informació viatja en les variacions d'amplitud de la portadora, fet que els fa més **vulnerables a qualsevol interferència** produïda per senyals paràsits.
- És el tipus de modulació utilitzat en les comunicacions terra-aire en VHF, o també anomenades ***Aeronautical Mobile Radiocommunication (R) Service***.

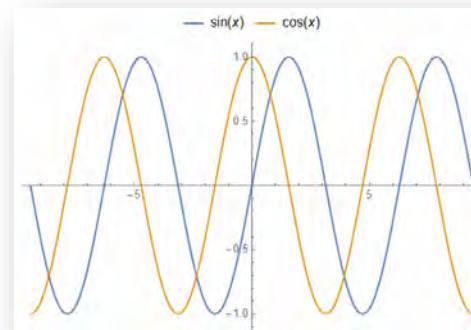
# Modulació fase/quadratura



# Modulació I/Q

## *In phase and Quadrature modulation*

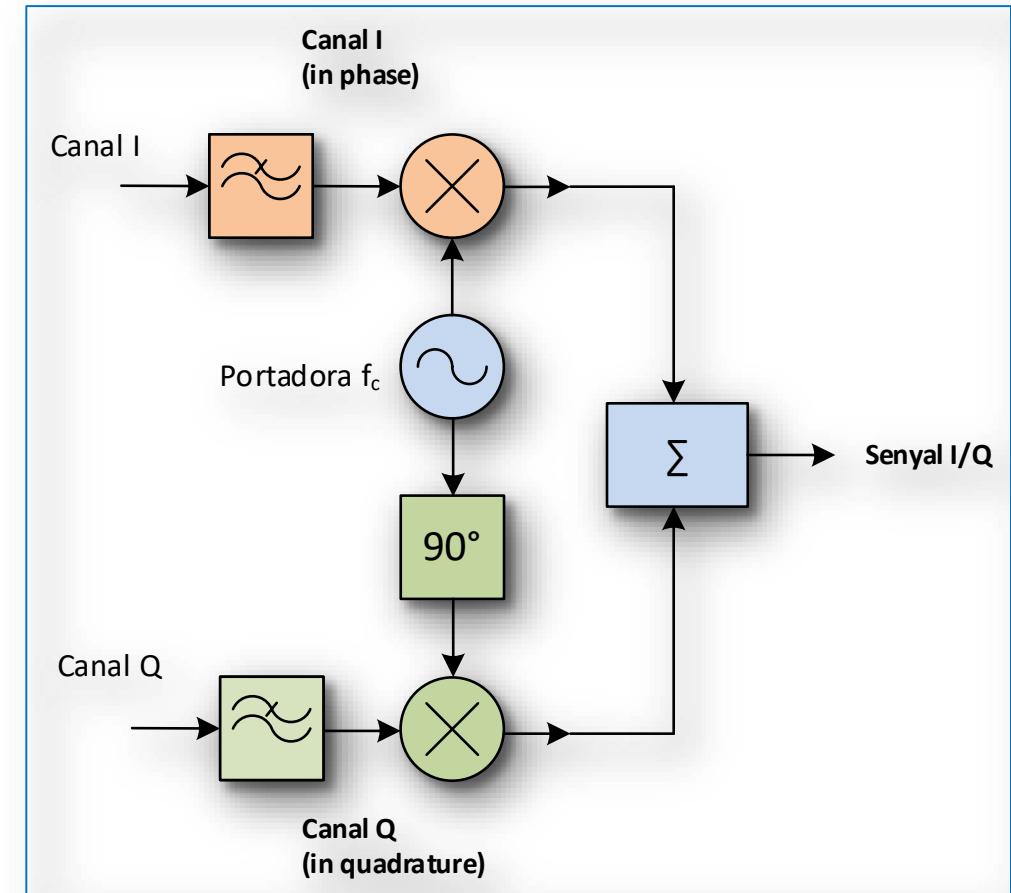
- Es tracta d'una modulació analògica d'amplitud, en la que dos senyals diferents, I i Q, modulen a la mateixa portadora, sense que s'interfereixin mitjançant el desfasament en  $90^\circ$  (quadratura) de la mateixa portadora.



- Utilitza **la meitat de l'amplada de banda** que caldria si es transmetés la mateixa informació fent servir una AM convencional.

$$B_{I/Q} = \frac{1}{2} B_{AM}$$

- Requereix més complexitat circuitual tant en el procés de generació com en la desmodulació.



# Modulació en Doble Banda Lateral (DBL)

DOUBLE SIDE BAND (DSB)



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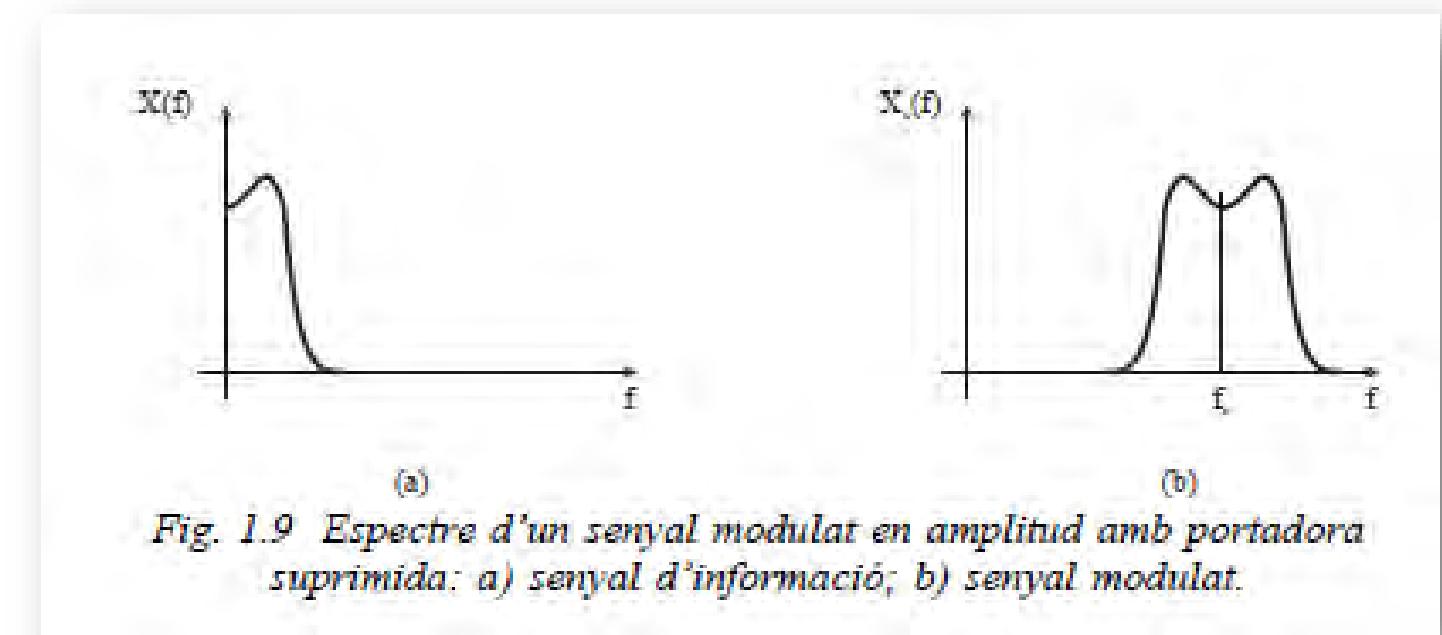
# Modulació en doble banda lateral (DBL)

- Es tracta del mateix tipus de modulació d'amplitud que l'anterior, però ara s'hi ha suprimit la portadora; per tant, l'expressió del senyal modulat és ara:

$$x_c(t) = A x(t) \cdot \cos(\omega_c t)$$

Cal assenyalar que, en aquest cas, **no té sentit parlar d'índex de modulació**.

L'espectre obtingut ara és idèntic a l'anterior, excepte que ja no hi apareix la portadora: és simplement l'espectre de banda base de la informació traslladat en freqüència.

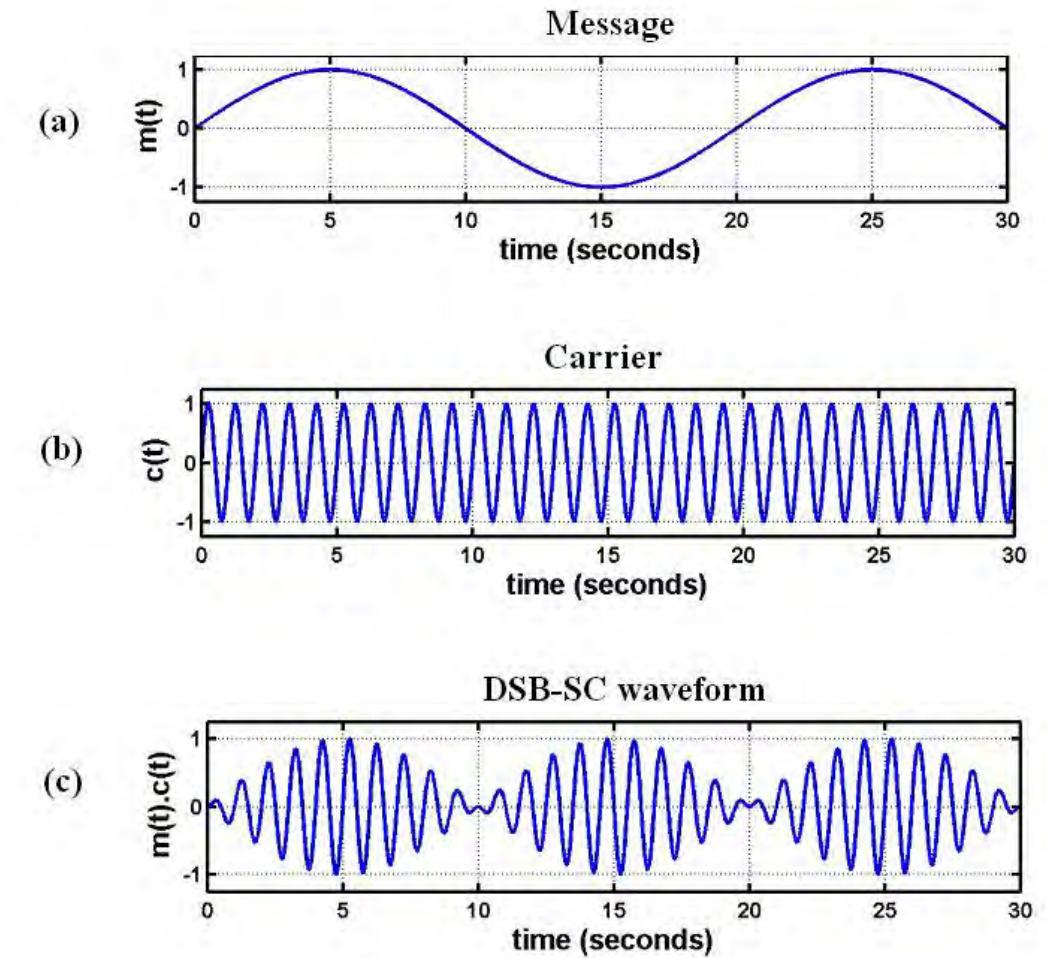
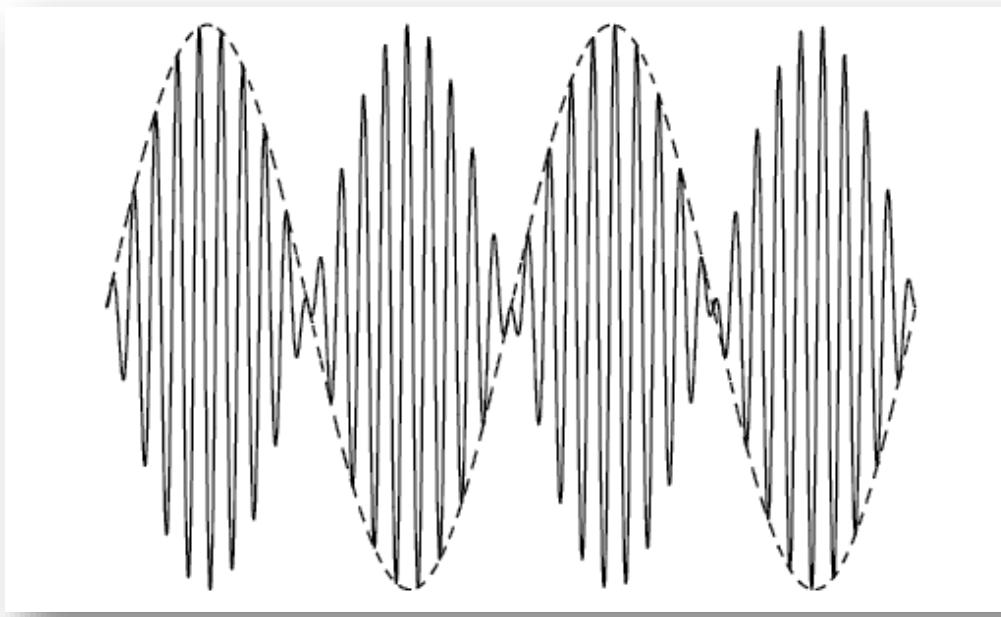


*Fig. 1.9 Espectre d'un senyal modulat en amplitud amb portadora suprimida: a) senyal d'informació; b) senyal modulat.*

L'amplada de banda de transmissió del senyal modulat (2B) és el doble del senyal en banda base (B).

# Modulació DBL – Senyal temporal

$$x_c(t) = A \cos(\omega_m t) \cdot \cos(\omega_c t)$$



# Característiques de la DBL

- Des del punt de vista energètic **és més eficient** que la modulació AM amb portadora, però es paga el preu en l'augment de la **complexitat del receptor**. El receptor ha d'incloure un sistema de recuperació de la portadora.
- És igualment **sensible a les interferències i al soroll**, ja que la informació viatja en l'amplitud de la portadora (envolupant).
- A l'igual que l'AM, **utilitza el doble de l'amplada de banda del senyal**. Per exemple utilitza 6 kHz per transmetre un senyal vocal de 3 kHz d'amplada de banda.

# Modulació en banda lateral única (BLU)

SINGLE SIDE BAND MODULATION (SSB)



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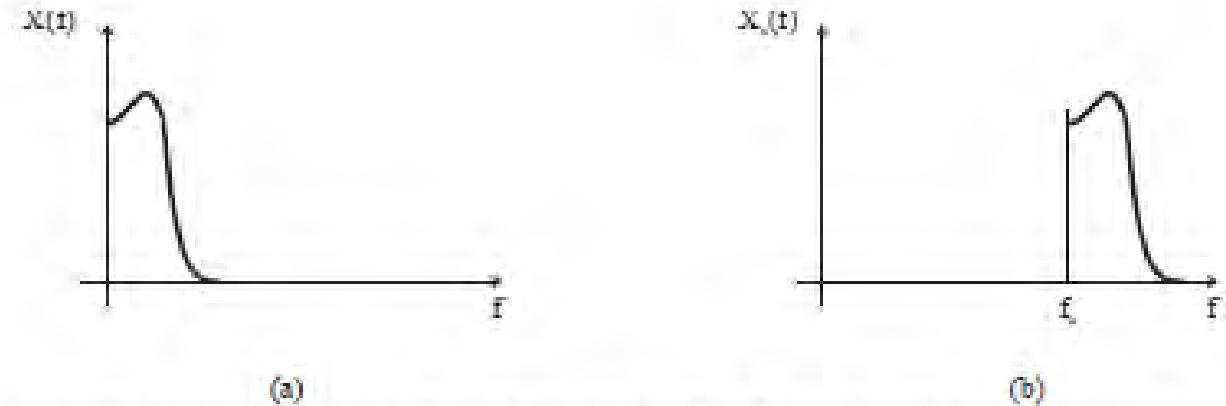
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# Modulació en banda lateral única (BLU)

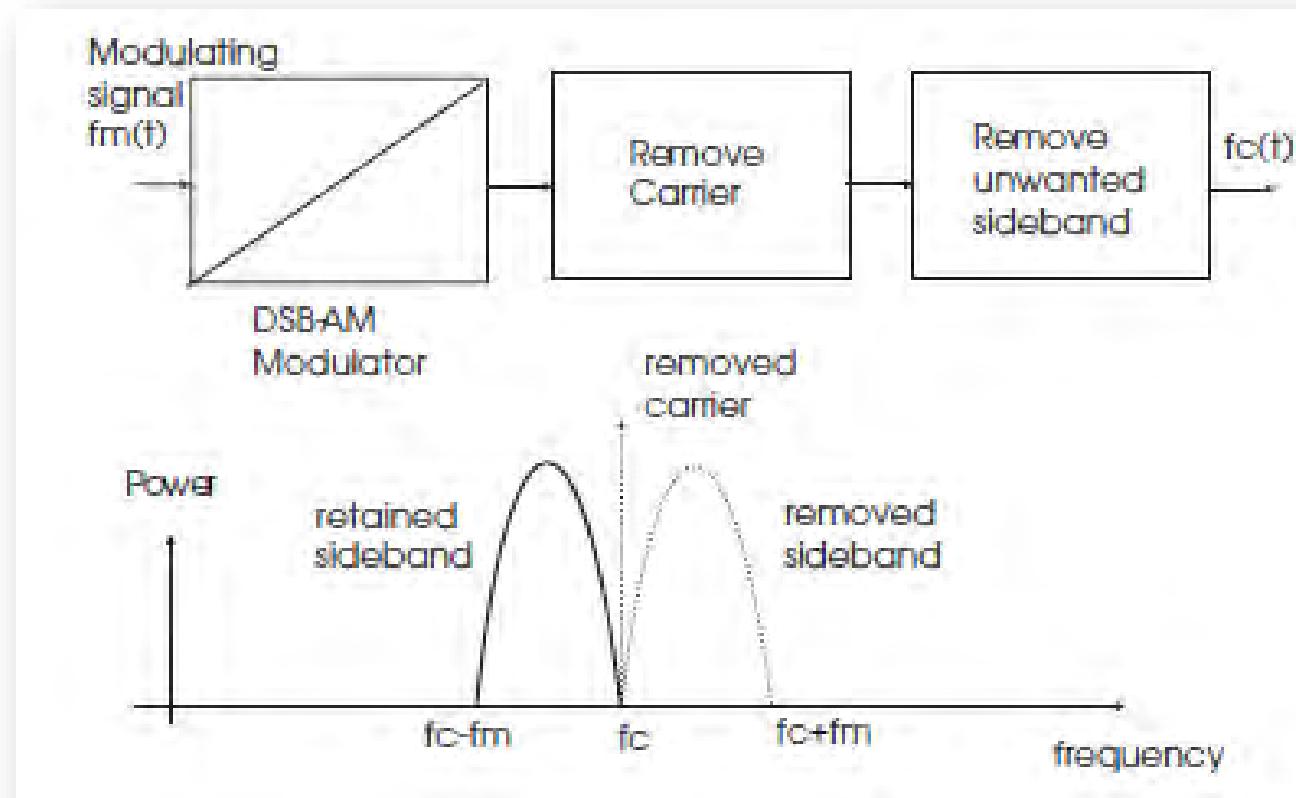
- Tant en la modulació AM com en la DSB, si observem l'espectre del senyal modulat veiem que hi apareixen dues bandes laterals simètriques respecte a la freqüència de la portadora, que es corresponen amb el senyal modulador.
- Podríem pensar que, si en suprimíssim una, el contingut de la informació no es veuria alterat a causa de la redundància de les dues bandes, amb el resultat de **no malbaratar la potència d'emissió i reduir l'amplada de banda de transmissió**.
- Els sistemes de modulació en banda lateral única s'encarreguen precisament d'això, **d'eliminar una de les bandes laterals del senyal DBL** i, per tant s'obté l'espectre que es veu a la figura.



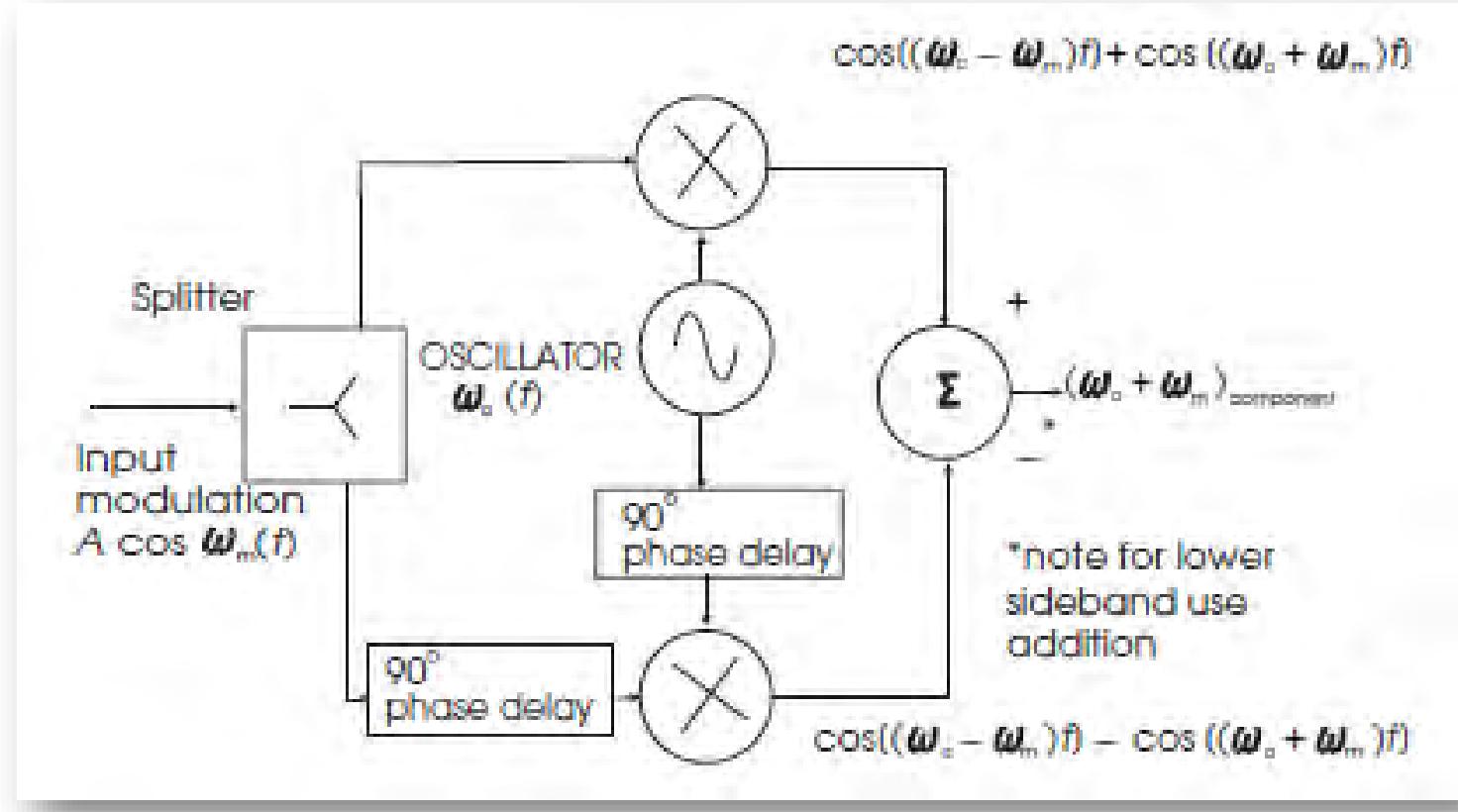
*Fig. 1.10 Espectre d'un senyal modulat en banda lateral única (superior): a) senyal d'informació; b) senyal modulat.*

L'amplada de banda de transmissió del senyal modulat (B) és identic al del senyal en banda base (B).

# Síntesis per filtrat d'una banda



# Síntesis directa – Modulador de Hilbert



# MODULACIONS ANGULARS

Modulacions de freqüència i de fase

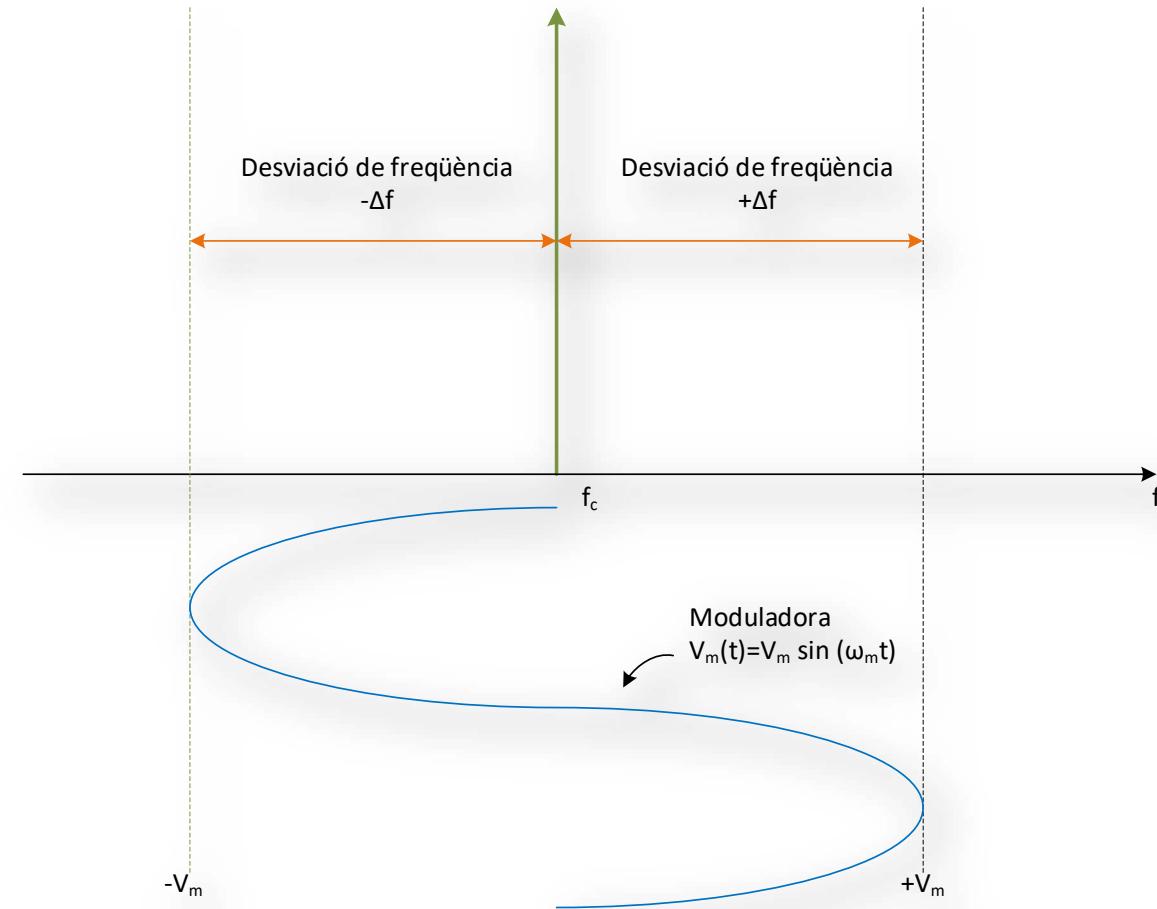
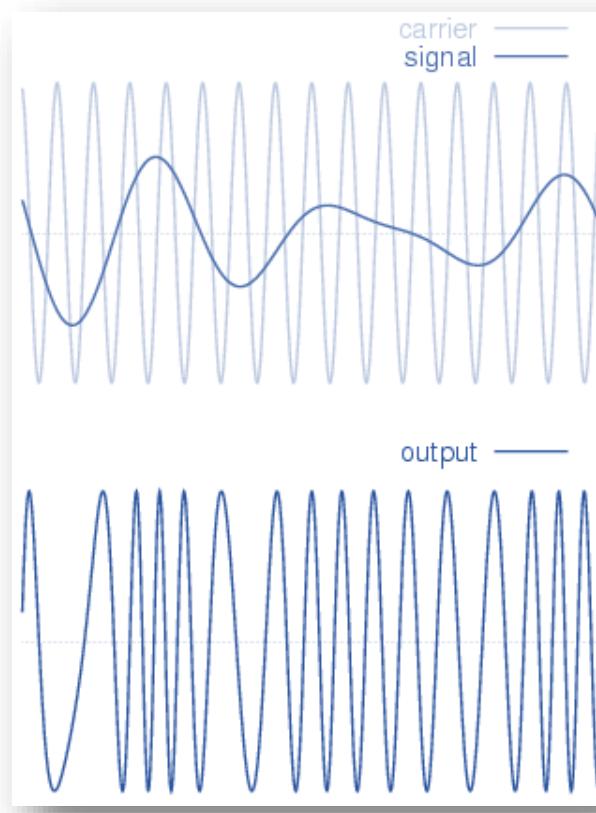


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# Modulació angular



# Modulació angular

- La modulació angular pot ser de freqüència (FM) o de fase (PM). Ambdues modulacions no es diferencien, ja que la freqüència és la derivada de la fase, i per tant quan s'actua sobre la freqüència també es modifica la fase, i a l'inrevés.
- Quan tenim un senyal modulat en freqüència o fase, de la forma:

$$v_M(t) = A_c \cos[\omega_c t + \varphi(t)]$$

- Podem definir els següents paràmetres:

- Desviació instantània de fase:

$$\Delta\theta = \varphi(t) \quad (\text{rad})$$

- Fase instantània:

$$\theta_i(t) = \omega_c t + \varphi(t) \quad (\text{rad})$$

- Desviació instantània de freqüència:

$$\Delta\omega_i = \frac{d\varphi(t)}{dt} \quad (\text{rad/s})$$

- Freqüència instantània:

$$\omega_i(t) = \frac{d}{dt} [\omega_c t + \varphi(t)] = \omega_c + \frac{d\varphi(t)}{dt} = \omega_c + \Delta\omega_i \quad (\text{rad/s})$$

$$f_i(t) = \frac{1}{2\pi} \omega_i(t) = f_c + \frac{1}{2\pi} \frac{d\varphi(t)}{dt} \quad (\text{Hz})$$

# Modulacions angulars

- Podem expressar un senyal en funció de la seva fase instantània, com:

$$v_M(t) = A_c \cos[\omega_c t + \varphi(t)] = A_c \cos[\theta_i(t)]$$

- O també en funció de la seva freqüència instantània, atès que la freqüència és la derivada de la fase, com:

$$v_M(t) = A_c \cos[\omega_c t + \varphi(t)] = A_c \cos\left[\int \omega_i(t) dt\right] = A_c \cos \int (\omega_c + \Delta\omega_i) dt = A_c \cos\left[\omega_c t + \int \Delta\omega_i(t) dt\right]$$

# Modulacions angulars

- **Modulació de fase (PM):**

$$\varphi(t) = K \nu_m(t)$$

$$v_{PM}(t) = A_c \cos[\omega_c t + \varphi(t)] = A_c \cos[\omega_c t + K \nu_m(t)]$$

- **Modulació de freqüència (FM):**

$$\Delta\omega_i(t) = \frac{d\varphi(t)}{dt} = K_1 \nu_m(t)$$

$$v_{FM}(t) = A_c \cos \left[ \omega_c t + \int \Delta\omega_i(t) dt \right] = A_c \cos \left[ \omega_c t + K_1 \int \nu_m(t) dt \right]$$

$\nu_m(t)$ : senyal modulador  
 $K$ : sensibilitat de la PM (rad/V)  
 $K_1$ : sensibilitat de la FM (rad/V·s)

# Modulacions angulares

*Índex de modulació per modulació sinusoidal de PM i FM*

- **Modulació de fase (PM):**

$$m = K \cdot V_m \quad (\text{rad})$$

$$v_{PM}(t) = A_c \cos[\omega_c t + m \cos(\omega_m t)] = A_c \cos[\omega_c t + KV_m \cos(\omega_m t)]$$

Portadora
Índex de modulació
Moduladora

- **Modulació de freqüència (FM):**

$$\Delta f = K_1 \cdot V_m \quad (\text{Hz})$$

 $v_m(t) = V_m \cos(\omega_m t)$ 

$m$ : índex de modulació de fase  
 $\beta$ : índex de modulació de freqüència  
 $\Delta f$ : desviació de freqüència

$$\beta = \frac{K_1 \left( \frac{\text{rad}}{\text{V}\cdot\text{s}} \right) \cdot V_m}{\omega_m} = \frac{K_1 \left( \frac{\text{Hz}}{\text{V}} \right) \cdot V_m}{f_m} = \frac{\Delta f}{f_m}$$

Portadora
Índex de modulació
Moduladora

$$v_{FM}(t) = A_c \cos[\omega_c t + \beta \sin(\omega_m t)] = A_c \cos \left[ \omega_c t + \frac{\Delta f}{f_m} \sin(\omega_m t) \right]$$

# Modulacions angulares

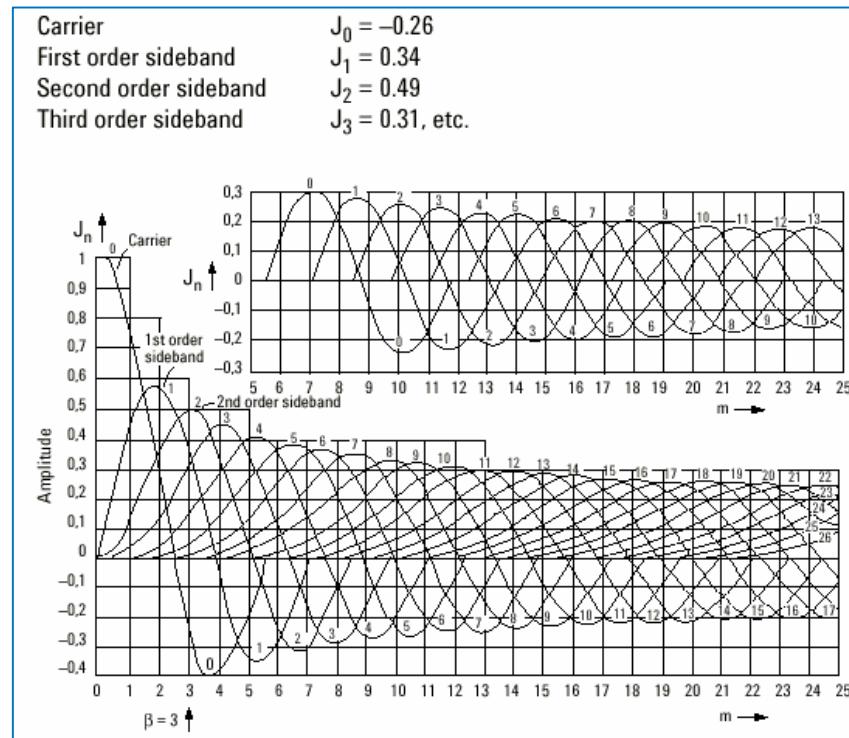
## *Cas de FM modulada per una sinusoida*

L'anàlisi d'un senyal modulat en freqüència presenta una certa dificultat matemàtica en comparació amb l'anàlisi dels senyals modulats en amplitud. Aquest es simplifica pel cas particular de que el senyal de modulació sigui sinusoidal, llavors es factible descompondre'l en sèrie de Fourier, però amb la particularitat de que ara els seus coeficients són **funcions de Bessel de primer ordre** i argument l'índex de modulació

$$x_{FM}(t) = A_c \sin \left[ \omega_c t + \frac{\Delta f}{f_m} \sin(2\pi f_m t) + \Theta_o \right]$$



$$\begin{aligned} x(t) = A_c & [ J_0(\beta) \cos \omega_o t + J_1(\beta) [\cos(\omega_o + \omega_m)t - \cos(\omega_o - \omega_m)t] \\ & + J_2(\beta) [\cos(\omega_o + 2\omega_m)t + \cos(\omega_o - 2\omega_m)t] \\ & + J_3(\beta) [\cos(\omega_o + 3\omega_m)t - \cos(\omega_o - 3\omega_m)t] \\ & + J_4(\beta) [\cos(\omega_o + 4\omega_m)t + \cos(\omega_o - 4\omega_m)t] + \dots ] \end{aligned}$$



# Modulacions angulares

## *Cas de FM modulada per una sinusoide*

El resultat és un espectre format per un conjunt discret de ratlles espectrals espaiades la freqüència de modulació  $f_m$ ; es tracta d'un espectre infinit, però discret, d'energia constant distribuïda entre totes les subportadores.

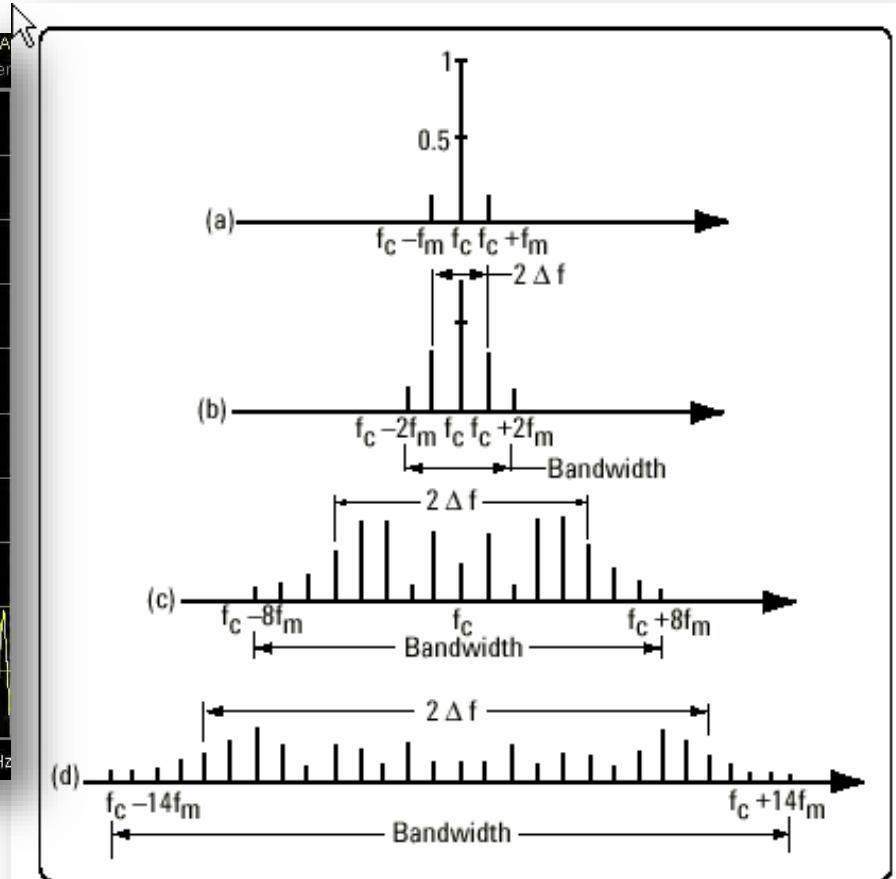
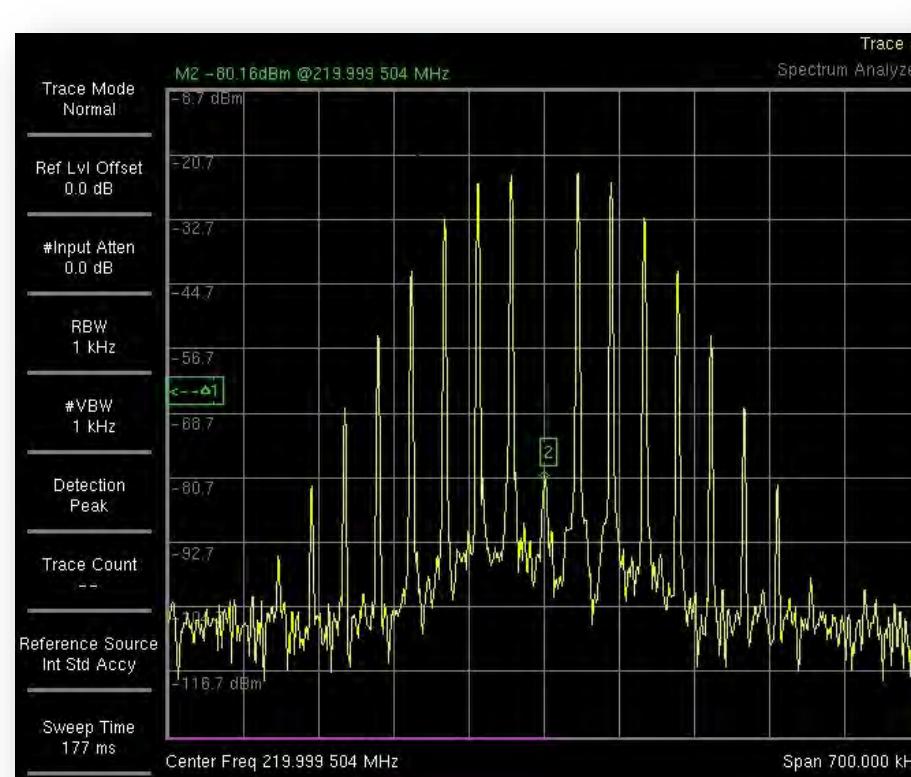
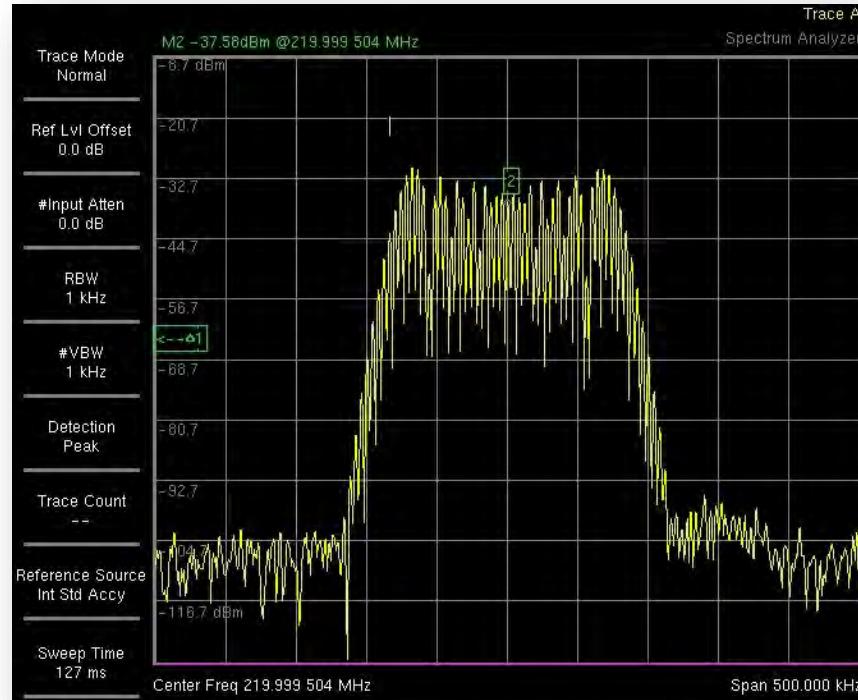


Figure 22. Amplitude-frequency spectrum of an FM signal (sinusoidal modulating signal;  $f$  fixed; amplitude varying). In (a),  $\beta = 0.2$ ; in (b),  $\beta = 1$ ; in (c),  $\beta = 5$ ; in (d),  $\beta = 10$

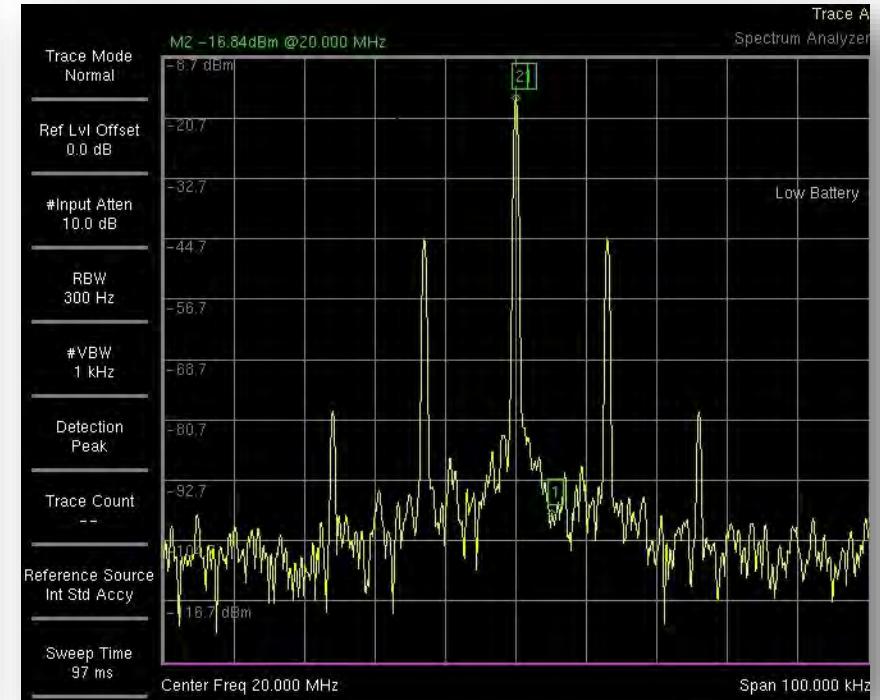
# Modulacions angulars

## *Cas de FM modulada per una sinusoida*

Segons sigui l'índex de modulació, podem distingir entre FM de banda estreta (**NBFM: Narrow Band FM**) i FM de banda ampla (**WBFM: Wide band FM**), aquesta darrera és la utilitzada en la FM comercial.



**WBFM: Wide band FM**



**NBFM: Narrow Band FM**

# Modulacions angulars

## Amplada de banda de la FM

- **Regla de Carson:**

$$B = 2(\Delta f + f_m) \quad (\text{Hz})$$

- Sent:
  - $f_m$ : freqüència màxima del senyal de modulació
  - $\Delta f$ : desviació de freqüència

Exemple:

- *Per la FM convencional, amb una  $\Delta f$  de 75 kHz i per una freqüència màxima d'àudio de 15 kHz, s'obté una amplada de banda per a un senyal monofònic de 180 kHz.*

# Característiques de les modulacions angulares

- Les modulacions FM i PM requereixen una major **complexitat** tant en el **modulador** com en el **desmodulador**. Si bé avui dia, la microelectrònica ha facilitat i abaratit el disseny dels moduladors.
- Són **insensibles a les interferències i al soroll**, ja que la informació viatja en la freqüència o en la fase de la portadora, i per tant no es pot alterar. Aquest tipus de modulació és idònia per les comunicacions per satèl·lit, ja que l'efecte de l'atenuació de l'atmosfera no altera el contingut de la informació,
- En canvi es paga el preu d'utilitzar un **ample de banda de transmissió molt més gran** que el senyal de banda base. (*Un senyal musical de 15 kHz d'amplada de banda precisa 180 kHz d'amplada de banda de transmissió*).

# Modulacions digitals



# MODULACIÓNS D'AMPLITUD

ASK - OOK



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# Modulació ASK

## *Amplitude shift keying*

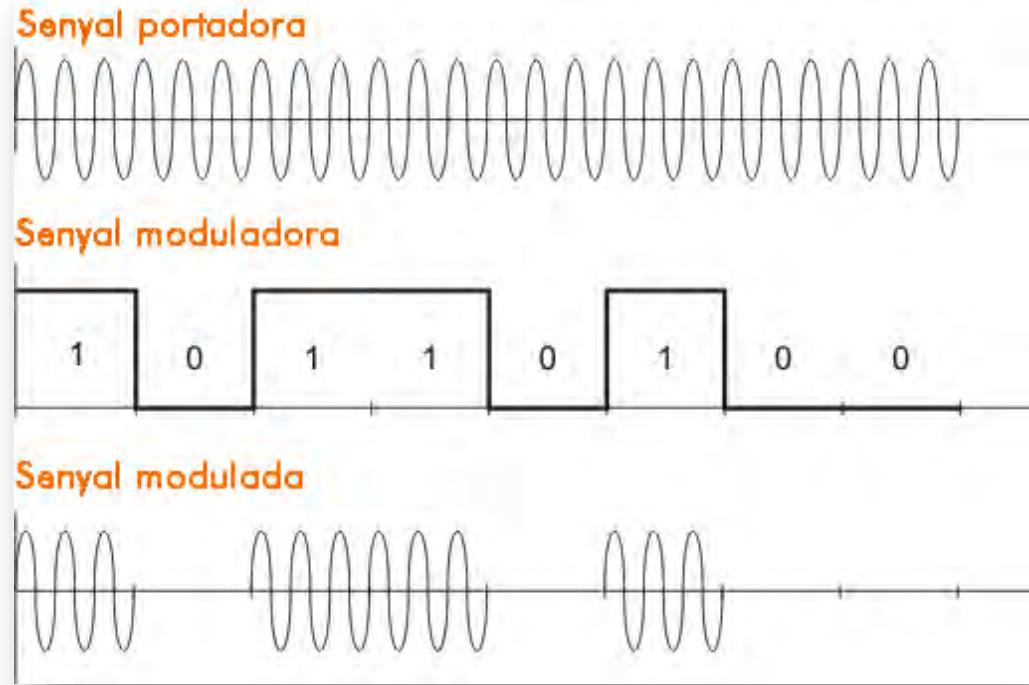
- Consisteix en un senyal modulat en amplitud (DBL) en que la moduladora és un senyal digital o binari.

$$v_{ASK}(t) = \frac{A}{2} \cdot [1 + v_m(t)] \cdot \cos(\omega_c t)$$

essent

$$v_m(t) = \begin{cases} +1V, \text{ per "1"} \\ -1V, \text{ per "0"} \end{cases} \Rightarrow \begin{cases} v_{ASK}(t) = A \cos(\omega_c t) \\ v_{ASK}(t) = 0 \end{cases}$$

- Equival també a un sistema ON/OFF, pel que a vegades s'anomena **OOK** (On-Off Keying).
- Té les mateixes propietats que una DBL, i per tant està **sotmesa a les interferències d'amplitud**, i precisa un ample de banda que és el doble del senyal en banda base.
- En aquest cas s'utilitza la **velocitat de bit  $R_b$**  expressada en bits/segon (bps), i per tant de dimensió (bit·Hz). Així doncs, **l'amplada de banda de transmissió és  $2 \cdot R_b$  (Hz)**.



<https://ca.wikipedia.org/wiki/Fitxer:1modo.jpg>

# MODULACIONS DE FREQUÈNCIA I FASE

FSK - PSK



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# Modulació FSK

## *Frequency Shift Keying*

- És un sistema discret de modulació en freqüència, en el que s'utilitzen dues o més freqüències diferents per transmetre cada bit.

$$v_{FSK}(t) = V_c \cdot \cos[\omega_c t + 2\pi\Delta f \cdot v_m(t)]$$

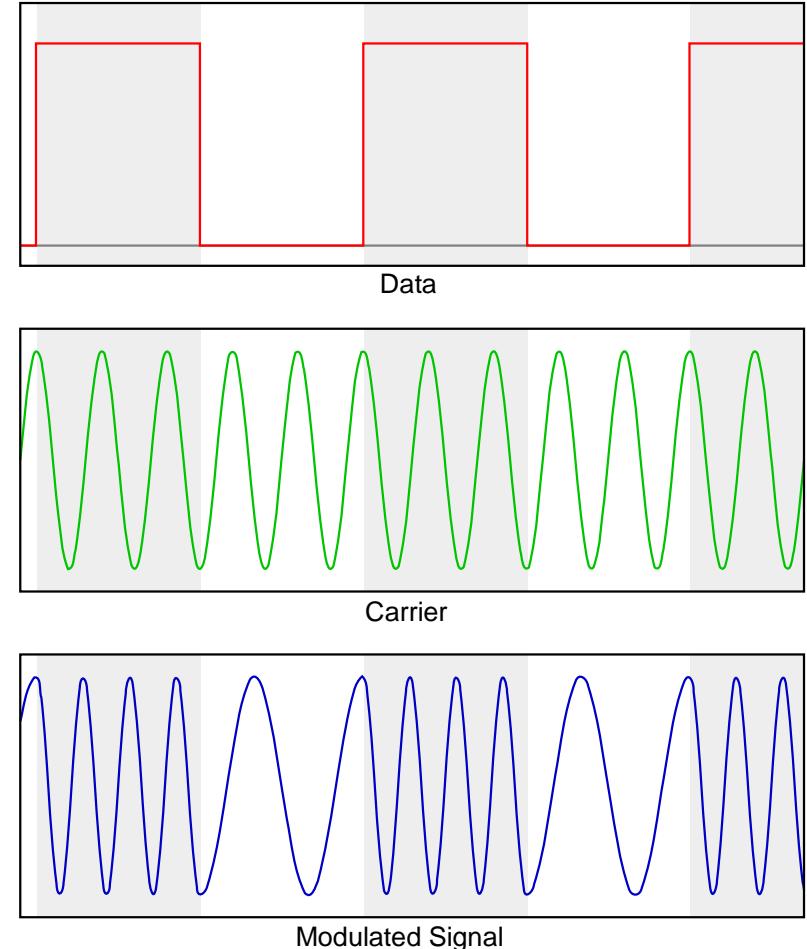
- Pel cas d'utilitzar només dues freqüències, l'anomenen **FSK binària**, on a cada bit se li assigna una única freqüència, tenim:

$$v_m(t) = \begin{cases} +1, \text{per "1"} \\ -1, \text{per "0"} \end{cases} \Rightarrow \begin{cases} v_{FSK}(t) = V_c \cdot \cos[\omega_c t + 2\pi\Delta f] = V_c \cdot \cos[2\pi f_1 t] \\ v_{FSK}(t) = V_c \cdot \cos[\omega_c t - 2\pi\Delta f] = V_c \cdot \cos[2\pi f_2 t] \end{cases}$$

- L'amplada de banda de la FSK ve determinada per la **regla de Carson**, on ara la freqüència màxima es correspon amb la velocitat de transmissió de bits  $R_b$ , expressada en bps (bits/s=bits·Hz), per tant:

$$B = 2(\Delta f + R_b)$$

- D'aquesta forma **a cada freqüència se li assigna un únic bit**, pel que la velocitat de símbol coincideix amb la de bit.



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# Modulació PSK

## *Phase Shift Keying*

- És un sistema discret de modulació de fase, en el que a cada bit se li assigna una fase diferent, mantenint constant la amplitud i la freqüència.
- Si només es transmeten dos bits, llavors s'anomena **BPSK (Binary Phase Shift Keying)**, utilitzant-se les fases de  $0$  i  $\pi$  en la transmissió dels símbols.

$$v_{BPSK}(t) = V_c \cdot \cos[\omega_c t + v_m(t) \cdot \pi]$$

- essent

$$v_m(t) = \begin{cases} 0, \text{per "1"} \\ +1, \text{per "0"} \end{cases} \Rightarrow \begin{cases} v_{BPSK}(t) = V_c \cos[\omega_c t] \\ v_{BPSK}(t) = V_c \cos[\omega_c t + \pi] = -V_c \cos[\omega_c t] \end{cases}$$

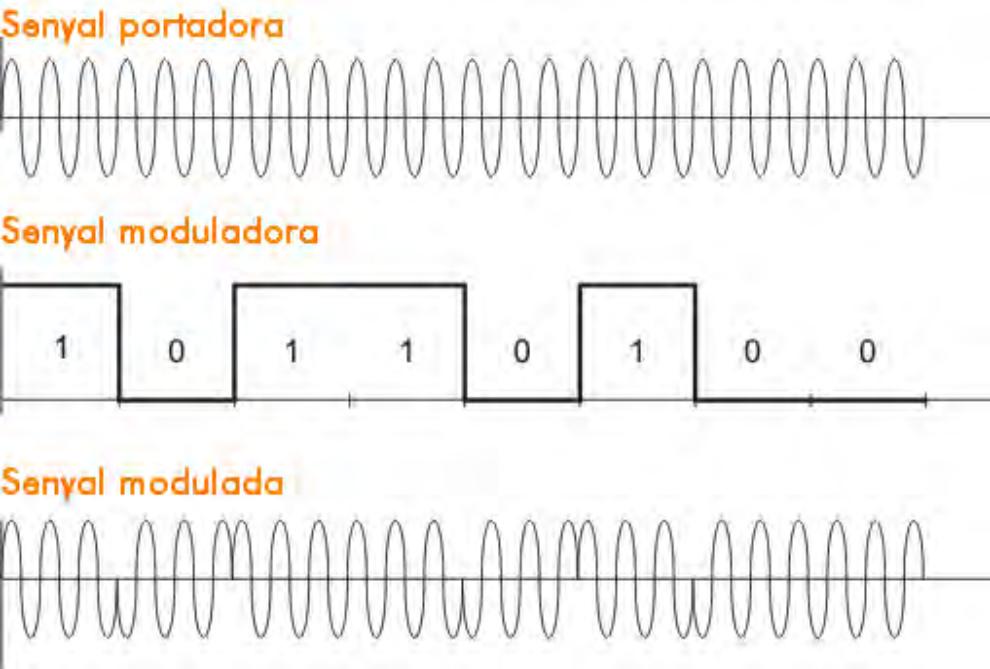
- D'aquesta forma **a cada fase se li assigna un únic bit**, pel que la velocitat de símbol coincideix amb la de bit.
- L'amplada de banda de la PSK** és igual a **velocitat de transmissió de bit  $R_b$** , de forma que:  

$$B = R_b$$
- De forma genèrica, si utilitzem més de dues fases, llavors tindrem:

$$v_{PSK}(t) = V_c \cdot \cos[\omega_c t + \varphi_i(t)], \quad \text{per } i = 1 \dots M$$

amb

$$\varphi_i(t) = \frac{2\pi}{M} \cdot i$$



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<https://commons.wikimedia.org/w/index.php?curid=8613227>

# Modulació QPSK

## *Quadrature Phase Shift Keying*

- És una modulació de tipus PSK en la que ara **utilitzem 4 fases**,  $(\pi/4, 3\pi/4, 5\pi/4 \text{ i } 7\pi/4)$  per a transmetre els bits. Així tenim:

$$\varphi_i(t) = \frac{2\pi}{4}i = \frac{\pi}{2}i, \quad \text{per } i = 0, 1, 2, 3$$

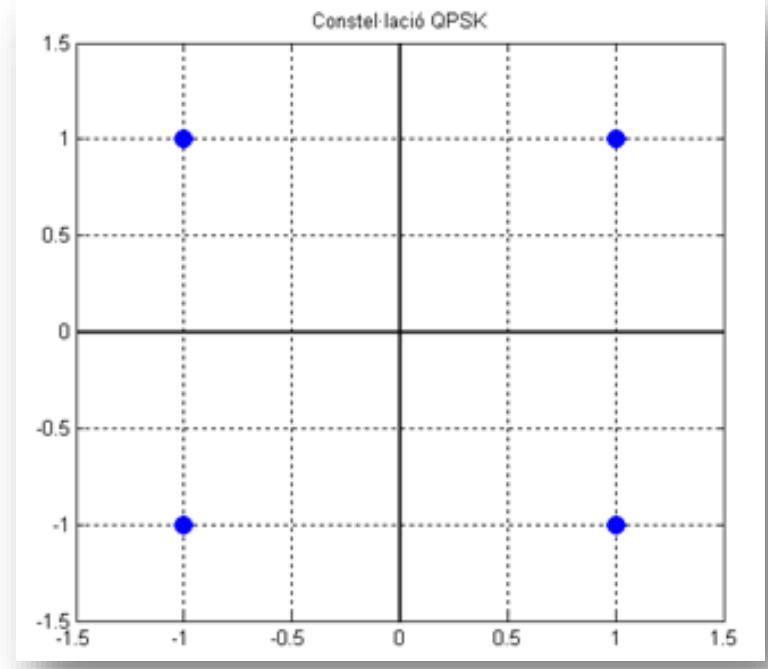
$$v_{QPSK}(t) = V_c \cdot \cos \left[ \omega_c t + (2i + 1) \frac{\pi}{4} \right], \quad \text{per } i = 0 \dots 3$$

- Per tant aquesta modulació **utilitza 4 símbols diferents**, un per cada fase. I per altre banda cada símbol el podem utilitzar per transmetre 2 bits, d'acord amb la següent taula:

Bit 1	Bit 2	Fase
0	0	$\pi/4$
0	1	$3\pi/4$
1	0	$5\pi/4$
1	1	$7\pi/4$

- Així doncs aconseguim transmetre dos bits en cada símbol. Per tant la **velocitat de transmissió de bits és el doble que la velocitat de transmissió dels símbols**.

$$R_{bit} = 2 \cdot R_{symbol}$$



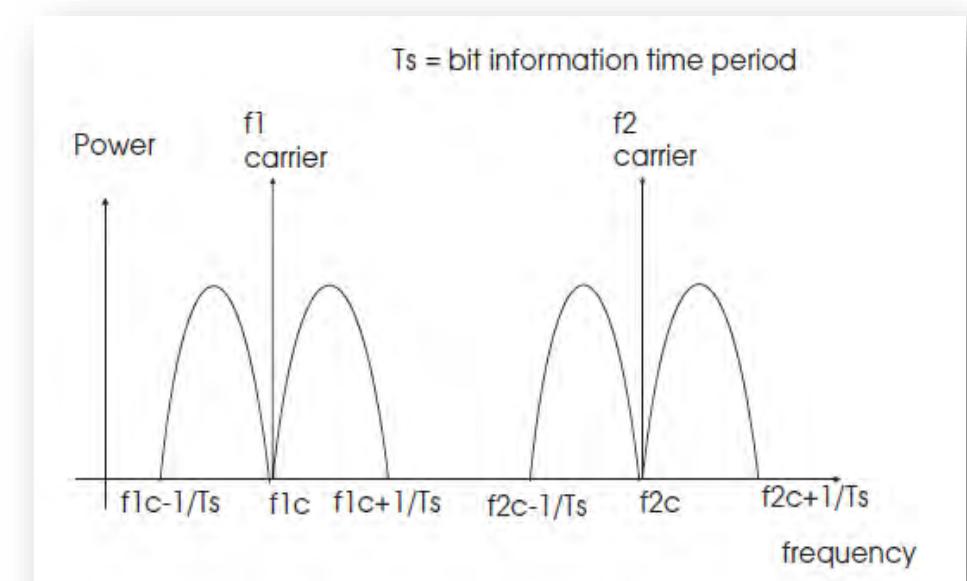
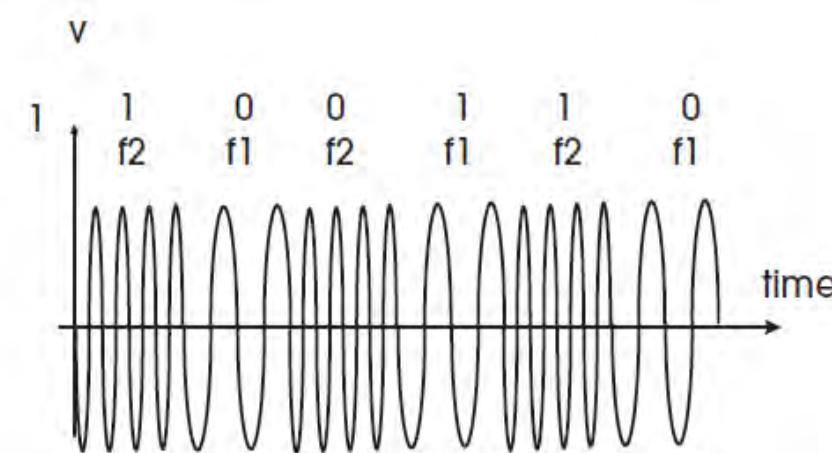
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# Velocitat de bit i velocitat de símbol

- El **BIT** (**Binary digIT**) és el dígit utilitzat en el sistema de numeració binari, representat generalment pels digits 0 i 1. La seva **velocitat de transmissió  $R_b$**  s'expressa en **bits/segon (bps)**, i per tant té també dimensions de  $\text{bit}\cdot\text{Hz}$ .
- El **BAUD** és una unitat de mesura que representa el **nombre de símbols per segon** que es transmeten en un medi de transmissió. *(Porta el nom d'Émile Baudot, enginyer francès que va desenvolupar el codi telegràfic Baudot.)*
- En general, cada **símbol** es compona **d'un o més senyals físics** en funció de l'esquema de modulació (freqüències, fases, etc.), que es corresponen a la vegada amb una quantitat d'informació expressada en bits.
- En un sistema binari, com una ASK, el bit coincideix amb el símbol, per tant la velocitat de bit i la velocitat de símbol són idèntiques. El mateix succeeix amb la FSK i la PSK binàries.
- En canvi, en un sistema QPSK, (una PSK amb 4 fases, és a dir 4 símbols), cada símbol correspon a 2 bits, de forma que si utilitza una velocitat de símbol d'**X Bauds**, la velocitat de transmissió de bit serà de **(2·X) bps**.

# Minimum Shift Keying (MSK)

- És una modulació de tipus FSK, que utilitza dues freqüències  $f_1$  i  $f_2$ . La freqüència  $f_1$  indica un canvi de bit respecte de l'anterior, mentre que la freqüència  $f_2$  indica que el bit anterior no ha canviat. Aquest tipus de modulació és que s'utilitza en el sistema ACARS i en el VDL1.
- El seu avantatge és que evita els canvis discontinus de fase que hi ha en la BPSK, ja que sempre garanteix la continuïtat en la fase de la ona generada.



# MODULACIONS D'AMPLITUD I FASE

QAM



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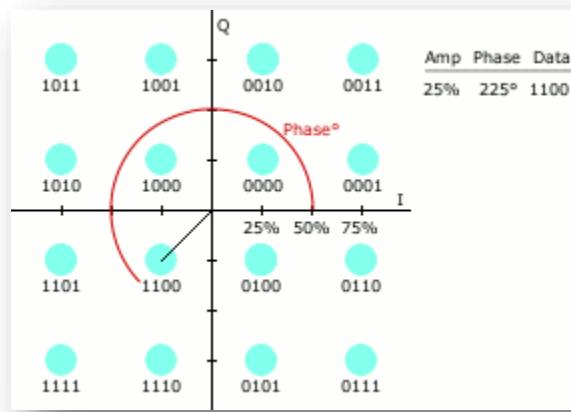
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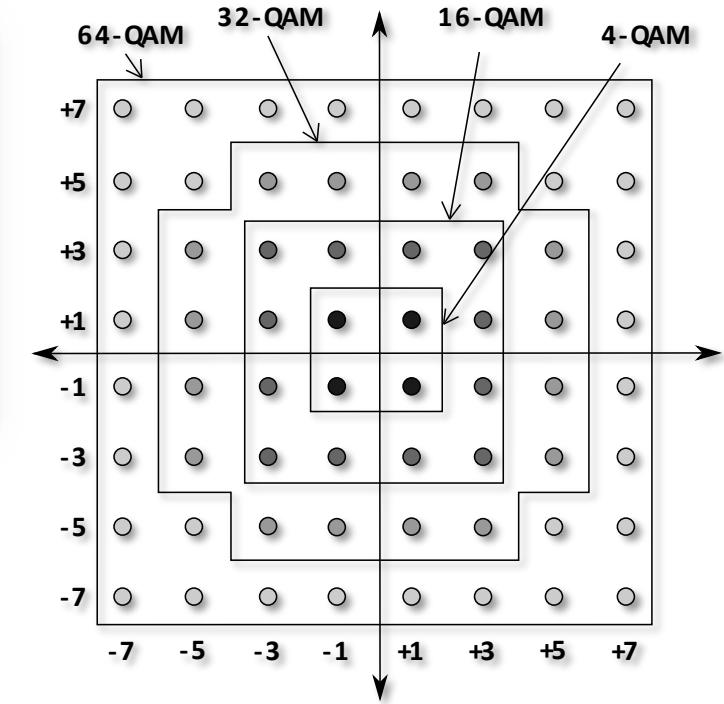
# Modulació QAM

## *Quadrature Amplitude Modulation*

- És una modulació digital simultània d'amplitud i de fase. Això li proporciona una gran capacitat de transmissió de dades.
- Pot ser de diversos nivells, 4-QAM, 8-QAM, 16-QAM, etc. arribant fins a 256-QAM, tal i com s'indica en diagrama de constel·lació de la figura.
- Aquest tipus de modulació és convenient utilitzar-la en sistemes cablats, ja que és molt sensible a les interferències d'amplitud.
- Per aquesta raó, no és convenient utilitzar-la en sistemes de radiocomunicacions.



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By Michel Bakni - Gilb, James (2005) The IEEE wireless dictionary, New York, NY: Standards Information Network, IEEE Press, p. 72 ISBN: 0-7381-4766-4., CC BY-SA 4.0, <https://commons.wikimedia.org/w/index.php?curid=110111966>

# RESUM I CONCLUSIONS



# Quadre resum de les modulacions digitals

Modulació	Codificació	Amplada de banda (Hz)	Bauds	Eficiència d'amplada de banda (bps/Hz)
FSK	1 bit	$2(\Delta f + R_b)$	$R_b$	$\leq 1$
BPSK	1 bit	$R_b$	$R_b$	1
QPSK	2 bits	$R_b / 2$	$R_b / 2$	2
8-PSK	3 bits	$R_b / 3$	$R_b / 3$	3
8-QAM	3 bits	$R_b / 3$	$R_b / 3$	3
16-PSK	4 bits	$R_b / 4$	$R_b / 4$	4
16-QAM	4 bits	$R_b / 4$	$R_b / 4$	4

# Conclusió

- Les modulacions d'amplitud, tant analògiques com digitals, son vulnerables a les interferències, ja que la informació viatja en la amplitud de la portadora (envoltant).
- Les modulacions ASK i QAM és convenient utilitzar-les en sistemes cablats o guiats, ja que es preserven de les interferències de l'exterior.
- Les modulacions de freqüència i fase són molt robustes davant de les interferències, ja que la informació viatja en la freqüència o fase de la portadora.
- Les modulacions QPSK de 4, 8 o més nivells, són les apropiades pels sistemes de comunicacions per satèl·lit, ja que són molt robustes davant de l'atenuació i les interferències que es poden trobar en creuar l'atmosfera.

# Tema 4: TECNOLOGIA I SISTEMES DE RADIOFREQÜÈNCIA

Pèrdues de retorn i d'inserció

Jordi Berenguer i Sau  
*Novembre 2021*



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# Pèrdues d'inserció i de retorn

DEFINICIÓ I SISTEMA DE MESURA



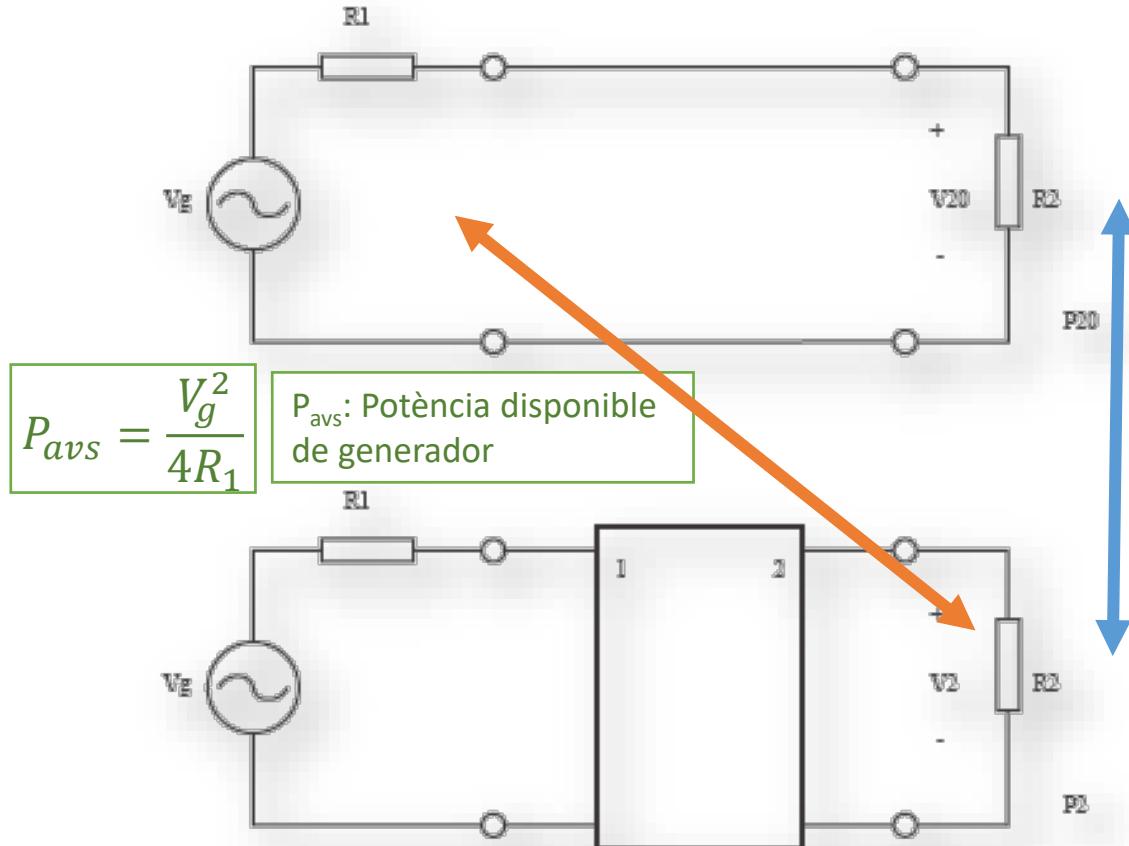
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# DEFINICIÓ DE PÈRDUES D'INSERCIÓ



$$IL = \frac{P_{20}}{P_2} = \left[ \frac{R_2}{R_1 + R_2} \right]^2 \cdot \left| \frac{V_g}{V_2} \right|^2$$

IL: Pèrdues d'Inserció  
Insertion Loss

$$IL = 10 \log \left( \frac{P_{20}}{P_2} \right) \text{ dB}$$

$$L_A = \frac{P_{avs}}{P_2} = \frac{1}{4} \frac{R_2}{R_1} \cdot \left| \frac{V_g}{V_2} \right|^2 = \frac{1}{|\tau|^2}$$

L<sub>A</sub>: Atenuació

$$L_A = 10 \log \left( \frac{P_{avs}}{P_2} \right) \text{ dB}$$

Fig. 5.1 Pèrdues d'inserció d'un biport.

# DEFINICIÓ DE PÈRDUES D'INSERCIÓ

Expressant l'atenuació en funció de les pèrdues d'inserció, tenim:

$$L_A(dB) = IL(dB) + 10 \log \left[ \frac{(R_1 + R_2)^2}{4R_1 R_2} \right]$$

I si com és habitual en RF, la **impedància de generador i la de càrrega són idèntiques** i de valor  $50\Omega$ , llavors l'atenuació i les pèrdues d'inserció són idèntiques:

$$L_A(dB) = IL(dB)$$

En aplicacions de RF i microones en què sempre es produeix l'adaptació d'impedàncies entre generador i càrrega, parlar de **pèrdues d'inserció** és el mateix que parlar de les **pèrdues de transferència del transductor**, o el que és el mateix, de **l'atenuació**; els dos conceptes es confonen.

Només en el cas de xarxes o **quadripols passius i sense pèrdues** (no dissipatius), **tota la potència no transmesa serà reflectida cap el generador**, i tindrem la següent relació entre el **coeficient de transmissió  $\tau$**  i el **coeficient de reflexió  $\rho$** :

$$\frac{P_{avs}}{P_2} = \frac{1}{|\tau|^2} = \frac{1}{1 - |\rho|^2}$$



# DEFINICIÓ DE PÈRDUES DE RETORN

En una línia de transmissió, la relació entre la ona de tensió reflectida i la ona de tensió incident és el que es defineix com a **coeficient de reflexió  $\rho$** :

$$\rho = \frac{V^-}{V^+}$$

Les **pèrdues de retorn (RL: return loss)** es defineixen com la **relació entre la potència incident i la potència reflectida**, i per tant les podem relacionar amb el coeficient de reflexió  $\rho$  de la següent forma:

$$RL = \frac{P^+}{P^-} = \frac{|V^+|^2/Z_0}{|V^-|^2/Z_0} = \frac{|V^+|^2}{|V^-|^2|\rho|^2} = \frac{1}{|\rho|^2}$$

Expressant-ho en dB, resultarà que:

$$RL(dB) = 20 \log\left(\frac{1}{|\rho|^2}\right) = -20 \log|\rho|^2$$

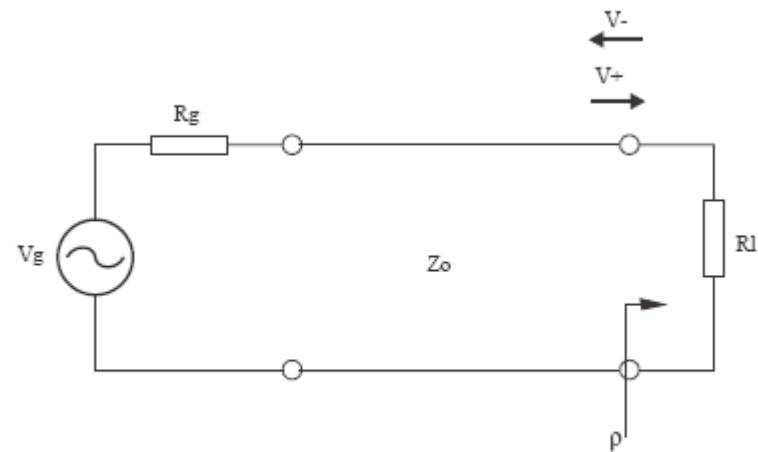
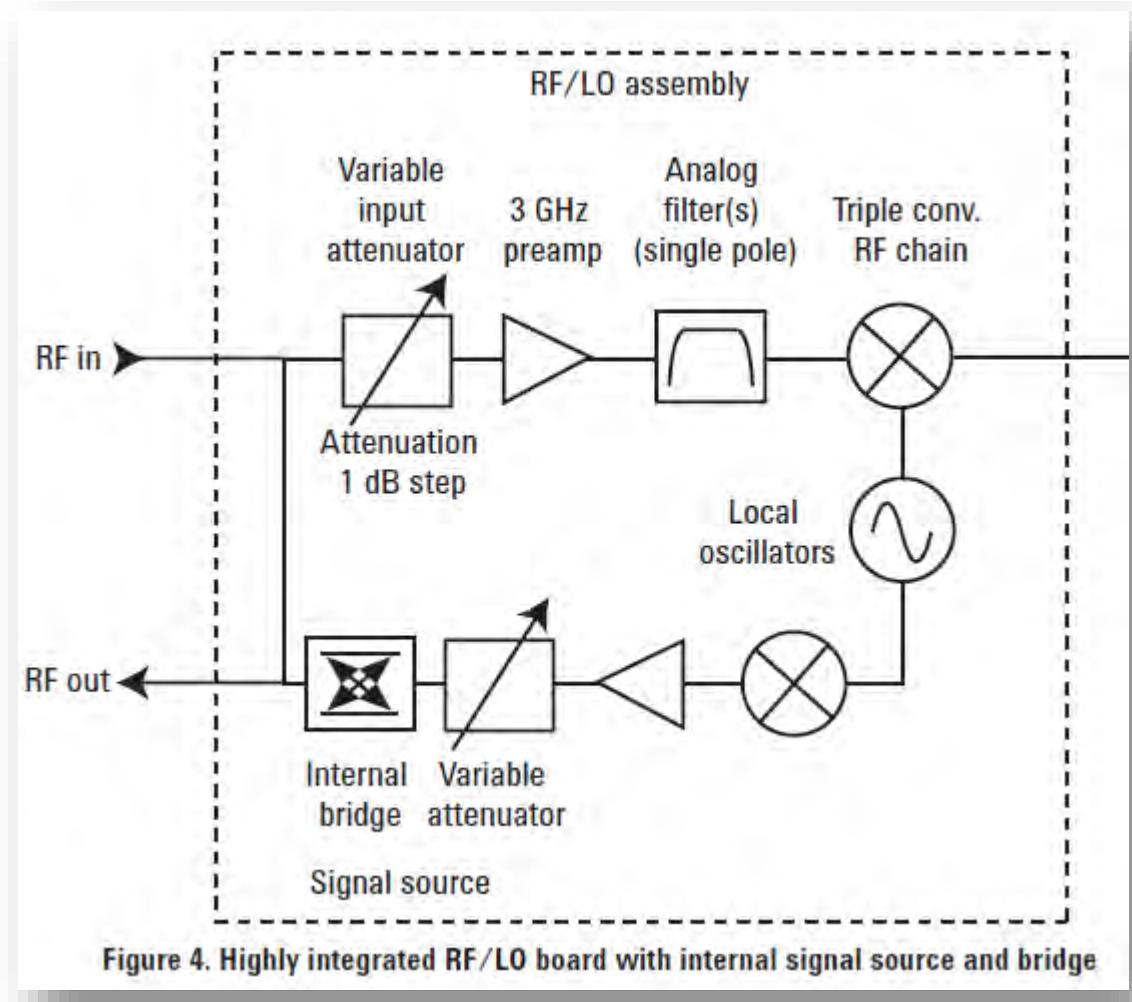


Fig. 5.2 Mesura de les pèrdues de retorn d'un quadripol.

# Sistema de mesura de les pèrdues de retorn i d'inserció:

## *Analitzador d'espectre + generador de tracking*



# MESURA DE LES PÈRDUES D'INSERCIÓ: Calibració

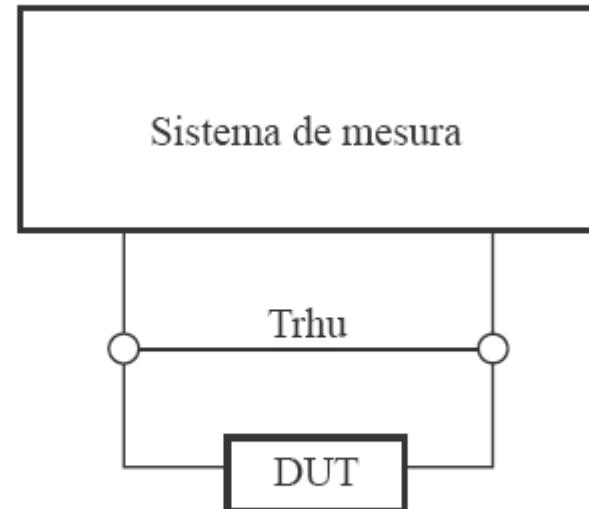


Fig. 5.4 Calibratge en transmissió mitjançant un thru.

# MESURA DE LES PÈRDUES DE RETORN: Calibració

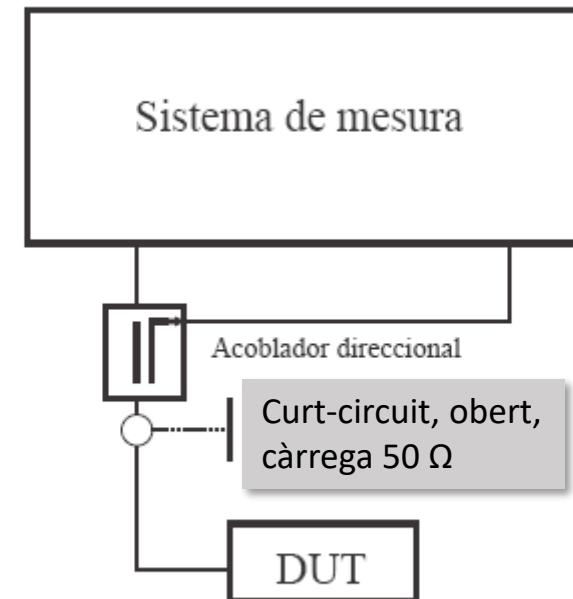


Fig. 5.5 Calibratge en reflexió mitjançant un curt circuit.

# Tema 4: TECNOLOGIA I SISTEMES DE RADIOFREQÜÈNCIA

Cables, connectors i components en guia d'ones

Jordi Berenguer i Sau  
*Novembre 2021*



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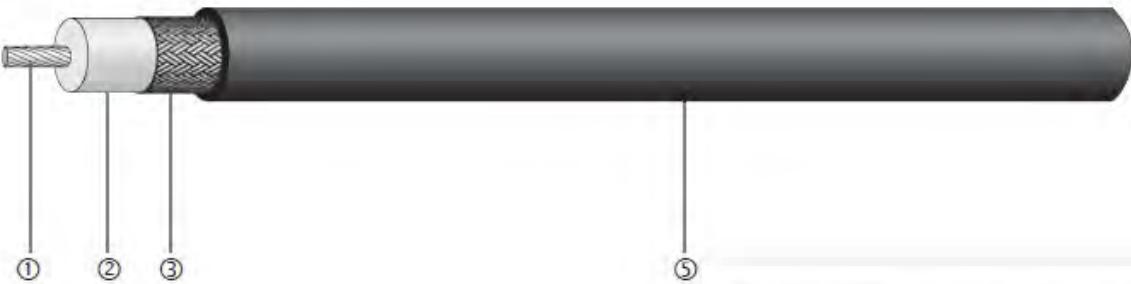
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# CABLES COAXIALS DE RF



## G - Standard PE coax cables

Cable design



$$Z_0 = \frac{1}{2\pi} \sqrt{\frac{\mu_0 \mu_r}{\epsilon_0 \epsilon_r}} \ln \left( \frac{b}{a} \right)$$

b: radi conductor exterior  
 a: radi conductor interior

Velocitat de propagació:

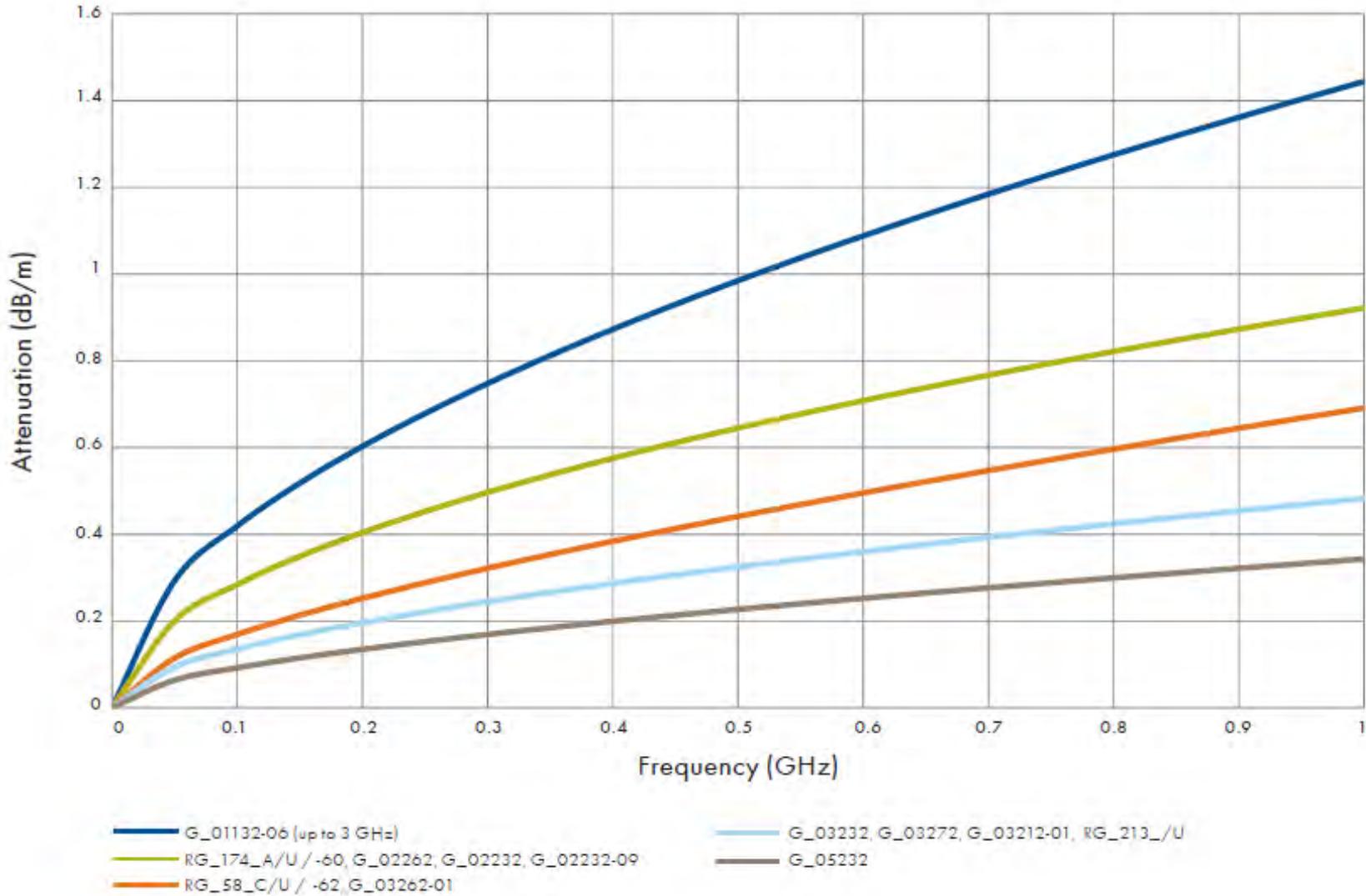
$$v_p = \frac{c}{\sqrt{\epsilon_r}}$$

## Electrical cable data

Impedance [Ω]	50
Capacitance	101 pF/m
Velocity of signal propagation	66 % of the speed of light
Epsilon r	2.3
Signal delay	5.0 ns/m
Insulation resistance	> 10 <sup>8</sup> MΩm
Screening effectiveness	≥ 40 dB up to 1 GHz

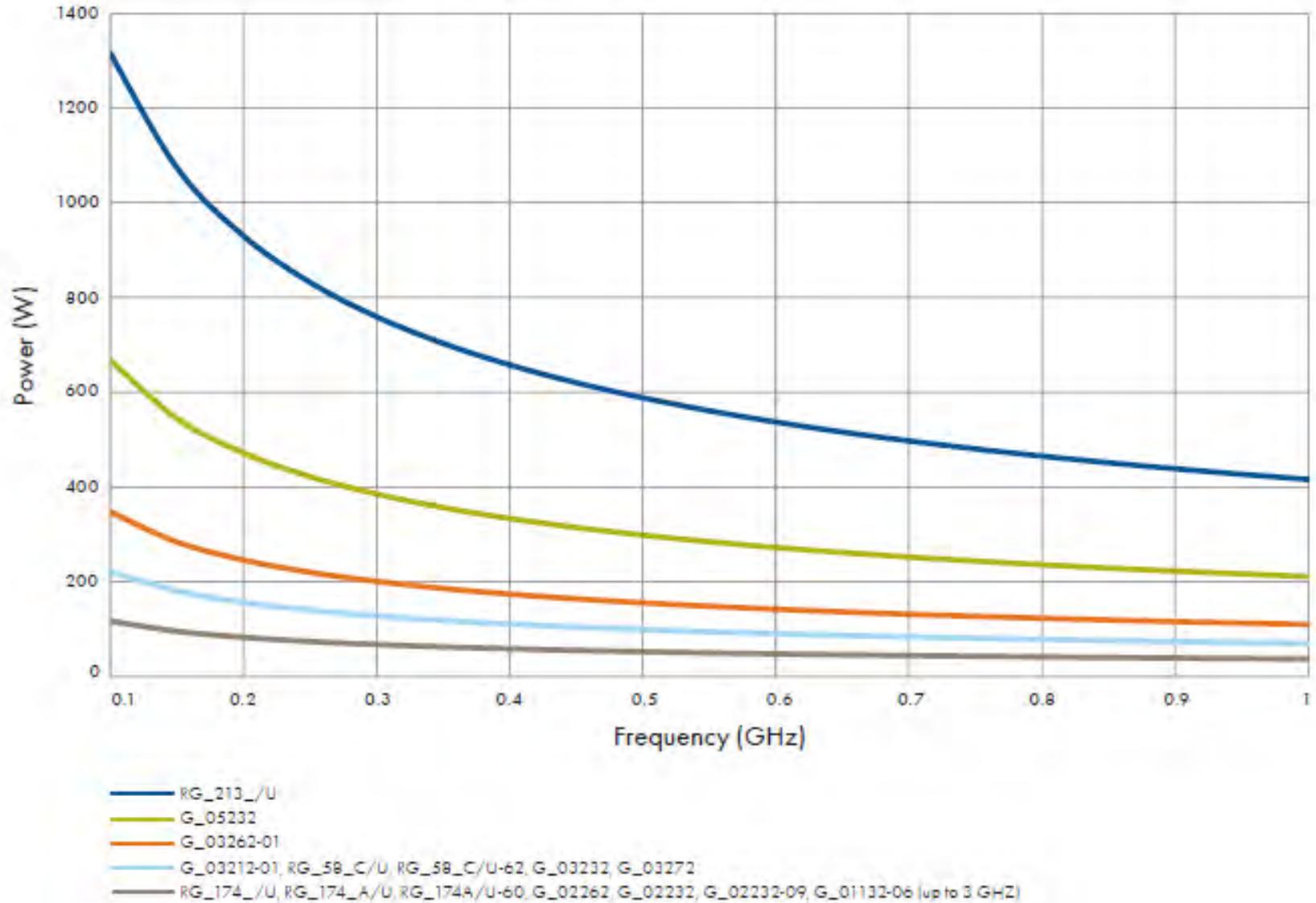
## Attenuation

typical values at +20 °C ambient temperature and sea level



## CW Power

max. values at +40 °C ambient temperature and sea level



## SX - Cross-linked low loss coax cables

Cable design

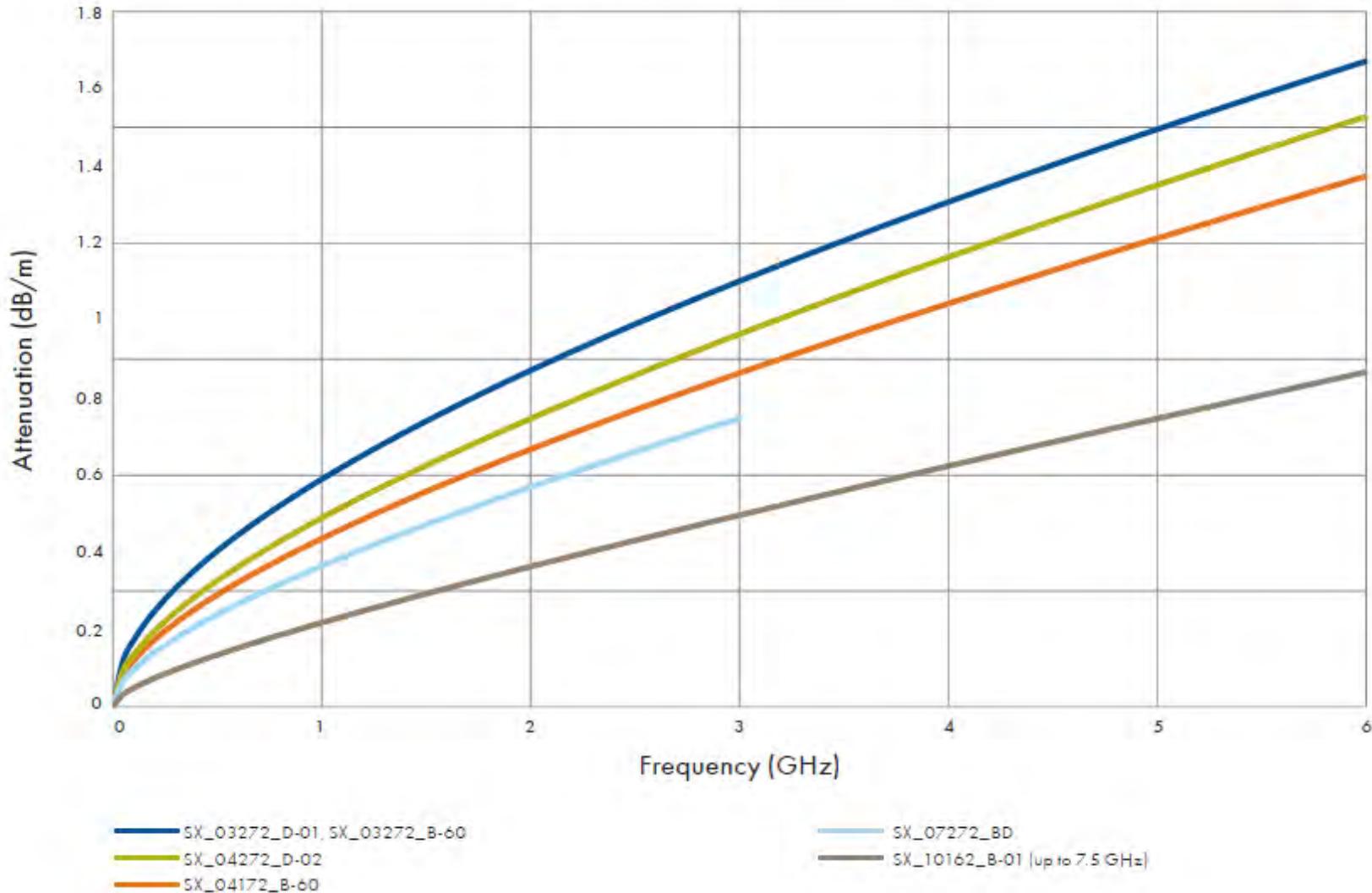


Electrical cable data	
Impedance ( $\Omega$ )	50
Capacitance	82 pF/m
Velocity of signal propagation	82 % of the speed of light
Epsilon r	1.5
Signal delay	4.1 ns/m
Insulation resistance	> 10 <sup>8</sup> M $\Omega$ m
Single screening effectiveness	≥ 80 dB up to 6 GHz

HUBER+SUHNER type	Item no.	Center conductor		①	Dielectric		②	Screen 1		③
		Design	Material	Dim. mm	Mat.	Dim. mm	Material	Dim. mm	Cover %	
SX_03272_B-60 <sup>a</sup>	84010513	wire	Cu	1.065	SPEX	2.96	Al-PES	3.05	100	
SX_03272_D-01	22511948	wire	CuAg	1.1	SPEX	2.96	CuAg	3.60	95	
SX_04172_B-60 <sup>a</sup>	84026748	wire	CuAg	1.40	SPEX	3.80	Al-PES	4.00	4.53	
SX_04272_D-02	22511926	wire	CuAg	1.40	SPEX	3.82	CuAg	4.20	97	
SX_07272_BD	22512245	strand-7	CuAg	2.85	SPEX	7.35	CuAg	8.10	96	
SX_10162_B-01	84013441	wire	AlCu	3.80	SPEX	9.90	Cu	10.00	100	

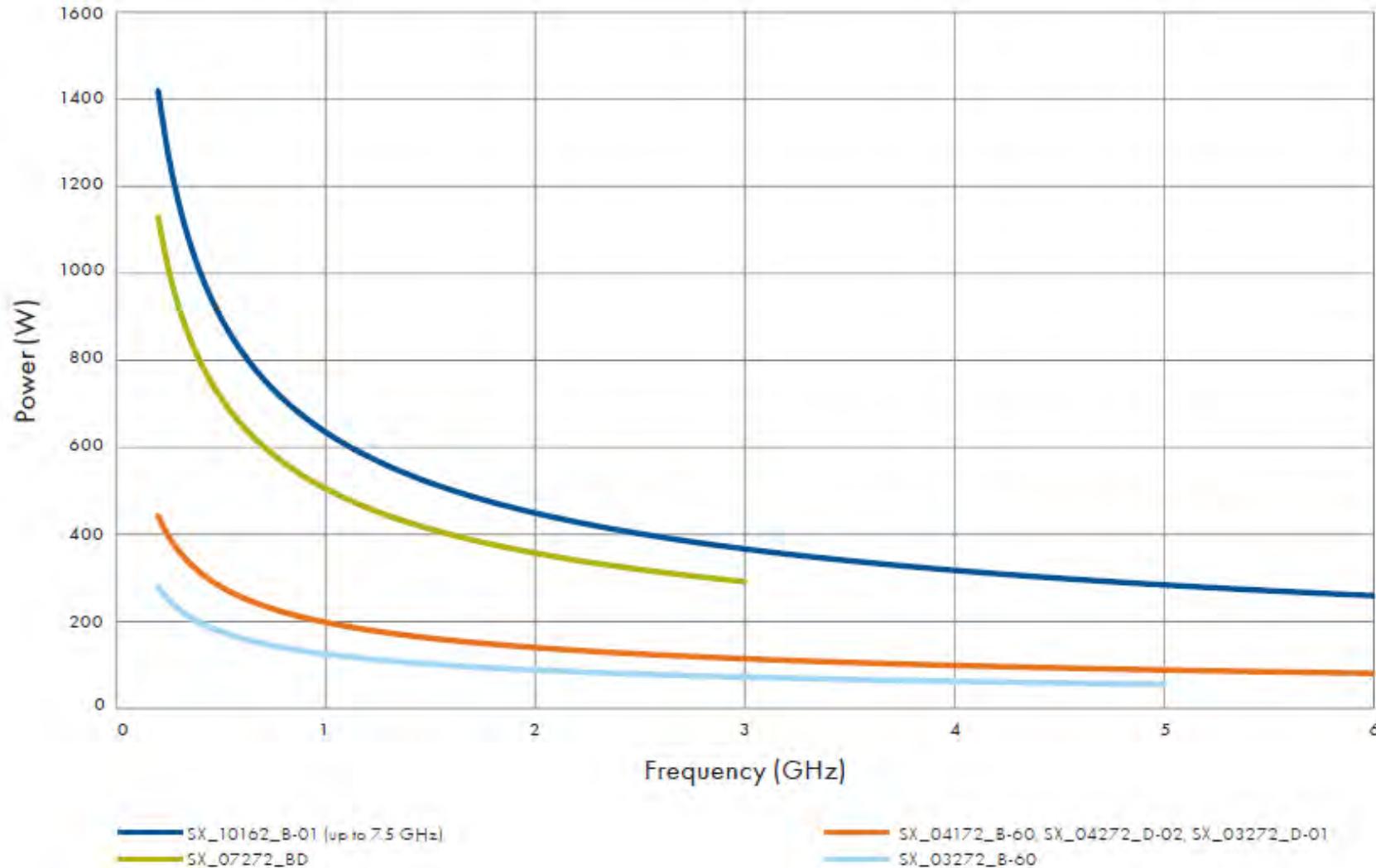
## Attenuation

typical values at +20 °C ambient temperature and sea level



## CW Power

max. values at +40 °C ambient temperature and sea level



solid  
strandedattenuation  
flexibility / flex lifePE  
SPE  
PTFEhalogenfree  
attenuation  
temperature up to +165 °Csingle  
double  
tapeup to 3 GHz  
up to 6 GHz  
above 6 GHzPVC  
PE  
PUR  
LSFH™  
RADOX®  
FEP/PFAflexibility  
chemical and abrasion resistance  
abrasion resistance, flexible  
halogenfree, flame retardant up to +85 °C  
halogenfree, flame retardant up to +105 °C  
excellent chemical resistance and abrasion resistant  
operation up to +165 °C (200 °C resp. 260 °C)

# CABLES COAXIALS SEMIRÍGIDS



**MICRO-COAX®**  
PROVEN RELIABLE



## Electrical and Physical Properties of Conductors

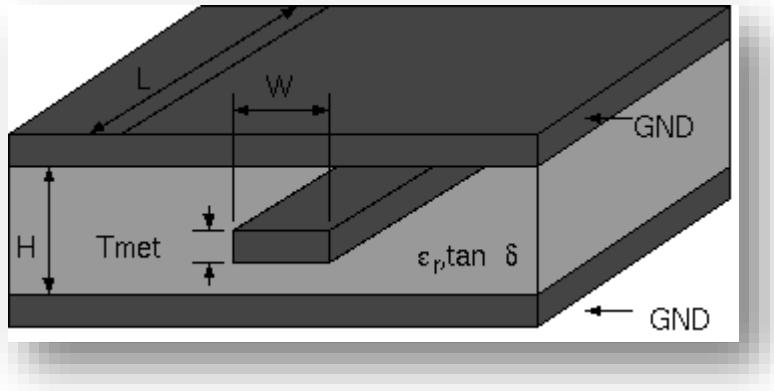
MIL-DTL-17/129			MIL-DTL-17/130			MIL-DTL-17/133			MIL-DTL-17/151			MIL-DTL-17/154			
ATTENUATION		POWER	ATTENUATION		POWER	ATTENUATION		POWER	ATTENUATION		POWER	ATTENUATION		POWER	
MHz	dB/100	Watts	MHz	dB1/100	dB2/100	Watts	MHz	dB/100	Watts	MHz	dB/100	Watts	MHz	dB/100	Watts
400	4.5	19,000	500	8	8.3	600	500	15	180	500	28	45	500	42	14
1000	7.5	1400	1000	12	12.1	450	1000	22	130	1000	40	32	1000	60	10
3000	16	750	3000	21	22.5	250	5000	50	54	3000	70	18	3000	100	6
10000	33	350	5000	29	30.1	180	1000	80	35	5000	90	13	5000	140	4.5
18000	48	200	10,000	45	45.5	120	20,000	130	20	10,000	130	9	10,000	190	3.1
—	—	—	20,000	70	70	70	—	—	—	20,000	190	6.5	20,000	280	2

Structural Return Loss		Structural Return Loss		Structural Return Loss		Structural Return Loss		Structural Return Loss	
MHz	dB	-MHz	dB	MHz	dB	MHz	dB	MHz	dB
500	26	500	30	500	28	1000	22	500	22
5000	21	5000	23	5000	23	10,000	18	5000	21
10,000	19	18,000	21	20,000	15	20,000	14	20,000	15
18,000	16	—	—	—	—	—	—	—	—

# LÍNIES DE TRANSMISSIÓ IMPRESES



# STRIPLINE



Línia de transmissió impresa sobre un substrat dielèctric de constant dielèctrica  $\epsilon_r$ , entre dos plans de massa.

La seva impedància  $Z_0$  depèn de l'amplada W de la línia, el gruix H del substrat i del gruix de la capa de coure t, habitualment de 35μm.

<http://wcalc.sourceforge.net/cgi-bin/stripline.cgi>

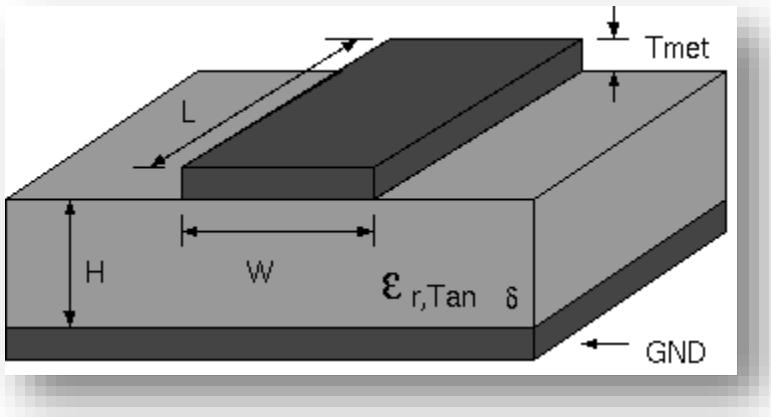
En ser un medi homogeni, la velocitat de propagació depèn de la constant dielèctrica del substrat:

$$v_p = \frac{c}{\sqrt{\epsilon_r}}$$

I per tant, la longitud d'ona de la línia és de:

$$\lambda_p = \frac{\lambda_0}{\sqrt{\epsilon_r}}$$

# MICROSTRIP



<http://wcalc.sourceforge.net/cgi-bin/microstrip.cgi>

Línia de transmissió impresa sobre un substrat dielèctric de constant dielèctrica  $\epsilon_r$

La seva impedància  $Z_0$  depèn de l'amplada W de la línia, el gruix H del substrat i del gruix de la capa de coure t, habitualment de 35μm.

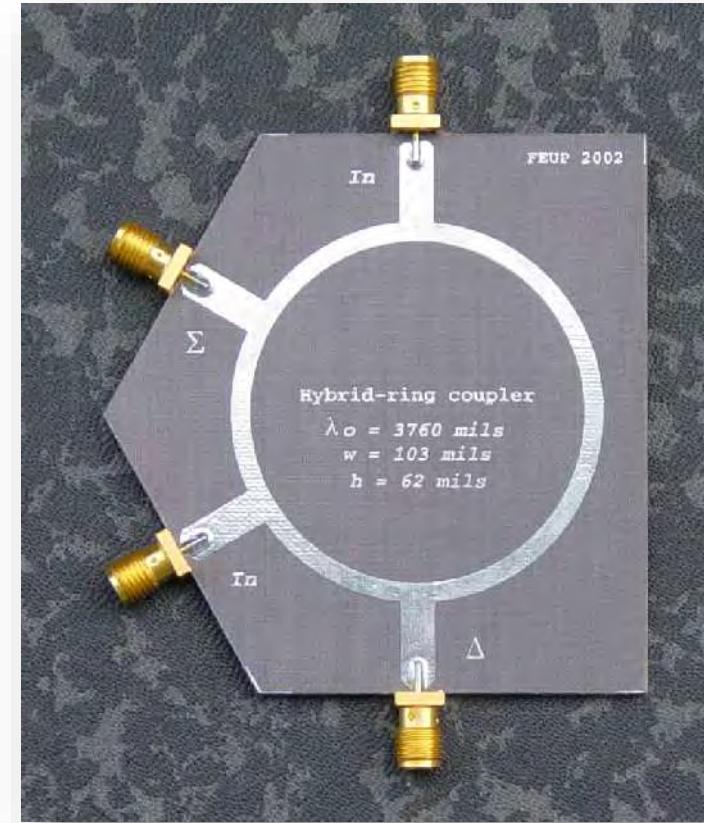
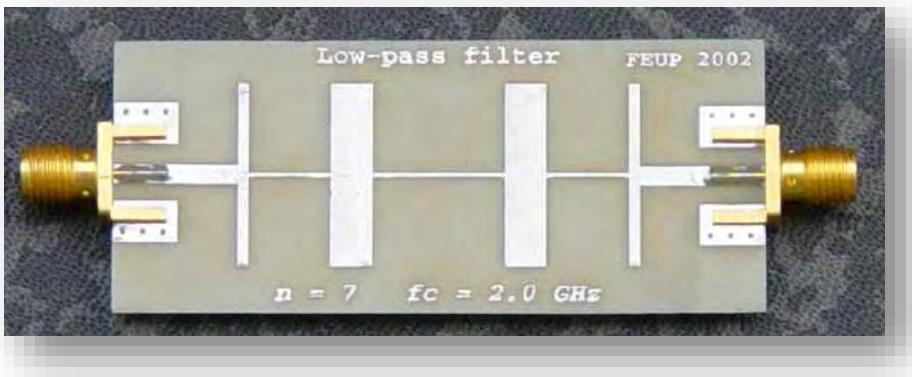
En ser un medi no homogeni, meitat aire, meitat dielèctric, es defineix una constant dielèctrica efectiva  $\epsilon_{eff}$  que depèn dels anteriors paràmetres, de forma que la velocitat de propagació és:

$$v_p = \frac{c}{\sqrt{\epsilon_{eff}}}$$

I per tant, la longitud d'ona en la línia és de:

$$\lambda_{eff} = \frac{\lambda_0}{\sqrt{\epsilon_{eff}}}$$

# CIRCUITS AMB LÍNIES DE TRANSMISSIÓ



# GUIES D'ONA

WAVEGUIDES



UNIVERSITAT POLITÈCNICA DE CATALUNYA

BARCELONATECH

Departament de Teoria del Senyal  
i Comunicacions

# Guia d'ona

Es tracta d'un conducte de parets metàl·liques, que pot ser rectangular, circular, el·líptic o corrugat, per l'interior del qual es propaga una ona electromagnètica.

Existeix una **freqüència de tall de la guia**, per sota de la qual no es possible la propagació. Actua doncs com un **filtre pas-alt**.

Pel cas de la guia rectangular de secció a, la freqüència de tall es aquella en el que la seva longitud d'ona és igual a  $2a$ ,

$$\lambda_c = 2a = \frac{v_p}{f_c}$$

I en la que la **velocitat de propagació** en la guia és:

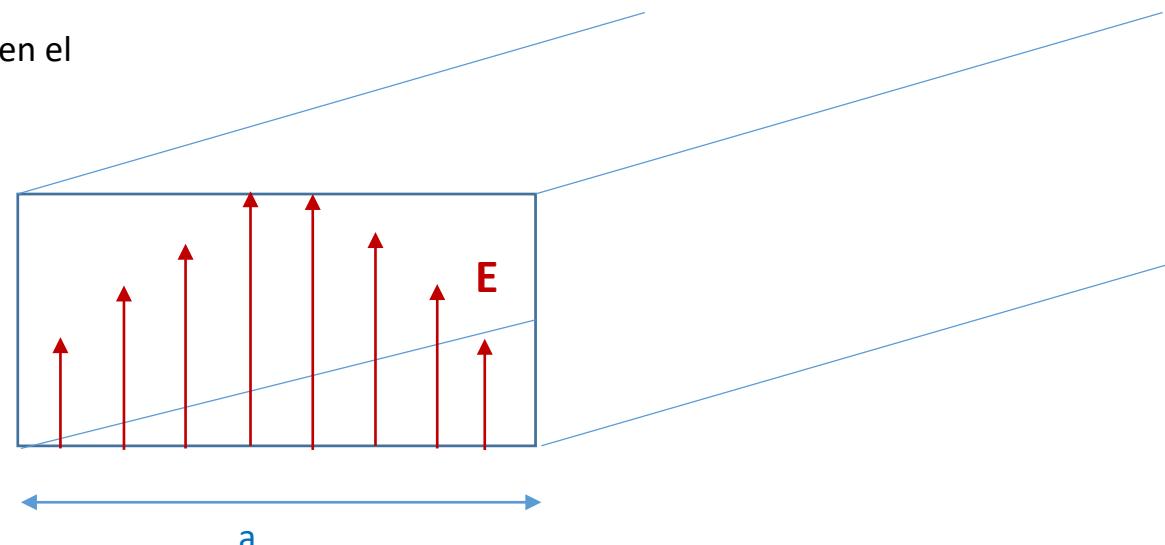
$$v_p = \frac{1}{\sqrt{\mu_0 \mu_r \epsilon_0 \epsilon_r}} = \frac{1}{\sqrt{\mu_0 \epsilon_0}} \cdot \frac{1}{\sqrt{\mu_r \epsilon_r}} = \frac{c}{\sqrt{\mu_r \epsilon_r}}$$

Per tant,

$$f_c = \frac{c}{2a\sqrt{\mu_r \epsilon_r}}$$

I la **longitud d'ona en la guia** és:

$$\lambda_g = \frac{\lambda_0}{\sqrt{1 - \left(\frac{\lambda_0}{\lambda_c}\right)^2}}$$



# TIPUS DE GUIA D'ONES RECTANGULARS



WR DESIGNATION	WG EQUIVALENT	STANDARD FREQ RANGE GHZ	INSIDE DIMENSIONS (INCHES)
WR340	WG9A	2.20 - 3.30	3.400 x 1.700
WR284	WG10	2.60 - 3.95	2.840 x 1.340
WR229	WG11A	3.30 - 4.90	2.290 x 1.150
WR187	WG12	3.95 - 5.85	1.872 x 0.872
WR159	WG13	4.90 - 7.05	1.590 x 0.795
WR137	WG14	5.85 - 8.20	1.372 x 0.622
WR112	WG15	7.05 - 10.00	1.122 x 0.497
WR90	WG16	8.2 - 12.4	0.900 x 0.400
WR75	WG17	10.0 - 15.0	0.750 x 0.375
WR62	WG18	12.4 - 18.0	0.622 x 0.311
WR51	WG19	15.0 - 22.0	0.510 x 0.255
WR42	WG20	18.0 - 26.5	0.420 x 0.170
WR28	WG22	26.5 - 40.0	0.280 x 0.140
WR22	WG23	33 - 50	0.224 x 0.112
WR19	WG24	40 - 60	0.188 x 0.094
WR15	WG25	50 - 75	0.148 x 0.074
WR12	WG26	60 - 90	0.122 x 0.061

**WR waveguide dimensions, sizes and waveguide cut-off frequencies  
for rigid rectangular RF waveguides**

# Guia d'ones rectangular



## Electrical Specifications

Description	Minimum	Typical	Maximum	Units
Frequency Range	7.05		10	GHz
VSWR		1.03:1		
Insertion Loss		0.1 [0.33]		dB/ft [dB/m]

## Mechanical Specifications

Waveguide Size  
WR-112  
Waveguide Design  
Commercial Grade  
Section Length  
12 in [304.8 mm]

Description	Flange 1	Waveguide	Flange 2
Interface	UG-51/U	WR-112	UG-51/U
Material	Copper Alloy	Copper Alloy	Copper Alloy
Plating	Paint	Paint	Paint
Color	Blue	Blue	Blue

# Guia d'ones rectangular flexible



## Electrical Specifications

Description	Minimum	Typical	Maximum	Units
Frequency Range	8.2		12.4	GHz
VSWR		1.07:1		
Insertion Loss		0.09		dB

## Mechanical Specifications

Waveguide Size	WR-90
Waveguide Design	Flexible
Section Length	12 in [304.8 mm]
E-Plane Minimum Bend Radius, One Time	0.87 in [22.1 mm]
H-Plane Minimum Bend Radius, One Time	1.69 in [42.93 mm]
Maximum Operating Pressure	45 psig

Description	Flange 1	Waveguide	Flange 2
Interface	UG-39/U	WR-90	UG-39/U
Material	Brass	Copper	Brass
Plating		Silver	
Color	Gold	Black	Gold

# Guia d'ona corrugada/el·líptica



EW132-144

EK-EW52 Corrugated waveguide freq. 5.85÷6.425 GHz

EK-EW63 Corrugated Waveguide freq. 6.425÷7.125 GHz

EK-EW77 Corrugated waveguide freq. 7.125÷8.5 GHz

EK-EW90 Corrugated waveguide freq. 10.0 ÷ 11.70 GHz

EK-EW127A Corrugated waveguide freq. 11.70 ÷13.25 GHz

EK-EW132 Corrugated waveguide freq. 14.0 ÷ 14.50 GHz

## Return Loss/VSWR

Frequency Band	VSWR	Return Loss (dB)
14.4-15.35 GHz	1.15	23.10

## Attenuation

Frequency (GHz)	Attenuation (dB/100 ft)	Attenuation (dB/100 m)	Average Power (kW)	Group Velocity %
14.4	4.882	16.018	0.843	76.8
14.6	4.838	15.874	0.85	77.5
14.8	4.798	15.74	0.858	78.2
15	4.76	15.616	0.865	78.9
15.2	4.725	15.501	0.871	79.5

# COMPONENTS EN GUIA D'ONES



# ACOBLADOR DIRECCIONAL TIPUS CROSS-COUPLER

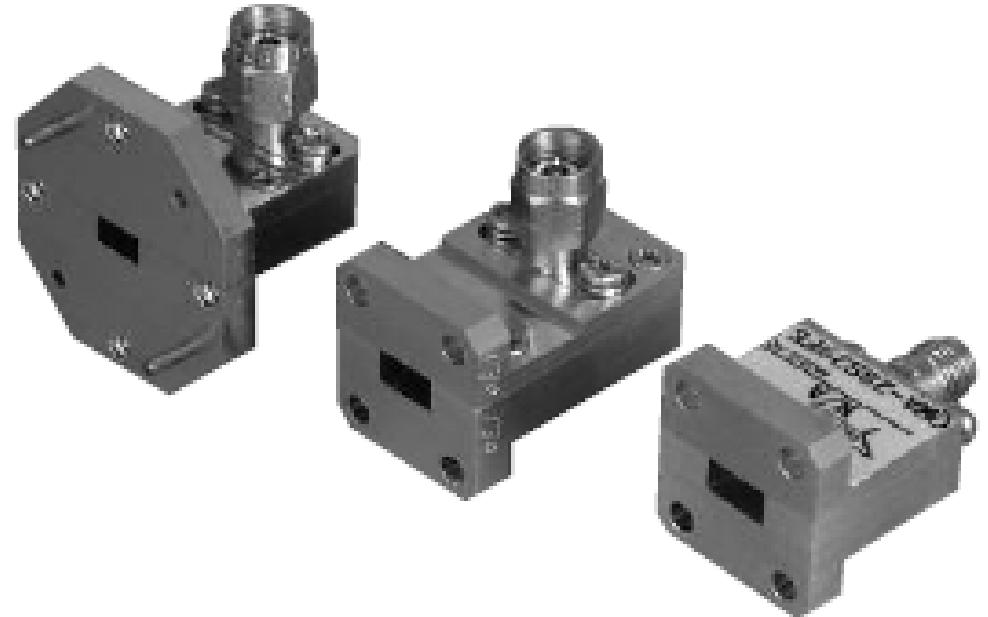


## Specifications

FREQUENCY BAND	K	Ka	Q	U
Frequency Range (GHz)	18-26.5	26.5-40	33-50	40-60
Waveguide Size	WR-42	WR-28	WR-22	WR-19
Coupling Values, (dB at center frequency)	20 and 30 ± 2 dB			
Bandwidth (min)	20% of waveguide band			
Insertion Loss (dB max) <sup>1</sup>	0.5	0.5	0.6	0.7
Directivity (dB typ) <sup>2</sup>	15			
Main Line VSWR (max)	1.15:1			
Secondary Line VSWR (max)	1.2:1			
Coupling Flatness (dB max)	± 1.5			



# TRANSICIÓNS COAXIAL – GUIA D'ONES



## Specifications

Model No. Range, (GHz)	Frequency	Waveguide	Flange	Standard Connectors Available	Insertion Loss (dB) max.		VSWR (typ.)	
					Right Angle	End Launch	Right Angle	End Launch
<b>QWA-62</b>	12.4-18	WR-62	UG-419/U	N, SMA	0.3	0.4	1.25:1	1.5:1
<b>QWA-51</b>	15-22	WR-51	UG-419/U	SMA, K	0.3	0.4	1.25:1	1.5:1
<b>QWA-42</b>	18-26.5	WR-42	UG-595/U	SMA, K	0.3	0.4	1.25:1	1.5:1
<b>QWA-34</b>	22-33	WR-34	UG-595/UM	K, 2.4 mm	0.35	0.45	1.25:1	1.5:1
<b>QWA-28</b>	26.5-40	WR-28	UG-599/U	K, 2.4 mm	0.4	0.5	1.25:1	1.5:1
<b>QWA-180</b>	18-40	WRD-180	UG-1587	K	N/A	0.6	N/A	1.5:1
<b>QWA-22</b>	33-50	WR-22	UG-383/UM	K*, 2.4 mm	0.6	0.7	1.35:1	1.5:1
<b>QWA-19</b>	40-60	WR-19	UG-383/UM	2.4 mm*, V	0.8	0.9	1.5:1	1.6:1
<b>QWA-15</b>	50-67	WR-15	UG-385/U	V	1.2	1.3	1.5:1	1.6:1

\* K connector up to 40 GHz only. Also, 2.4 mm connector up to 50 GHz only.



# JUNTES ROTATÒRIES



Model No	Freq Range (GHz)	Operating Bandwidth (MHz)	VSWR (Max)	VSWR WOW	IL(dB) (Max)	IL WOW (dB)	WG Type		Material
							IEC	EIA	
VT32WRJI	2.60-3.95	200	1.20	0.05	0.3	0.1	R32	WR284	Al/Cu
VT32WRJL	2.60-3.95	200	1.20	0.05	0.3	0.1	R32	WR284	Al/Cu
VT32WRJU	2.60-3.95	200	1.20	0.05	0.3	0.1	R32	WR284	Al/Cu
VT40WRJI	3.22-4.90	200	1.20	0.05	0.3	0.1	R40	WR229	Al/Cu
VT40WRJL	3.22-4.90	200	1.20	0.05	0.3	0.1	R40	WR229	Al/Cu
VT40WRJU	3.22-4.90	200	1.20	0.05	0.3	0.1	R40	WR229	Al/Cu
VT48WRJI	3.94-5.99	200	1.20	0.05	0.3	0.1	R48	WR187	Al/Cu
VT48WRJL	3.94-5.99	200	1.20	0.05	0.3	0.1	R48	WR187	Al/Cu
VT48WRJU	3.94-5.99	200	1.20	0.05	0.3	0.1	R48	WR187	Al/Cu
VT58WRJI	4.64-7.05	300	1.25	0.05	0.25	0.1	R58	WR159	Al/Cu
VT58WRJL	4.64-7.05	300	1.25	0.05	0.25	0.1	R58	WR159	Al/Cu
VT58WRJU	4.64-7.05	300	1.25	0.05	0.25	0.1	R58	WR159	Al/Cu

# JUNTES ROTATÒRIES

Model No.	Frequency Range [GHz]	VSWR	VSWR WOW	Insertion Loss	Avg. Power
ARJ-28UU1-L*	32 ~ 35 GHz	1.2:1	1.05:1	0.2dB max.	100W
ARJ-62UU1-L	12 ~ 18 GHz	1.5:1	1.05:1	0.5 dB max.	20W
ARJ-75UU1-L	13.75 ~ 14.5 GHz	1.2:1	1.05:1	0.3 dB max.	200W
ARJ-75UU2-L*	13.75 ~ 14.5 GHz	1.2:1	1.05:1	0.2 dB max.	1,000W
ARJ-90UU1-L	8.5 ~ 9.6 GHz	1.2:1	1.05:1	0.3 dB max.	1,00W
ARJ-90UU2-L	8.5 ~ 9.6 GHz	1.15:1	1.05:1	0.2 dB max.	600W
ARJ-90UU3-L*	10 ~ 10.5 GHz	1.2:1	1.05:1	0.2 dB max.	2,000W
ARJ-137UU1-L	5.86 ~ 6.65 GHz	1.20:1	1.05:1	0.3 dB max.	150W
ARJ-187UU1-L*	5.4 ~ 5.9 GHz	1.2:1	1.05:1	0.2 dB max.	10,000W
ARJ-430UU1-L	2.025 ~ 2.12 GHz	1.20:1	1.05:1	0.2 dB max.	5,000W



# CONNECTORS COAXIALS



**Paul Neill**

(September 6, 1882 – October 1968) was an American electrical engineer at Bell Labs in the 1940s. He is credited with helping to invent the BNC, TNC and Type N connectors used for microwave and RF communications. He joined Bell in 1916 after spending 12 years at the Westinghouse Electric Company. He retired from Bell on September 30, 1947.

**Carl Concelman**

(December 23, 1912 – August 1975) was the electrical engineer who, while working for Amphenol, invented the C connector and teamed up with Paul Neill of Bell Labs to invent the BNC connector and TNC connector.

# “BNC” (*Bayonet Neill Concelman*) (DC – 4 GHz)



**Amphenol®RF**

## 50 Ω BNC Specifications

### Electrical

Impedance  
Frequency range  
VSWR

RF-leakage  
Voltage rating (at sea level)  
Contact resistance

Insulation resistance  
Insertion loss maximum  
Dielectric withstand voltage

### Mechanical

Mating  
Attachment method (inner / outer)  
Coupling torque, min./max.  
Coupling nut retention force  
Center contact retention force  
Braid/Jacket cable affixment  
Center conductor cable affixment  
Engagement force  
Disengagement force  
Durability (matings)

50 Ω nominal  
DC - 4 GHz (usable to 11 GHz)  
1.3 max. @ DC - 4 GHz (straight)  
1.35 max. @ DC - 4 GHz (right-angle)  
55 dB minimum @ 3 GHz  
≥ 500 V peak (depending on cable)  
center contact: ≤ 1.5 mΩ  
outer contact: ≤ 0.2 mΩ  
braid to body: ≤ 0.1 mΩ  
5,000 MΩ minimum  
0.2 dB max. @ 3 GHz  
1,500 Vrms (at sea level)

2-stud bayonet lock coupling (MIL-STD-348)  
Crimp, clamp  
0.6 / 2.5 in-lbs (7 / 28 N·cm)  
101 lbs (450N) min.  
≥ 6.1 lbs (27N)  
Hex crimp or screw-threaded clamps  
Crimp or solder  
≤ 5 lbs (22N)  
≥ 1.5 lbs (7N)  
500 cycles minimum

# “TNC” (*Threaded Neill Concelman*) (DC – 11 GHz)



**Amphenol®RF**

## Standard TNC Specifications

### Electrical

Impedance	50 Ω nominal
Frequency range	DC - 11 GHz
VSWR	1.3 max. @ DC - 11 GHz (straight) 1.35 max. @ DC - 11 GHz (right-angle)
RF-leakage	60 dB minimum @ 3 GHz
Voltage rating (at sea level)	≥ 500 V peak (depending on cable)
Contact resistance	center contact: ≤ 1.5 mΩ outer contact: ≤ 0.2 mΩ braid to body: ≤ 0.1 mΩ
Insulation resistance	5,000 MΩ minimum
Insertion loss maximum	0.18 dB @ 9 GHz
Dielectric withstanding voltage	1,500 Vrms (at sea level)

### Mechanical

Mating	7/16 threaded coupling (MIL-STD-348)
Coupling torque, min./max.	4.1 / 6.1 in-lbs (46 / 69 N-cm), recommended
Coupling nut retention force	101 lbs (450N) min.
Braid/Jacket cable affixment	Hex crimp or screw-threaded clamps
Durability (matings)	500 cycles minimum

# “N” (Paul Neill de la Bell Labs) (DC – 11 GHz)



50Ω	DC - 11 GHz (standard N) DC - 18 GHz (N 18 GHz)
75Ω	DC - 1.5 GHz

## GENERAL

- Standard coaxial connectors
- Screw-on coupling
- High durability and proven strength
- High power rating
- Excellent RF performance

## APPLICATIONS

- Wireless communications
- Civil and military radio-telecommunication equipment
- Countermeasure
- Navy equipment
- Industrial applications

## APPLICABLE STANDARDS

- MIL-C-39012 / MIL STD 348-304
- CEI 169-16
- CECC 22210
- NF-C-93566
- DS 8811



# “SMA” (*SubM*iniature version *A*) (DC – 27 GHz)



## GENERAL

- Sub-miniature coaxial connectors
- Screw-on coupling
- High RF performance
- 2 plating options:
  - passivated stainless steel
  - gold plated
- Wide hermetically sealed range
- Space qualified range of products
- SMA extended frequency 27 GHz

## APPLICABLE STANDARDS

- MIL-C-39012
- EC 169-1
- CECC 22110
- CECC 22111 - 801 to 808
- BS 9210 N006

## SPACE QUALIFIED/APPROVALS

(For space range)

- SCC 3402 (ESA)
- CNES

# “K” (DC – 40 GHz)



The K Connector® is a precision coaxial connector system that operates up to 40 GHz. It is compatible with SMA, WSMA, and 3.5 mm connectors. It is well suited to applications in components, systems, or instrumentation.

## K Connector® features

- *Excellent performance up to 40 GHz*
- *Performance exceeding SMA below 18 GHz*
- *Superior reliability*
- *Compatibility with SMA, WSMA, and 3.5 mm*
- *Complete testability on existing network analyzers*

### Electrical

Contact Resistance:

Center Contact — <3 mΩ

Outer Contact — <2 mΩ

Dielectric Withstanding Voltage:

500V RMS

Insulation Resistance:

5,000 Megohms

Voltage Standing Wave Ratio:

DC to 26.5 GHz — 1.10 max.

26.5 to 40 GHz — 1.15 max.

40 to 50 GHz — 1.20 max.

(2.4mm only)

RF Leakage: <-100dB

RF Insertion Loss:

$0.03 \times \sqrt{f}$  (GHz) dB max.

**molex®**

# COMPONENTS COAXIALS



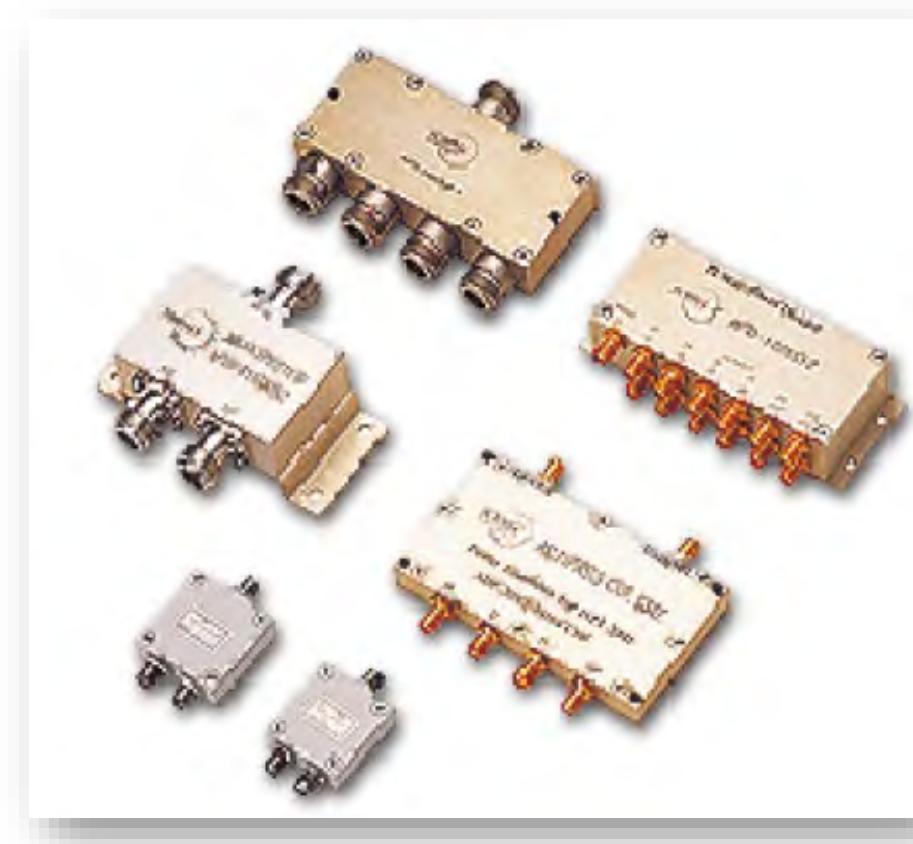
# JUNTES ROTATÒRIES COAXIALS



Model No.	ACRJ-4GSF-50S50	ACRJ-4GSF-40S20
Frequency Range	DC ~ 4 GHz	DC ~ 4 GHz
VSWR	1.20:1max.	1.20:1max.
VSWR WOW	1.03:1max.	1.03:1max.
Insertion Loss	0.30 dB max.	0.30 dB max.
Power	10W max.	10W max.
Dimension(D×H)[mm(inch)]	ø80×50(ø3.15×1.97)	ø35×40(ø1.38×1.57)

# Divisors de potència (power splitters)

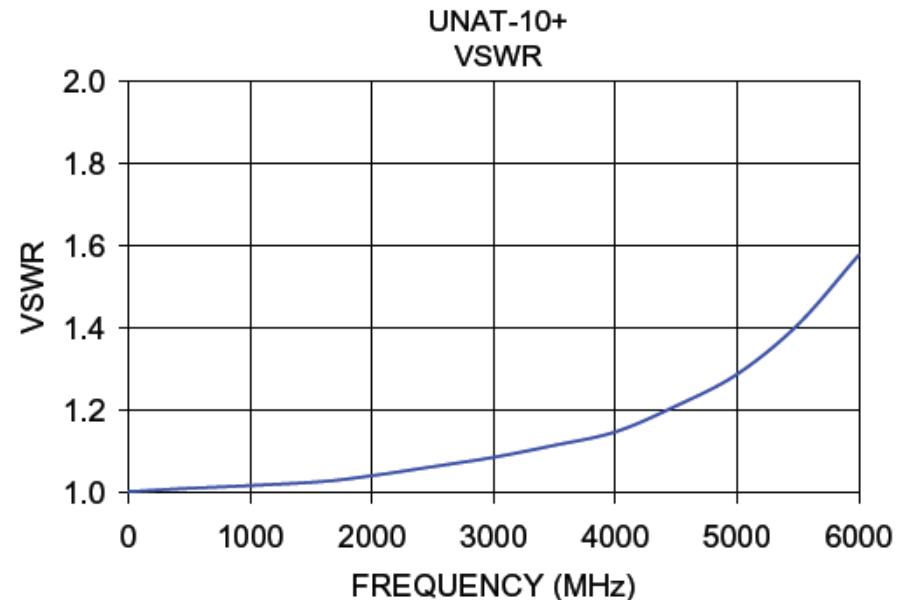
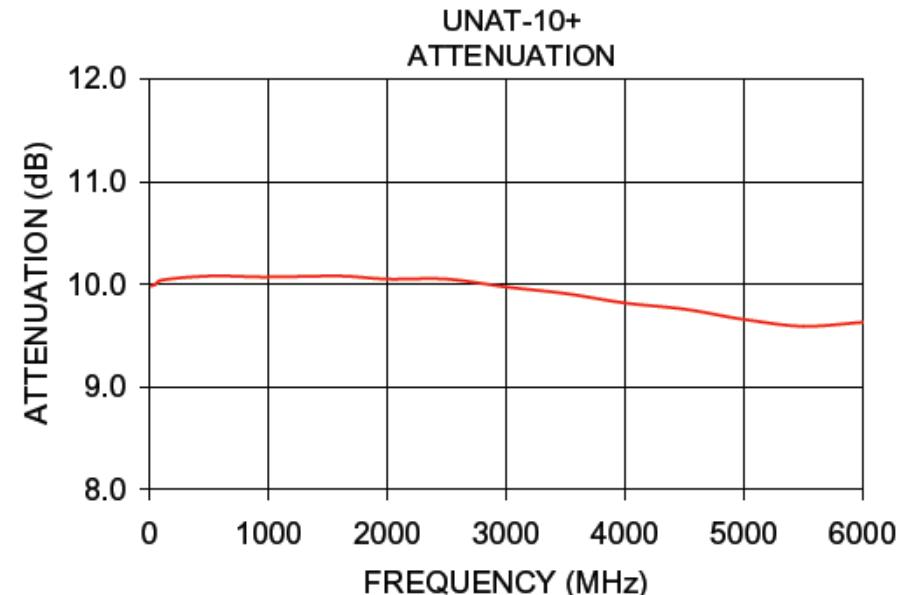
Model No.	APD-859 /70N2	APD-859 /70N3	APD-859 /70S4	APD-859 /70S6	APD-10 /3S12
Frequency Range	824 ~ 894 MHz	824 ~ 894 MHz	824 ~ 894 MHz	824 ~ 894 MHz	8.75 ~ 11.25 MHz
n-Way	2	3	4	6	12
Insertion Loss	0.5 dB max.	0.7 dB max.	2.2 dB max.	2.2 dB max.	0.7 dB max.
Isolation	20 dB min.	20 dB min.	15 dB min.	20 dB min.	20 dB min.
VSWR	1.2:1max.	1.2:1max.	1.5:1max.	1.2:1max.	1.38:1max.
Operating Power	20 W	20 W	0.75 W	0.5 W	1 W
Impedance	50 ohm	50 ohm	50 ohm	50 ohm	50 ohm
Connector Type[I/O]	Type-N(F)	Type-N(F)	SMA(F)	SMA(F)	SMA(F)
Dimension (W×L×H)[mm(inch)]	91×41×34 (3.6×1.6×1.3)	123×59×33.5 (4.8×2.3×1.3)	94×51.5×13 (3.7×2.0×0.5)	180×60×13 (7.1×2.4×0.5)	101.5×38×25 (4.0×1.5×1.0)



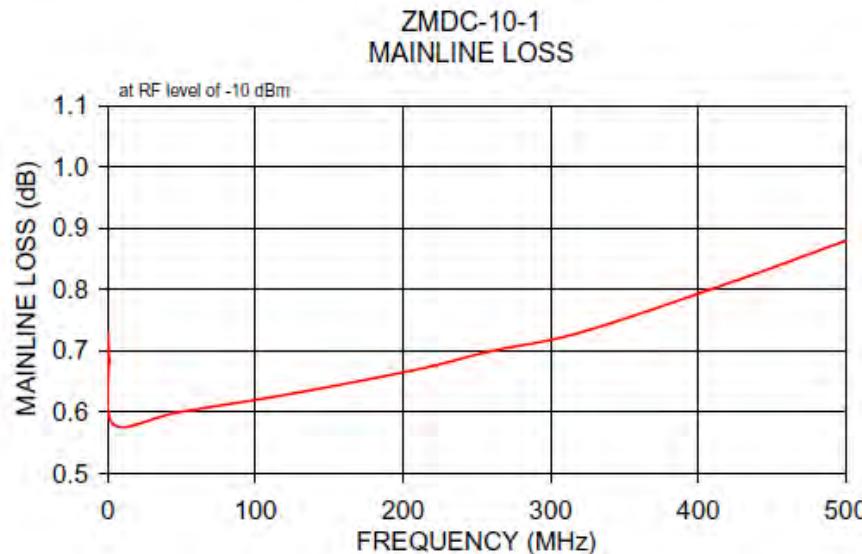
# Atenuadors



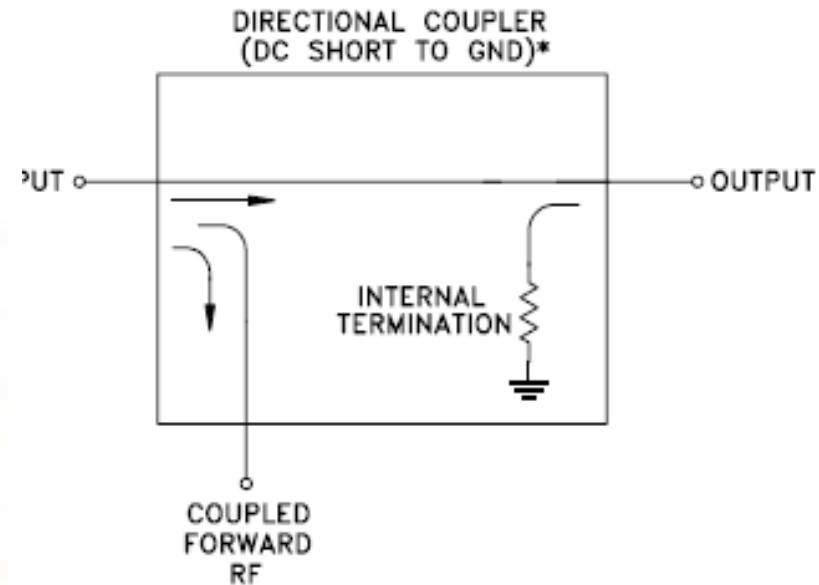
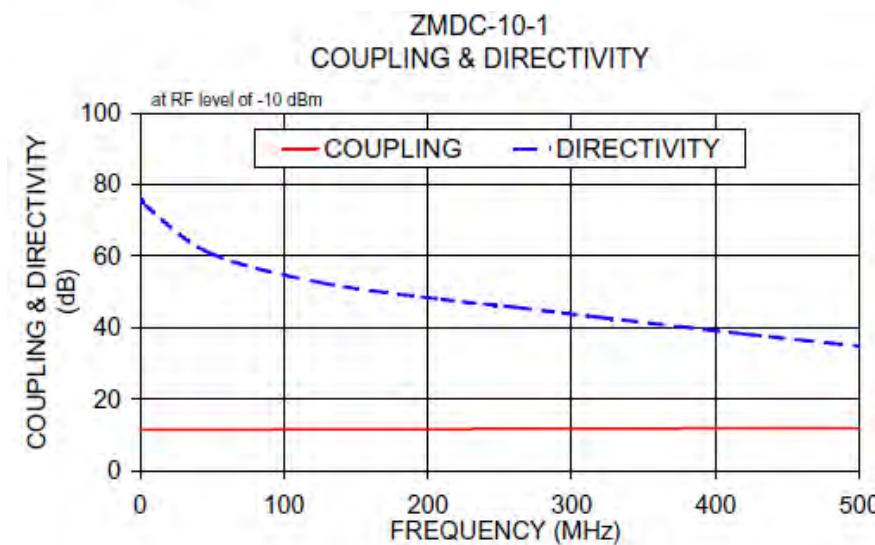
**Mini-Circuits®**  
ISO 9001 ISO 14001 AS9100 Certified



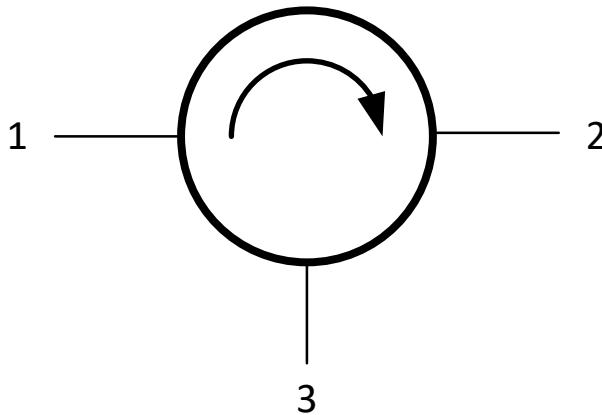
# Acobladors direccionals



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ISO 9001 ISO 14001 AS9100 Certified



# Circuladors



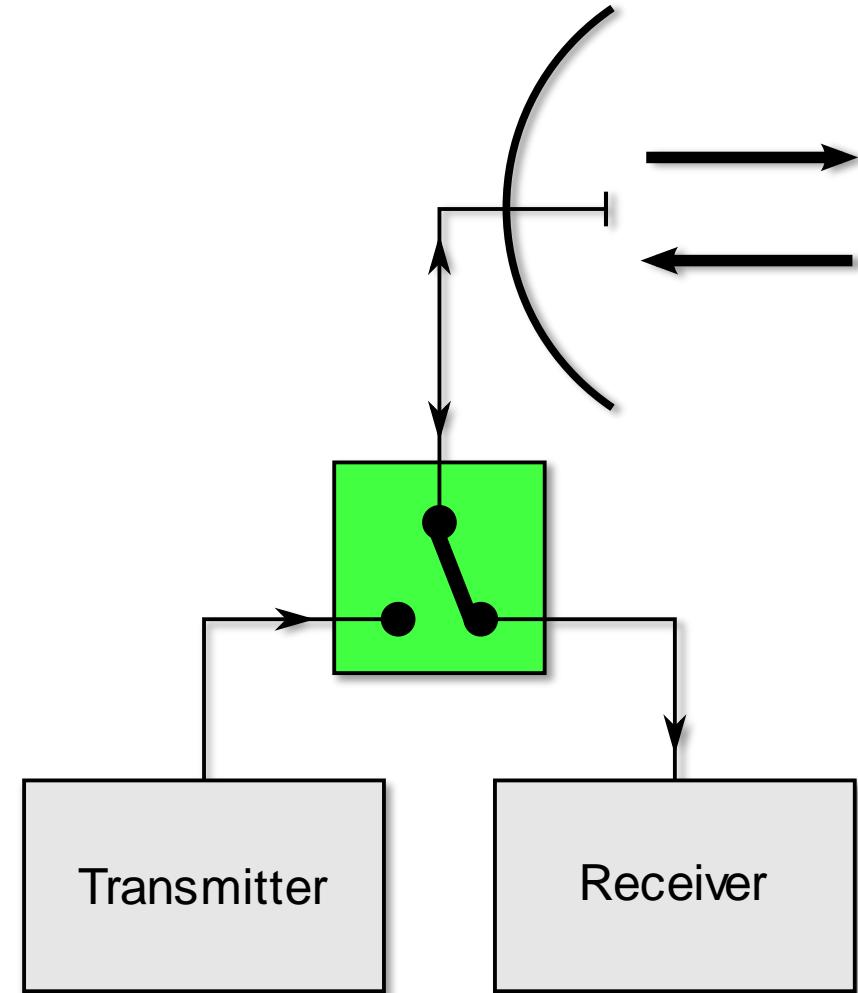
**Electrical Specifications** (Values at 25°C, sea level)

Description	Minimum	Typical	Maximum	Units
Frequency Range	2		4	GHz
Impedance		50		Ohms
Insertion Loss			0.6	dB
Forward Power			10	Watts
Reverse Power			10	Watts
Input VSWR			1.3:1	
Isolation	18			dB

# Duplexor

Dispositiu commutador que permet connectar una mateixa antena a un transmissor i a un receptor de forma alternada.

L'aplicació típica és el Radar polsat, en que mentre l'antena es connecta al transmissor per emetre un pols de RF de l'ordre d'10kW de potència, el receptor queda disconnectat. Un cop emès, es disconnecta l'antena del transmissor i es connecta al receptor, per rebre l'eco, fins que es torna a connectar el transmissor per emetre el següent pols.



De Bsp\_Duplex.svg: The original uploader was Averse de Wikipedia en alemán.derivative work: Catslash (talk) - Bsp\_Duplex.svg, CC0, <https://commons.wikimedia.org/w/index.php?curid=36776136>

# Diplexor

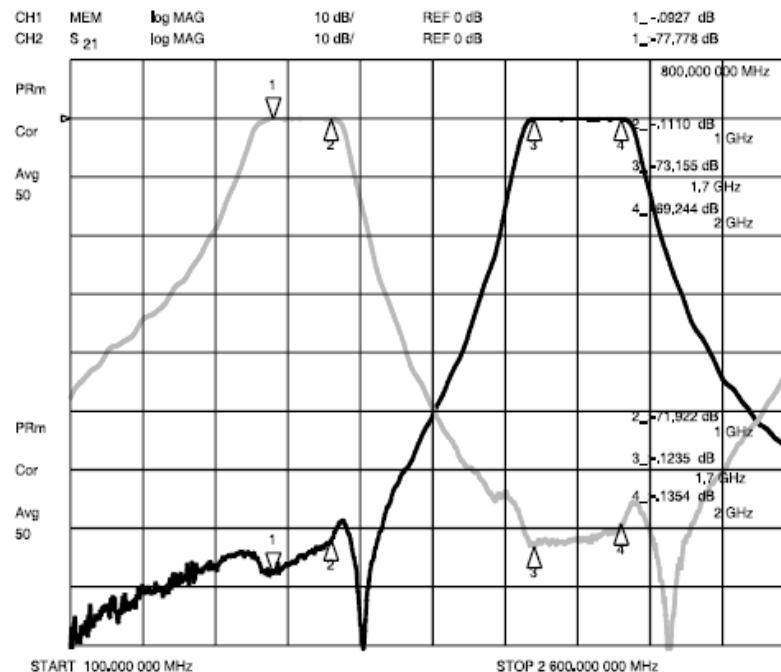
- Dispositiu, normalment dos filtres interconnectats, que permet la connexió simultània d'una única a antena a dos emissors o receptors diferents.

## SPECIFICATIONS

MODEL NUMBER	AFD-21A-8020-01
PASSBAND AMPS or GSM PCS OR DCS1800	800 - 1000 MHz 1700 - 2000 MHz
PASSBAND INSERTION LOSS	0.2 dB MAX
PASSBAND LOSS VARIATION	0.1 dB MAX
PASSBAND RETURN LOSS	17 dB MIN
ISOLATION	60 dB MIN
POWER HANDLING <sup>1</sup> CW	500 W (800-1000 MHz) 250 W (1700-2000 MHz)
PEAK	10 kW (800-1000 MHz) 2.5 kW (1700-2000 MHz)
OPERATING TEMP	0 TO +65°C
STORAGE TEMP	-20 TO +85°C
CONNECTORS	TYPE 'N' FEMALE
SIZE	19" x 3.59" x 1U 482.6 mm x 91.1 mm x 1U



**narda**  
west  
an  communications company



# Tema 5:

## ELS EQUIPS I ELS SISTEMES RADIOELÈCTRICS AEROPORTUARIS

Jordi Berenguer  
Novembre 2021



UNIVERSITAT POLITÈCNICA DE CATALUNYA  
BARCELONATECH

Departament de Teoria del Senyal  
i Comunicacions

# Comunicacions Aeronaòtiques

Jordi Berenguer

Maarten Uijt



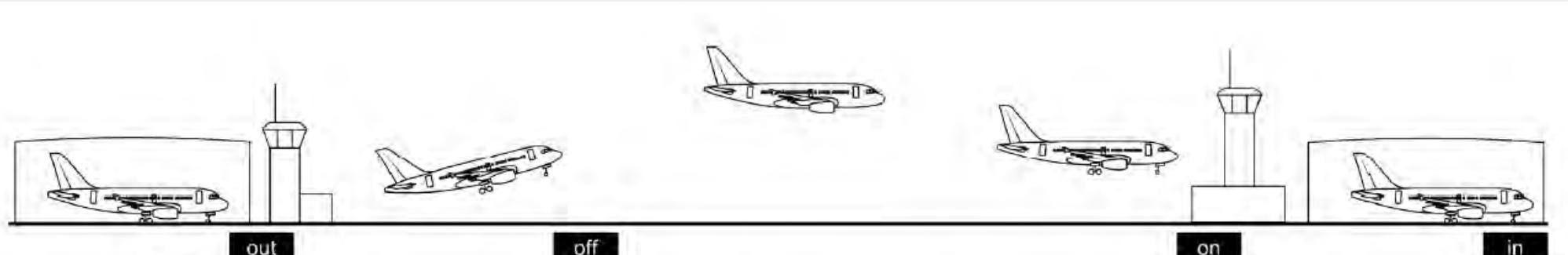
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BARCELONATECH

Departament de Teoria del Senyal  
i Comunicacions

# Classificació de les comunicacions aeronàutiques

- Servei fix aeronàutic:
  - Aeronautical Fixed Telecommunication Network (AFTN)
    - Xarxa de commutació de missatges de baixa velocitat, de 50 bps a 600/1200 bps.
  - Common ICAO Data Interchange Network (CIDIN)
    - Xarxa de commutació de paquets, d'alta velocitat de transmissió, basada en les xarxes X.25.
  - Aeronautical Telecommunication Network (ATN)
    - Xarxa en fase de desenvolupament, equivalent a el Internet aeronàutic, que permet la interconnexió de tots els elements de la comunitat aeronàutica.
    - Integra diferents xarxes: xarxes locals, enllaços per satèl·lit, comunicacions en VHF, Mode-S, etc.
    - Utilitza el model OSI.
- Servei mòbil aeronàutic:
  - Comunicacions en HF
  - Comunicacions en VHF

# Aircraft operational control at various “out-off-on-in” (OOOI) stages



out	off	en route	on	in
<p>On the ground Voice communications: VHF Data communications: VDL   <i>From the aircraft</i> Fuel data Crew information Link test etc.   <i>To the aircraft</i> Weight and balance data Airport information Flight plan Meteorological data PDC/ATIS Ground handling etc.</p>	<p>Take-off and departure Voice communications: VHF Data communications: VDL   <i>From the aircraft</i> Engine data etc.   <i>To the aircraft</i> Flight plan update Weather reports Traffic updates etc.</p>	<p>En route <i>Within LOS</i> Voice communications: VHF Data communications: VDL <i>Outside LOS</i> Voice communications: HF Data communications: HFDL and SATCOM   <i>From the aircraft</i> Position reports ETA/Delay information Weather reports Engine information Maintenance reports etc.   <i>To the aircraft</i> Flight plan update Weather reports Oceanic clearances etc.</p>	<p>Arrival and landing Voice communications: VHF Data communications: VDL   <i>From the aircraft</i> Gate requests Provision requests ETA Engine information Maintenance reports etc.   <i>To the aircraft</i> Gate assignment Passengers and crew data ATIS etc.</p>	<p>On the ground Voice communications: VHF Data communications: VDL   <i>From the aircraft</i> Fuel information Crew information Fault data from CMC etc.   <i>To the aircraft</i> Taxi information Ground handling etc.</p>

**OOOI: Out, Off, On, In.** The collective term for the four phases of an aircraft's flight: **Out (leaving the gate)**, **Off (takeoff)**, **On (touchdown)**, and **In (arriving at the gate)**. ACARS messages are sent at the start of each of those phases, providing the aircraft movement information and other data to operations center computers.

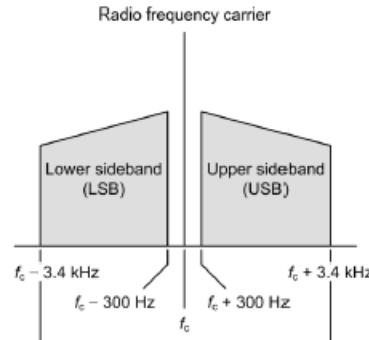
# Voice Communications

	Terrestrial										SAT	Airport	Ground-Ground network			
	VHF (25 kHz and 8,33 kHz)	VDL2	ATN	Mobile IP	B-AMC (Broadband VHF)	P-34	Wideband CDMA	AMACS	Narrowband LDL	SATCOM	802.16 (C-band)	V-SAT	PENS IP V6 Transport Layer	AMHS	Voice Over IP	ATS Qsig
1. Mobile Communications																
Air-Ground: ATS and AOC data		+														
Air-Ground Voice	+			+		+										
Network Management			+	+												
Air-Air Datalink				+	+	+	+	+	+							
Air-Air Voice	+			+												
2. Fixed Communications																
Ground-Ground Datalink			+	+								+	+	+	+	+
Ground-Ground Voice Communications			+									+	+	+	+	+

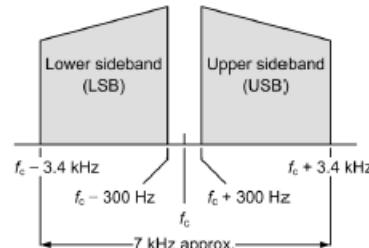
# COMUNICACIÓNS AERONÀUTIQUES:

## Modulacions

### VHF – Modulació AM amb portadora (DBL) (DSB)

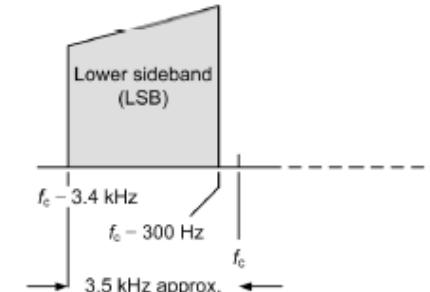


(a) Double sideband (DSB) full-carrier AM

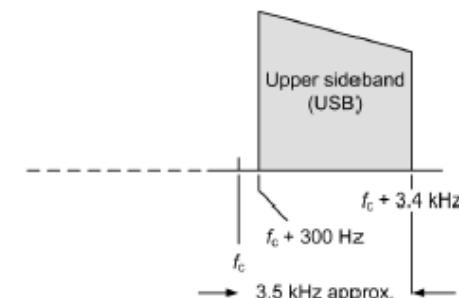


(b) Double sideband suppressed-carrier (DSB-SC)

### HF – Modulació Banda Lateral única (BLU) (SSB)



(c) Single sideband suppressed-carrier (SSB-SC)



(d) Single sideband suppressed-carrier (SSB-SC)

# Comunicacions en HF

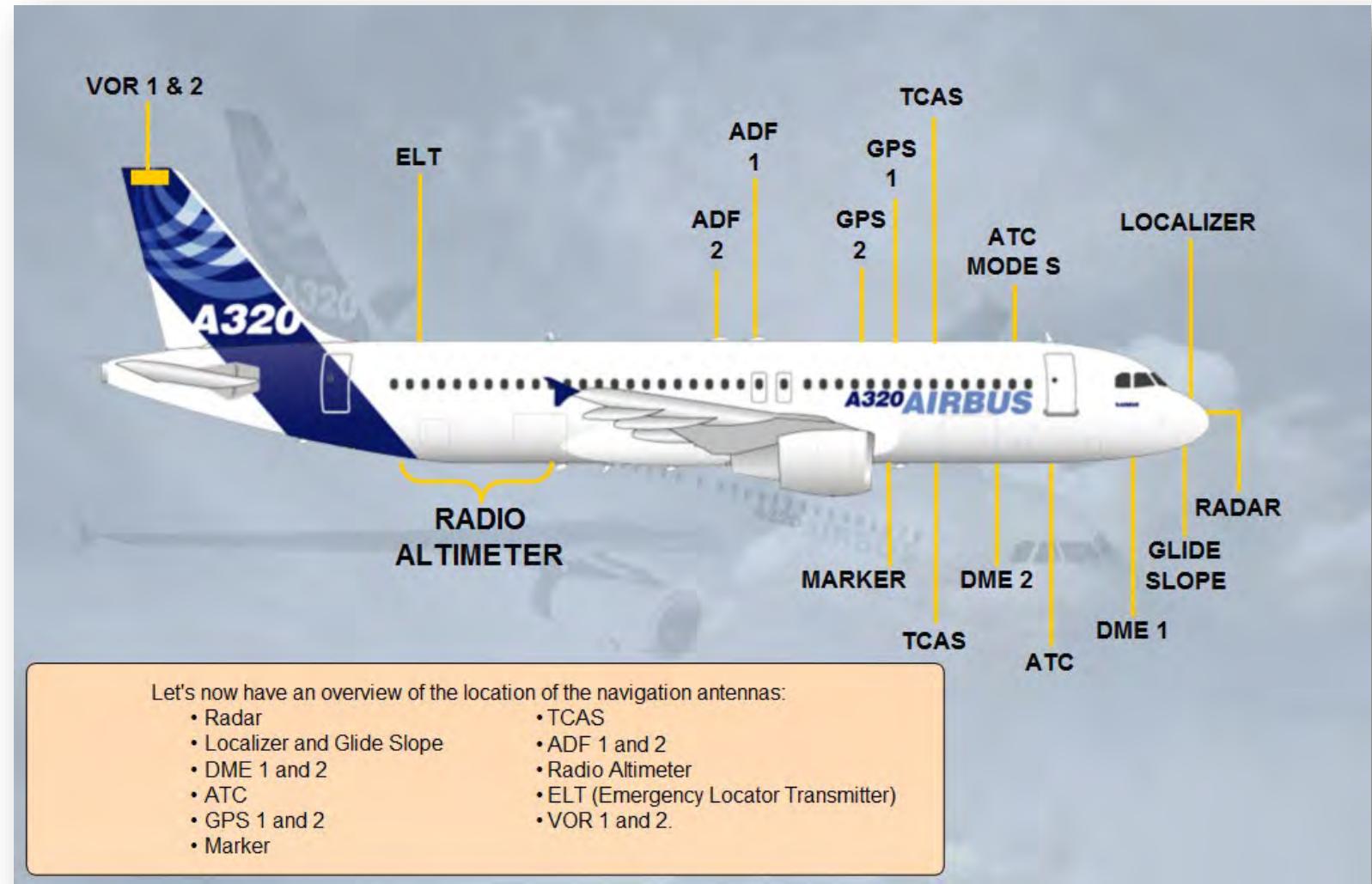
<b>Marge de freqüències</b>	De 2,8 a 22 MHz
<b>Modulació</b>	Habitualment, banda lateral única superior (USB)
<b>Tipus d'emissió</b>	J3E, A3E i H3E
<b>Audiofreqüència</b>	De 300 a 2.700 Hz
<b>Mode d'operació</b>	Semidúplex
<b>Freqüències de salvament</b>	3,023 i 5,680 MHz
<b>Cobertura</b>	Grans distàncies, depenent de la ionosfera.

Classificació Unió Internacional de Telecomunicacions	
Nom emissió	Modulació
A3E	BLU sense portadora
H3E	BLU amb portadora
J3E	AM amb portadora (DBL)

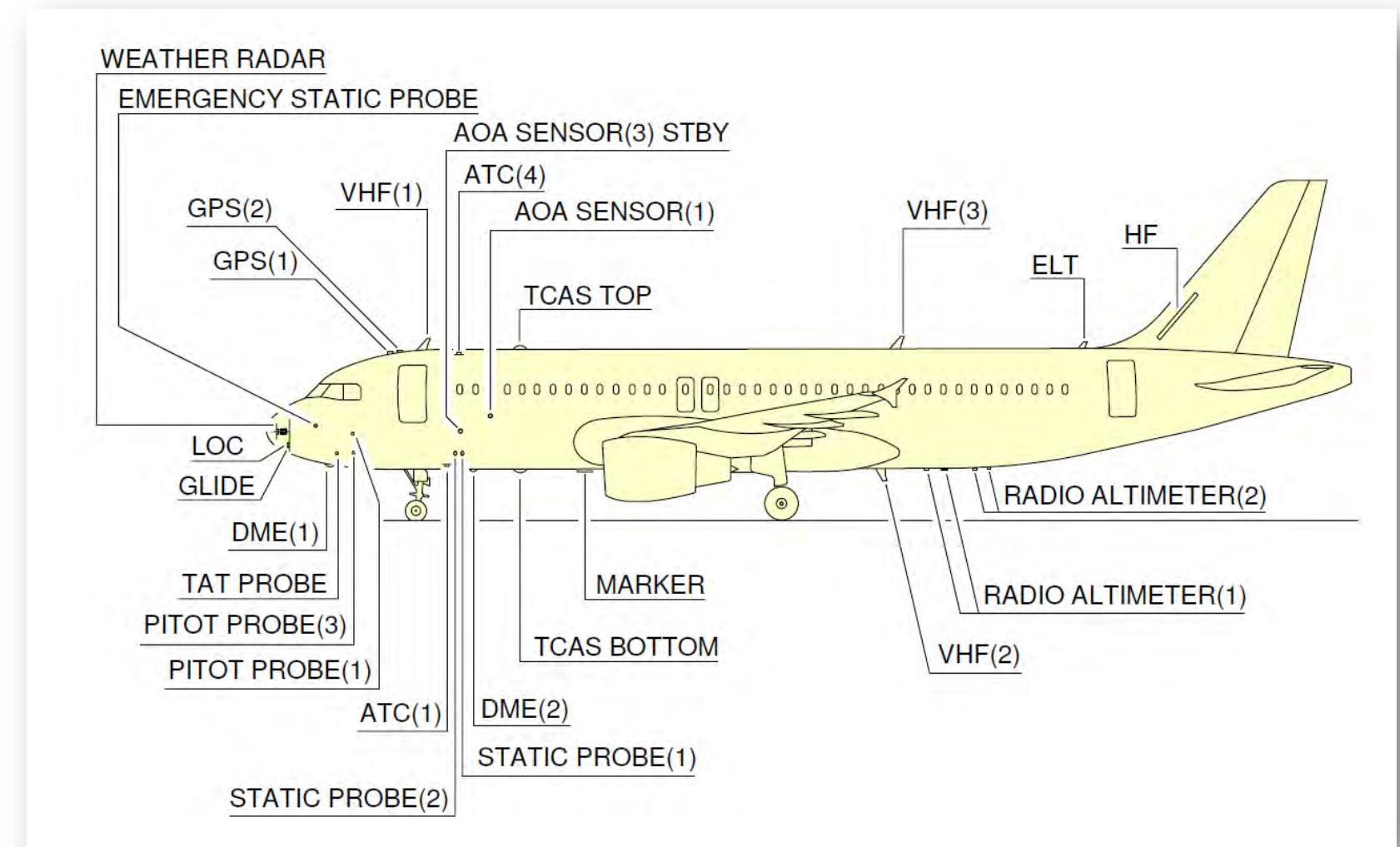
# Comunicacions en VHF

<b>Marge de freqüències</b>	De 117,975 a 136 MHz per freqüències civils i de 136 a 143 MHz per a freqüències militars
<b>Modulació</b>	AM amb índex de modulació > 0,85
<b>Tipus d'emissió</b>	J3E
<b>Audiofreqüència</b>	300 a 2.700 Hz
<b>Mode d'operació</b>	Semidúplex
<b>Freqüències de salvament</b>	121,5 MHz
<b>Cobertura</b>	Nominal 200 NM. (370 km)
<b>Canalització</b>	8,33 kHz (també 25 kHz)
<b>Densitat de potència mínima</b>	-139 dBm/m <sup>2</sup> ( $ E  = 75 \mu\text{V}/\text{m}$ )

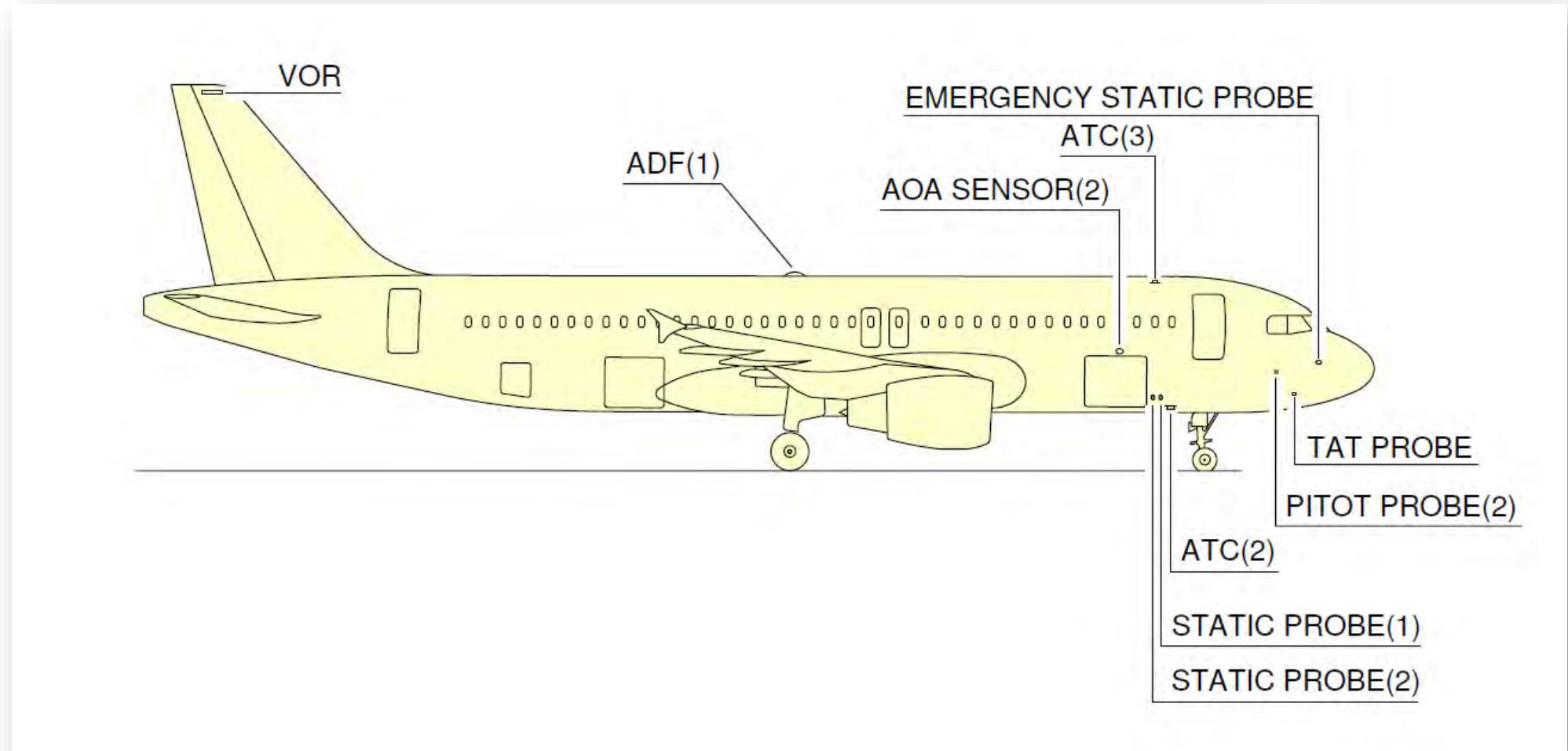
# Antenna location



# Airbus 320



# Airbus 320



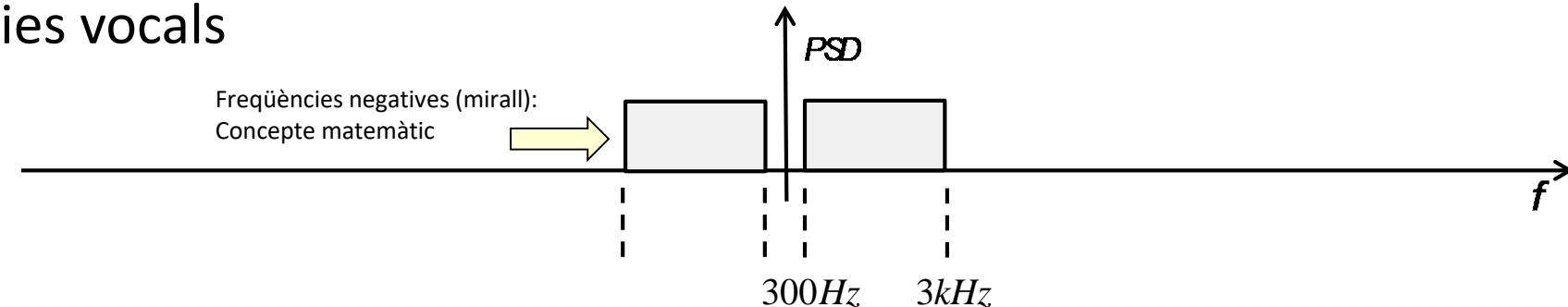
# Comunicacions Aeronàutiques en VHF

L' *Aeronautical Mobile Radiocommunication (R) Service «AM(R)S»*, utilitza DSB-AM, principalment per raons històriques, de robustesa i per simplicitat.

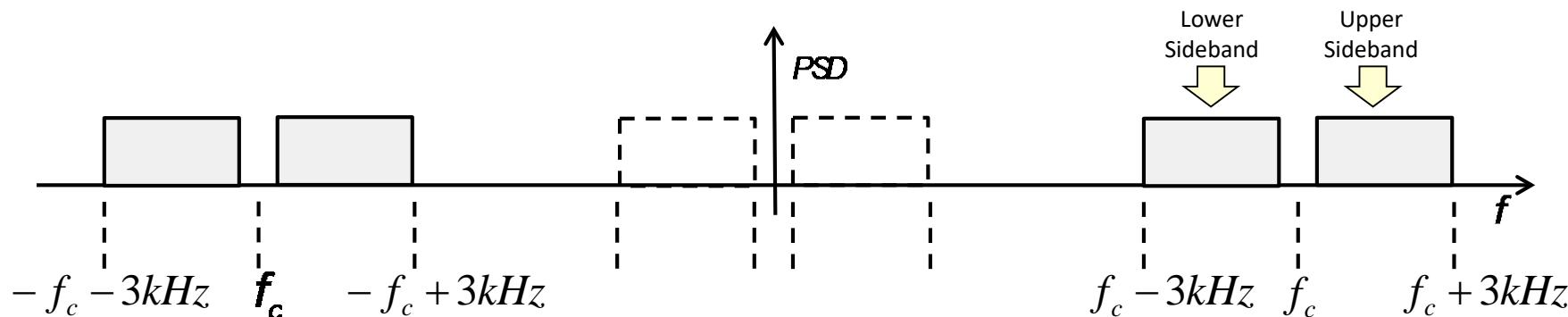
Es va posar en marxa quan el recurs d'espectre no era un bé tant preuat.

# Canalitzacions

- Freqüències vocals

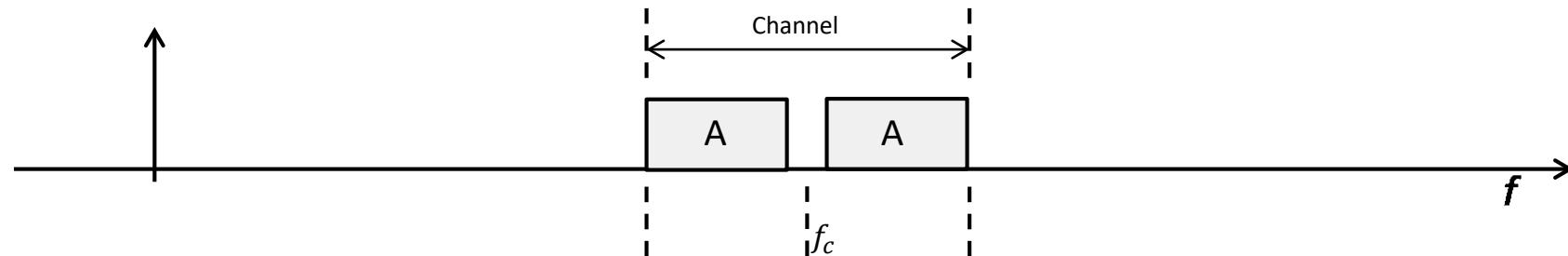


- Quan multipliquem aquest senyal en banda base per una ona sinusoidal de freqüència  $f_c$  Hz, generem una modulació en AM en la banda de VHF.

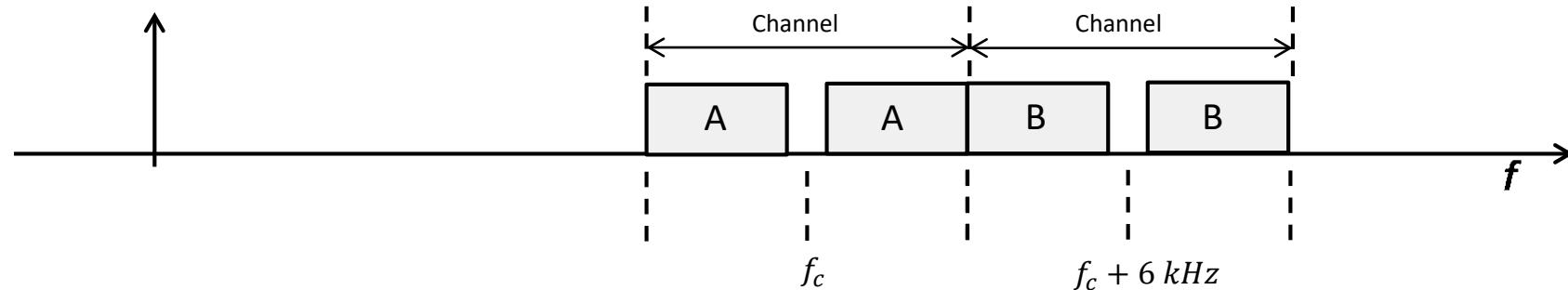


# Canalitzacions

- Let just look at the positive frequencies for voice of Pilot A:



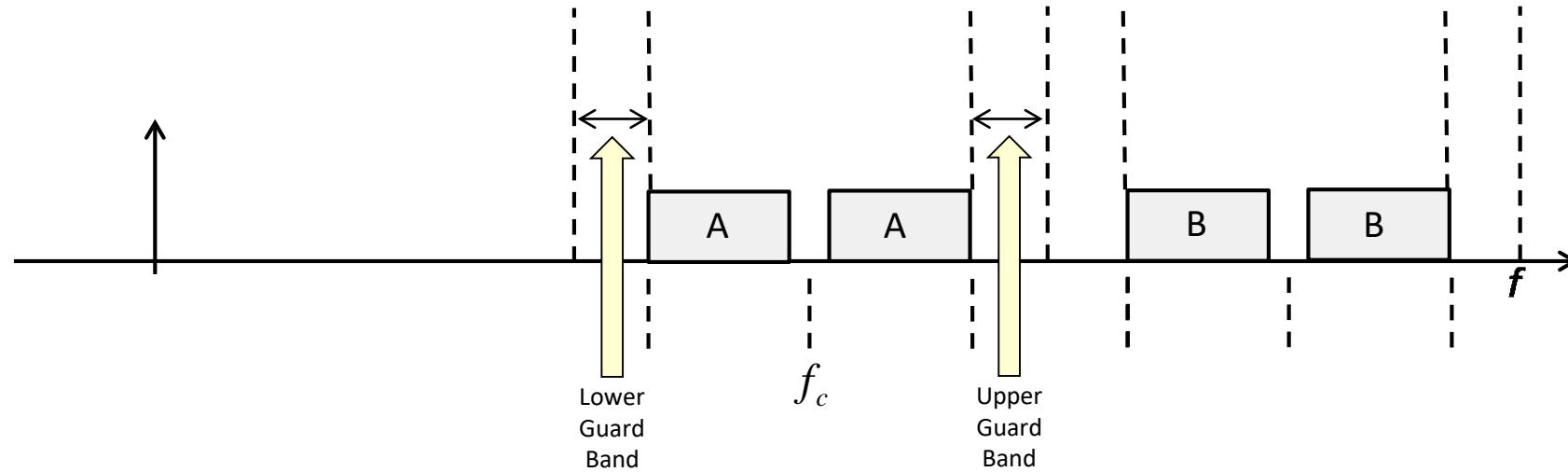
- Where would you put the another voice?



- Do you foresee any problems?

# Channels ? (cont'd)

- Instead we include some extra space in between



- Originally the channel was 25 kHz wide.
- To compensate for errors such as the oscillator error.
- For example: oscillator tolerance ( $S$ ) is 10 ppm (parts-per-million):

$$\Delta f(\text{Hz}) = f_0(\text{Hz}) \cdot S(\text{ppm}) \cdot 10^{-6} = 120 \text{ MHz} \cdot 10 \cdot 10^{-6} = 1,2 \text{ kHz}$$

# VHF Voice for Air-to-Air, Air-to-Ground

- Voice bandwidth: 300 Hz-3 kHz
- Originally: From 118 MHz-132 MHz with 200 kHz channels.
- 1958: From 118 MHz-132 MHz with 100 kHz channels.
- 1959: From 118 MHz-**136 MHz** with 100 kHz channels.
- 1964: From 118 MHz-136 MHz with **50 kHz** channels.
- 1974: From 118 MHz-136 MHz with **25 kHz** channels.
- 1979: From **118 MHz-137 MHz** with **25 kHz** channels.
- New proposed standard put the channels **8.33 kHz** apart.
- Used only in Europe right now.
  - $19 \text{ MHz}/25 \text{ kHz} = 760 \text{ channels}$
  - $19 \text{ MHz}/8,333 \text{ kHz} = 2280 \text{ channels}$
- Navaid in the VHF band: VHF Omni-Range (VOR)
  - 108 MHz-117.5 MHz

# Channels – ARINC-716 – VHF Communications

**APPENDIX 1**  
**FREQUENCY-CHANNEL PAIRING PLAN**

Frequency (MHz)	Channel Spacing (kHz)	Channel Name	Labels Transmitted	ARINC 429 Word Content
118.0000	25	118.000	030	18.000
118.0000	8.33	118.005	047	18.000
118.0083	8.33	118.010	047	18.008
118.0167	8.33	118.015	047	18.017
118.0250	25	118.025	030	18.025
118.0250	8.33	118.030	047	18.025
118.0333	8.33	118.035	047	18.033
118.0417	8.33	118.040	047	18.042
118.0500	25	118.050	030	18.050
118.0500	8.33	118.055	047	18.050
118.0583	8.33	118.060	047	18.058
118.0667	8.33	118.065	047	18.067
118.0750	25	118.075	030	18.075
118.0750	8.33	118.080	047	18.075
118.0833	8.33	118.085	047	18.083
118.0917	8.33	118.090	047	18.092
118.1000	25	118.100	030	18.100
.	.	.	.	.
.	.	.	.	.
136.9750	25	136.975	030	36.975
136.9750	8.33	136.980	047	36.975
136.9833	8.33	136.985	047	36.983
136.9917	8.33	136.990	047	36.992

# VHF Voice Communications

- ~2/3 for communication with
  - **Air Traffic Control** (ATC)
- ~1/3 for communication with
  - **Aeronautical Operations Control** (AOC)



**S65-8280-45**

**Electrical:**

Frequency.....	118 - 152 MHz
VSWR.....	≤2.5:1
Pattern.....	1/4 Wave Monopole
Polarization.....	Vertical
Impedance.....	50 Ohms
Power.....	40 Watts
Lightning Protection.....	DC Grounded

**Mechanical:**

Weight.....	2.0 lbs.
Height.....	10.03 in.
Material.....	A356 Aluminum Alloy
Connector.....	BNC Female
Finish.....	Sydrol Resistant Polyurethane Enamel
Drag.....	M.80 @ 35,000 ft. = 0.7 lbs.

**Environmental:**

Temperature.....	-53°C (-64°F) to +95°C (+203°F)
Side Load.....	12 PSI
Vibration.....	10 Gs
Altitude.....	80,000 ft.

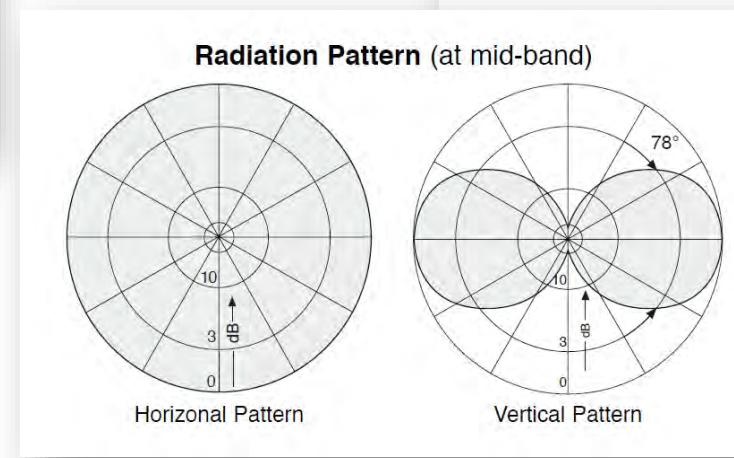
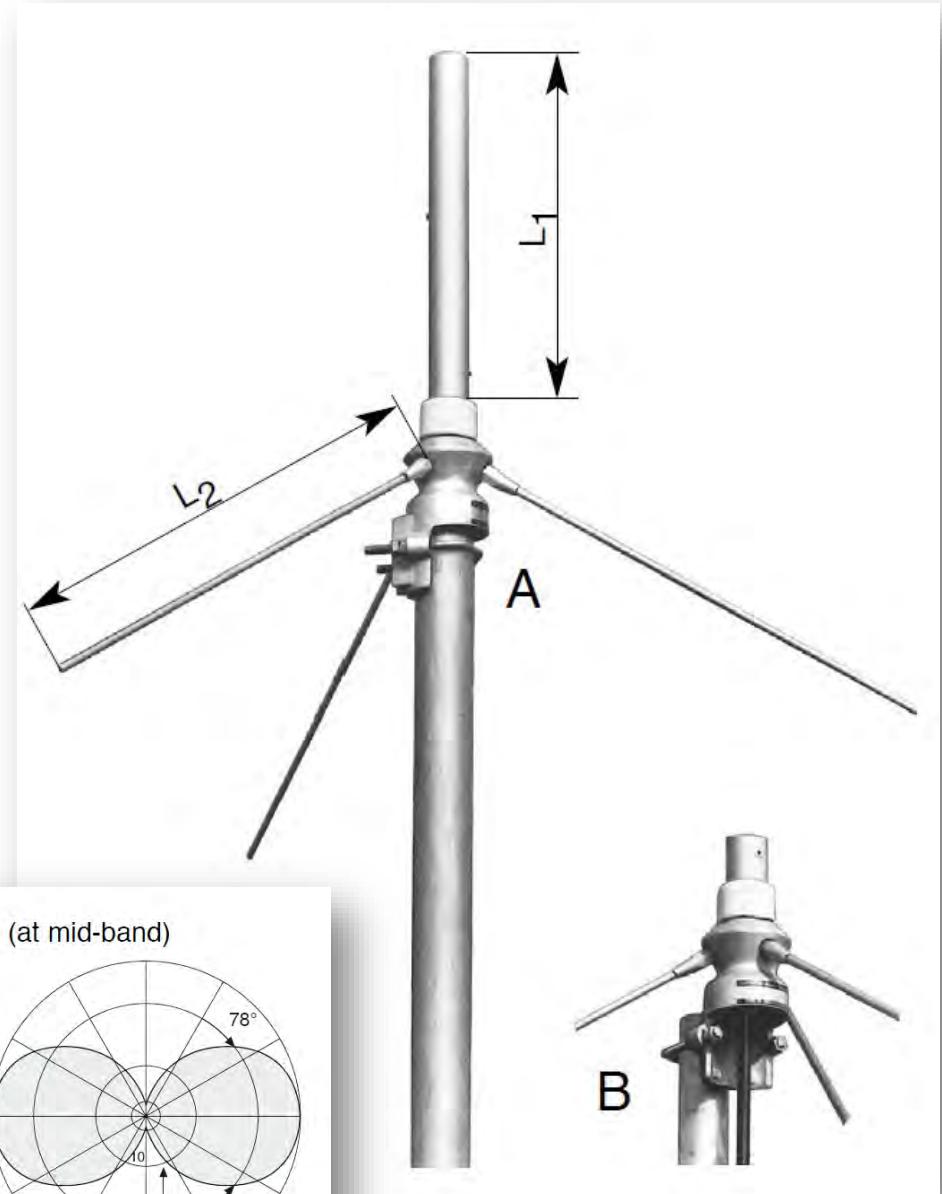
# Antenna on Aircraft



# VHF Voice Communications

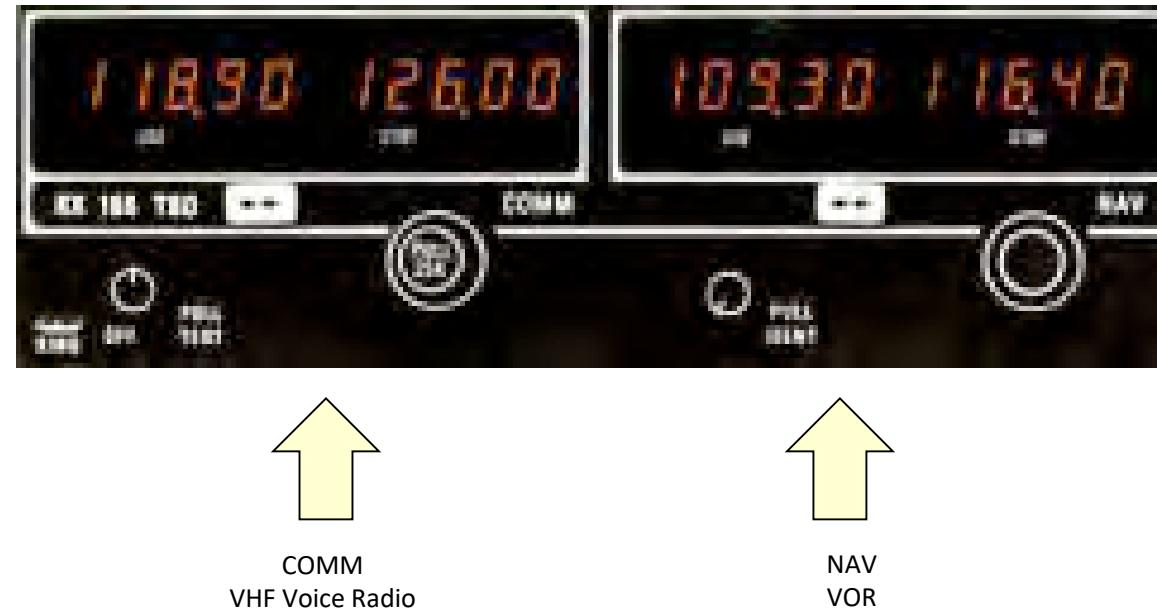
**Broadband aluminium groundplane-antenna  
with stainless steel radials**

Type No.	<b>K 51 26 31</b>
Input	N female connector in the antenna base
Connector position	Bottom
Frequency range	116 – 152 MHz
Bandwidth	36 MHz
VSWR	< 1.6 (118 – 144 MHz) < 2.0 (116 – 152 MHz)
Gain	0 dB (ref. to the half wave dipole)
Impedance	50 Ω
Polarization	Vertical
Max. power	60 W (at 50 °C ambient temperature)
Weight	1.5 kg
Wind load	50 N (at 160 km/h)
Max. wind velocity w/o ice	200 km/h
1/2" radial ice	135 km/h
Packing size	100 x 85 x 720 mm
Height	L <sub>1</sub> : 430 mm, L <sub>2</sub> : 700 mm



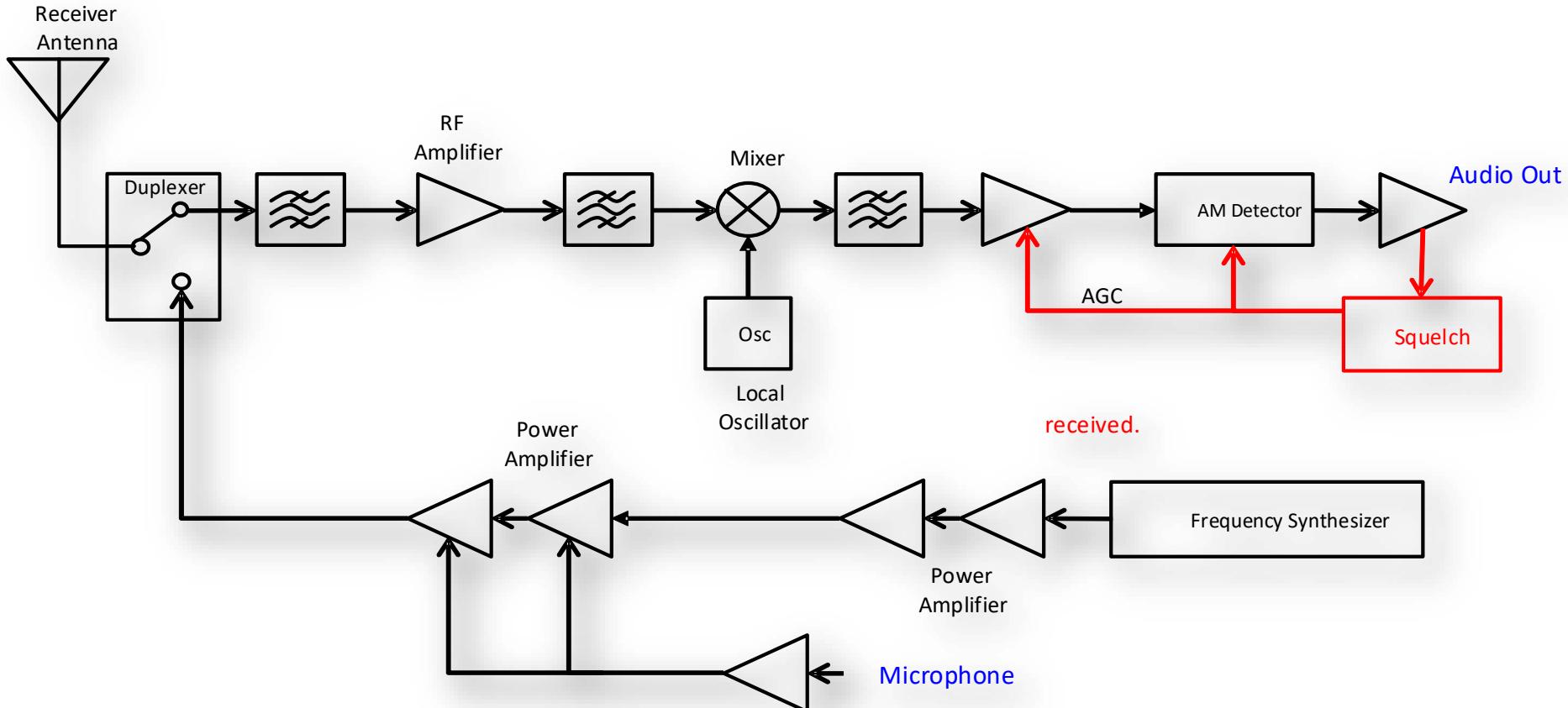
# NAVCOM

- Often the VHF Voice transceiver and the VOR navaid comes together in one box:



# Transceiver

- Combination of superheterodyne receiver and transmitter.



# Comunicacions Aeronàutiques en HF

HF COMMUNICATIONS



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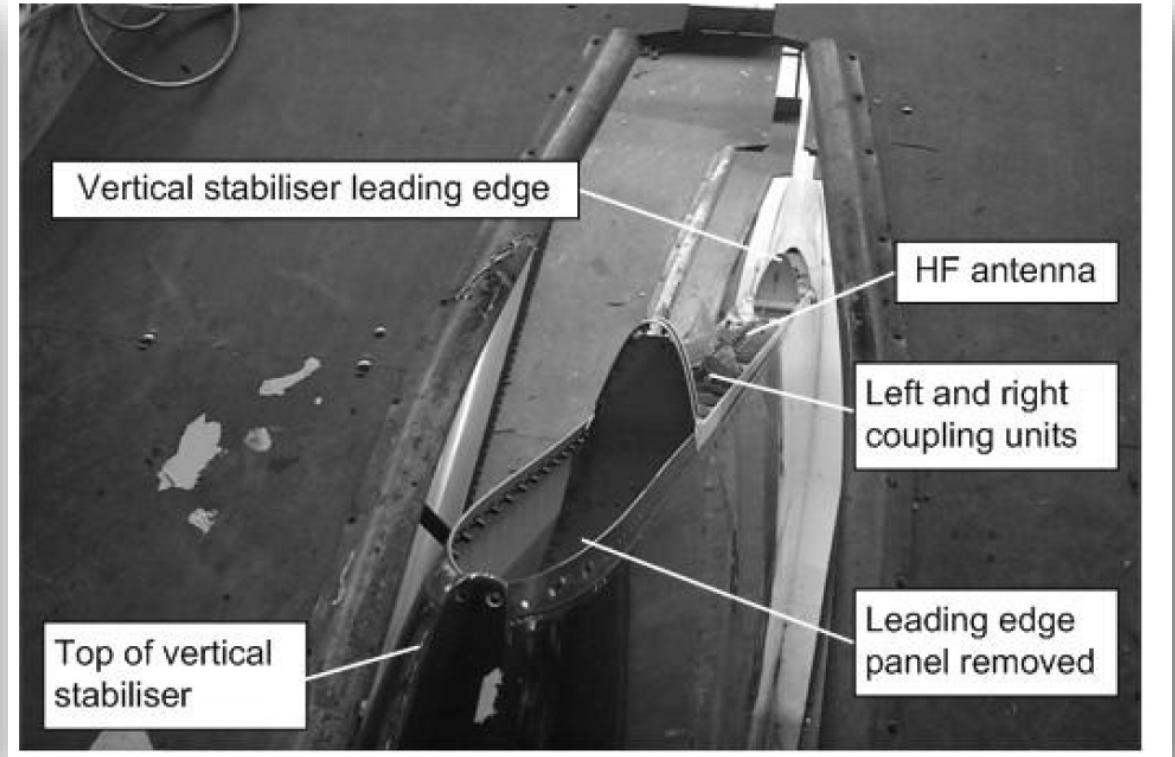
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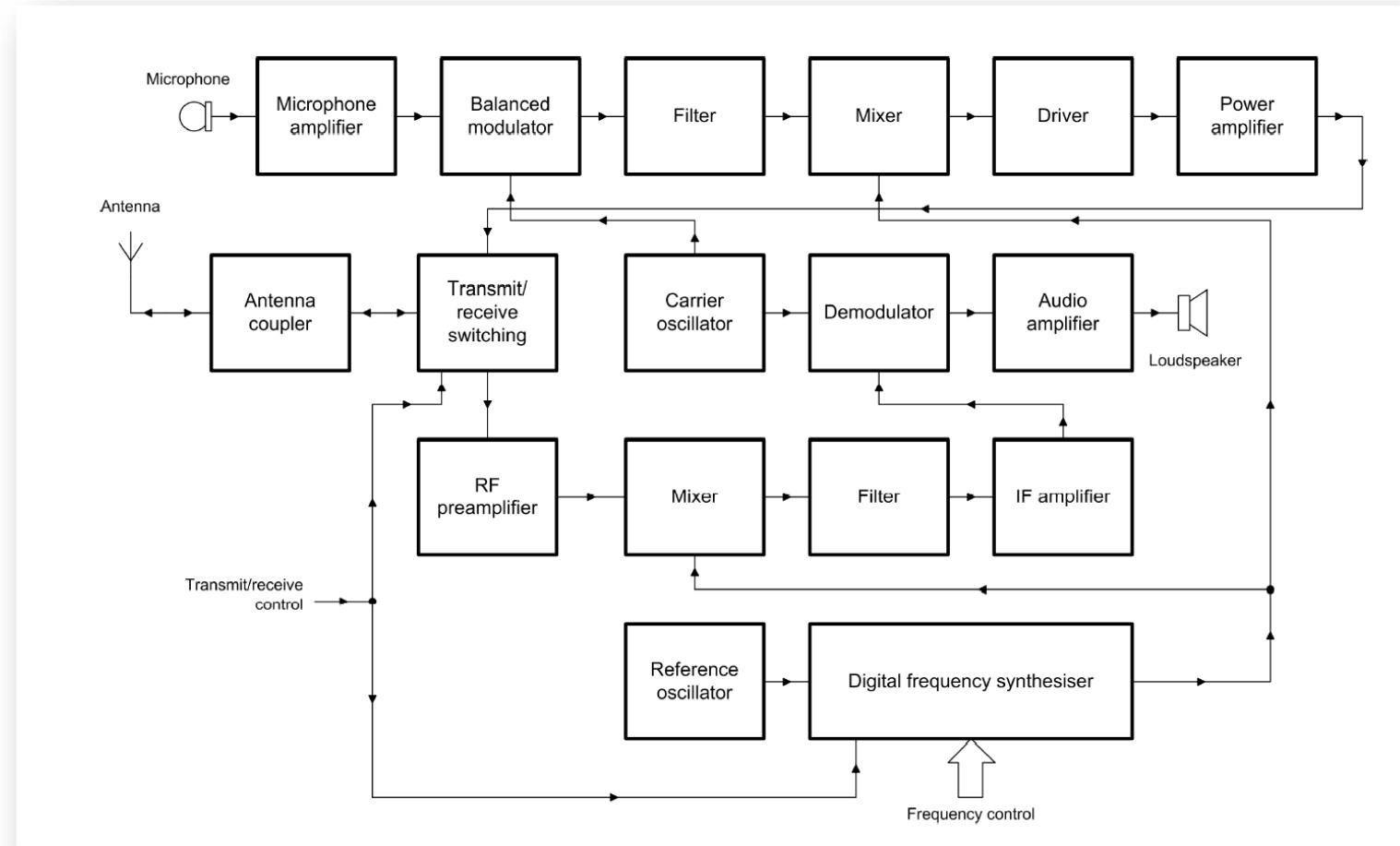
# High Frequency Communications

- For longer distances HF voice communications or SATCOM (Satellite Communications) are used.
  - Over oceans
  - Remote areas
- A typical HF transceiver cover 3MHz-29,9999MHz using 4kHz channels (200-2,4kHz voice bandwidth).
  - SSB-AM
- Remember propagation:
  - Ground wave:
    - Near the ground for short distances, up to 100 km over land and 300 km over sea. Attenuation of the wave depends on antenna height, polarization, frequency, ground types, terrain and/or sea state;
  - Direct or line-of-sight wave:
    - This wave may interact with the earth-reflected wave depending on terminal separation, frequency and polarization;
  - Sky wave: reflected by the ionosphere; all distances.

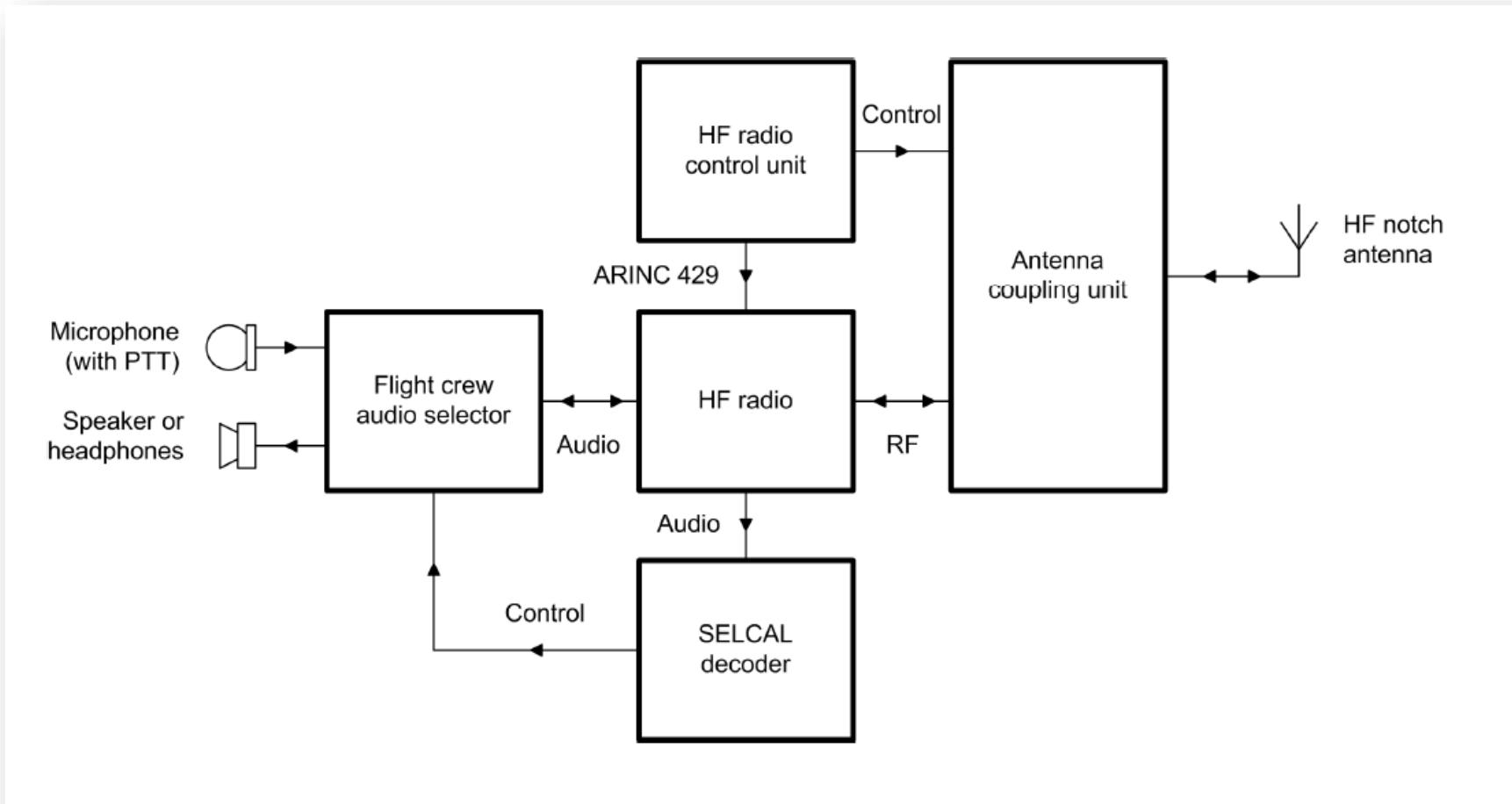
# HF antenna location



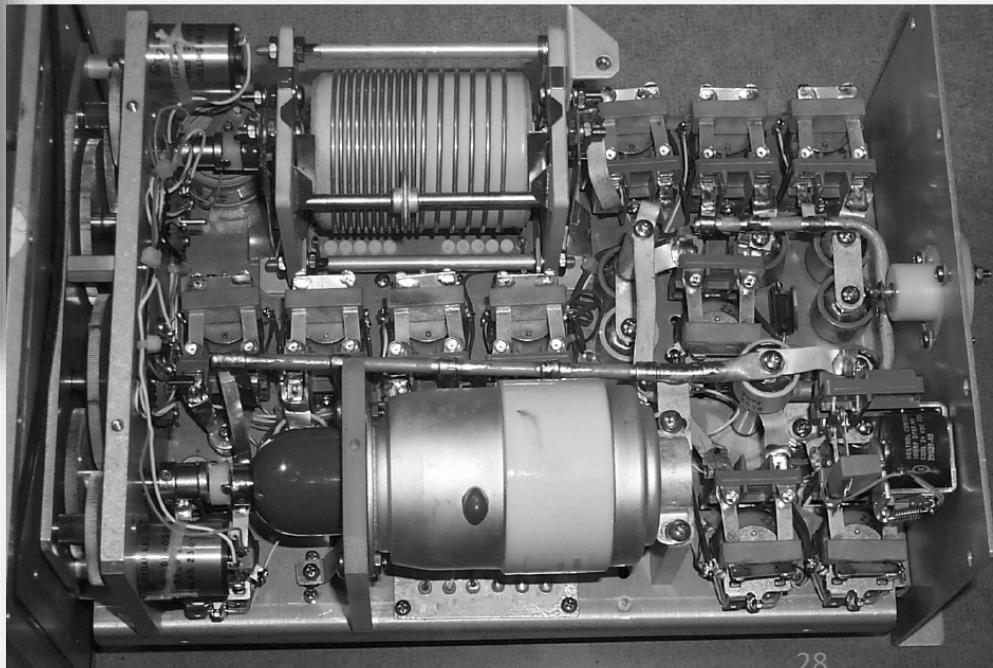
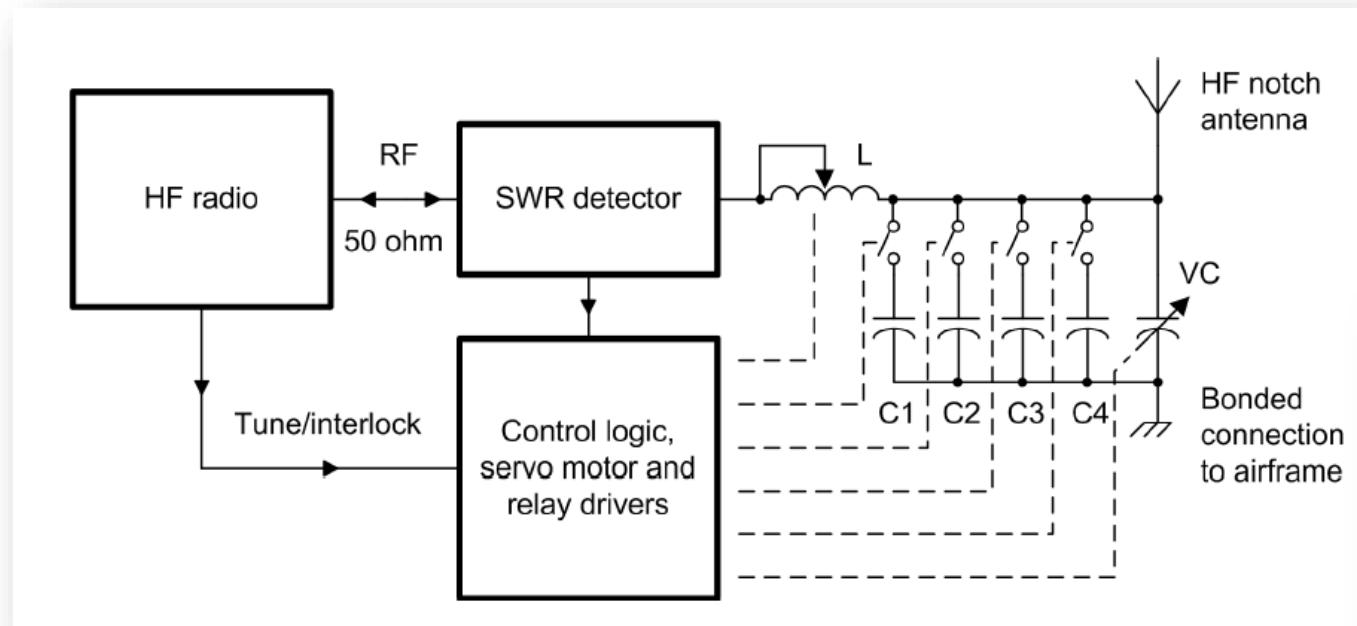
# Esquema de blocs del transmissor HF



# Sistema de connexions antena-transmissor HF

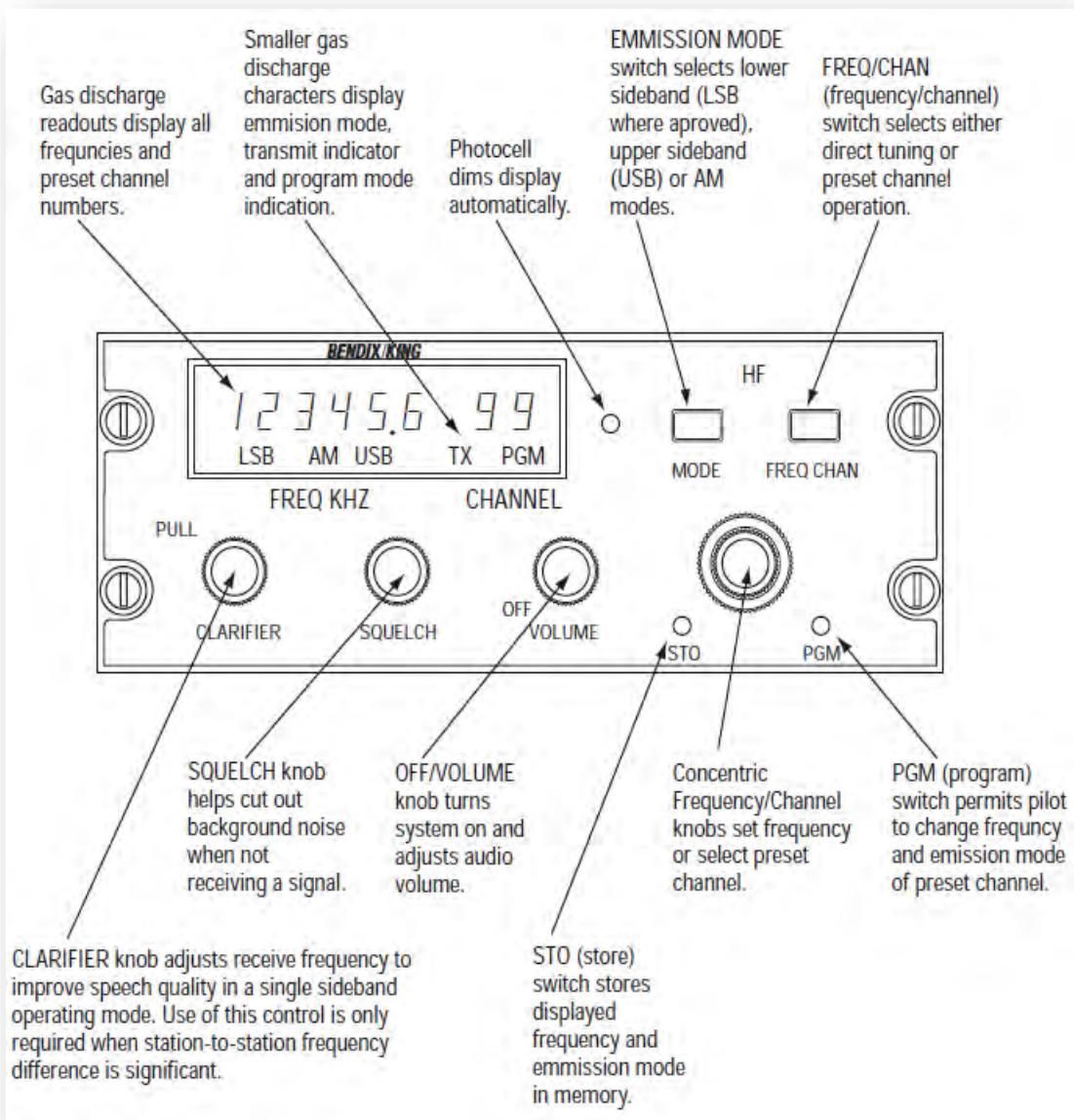


# Sistema automàtic d'adaptació d'impedància d'antena HF



# Especificacions típiques d'un transmissor HF

<i>Parameter</i>	<i>Specification</i>
Frequency range	2.0000 MHz to 29.9999 MHz
Tuning steps	100 Hz
Operating modes	SSB SC analogue voice (ARINC 719) and analogue data (ARINC 753 and ARINC 635) at up to 1800 bps; DSB AM (full carrier)
Sensitivity	1 µV for 10 dB (S+N)/N SSB; 4 µV for 10 dB (S+N)/N AM
Selectivity	6 dB max. attenuation at +2.5 kHz 60 dB min. attenuation at +3.4 kHz
Audio output	50 mW into 600 Ω
SELCAL output	50 mW into 600 Ω
RF output power	200 W pep min. SSB; 50 W min. DSB AM
Frequency stability	±20 Hz
Audio response	350 Hz to 2500 Hz at -6 dB
Mean time between failure	Greater than 50,000 hours

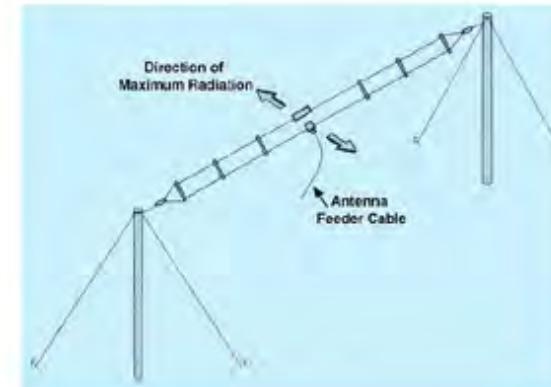


# Estació terrestre HF

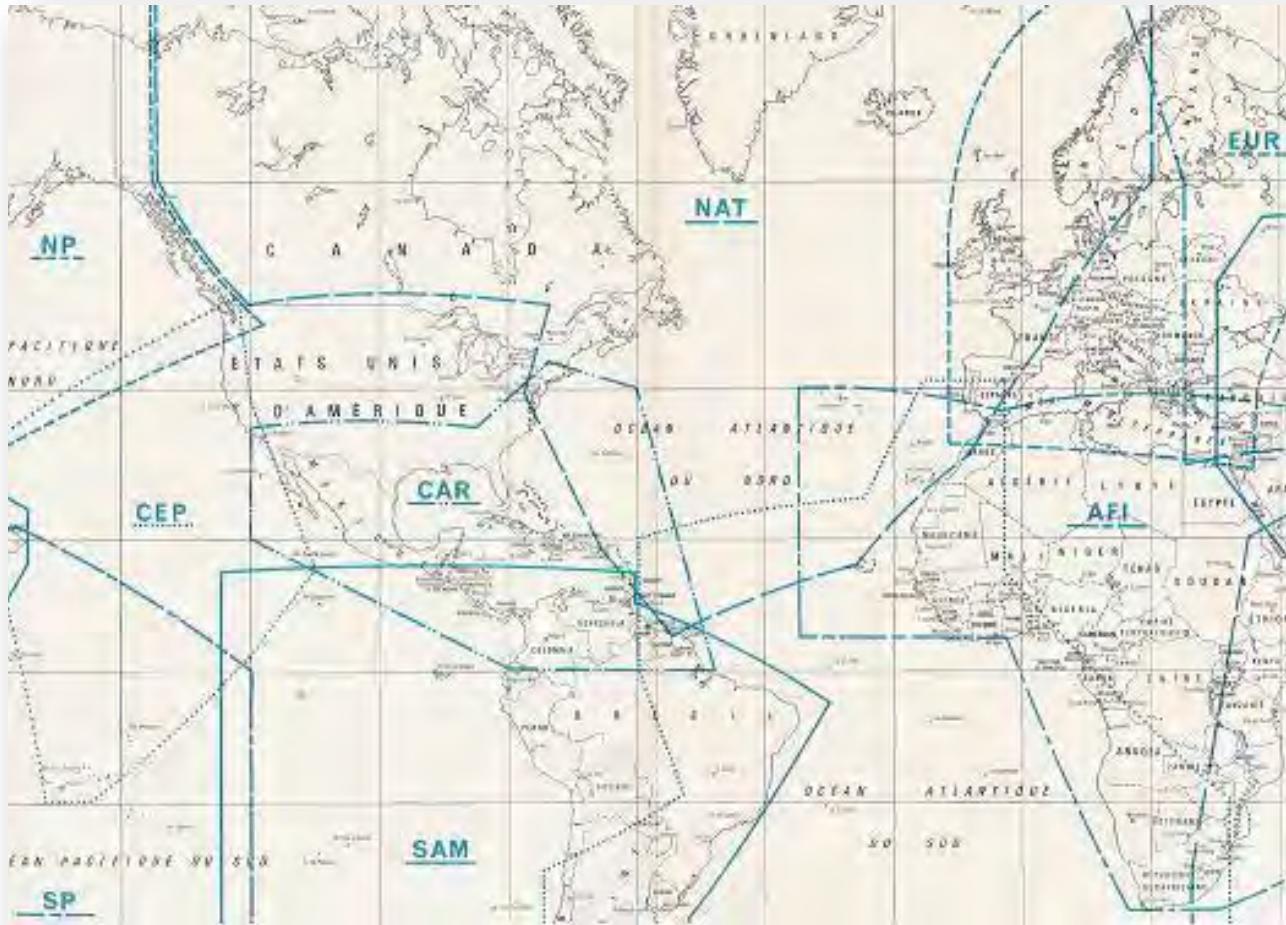
ELECTRICAL DATA		MECHANICAL DATA	
Frequency Range (MHz.)	3 - 30	Weight (Kgs)	4
Gain (dBi.)	Unity	Wind Rating (KMPH)	150
Bandwidth (MHz.)	27	Overall Length (Meters)	23
Polarization	Horizontal or Inverted	Dipole Material	Twisted Copper with Insulator
Input Impedance (Ohms.)	50	Spreaders Material	upVC
VSWR	1:1.5 or Better	Insulator Material	Nylon
RF Power Handling Capacity (Watts)	100	Recommended Mast Height	15 Meters (50 Feet)
Input Termination	N-Female	Distance between Mast	27 Meters
Lightning Protection	Direct Ground	Operating Temperature	(-)20 to +50 Degree Celcius
		Storage Temperature	(-)30 to +60 Degree Celcius
		Humidity	0 to 95% RH

## HF BROADBAND TWO FOLDED DIPOLE ANTENNA

SXO-100(2)                    3 - 30 MHz                    Unity Gain



# Major World Air Route Area – North Atlantic (MWARA - NAT)

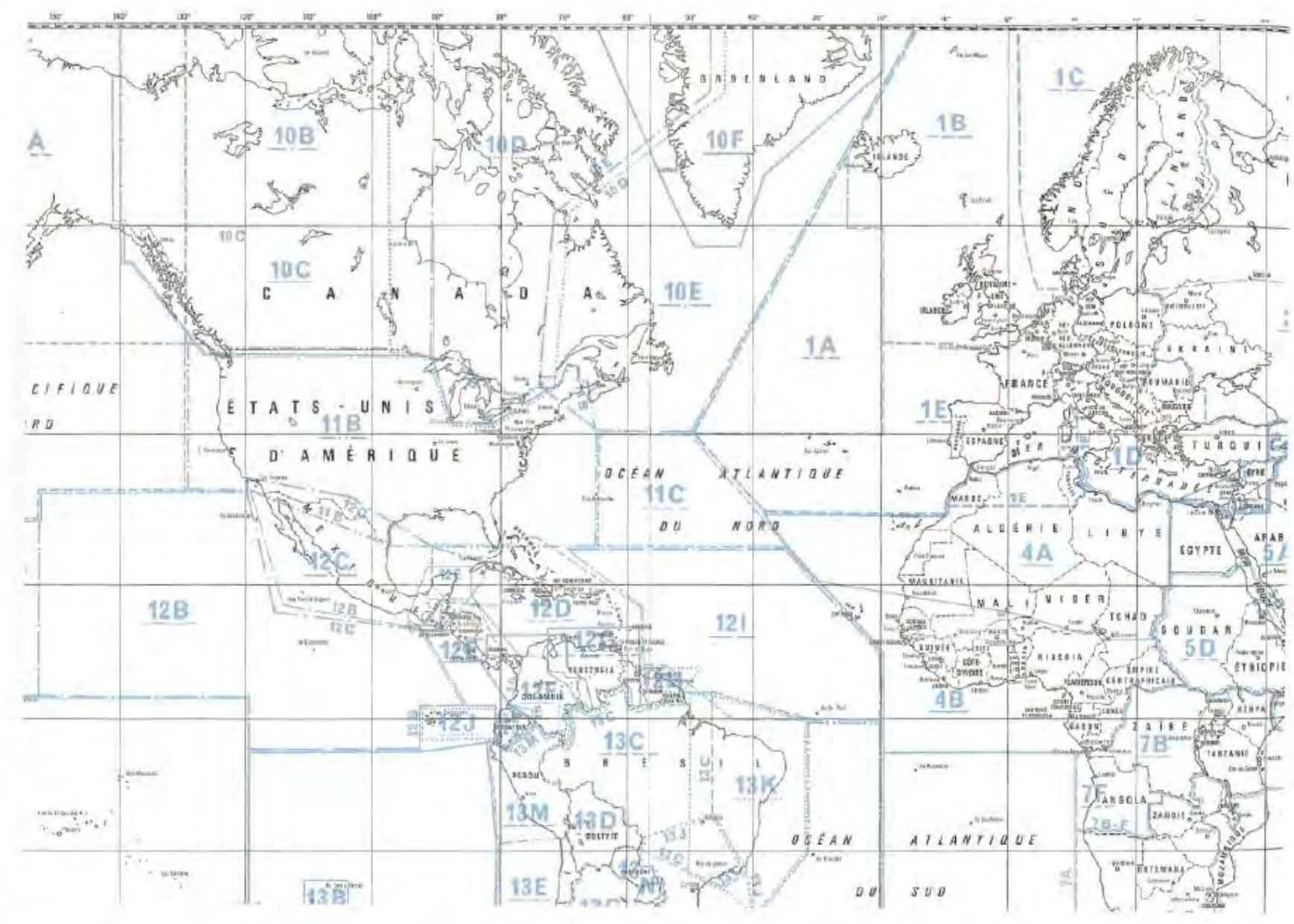


The MWARA - NAT is an area defined as the area from the North Pole through the points 60N135W, 49N120W, 49N074W, 39N078W, 18N066W, 05N055W, 16N026W, 32N008W, 44N002E, 60N020E, to the North Pole, and can be viewed on Figure 3 (Ref. ITU Appendix 27 Aer2).

# ATS COMMUNICATIONS in the NAT Region

- Routine air/ground ATS Voice communications in the NAT Region are conducted via aeradio stations. Messages are relayed by the ground station to/from the air traffic controllers in the relevant OAC. This is the case, whether **communications are via HF, GP/VHF or SATCOM Voice**.
- In the North Atlantic Region there are **six aeronautical radio stations**, one associated with each of the Oceanic Control Areas.
  - *Bodø Radio (Norway, Bodø ACC)*
  - *Gander Radio (Canada, Gander OACC)*
  - *Iceland Radio (Iceland, Reykjavik ACC)*
  - *New York Radio (USA, New York OACC)*
  - *Santa Maria Radio (Portugal, Santa Maria OACC)*
  - *Shanwick Radio (Ireland, Shanwick OACC)*.
- In addition there are **two other stations** that operate NAT frequencies:
  - *Canarias Radio which serves Canarias ACC*
  - *Arctic Radio serving Edmonton, Winnipeg and Montreal ACC's.*

# Regional and domestic Air Route Area – North Atlantic (RDARA - NAT)



# NAT - HF Voice Communications

- A significant volume of NAT air/ground communications are conducted using voice on SSB HF frequencies supported by twenty-four HF frequencies allocated in bands ranging from 2,8 to 18 MHz.
- The factors which affect the optimum frequency for communications over a specific path are the diurnal variation in intensity of the ionisation of the refractive layers of the ionosphere:
  - Frequencies from the lower HF bands tend to be used for communications during night-time. ( $f < 7 \text{ MHz}$ )
  - Frequencies from the higher bands during day-time. ( $f > 8 \text{ MHz}$ )
- The 24 NAT frequencies are organized into six groups known as Families identified as NAT Family A, B, C, D, E and F.
- Each Family contains a range of frequencies from each of the HF frequency bands.
- A number of stations share families of frequencies and co-operate as a network to provide the required geographical and time of day coverage.
- A full listing of the frequency hours of operation of each NAT aeradio station is contained in the “HF Management Guidance Material for the North Atlantic Region” (NAT Doc 003) (Appendices C- 1 thru 6), available at [www.icao.int/EURNAT/](http://www.icao.int/EURNAT/), following “EUR & NAT Documents”, then “NAT Documents”, in folder “NAT Doc 003”.
- Each individual aircraft is normally allocated a primary and a secondary HF frequency, either when it receives its clearance or by domestic controllers shortly before the oceanic boundary.

# Shanwick Radio (Ireland)

*Transmitter at Urlanmore (52°45'N 008°56'W)*



# SELCAL

Selective calling



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# Selective Calling (SELCAL)

- SELCAL
  - Permits selective calling of individual aircraft over the aeronautical mobile voice channels.
- It operates on high frequency (HF) or very high frequency (VHF) channels
- Objective:
  - Relieve flight crews from the need to continuously maintain a listening watch on their assigned radio channels.
- Benefits include:
  - Reduced flight crew workload and cockpit noise both of which can have a negative effect on human performance.

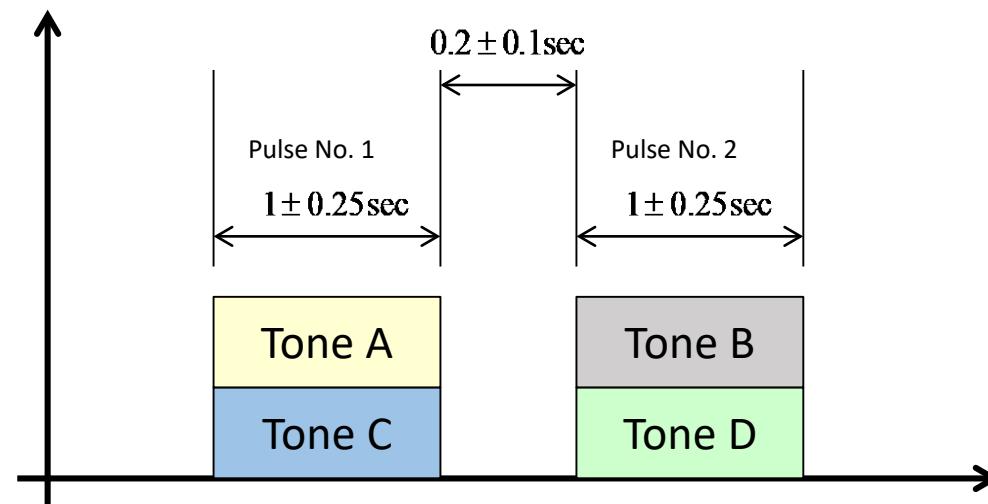
# Selective Calling (SELCAL)

- Each aircraft has its own unique four letter SELCAL code;
- When the ground needs to contact a specific aircraft the ground transmitter encodes the aircraft's unique code by four tones (on the audio output) corresponding to the four letters as follows:

- 1) The letters within a given pair are written or transmitted in alphabetical order;
- 2) Letters may not be repeated;

Example:

Transmit the code AC-BD



# Selective Calling (SELCAL)

DESIGNATION	FREQUENCY (Hz)	DESIGNATION	FREQUENCY (Hz)
Red A	312.6	Red J	716.1
Red B	346.7	Red K	794.3
Red C	384.6	Red L	881.0
Red D	426.6	Red M	977.2
Red E	473.2	Red P	1083.9
Red F	524.8	Red Q	1202.3
Red G	582.1	Red R	1333.5
Red H	645.7	Red S	1479.1

Table: 2-1 SELCAL Tones

From [3]

Note: ratio between frequencies is 1,10917



# Selective Calling (SELCAL)

- On the receiving end:
  - All aircraft receive the four tones as transmitted by the ground;
  - Only the aircraft that is being addressed (the received code equals the aircraft's unique code) will enable communication, all others are “silenced”.
- Error-free SELCAL operation on HF has been harder to achieve due to frequency translation from errors in the virtual carrier frequency of the transceiver.
- Older aircraft use only 12 possible tones.
- Codes assigned by Aviation Spectrum Resources, Inc.
  - They are the so-called world-wide registrar for the codes.

# ACARS

Aircraft Communications and Reporting System



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# Data Communication - ACARS

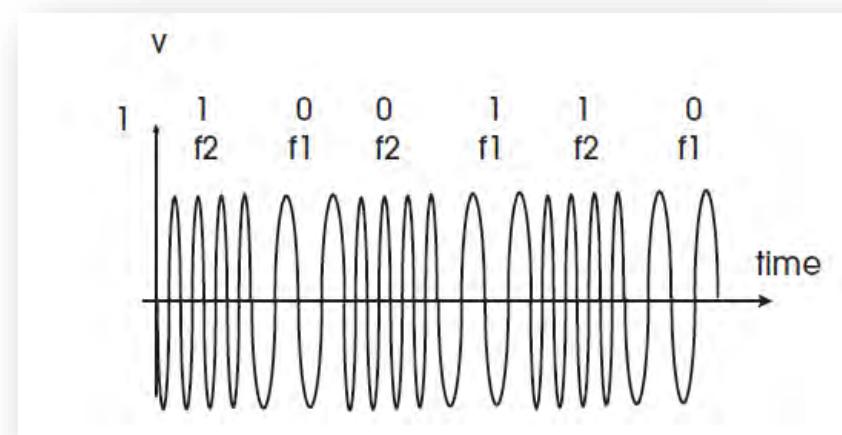
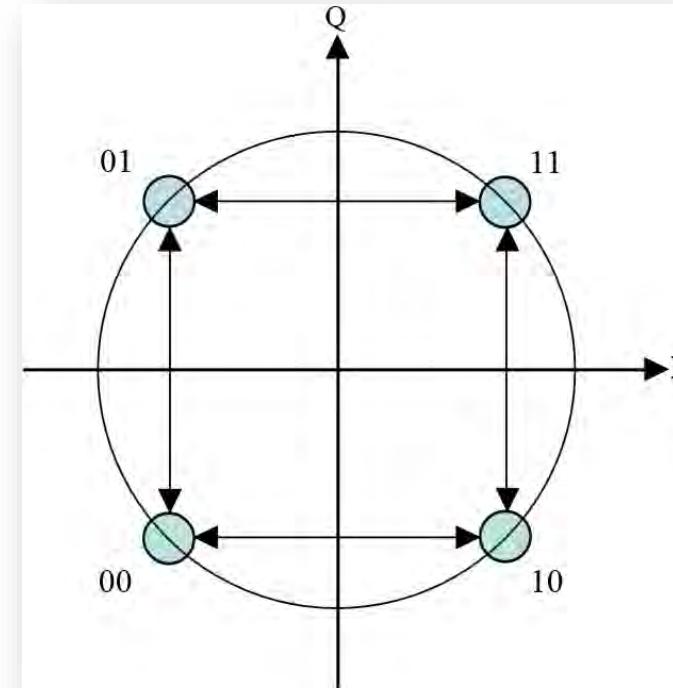
- Aircraft Communications and Reporting System (ACARS)
- For **transmission of data** not voice.
- Character-oriented
  - Send 7-bit characters
  - Maximum message of 220 characters
- Modulation on VHF band:
  - 2400 bps (bits-per-second) over AM (amplitude modulation) using **MSK (Minimum Shift Keying)** in the 25 kHz channels.
- Many messages are generated automatically based on discrete events:
  - i.e. Doors closed and parking brake released;
  - i.e. Weight-on-wheels sensor transition from no weight to weight.
- ACARS Management Unit (MU) and a Control Display Unit (CDU)

# MODULACIÓ MSK

Modulació equivalent a una FSK de fase continua.

$$s(t) = \cos \left[ 2\pi f_c t + b_k(t) \frac{\pi t}{2T} + \phi_k \right]$$

$b_k$	$\phi$	X1	X2
+1	0	0	0
-1	0	0	1
-1	$\pi$	1	0
+1	$\pi$	1	1



# Data Communication - ACARS

- Originally, for private (= not directly related to Air Traffic Control) communications between aircraft and the Airline Operational Centers (AOC) (ground stations) for organizational matters:
  - OOOI (Out of the gate, Off the ground, On the ground, and Into the gate messages): Pushback from gate, wheels off, wheels on, arrival time at the gate, number of passengers, wheel chairs required, etc.
- Last decades it has been extended to include Air Traffic Control (ATC) data:
  - For example for in-flight weather updates (METAR)

*OOOI: Out, Off, On, In. The collective term for the four phases of an aircraft's flight: Out (leaving the gate), Off (takeoff), On (touchdown), and In (arriving at the gate). ACARS messages are sent at the start of each of those phases, providing the aircraft movement information and other data to operations center computers.*



000I

## Automatically Generated Report Example

## ◆ QG - OUT/RETURN IN REPORT

.N330AA QG  
3115AA001SFO05070516

Tail Number N330AA  
Message Type QG

Return Back To Gate 0516  
Out From Gate 0507  
Origin San Francisco  
Flight Number American #1  
Message Sequence 3115  
in min. and sec. past the hour.



# ARINC Standards

- ARINC 618:
  - Defines the air / ground protocols for communicating between the ACARS / CMU and VHF ground systems.
  - Defines the format of the ACARS messages sent by the ACARS / CMU as well as received by the ACARS CMU.
- ARINC 620:
  - Defines ground-to-ground communication protocols.
  - Defines the message format of messages routed between a service provider and an airline or other ground system.
- And various other ARINC standards do apply.

# ACARS – Communication Networks

- Very High Frequency (VHF):
  - Using a network of VHF ground radio stations;
  - Uses audio frequency shift keying, FSK (MSK);
  - Domestic flights.
  - Data service providers: ARINC (GLOBALink) and SITA
- SATCOM:
  - Using INMARSAT communication satellites;
  - Provides worldwide coverage, with the exception of operation at the high latitudes;
  - Problem when you fly over the poles.
- High Frequency (HF):
  - Using a network of HF ground radio stations;
  - Works for polar routes;
  - ARINC is the only service provider here.

# FREQUÈNCIES ASSIGNADES AL SISTEMA ACARS

Table 3.12 ACARS channel allotments (worldwide).

Frequency (MHz)	ARINC	SITA
129.125	United States and Canada	
130.025	United States and Canada secondary	
130.425	United States	
130.450	United States and Canada additional	
131.125	United States additional	
131.450	Japan primary channel	
131.475	Air Canada company channel	
131.525		From Sept 2004 in Europe secondary
131.550	Worldwide channel	
131.725	Primary channel in Europe	From Sept 2004 in Europe
131.825	<i>From Sept 2004 main ARINC in Europe</i>	
131.850		New European channel
136.700	United States additional	
136.750	United States additional	<i>From Sept 2004 main SITA in Europe</i>
136.800	United States additional	
136.900		Was ACARS vacated for VDL2
136.925	Was ACARS vacated for VDL2	

# VDL

VHF Data Link



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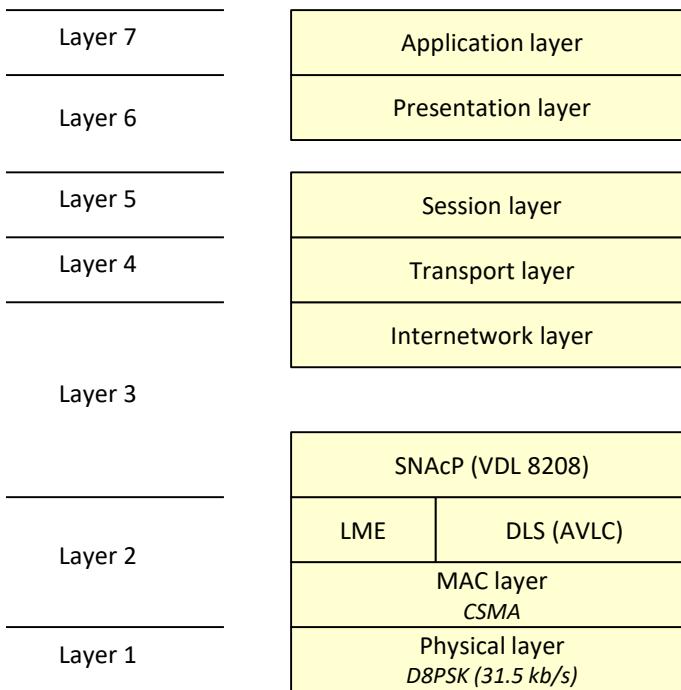
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# VHF Data Link (VDL)

- VDL Mode 2:
  - Designed to replace ACARS; ~10 times the bandwidth of VHF ACARS;
  - Is currently being used in a large amount of aircraft for CPDLC applications in both Europe and the US.
  - Supports connectivity to ATN (Aeronautical Telecommunications Network).

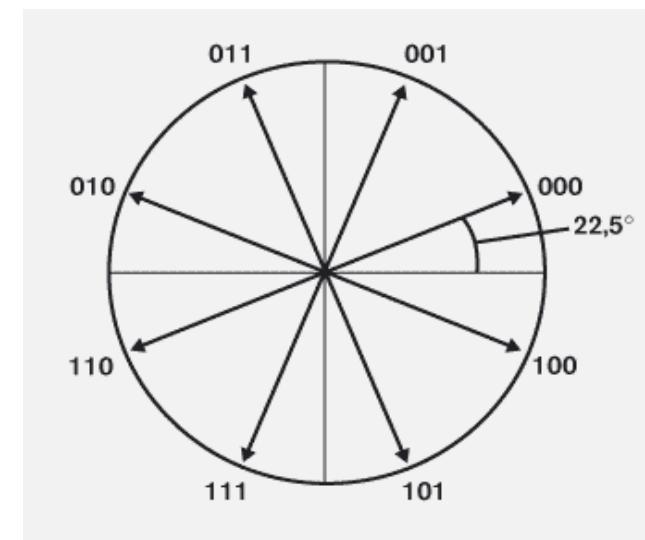
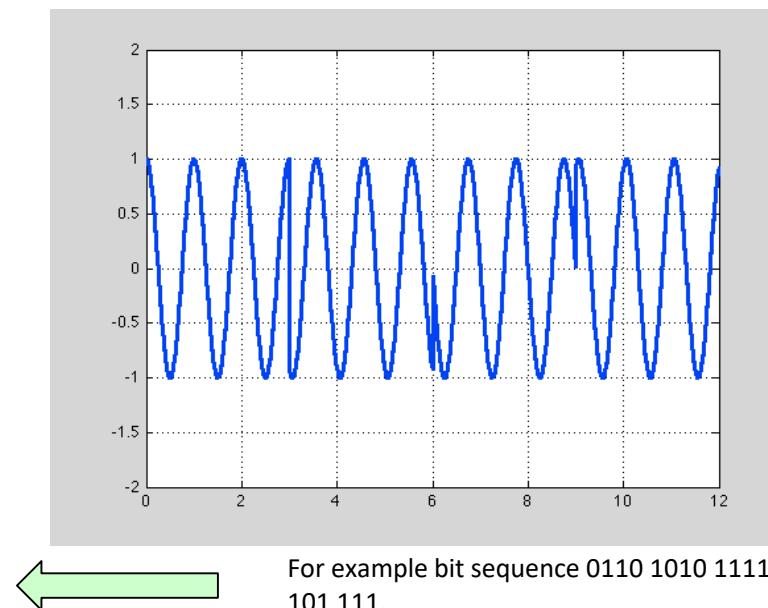
Mode 1	Mode 2	Mode 3	Mode 4
<ul style="list-style-type: none"> <li>• Carrier Sense Multiple Access (CSMA)</li> <li>• Amplitude Modulated Shift Keying (AM-MSK)</li> <li>• 2,400 bits per second</li> <li>• Connection-oriented</li> <li>• Lacks support for priority</li> <li>• Will not be implemented</li> </ul>	<ul style="list-style-type: none"> <li>• Carrier Sense Multiple Access (CSMA)</li> <li>• Differential 8 Phase Shift Keying (D8PSK)</li> <li>• 31,500 bits per second</li> <li>• Connection-oriented</li> <li>• Lacks support for priority</li> </ul>	<ul style="list-style-type: none"> <li>• Time Division Multiple Access (TDMA)</li> <li>• Differential 8 Phase Shift Keying (D8PSK)</li> <li>• 31,500 bits per second</li> <li>• Acknowledged connection-less</li> <li>• Supports Priority (4 levels)</li> </ul>	<ul style="list-style-type: none"> <li>• Self-Organizing TDMA (STDMA)</li> <li>• Gaussian-Filtered Frequency Shift Keying (GFSK)</li> <li>• 19,200 bits per second</li> <li>• Connection-oriented</li> <li>• Built-in support for ADS-B</li> </ul>

# VDL Mode 2 – Protocol Stack



Differential 8-phase modulation at a symbol rate of 10.5 kBauds or 31.5 kbps (eight phase states yield 3-bit symbols).

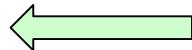
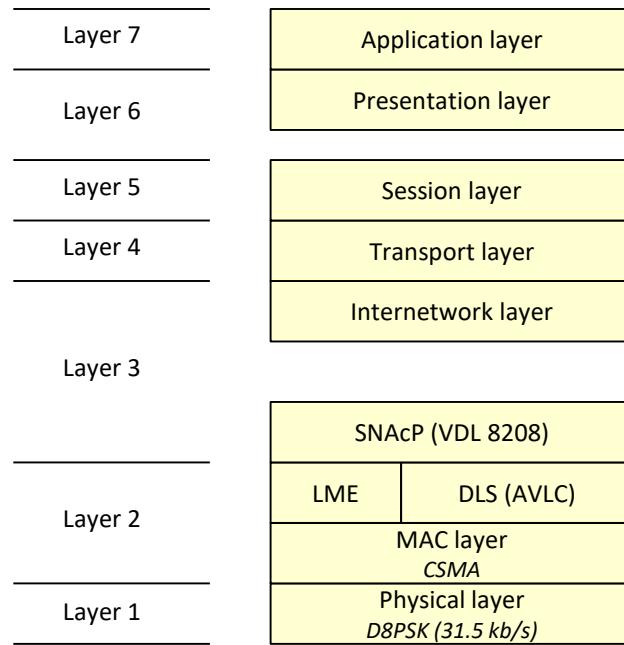
In Europe a common signaling frequency has been allocated to VDL-M2, 136,975 MHz on which all stations must transmit their identification messages.



For example bit sequence 0110 1010 1111 turns into four 3-bit symbols 011 010 101 111.

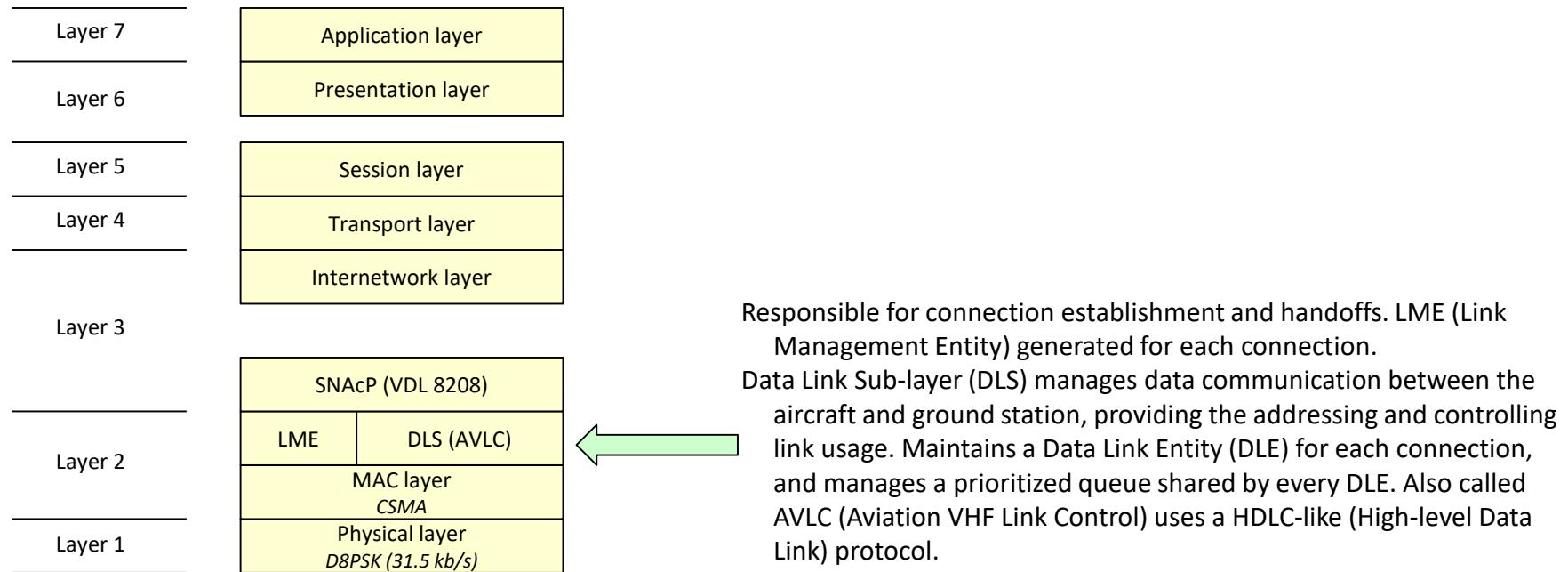
011 => 010: *change* the phase by  $157.5^\circ$  at the bit interval  
 010 => 101: *change* the phase by  $292.5^\circ$  at the bit interval  
 101 => 111: *change* the phase by  $247.5^\circ$  at the bit interval

# VDL Mode 2 – Protocol Stack

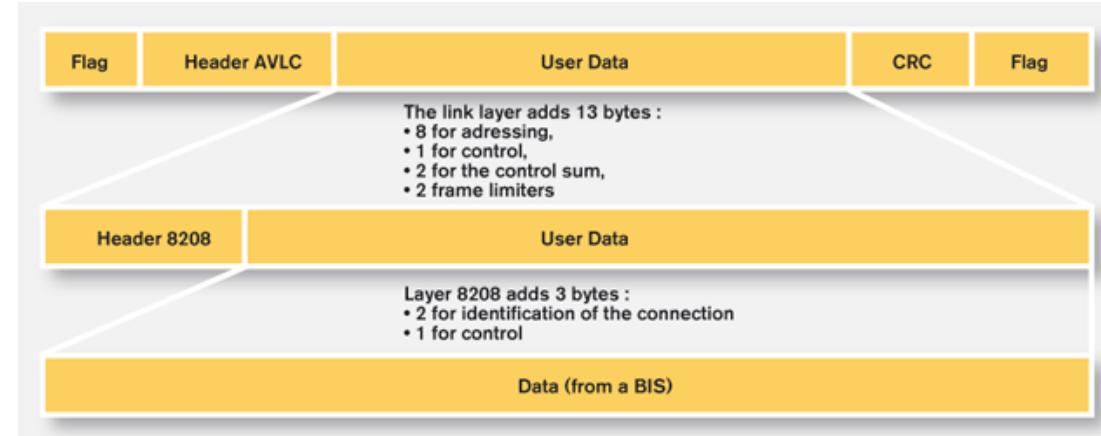
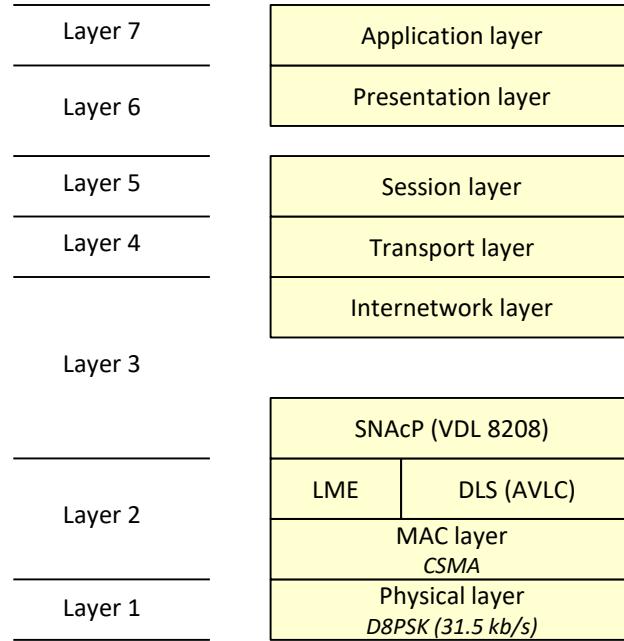


MAC (Media Access Control) implements the **CSMA (Collision Sense Multiple Access)** algorithm – *the radio listens to the channel and if it is free it transmits*; if not it retries after a random interval. There is no priority mechanism in VDL-M2.

# VDL Mode 2 – Protocol Stack



# VDL Mode 2 – Protocol Stack



The network layer is partly implemented using the ISO 8208 protocol (X.25 Packet Layer Protocol) and acts as adaptive layer which for instance reassembles packets delivered by the data link layer.

# CPDLC

- **Controller pilot data link communication (CPDLC)** is a means of communication between controller and pilot, using data link for ATC communication.
- The FANS-1/A System that was originally developed by Boeing, and later adopted by Airbus, is primarily used in oceanic routes by wide-bodied long haul aircraft. FANS-1/A is an ACARS based service and, given its oceanic use, mainly uses satellite communications provided by the Inmarsat Data-2 (Classic Aero) service.
- The ICAO Doc9705 compliant ATN/CPDLC system, which is operational at Eurocontrol's Maastricht Upper Airspace Control Centre (above FL245) and has now been extended by Eurocontrol's LINK2000+ Programme to many other European Flight Information Regions (FIRs). The VDL Mode 2 networks operated by ARINC and SITA are used to support the European ATN/CPDLC service.



# DATALINK EVOLUTION

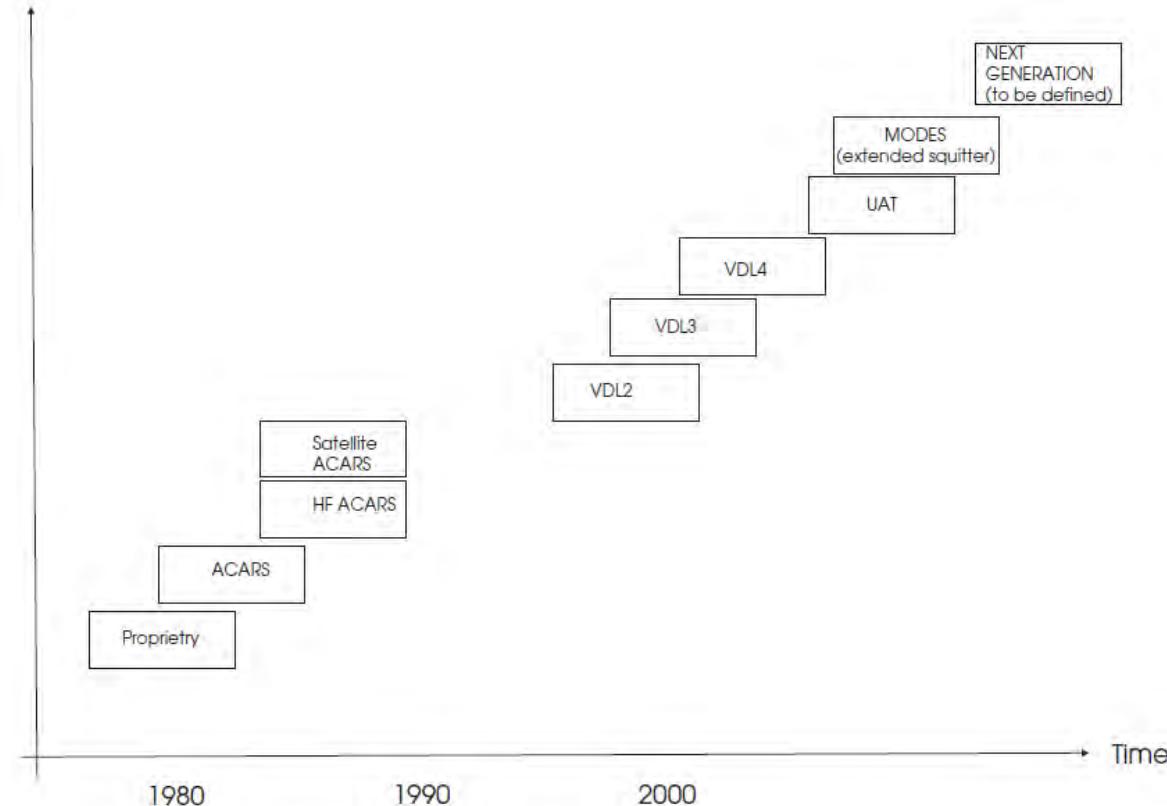


Figure 3.18 Datalink evolution.

# OVERVIEW OF VDL MODES

**Table 3.16** Overview of VDL modes.

	ACARS/VDL0/VDLA	VDL1	VDL2	VDL3	VDL4
Standardization complete	Not standardized	NA	1997	2000	2000
In operation	Since late 1970s	Obsolete	2002	Experimental networks since 2003	Imminent
Modulation	AM-ASK	AM-ASK	8DPSK	8DPSK	GFSK
Air interface format + protocol	Unstructured	CSMA	TDMA-CSMA	TDMA	S-TDMA
Air interface speed	2.4 kbps	2.4 kbps	31.5 kbps	31.5 kbps	19.2 kbps
Payload (speed)	300 bps	300 bps	>10 kbps	Up to 4 × 4.8 kbps (19.2 kbps)	<19.2 kbps
Prioritization	Not supported	Not supported	Not supported	Supported	Supported 4 levels
Data services supported	✓	✓	✓	✓	✓
ATC (DCL, D-ATIS, OCM)	✓	✓	✓	✓	✓
AOC			✓	✓	✓
Link 2000+					✓
Navigation and Surveillance functions					
Voice services supported	No	No	No	Yes	No
Service providers	ARINC/SITA	ARINC/SITA		SITA	
Channelization	25 kHz + guard bands	25 kHz + guard bands	25 kHz + guard bands	25 kHz	25 kHz + guard bands
Deployment region	All	None	All	North America	Europe
Channel capacity (users)		Typical 600+ per channel	Dependent on coverage volume	Theoretically up to 4500 users, not validated	
Rx sensitivities					

# STRENGTHS AND WEAKNESSES OF VDL MODES

**Table 3.17** Strengths and weaknesses of VDL modes.

	ACARS/VDL0/VDLA	VDL1	VDL2	VDL3	VDL4
Strengths	Resilient		Standardized	Voice and data on one radio	Efficient payload data throughput
	Proven		Moderate speed	Supports prioritization and time-critical applications	Flexible applications (+ nav + surv)
	Mature		Applications tested	More efficient payload throughput than ACARS/VDL2	Air-air communications
Weaknesses	Deployed		Proven		Self-managing, good for remote areas
	Limited speed and application	Obsolete	Deployed		Validation testing not complete
	Saturated		Co-channel problems	Not fully tested, validated	
	Non-standardized		No prioritization of traffic	Late implementation as yet	Does not support real-time voice
			No voice or real-time handling	Commitment to deploy	Single point of failure for multiple systems
			Weak protocol	Single point of failure for data and voice	Not implemented as yet

# VDL SERVICES

**Table 3.18** VDL services.

		Acronym	ACARS/ VDL0/VDLA	VDL1	VDL2	VDL3	VDL4
ATC	Automatic dependent surveillance	ADS					✓
	Controller pilot datalink communications	CM CPDLC			✓	✓	✓
	Digital flight information services/automatic terminal information service	D-FIS/ATIS	✓	✓	✓	✓	✓
	Cockpit display of traffic information	AIDC AMHS CDTI			✓	✓	✓
Non-ATC function	ADS broadcast B mode	ADS-B					✓
	ADC broadcast C mode	ADS-C					✓
	Flight status	FS	✓	✓	✓	✓	✓
	Aircraft situational awareness	AIRSAW					✓
	Engine performance		✓	✓	✓	✓	✓
	Fuel status		✓	✓	✓	✓	✓
	Crew identification		✓	✓	✓	✓	✓
	Weight and balance		✓	✓	✓	✓	✓
	Off, out, on and in times	OOOI	✓	✓	✓	✓	✓

CM, Context management; AIDC, ATS interchange data communications (where ATS stands for air traffic services); AMHS, ATS message handling services.



# AERONAUTICAL MOBILE SATELLITE ROUTE SERVICE

AMS(R)S



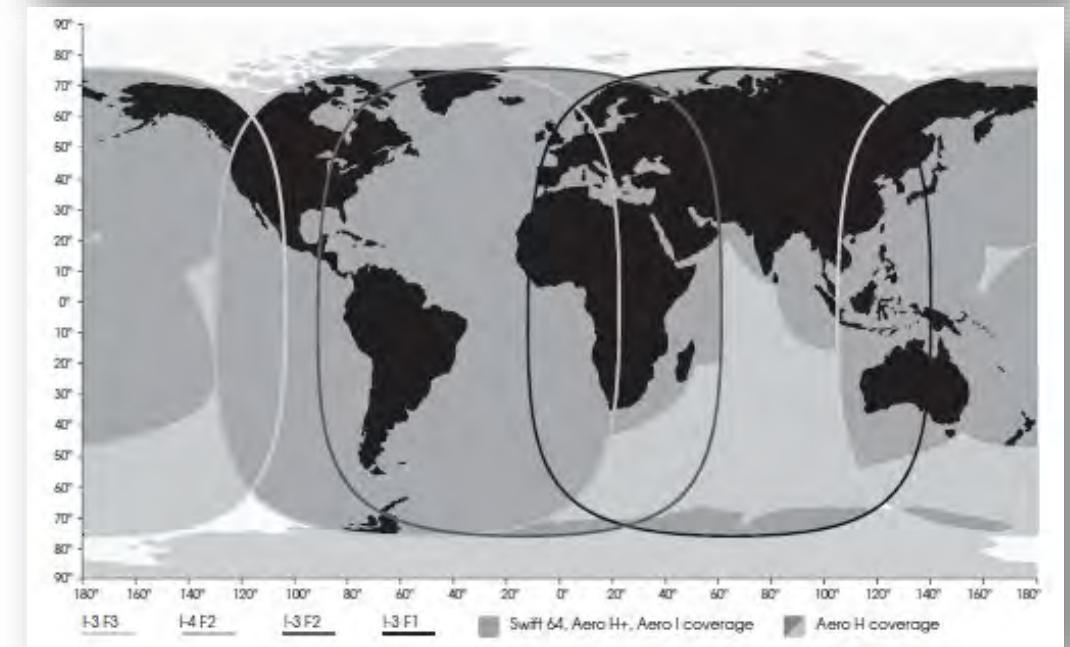
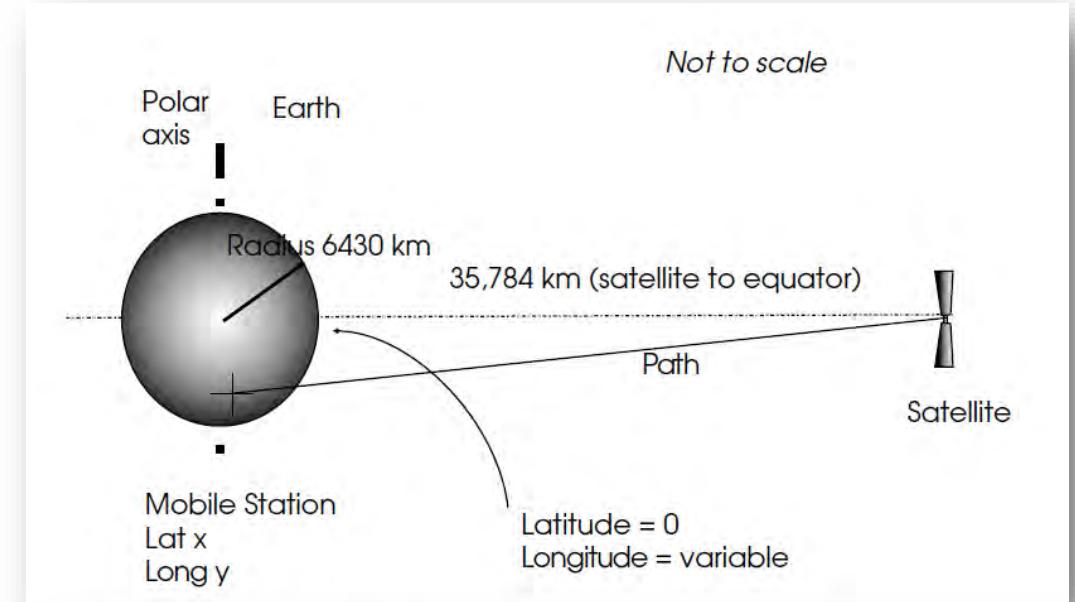
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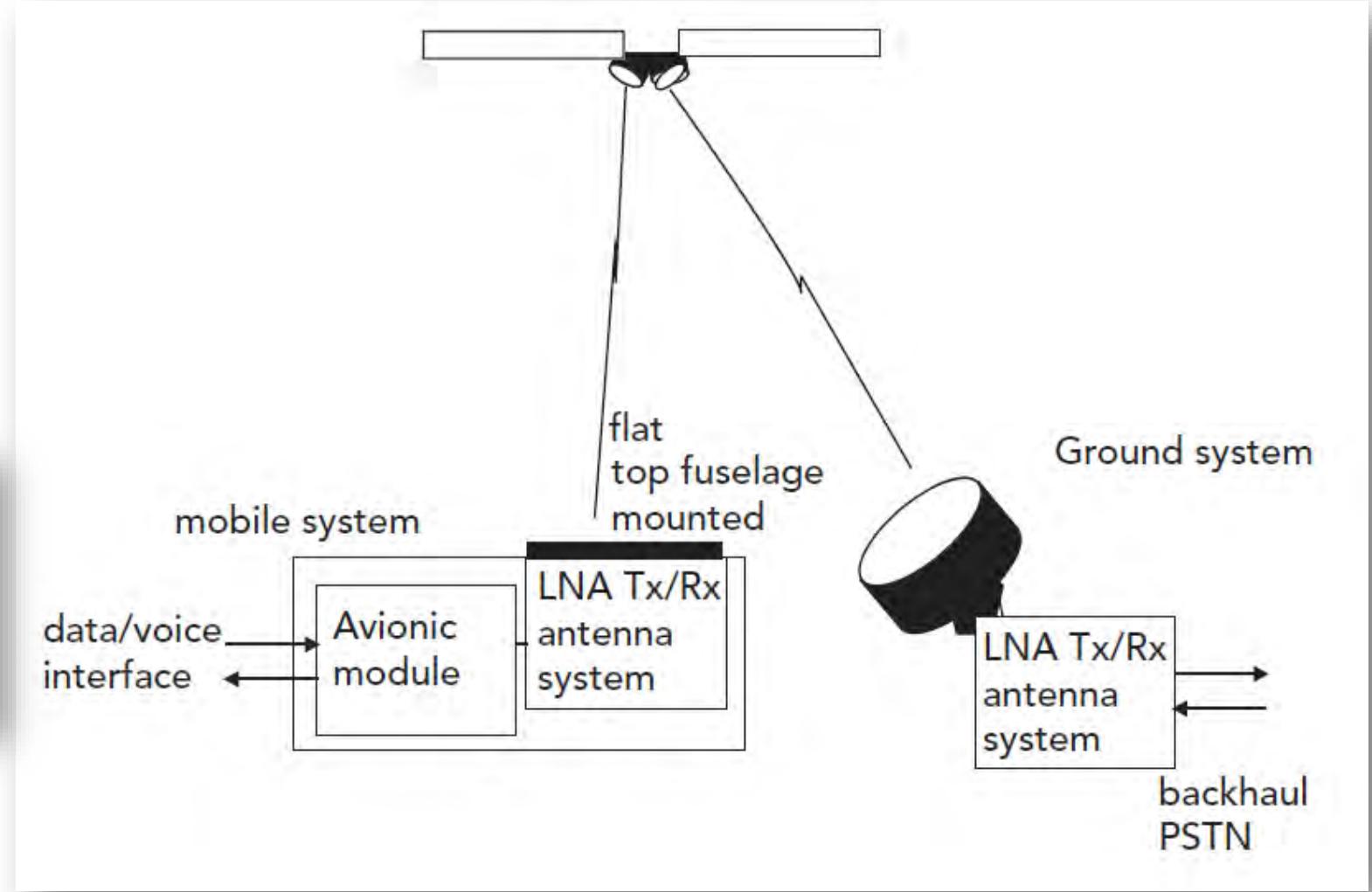
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# CARACTERISTIQUES

- Basat en satèl·lits geostacionaris situats a 36.000 km de l'equador.
- Poden operar en Banda L (1,4 GHz), Banda C (3,4 -4,8 GHz), Banda Ku (10,7 – 12,75 GHz) i Banda Ka (19-22 GHz).
- Bona cobertura mundial, a excepció dels pols.
- Utilitzen modulació Aviation Binary Shift Keying (ABPSK) amb velocitats de 2.4, 1.2 or 0.6 kbps.
- Per velocitats més grans de 2400 kbps, utilitzen la modulació Aeronautical Quadrature Shift Keying (A-QPSK).

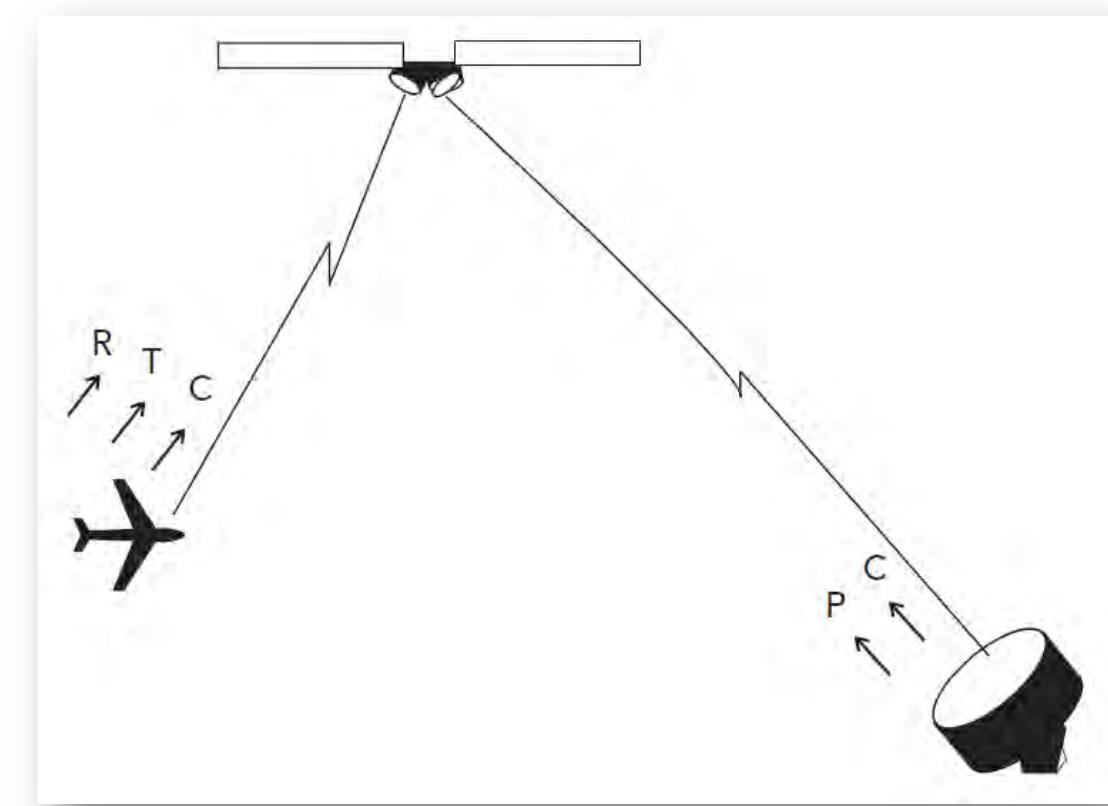


# SISTEMA AMS(R)S



# SISTEMA AMS(R)S

- **The P channel** operates in packet mode, using time division multiplexed frames transmitted continually from aeronautical ground earth station to the aircraft via the transponder on the satellite; this provides the signalling data for the link set-up and synchronization.
- **The R channel** is a random access protocol using a slotted Aloha format. This is transmitted from the aircraft (or mobile station) when initiating a call or data message set-up. It can also carry local synchronization and network management information.
- **The T channel** is a data channel using the TDMA protocol for assignment of slots channel from aircraft only. Receiving geostationary earth station (GES) reserves time slots according to message length.
- **The C channel(s)**, circuit mode channel, single channel per carrier are used both ways.



# REFERÈNCIES

- **Dale Stacey**, “Aeronautical Radio Communication Systems and Networks”. John Wiley & Sons, 2008.
- **Mike Tooley and David Wyatt**, “Aircraft Communications and Navigation Systems: Principles, Operation and Maintenance”, Elsevier, 2007.

# Tema 5:

## ELS EQUIPS I ELS SISTEMES RADIOELÈCTRICS AEROPORTUARIS

Jordi Berenguer  
Novembre 2021



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# Sistemes de Radiogoniometria

*Radiogoniometria:* f. [TC] Mètode per a determinar la direcció i la posició d'un emissor de ràdio.

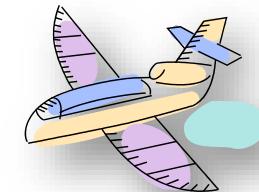


# RADIOGONIOMETRIA

- Tècnica que permet determinar la direcció de procedència d'una ona electromagnètica.
- Quan es coneix la posició del sistema transmissor, s'utilitza com un sistema d'ajuda a la navegació aèria. Es tracta del sistema **ADF (Automatic Directional Finder)**, el receptor del qual es troba embarcat en l'aeronau, que mesura l'angle de recepció respecte d'una radio balisa que s'anomena **NDB (Non Directional Beacon)** que emet un senyal de forma omnidireccional.



NDB



ADF



# VDF (VHF Directional Finder)

- En mode invers, en aeronàutica s'utilitza per determinar la posició d'una aeronau a partir de la localització del sistemes de comunicacions per veu en VHF. En aquest cas, el sistema es denomina **VDF**.
- Està format per una antena receptora, anomenada **màster** que està sempre connectada a un receptor, al voltant de la qual i en cercle, es disposen N antenes anomenades **slave**, (habitualment són 8), que es connecten seqüencialment a un altre receptor. A partir de la mesura de la diferència entre les fases dels senyals elèctrics rebuts es pot determinar l'angle d'on procedeix el senyal emès per l'aeronau.



# RADIOGONIOMETRIA

## *Direction Finding (DF)*

PRINCIPI DE FUNCIONAMENT



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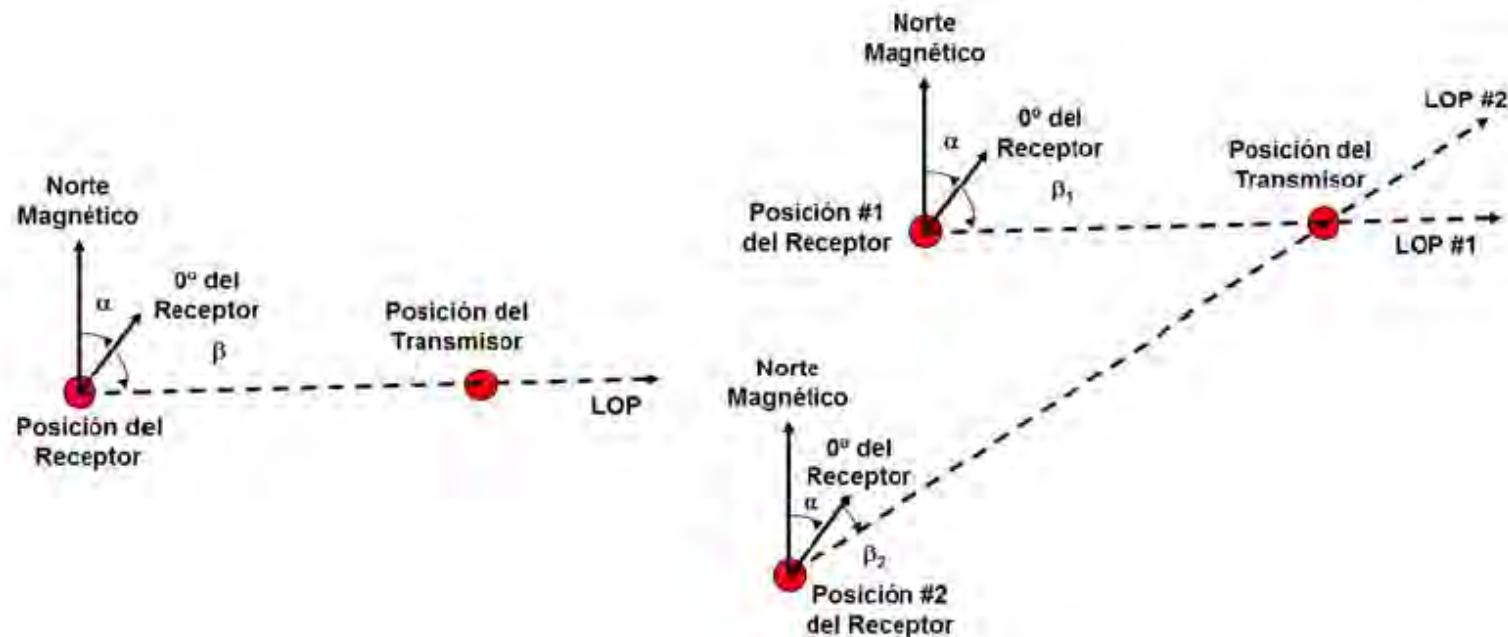
# DETERMINACIÓ DE LA POSICIÓ PER TRIANGULARITZACIÓ

Es basa en la utilització d'un receptor situat en un emplaçament coneugut.

En una situació ideal (figura 2), a partir de la mesura des de dues ubicacions diferents i conegudes de l'angle d'arribada (AOA, Angle Of Arrival) de les ones emeses pel transmissor és possible determinar la posició de l'estació.

Traçant des de cadascun dels dos emplaçaments de mesura una línia de posició (LOP, Line Of Position) s'obté la situació del transmissor per la intersecció de les dues línies.

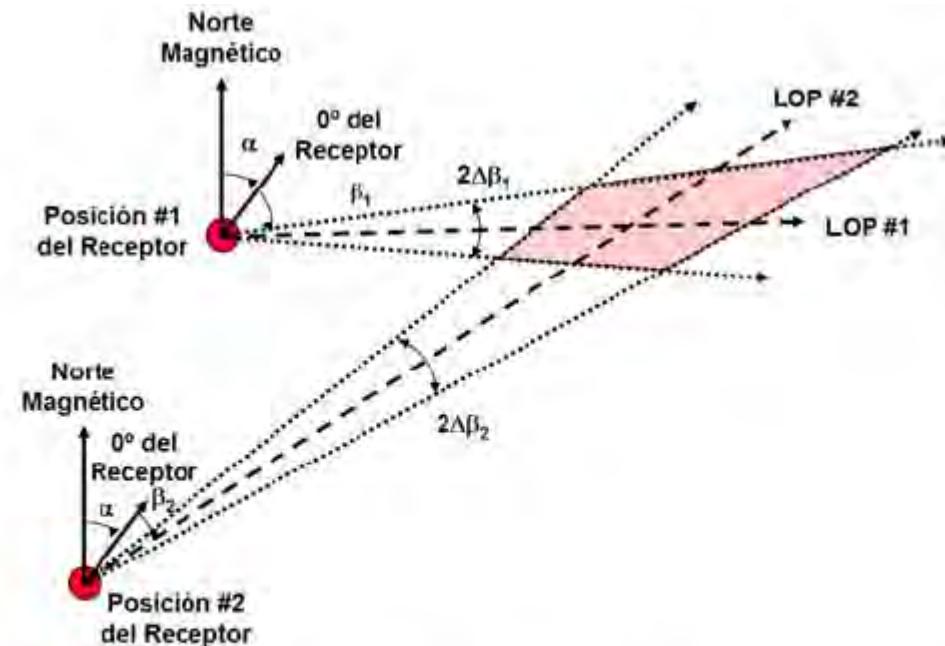
Cadascuna de les LOP representa els possibles llocs on es troba l'estació emissora.



**Figura 2.** Determinación de la posición de un transmisor mediante radiogoniometría. (Izqda.) En el gráfico, el ángulo  $\alpha$  se determina con la brújula, y el ángulo  $\beta$  con el radiogoniómetro. (Dcha.) A partir de la intersección de dos LOP se obtiene la posición (inicialmente desconocida) del transmisor.

# SUPERFÍCIE D'INCERTESA

En un entorn real, i degut a les possibles reflexions i difraccions de les ones electromagnètiques, que depenen de la freqüència es deriven del mecanisme del seu mecanisme propagació, es produeix una **superfície d'incertesa**, de forma que es crea un **error** en la determinació de la posició del transmissor.

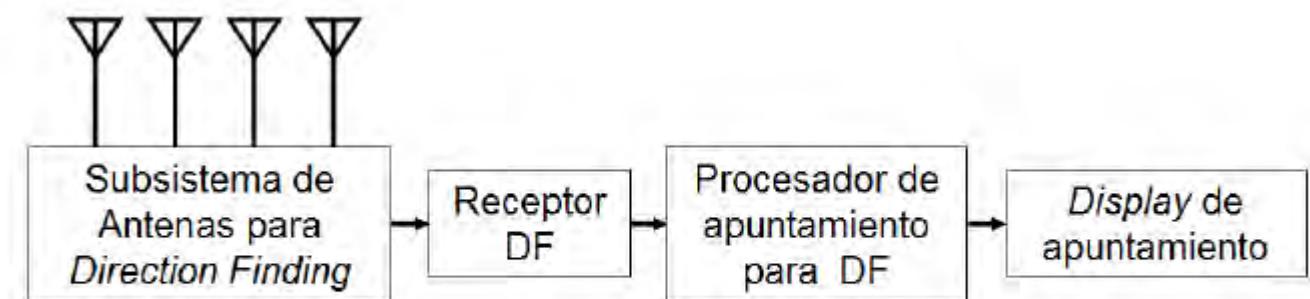


**Figura 3.** Superficie de incertidumbre debida a la imprecisión en la medida del AOA de las señales procedentes del transmisor.

# ESQUEMA DE BLOCS D'UN RECEPTOR

El receptor consisteix en un sistema d'antenes connectades a un receptor que incorpora un processador que determina la direcció a partir de la mesura de la diferència de fase dels senyals obtinguts en les antenes, d'on s'obté l'angle d'arribada del senyal que es representa en un display.

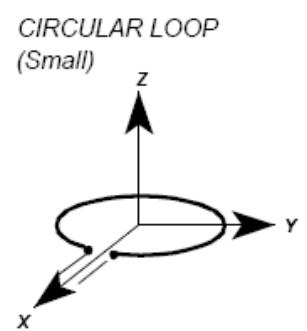
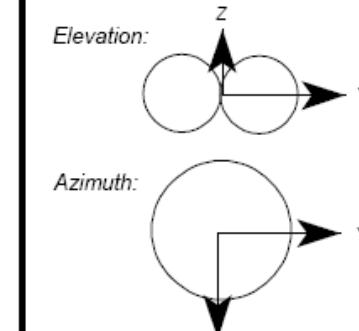
A la figura 4 es mostra un diagrama de blocs molt simple d'un sistema de DF convencional.



*Figura 4.* Diagrama de blocs de un sistema DF convencional.

# Principi de funcionament

- Els sistemes de radiogoniometria requereixen la utilització d'antenes receptors de **banda ampla**, i que a la vegada siguin directives. Com que això no és possible, es busquen antenes que presentin un nul de recepció molt marcat, i per tant **la detecció es fa buscant el nul en la recepció**.
- Les antenes d'espira o de quadre, son antenes de banda ampla, que presenten dos nuls molt marcats en el seu diagrama de radiació.
- Per suprimir aquesta indeterminació el que es fa és afegir una segona antena, habitualment un monopol, de forma que el conjunt acaba conformant un diagrama de radiació de tipus cardioide, en el qual només hi apareix un nul.
- Aquest dipol que s'hi afegeix, s'anomena **antena de sentit**.

Antenna Type	Radiation Pattern	Characteristics
CIRCULAR LOOP (Small)	<p>Elevation:</p>  <p>Azimuth:</p> 	<p>Polarization: Linear Horizontal as shown</p> <p>Typical Half-Power Beamwidth: 80 deg x 360 deg</p> <p>Typical Gain: -2 to 2 dB</p> <p>Bandwidth: 10% or 1.1:1</p> <p>Frequency Limit: Lower: 50 MHz Upper: 1 GHz</p>

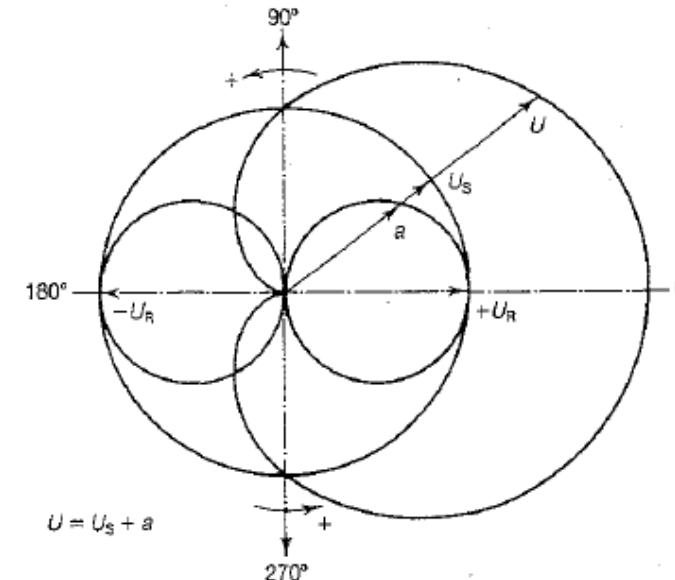
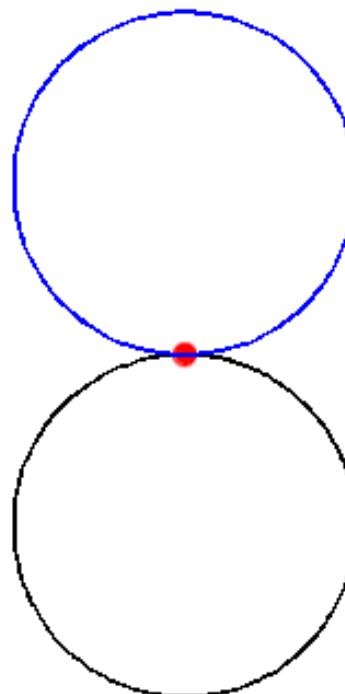
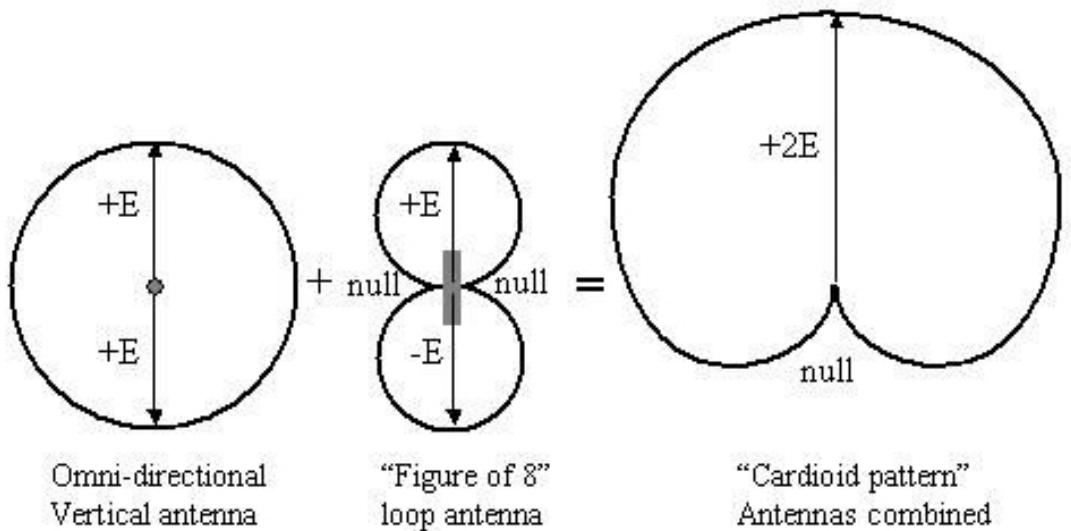


Diagrama resultant de combinar una antena d'espira i un monopol, resultant en un diagrama de tipus cardioide.

Diagrama de radiació d'una antena omnidireccional més una antena de quadre o espira = Cardioide.



# RECEPTORS DF



# ANTENA DE QUADRE AMB GONIÒMETRE

El goniòmetre genera un camp magnètic similar al que rep l'antena, de forma que és capaç d'orientar una agulla imantada que indica la mateixa posició que el camp elèctric incident.

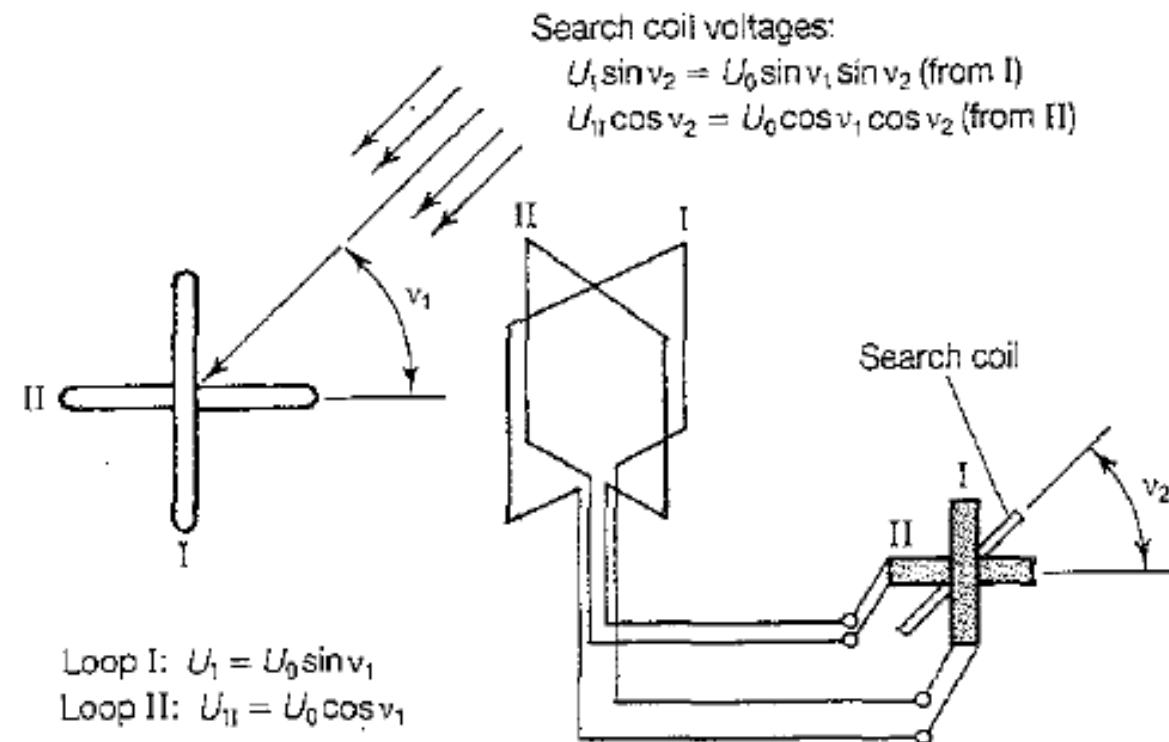


Figure 5.8 Crossed-loop antenna with goniometer

# ESQUEMA DE BLOCS D'UN RECEPTOR AMB ANTENA DE QUADRE I ANTENA DE SENTIT

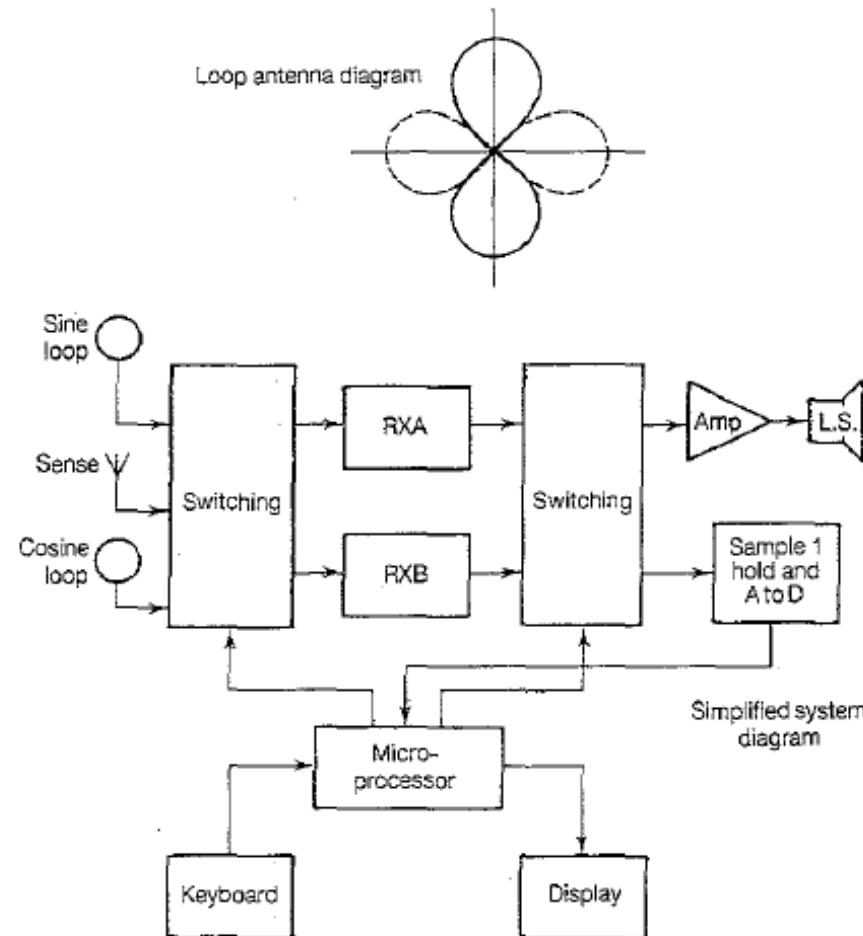
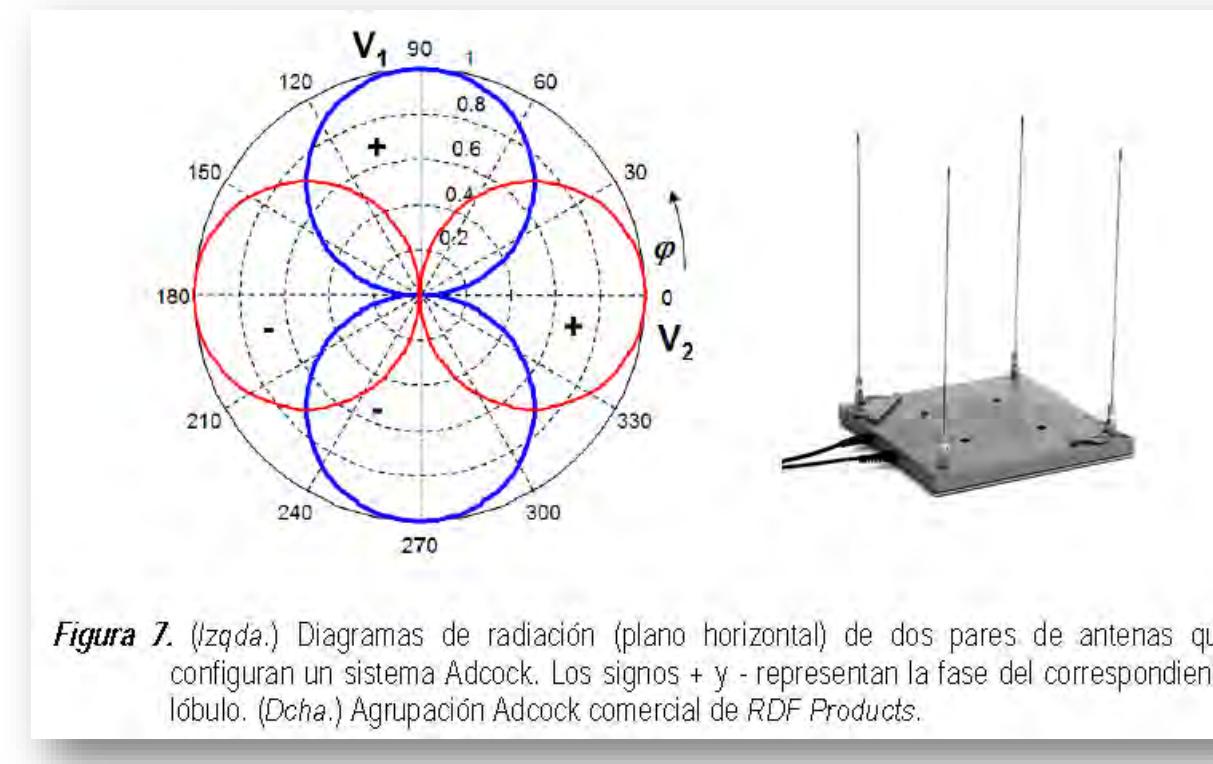


Figure 5.10 ADF antenna pattern and receiver system block diagram  
(courtesy Standard Marine A/S)

# ANTENA ADCOCK

Si no es vol utilitzar una antena mòbil o giratòria per fer DF, com ho seria la espira més l'antena de sentit, es pot utilitzar l'antena Adcock.

Consisteix en un doble parell de dipols o monopolis creuats, que sense requerir cap moviment giratori genera quatre senyals aptes per a ser processats i determinar l'angle d'arribada del senyal.



# Compact Direction Finding Antenna

## PRODUCT DESCRIPTION:

The DF-A0250 direction finding antenna covers a frequency range of 400 MHz to 6000 GHz.

The full-size elements on all bands give excellent DF sensitivity. Ultimate angular resolution for strong signals is well under 1° for most of the frequency range.

Dipole elements provide good crosspolarization rejection, and fair performance for signals arriving from up to 15° above or below the horizon.

This DF antenna is designed to be used either a 5- or 2-channel phase-sensitive receiver, and correlative algorithm. Characterization of the antenna can be performed on request.

The antenna also includes a dedicated wide band Monitoring channel

## Product Code: DF-A0250

### SPECIFICATIONS:

#### Electrical:

Frequency range 400 – 6000 MHz

Polarisation Vertical

#### DF:

Frequency range 400 – 6000 MHz

Band B 400 – 1000 MHz

Band C 1000 – 3000 MHz

Band D 3000 – 6000 MHz

Nominal input impedance 50 Ω

Antenna type 5-element DF interferometer

Channels per band 5

#### Monitoring:

Frequency Range 400 – 6000 MHz

#### RF Interface:

Connectors 16 x TNC female

#### Mechanical:

Maximum wind speed

Operational - 160 km/h (without ice load)  
Max 251 km/h gusts in a debris free environment, short interval gusts only

Assembled height 2.1 m

Assembled diameter (max) 0.77 m

Weight of antenna < 30 kg

#### Environmental: designed to meet the following specifications

Operating Temperature -30°C to +70°C

IP Rating IP55



<http://www.alarisantennas.com>



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# SISTEMA ADF

Automatic Direction Finding

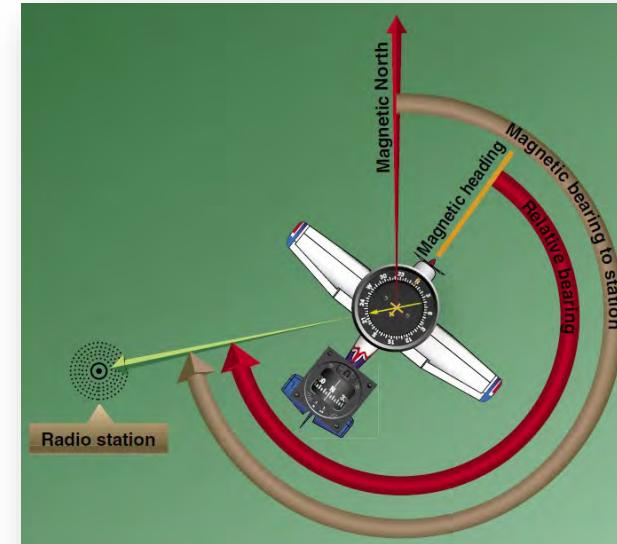


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# SISTEMA ADF

El sistema es basa en la utilització d'un transmissor de referencia (NDB) ubicat en un posició precisa i coneguda, que emet un senyal que detecta el receptor embarcat en l'aeronau, a partir del qual determina el seu radial respecte del NDB.

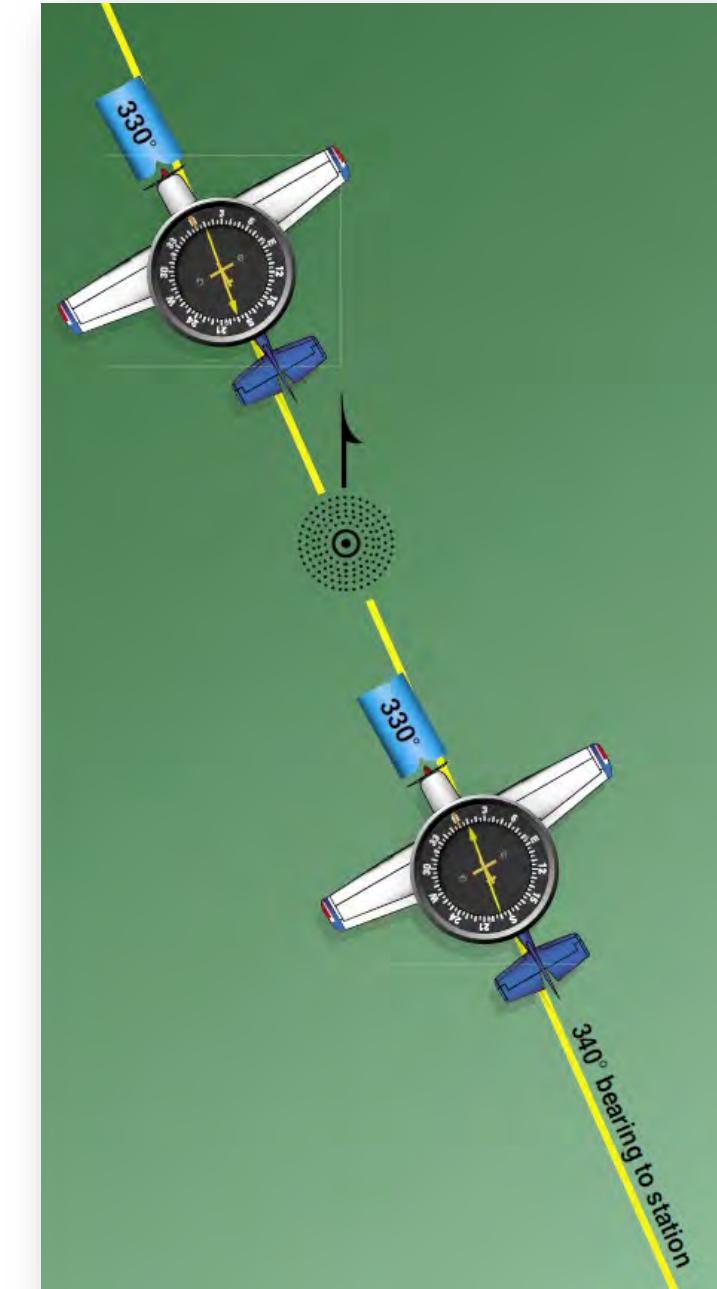


## NONDIRECTIONAL RADIOBEACON (NDB)

(Usable Radius Distances for All Altitudes)

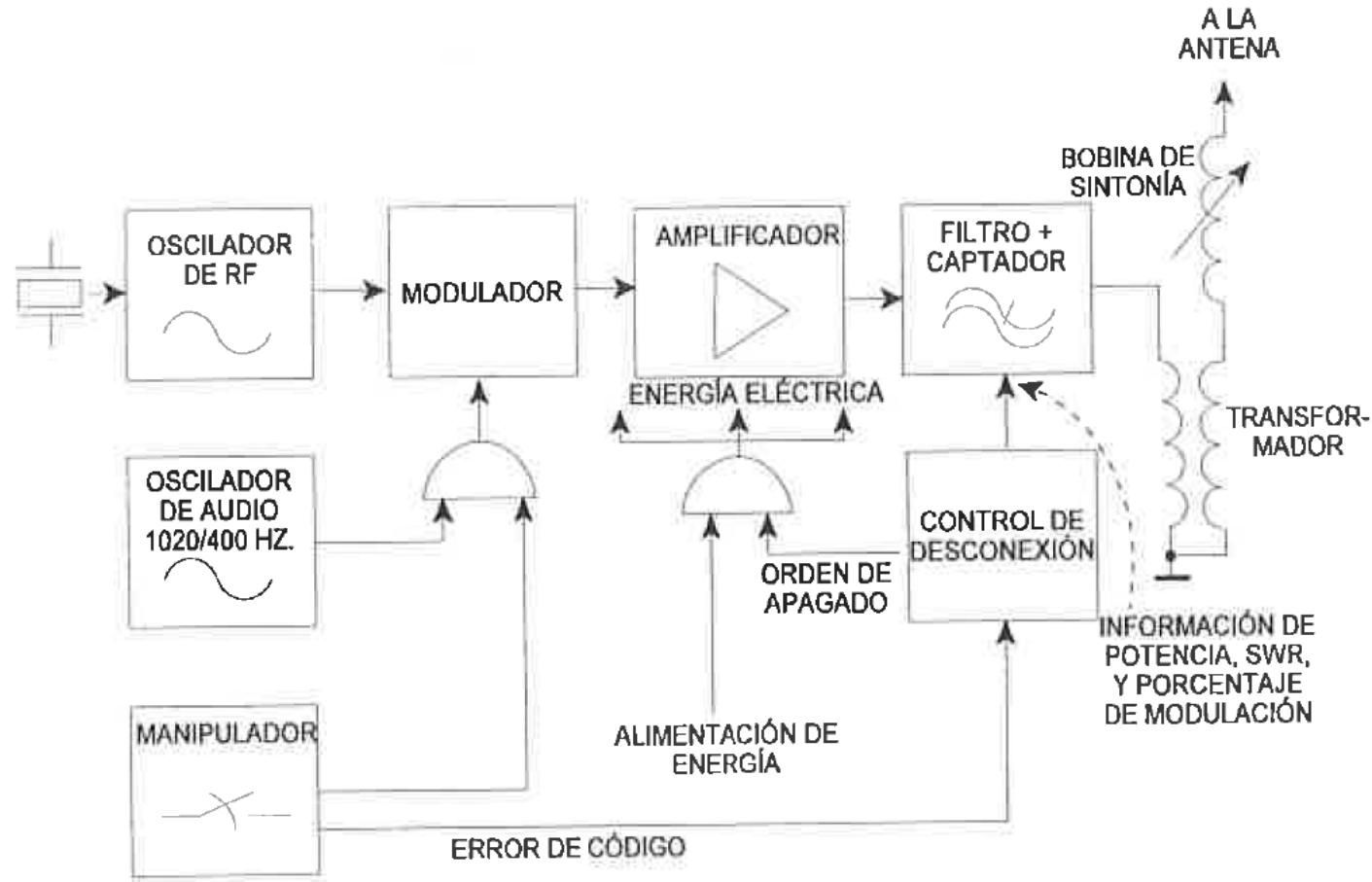
Class	Power (Watts)	Distance (Miles)
Compass Locator	Under 25	15
MH	Under 50	25
H	50–1999	*50
HH	2000 or more	75

\*Service range of individual facilities may be less than 50 miles.



# NON DIRECTIONAL BEACON (NDB)

## Esquema de blocs



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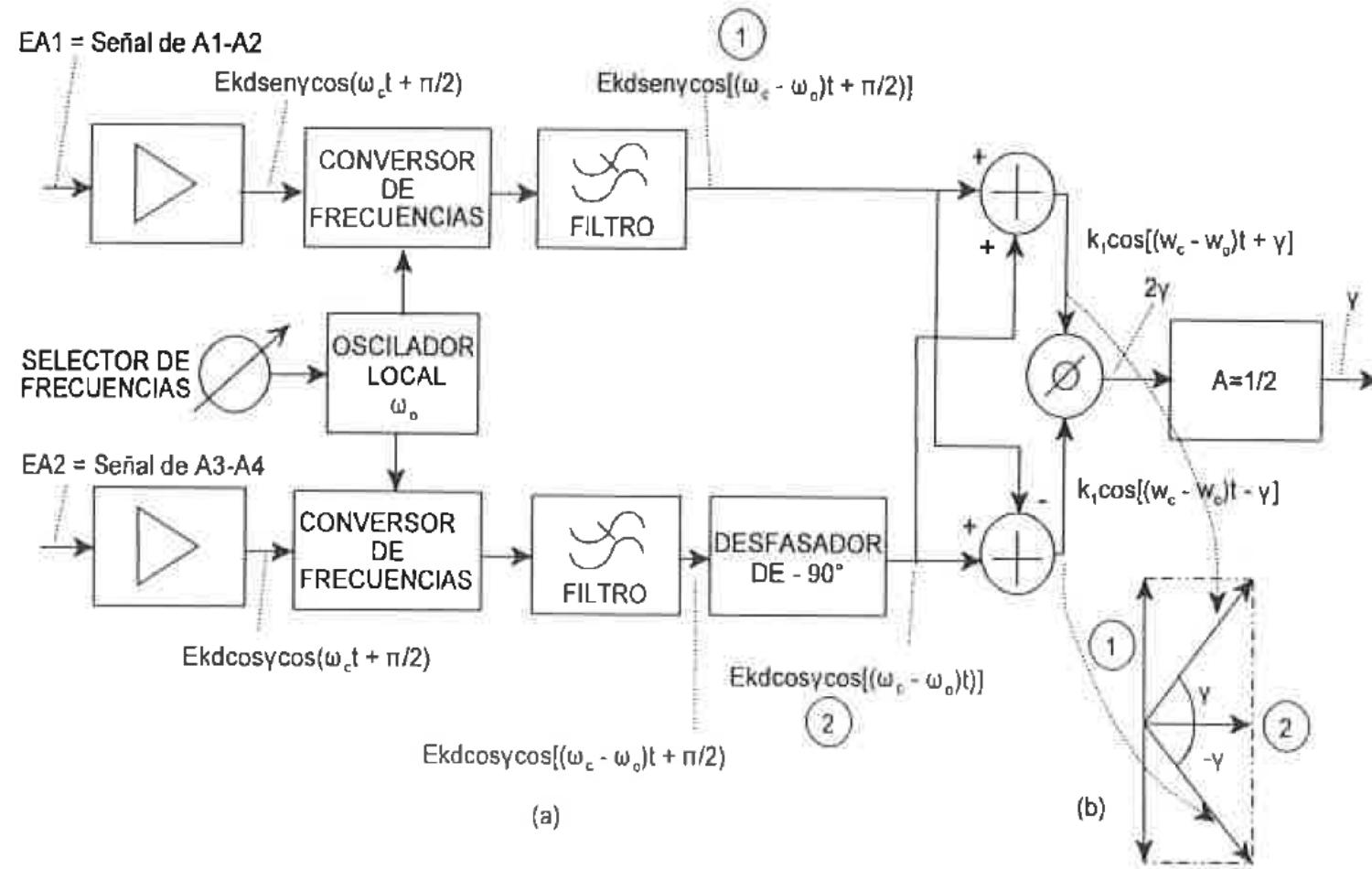


Fig. 3.5.- (a) Diagrama de bloques de un ADF con determinación electrónica de  $\gamma$ ; (b) Diagrama fasorial.

# ANTENA ADF INTEGRADA S72-



Top



Bottom

# ADF Antenna S72-1712-9



## DESCRIPTION

**S72-1712-9:** The ADF ARINC 712 digital receiver uses a combined loop/sense antenna for operation with the digital ADF receiver incorporated in the shell. A test loop feature is provided on pin numbers 15 & 16. The ferrite loop is a unique rugged design that provides repeatable bearing accuracy. Compatible with Allied Signal and Collins ARINC 712 specs. The baseplate radius is 66 inches (1676 mm) for DC-9 and MD-80 installations.

**FEDERAL & MILITARY SPECS:** ARINC-712, DO-160A, MIL-E-5400, FAA TSO-C41c.

## S72-1712-9

### Electrical:

Frequency.....	190-1750 KHz
VSWR.....	1.2:1
Output Impedance ( $\pm 5\%$ ).....	78 Ohms balanced ..... 1 M Ohms to ground min.
Power.....	$\pm 12V$ , 150 MA. (Max.)
Pattern.....	Omnidirectional
Bearing Accuracy.....	Better than 0.4°
Effective Height ( $\pm 10\%$ ).....	Sense: 0.03 meter ..... Loop: 190 KHz 0.23 meter ..... 577 KHz 0.038 meter ..... 1750 KHz 0.023 meter
Loop Resonance Freq. ( $\pm 5\%$ ).....	577 KHz
Loop Operating Q ( $\pm 10\%$ ).....	0.5
Loop Amplitude Tracking.....	0.25 dB
Loop Phase Charact.(s).....	$\pm 8^\circ$ of (90-2 TAN $^{-1}$ f/577)
Noise Output into 78Ω.....	Sense: 3.3 nV / $\sqrt{Hz}$ max. ..... Loop: 8.0 nV / $\sqrt{Hz}$ max.

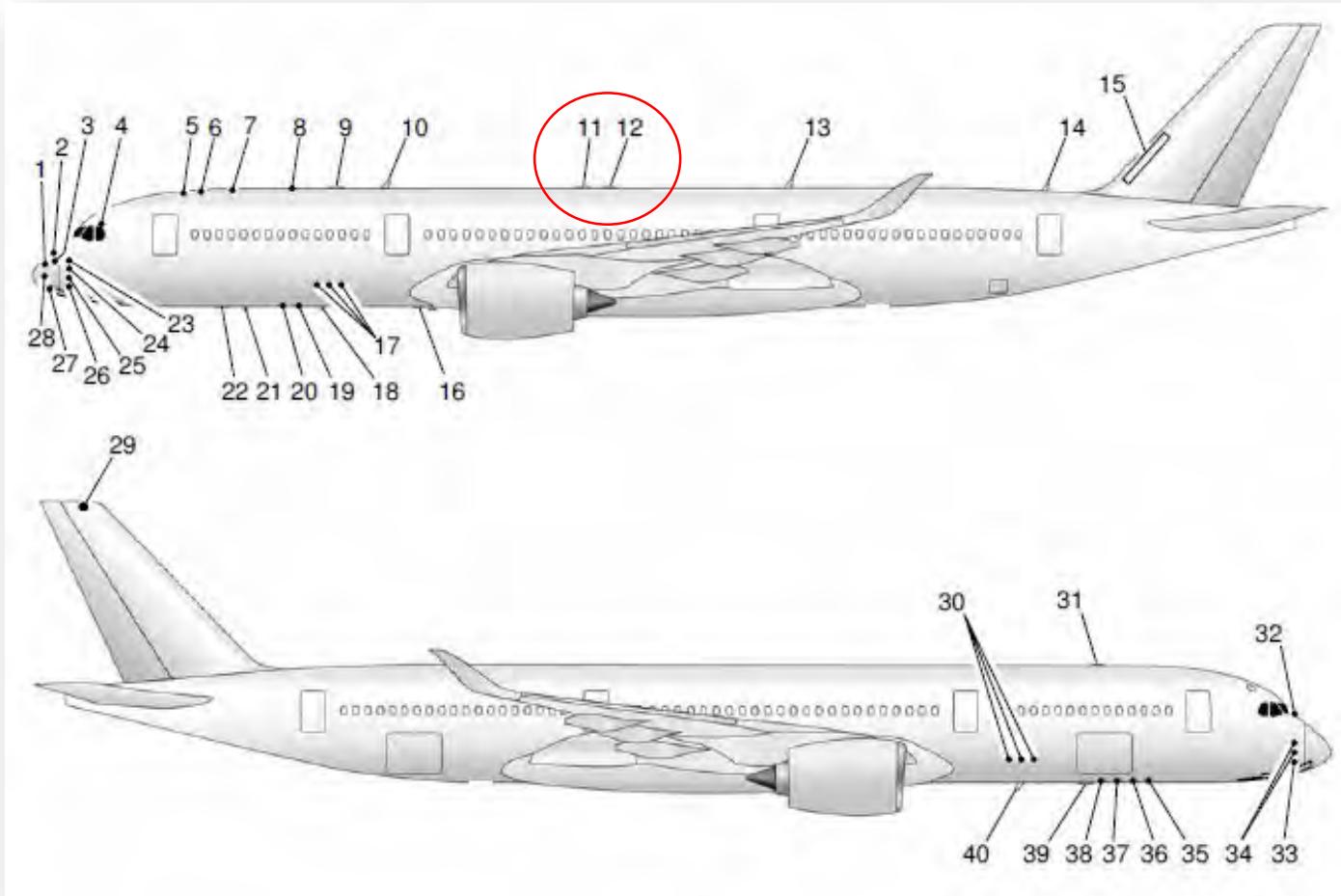
### Mechanical:

Weight.....	8.8 lbs.
Height.....	1.77 in.
Length.....	30 in.
Width.....	10.62 in.
Material.....	Glass-reinforced thermoplastic
Connector.....	M83723-72R 2016N
Finish.....	Skydrol Resistant Polyurethane

### Environmental:

Temperature.....	-65°C (-85°F) to +90°C (+194°F)
Vibration.....	10 G's RMS-Random
Altitude.....	50,000 ft.

A350-900



- |                    |                          |
|--------------------|--------------------------|
| 1 - LOC            | 21 - DME 1               |
| 2 - SSA 1          | 22 - TCAS 1 (BOTTOM)     |
| 3 - TAT PROBE 1, 2 | 23 - PITOT               |
| 4 - ICE PROBE      | 24 - MFP 1               |
| 5 - GNSS 1         | 25 - AOA                 |
| 6 - GNSS 2         | 26 - ICE PROBE DETECTOR  |
| 7 - TCAS 2 (TOP)   | 27 - GLIDE               |
| 8 - WACS           | 28 - WEATHER RADAR       |
| 9 - SATCOM         | 29 - VOR                 |
| 10 - VHF 1         | 30 - ISP RH              |
| 11 - ADF 1         | 31 - TCAS 1 (TOP)        |
| 12 - ADF 2         | 32 - SSA 2, 3            |
| 13 - VHF 3         | 33 - ICE PROBE PROTECTOR |
| 14 - ELT           | 34 - MFP 2, 3            |
| 15 - HF            | 35 - RADIO ALT E1        |
| 16 - MARKER        | 36 - RADIO ALT R1        |
| 17 - ISP LH        | 37 - RADIO ALT R3        |
| 18 - DME 2         | 38 - RADIO ALT E3        |
| 19 - RADIO ALT R2  | 39 - TCAS 2 (BOTTOM)     |
| 20 - RADIO ALT E2  | 40 - VHF 2               |

# SISTEMA VDF

VHF Direction Finding



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# VHF Direction Finder

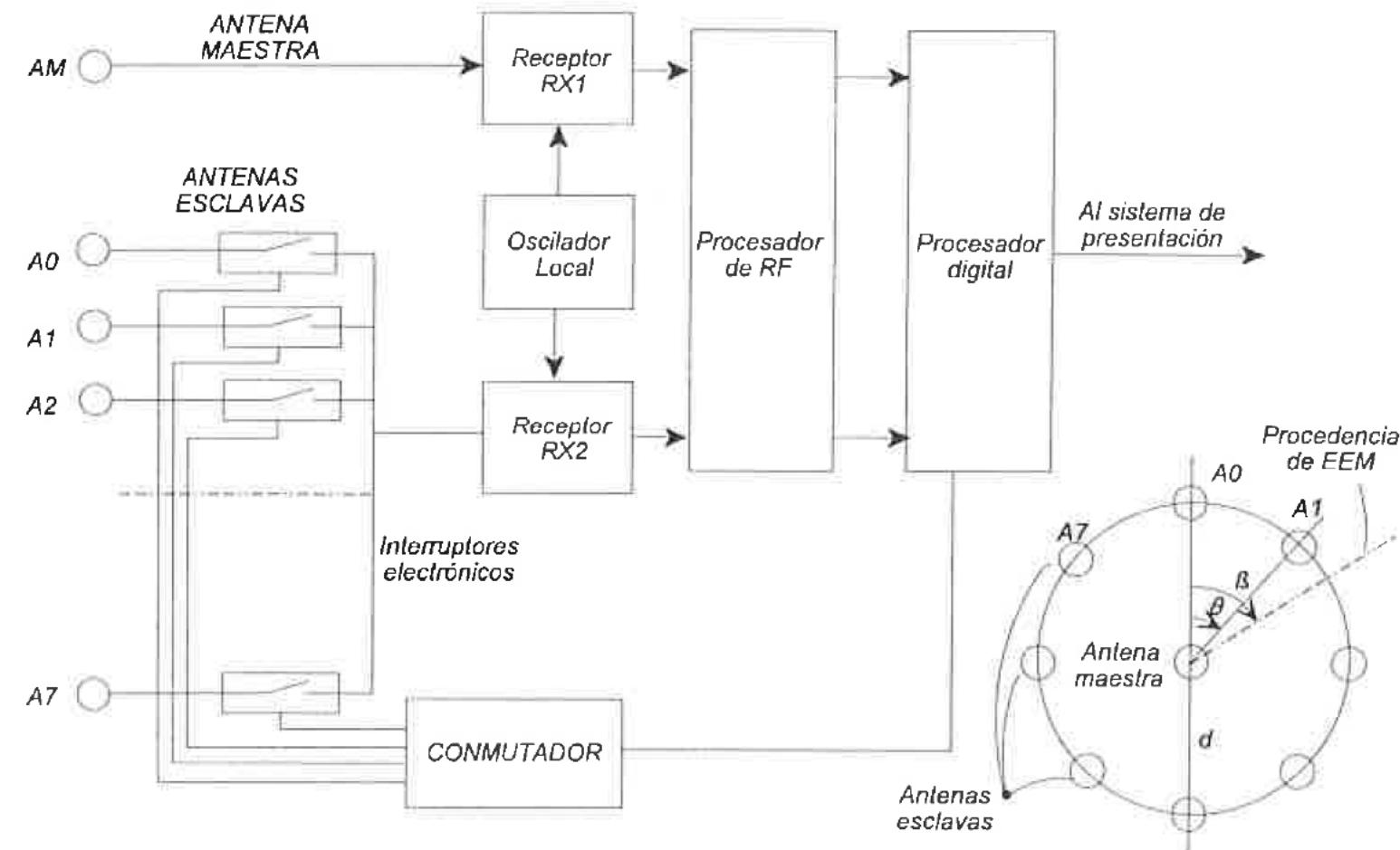
## 1-1-16. VHF Direction Finder

- a) The VHF Direction Finder (VHF/DF) is one of the common systems that helps pilots without their being aware of its operation. It is a ground-based radio receiver used by the operator of the ground station. FAA facilities that provide VHF/DF service are identified in the A/FD.
- b) The equipment consists of a directional antenna system and a VHF radio receiver.
- c) The VHF/DF receiver display indicates the magnetic direction of the aircraft from the ground station each time the aircraft transmits.
- d) DF equipment is of particular value in locating lost aircraft and in helping to identify aircraft on radar.

### ***REFERENCE-***

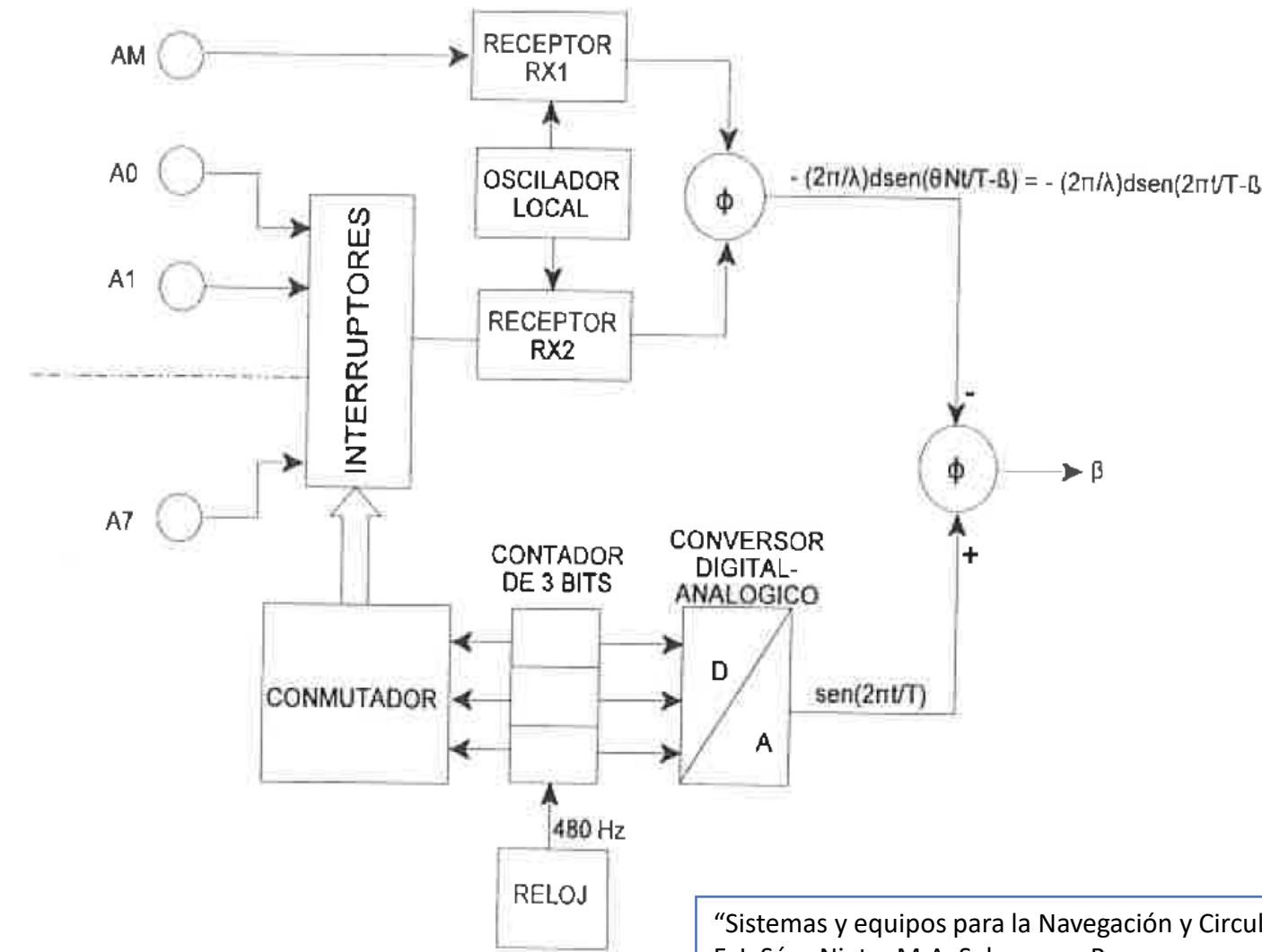
*AIM, Direction Finding Instrument Approach Procedure, Paragraph 6-2-3.*

# ESQUEMA DE BLOCS D'UN SISTEMA VDF



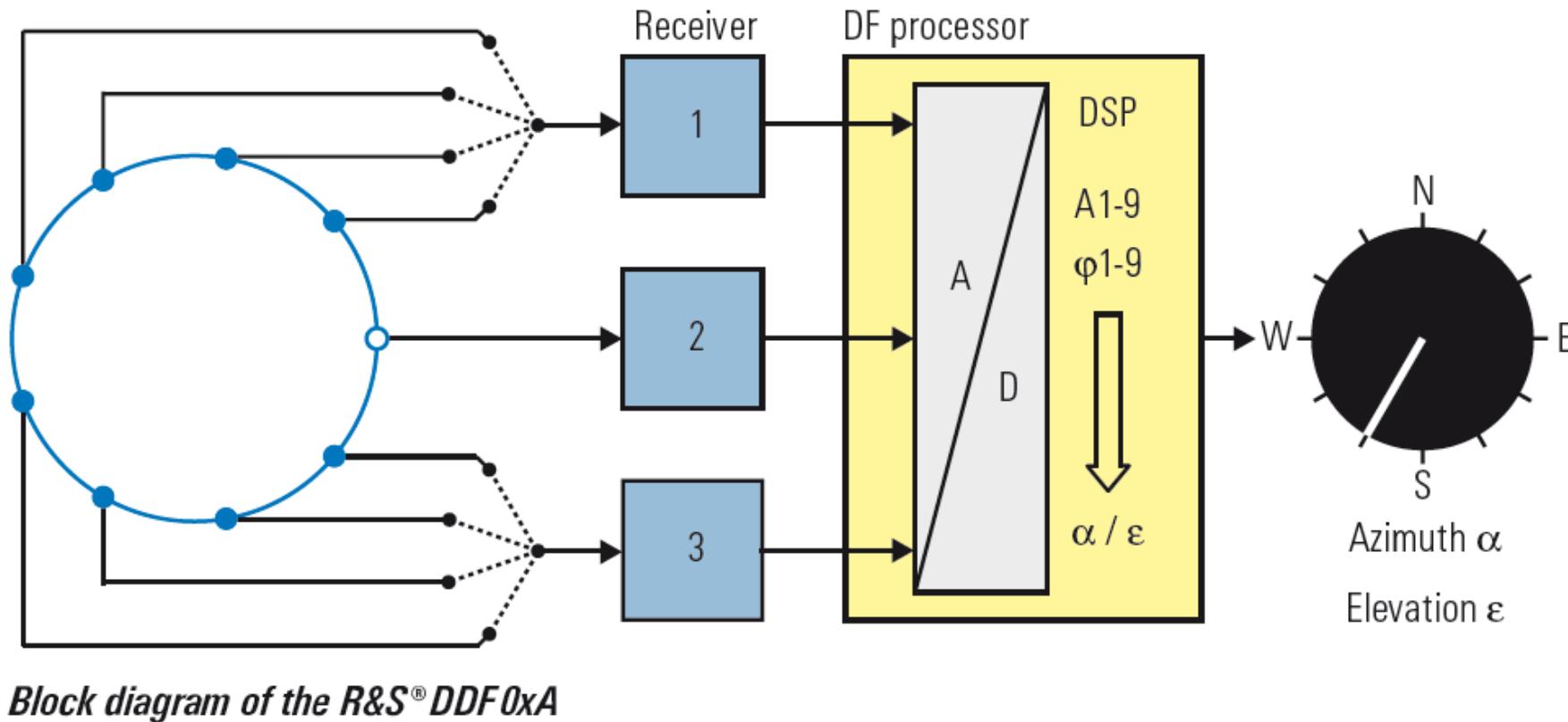
"Sistemes y equipos para la Navegación y Circulación Aérea."  
F. J. Sáez Nieto, M.A. Salamanca Bueno

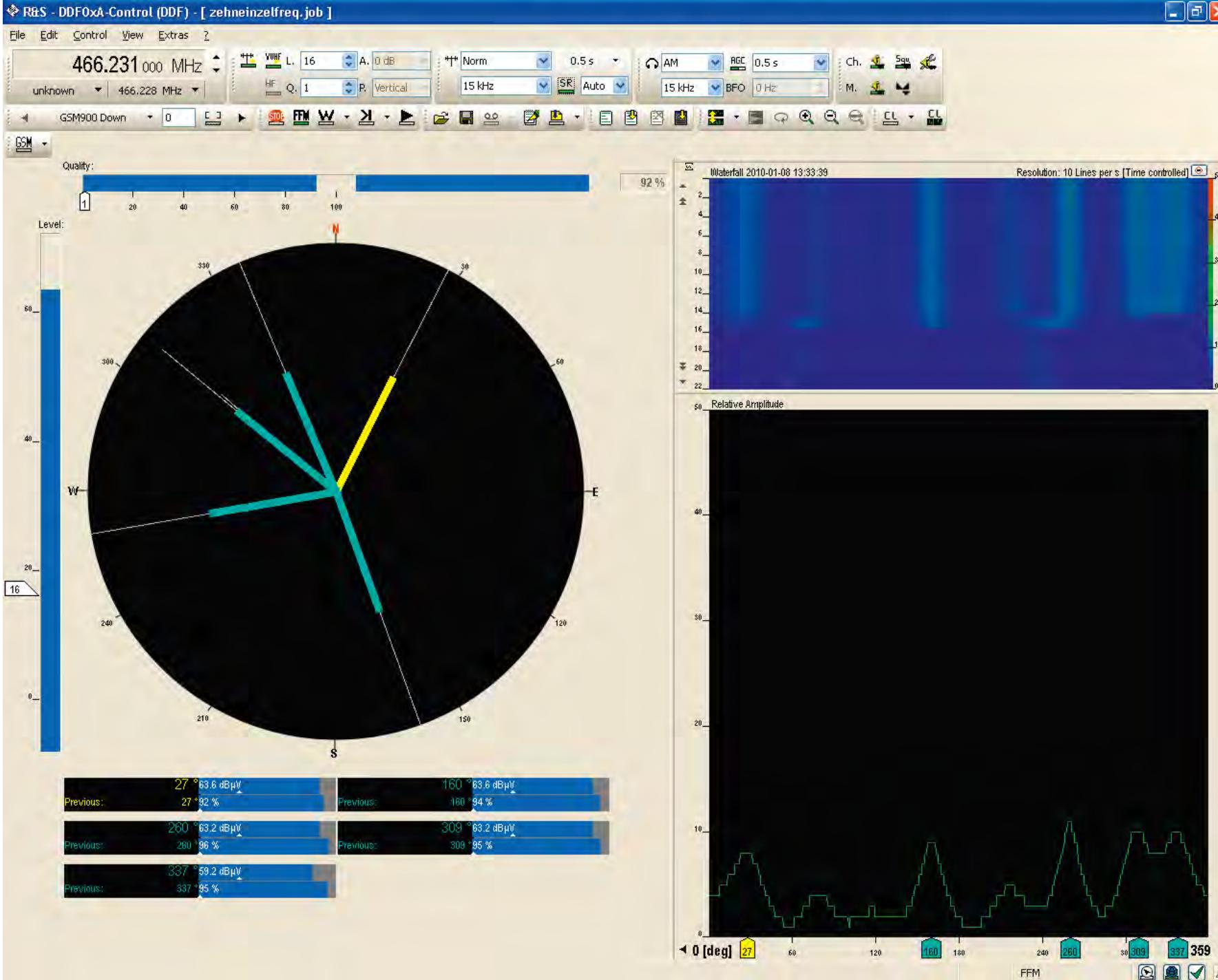
# CIRCUIT BÀSIC D'UN VDF



"Sistemas y equipos para la Navegación y Circulación Aérea."  
F. J. Sáez Nieto, M.A. Salamanca Bueno

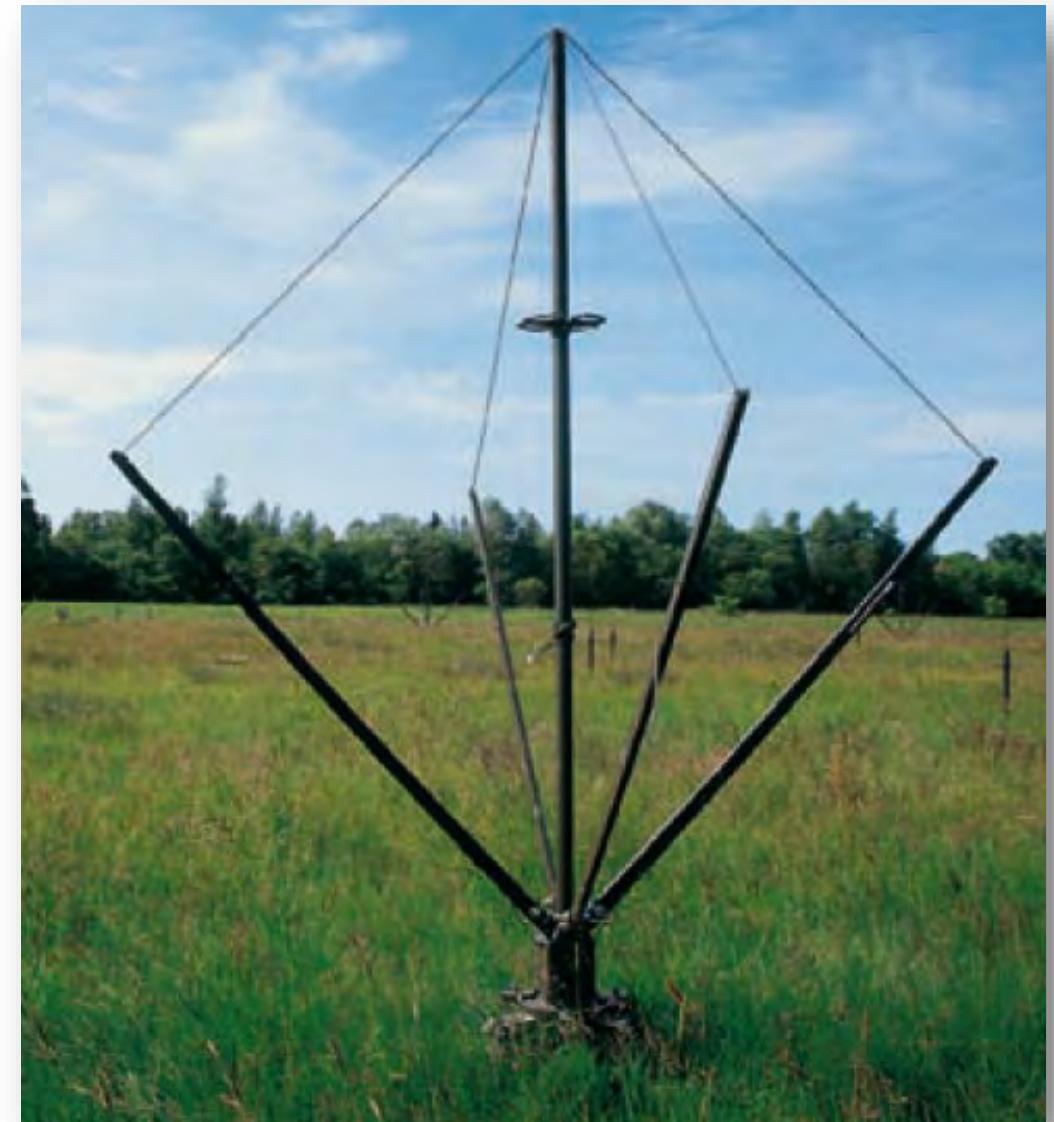
# Model comercial de Rhode&Schwarz





# DF per HF

- Stationary and transportable DF antenna for the frequency range from 300 kHz to 30 MHz.
- Suitable for ground waves and sky waves.
- Multi-element DF antenna with 9/18 antenna elements.
- DF measurements up to ITU class A DF accuracy.
- Available in different diameters (50 m, 100 m and 150 m).
- Model with 18 antenna elements in two concentric DF circles for especially high DF sensitivity and accuracy.
- Measurement of elevation enabling single station location (SSL) (optional).
- Ready for the super-resolution DF method.
- Antenna elements with active/passive switchover for adaptation to the signal environment.



# Tema 5:

## ELS EQUIPS I ELS SISTEMES RADIOELÈCTRICS AEROPORTUARIS

Jordi Berenguer  
Novembre 2021



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# Sistemes de cerca i rescat

COSPAS-SARSAT



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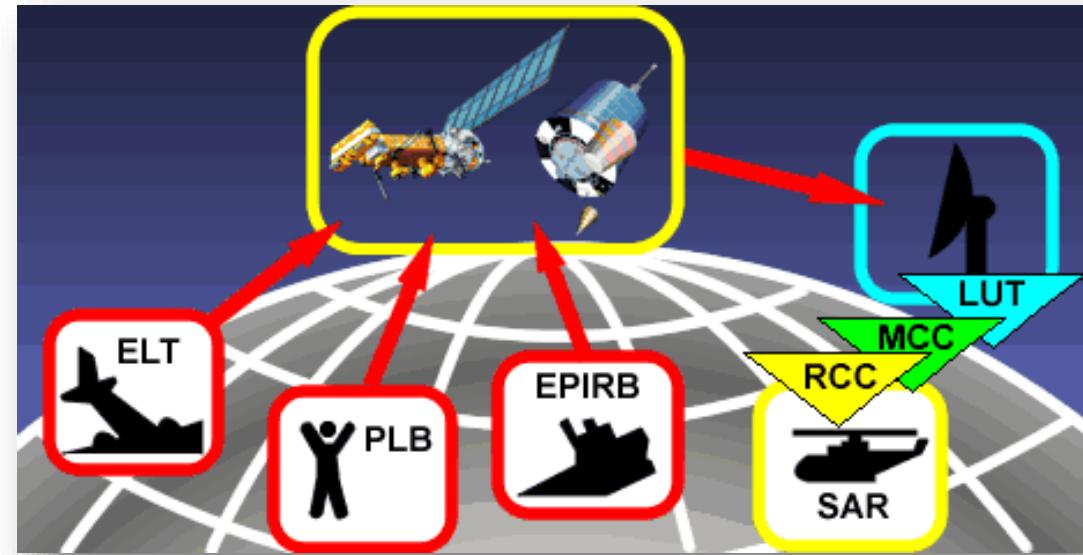
# COSPAS - SARSAT

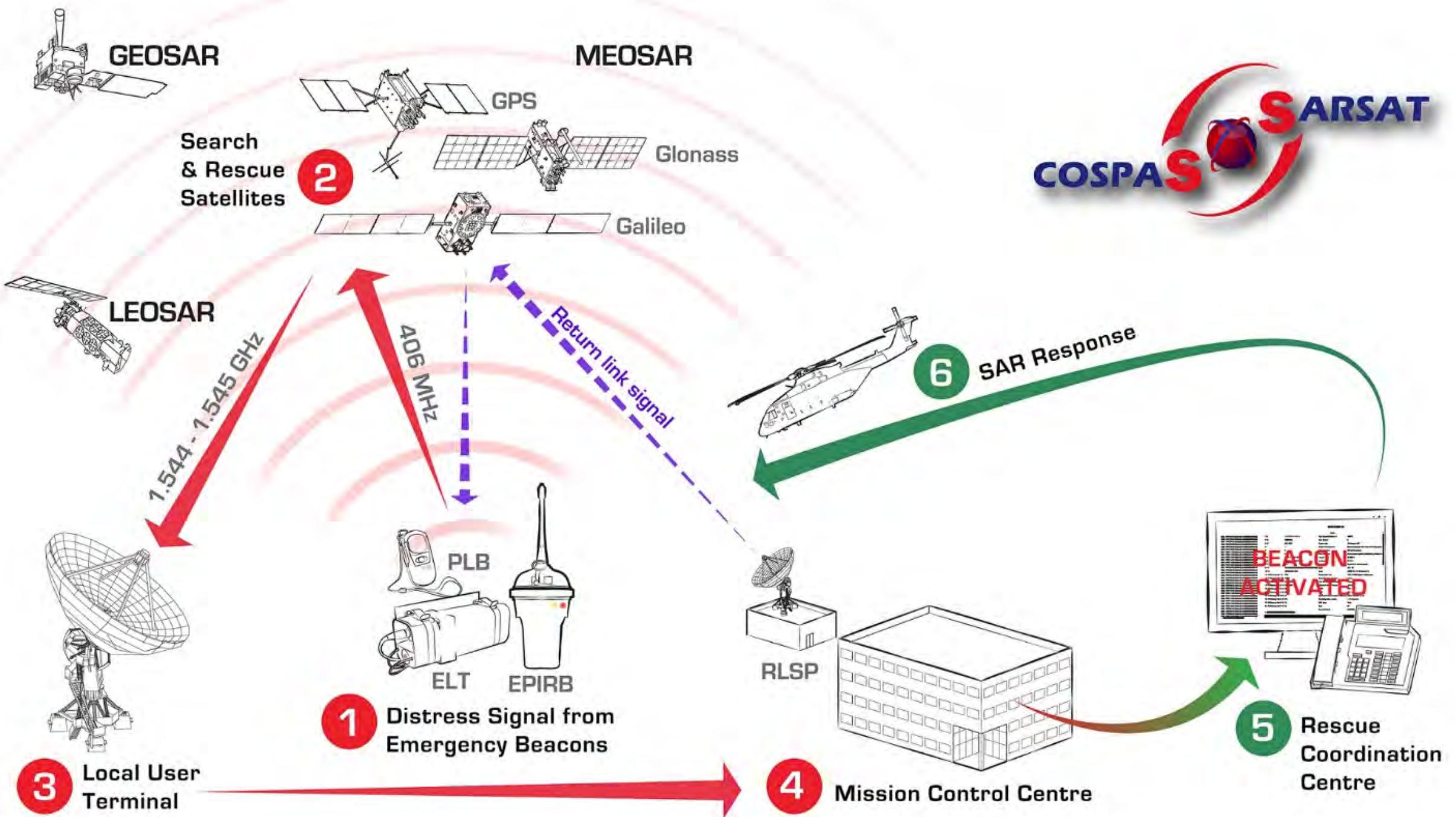
- The System is available to maritime and **aviation** users and to persons in distress situations. Access is provided to all States on a non-discriminatory basis, and **is free of charge** for the end-user in distress. On average, about 5 persons are rescued every day with the assistance of Cospas-Sarsat alert and location data.
- The System is composed of:
  - distress beacons operating at **406 MHz**;
  - SAR payloads on satellites in low-altitude Earth orbit and in geostationary orbit;
  - ground receiving stations (LUTs) spread around the world; and
  - a network of Mission Control Centres (MCCs) to distribute distress alert and location information to SAR authorities, worldwide.
- <https://www.cospas-sarsat.int>



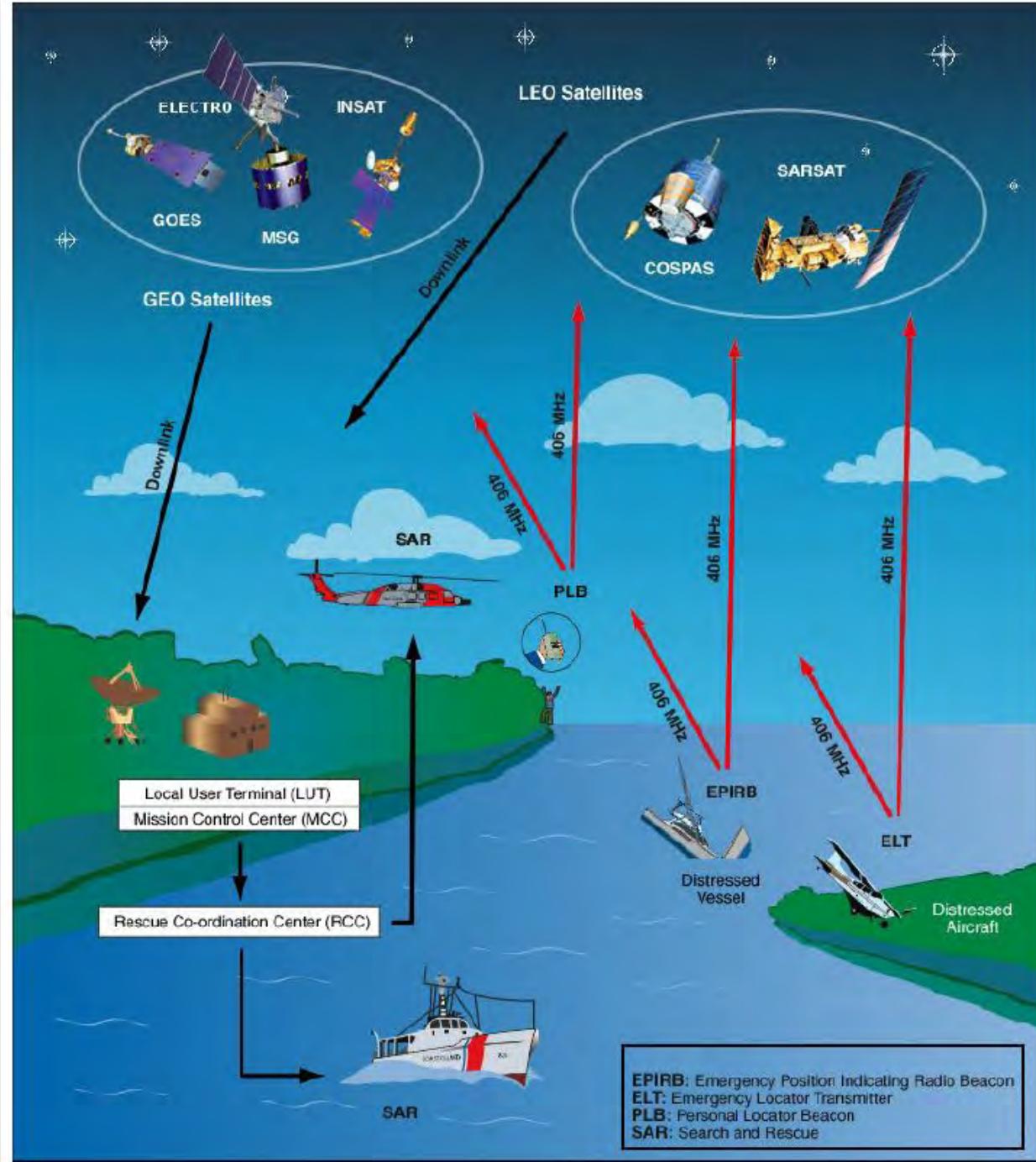
# DETAILED COSPAS-SARSAT SYSTEM DESCRIPTION

- The Cospas-Sarsat system only detects and locates distress beacons operating at 406 MHz; 121,5/243 MHz processing by Cospas-Sarsat ceased on 1 February 2009.
- The Cospas-Sarsat System is composed of:
  - 406 MHz radiobeacons carried aboard
    - ships (EPIRBs),
    - aircraft (ELTs),
    - or used as personal locator beacons (PLBs);
  - ship security alert devices (SSAS);
  - polar-orbiting satellites in low Earth orbit from the LEOSAR system and geostationary satellites from the GEOSAR system; and
  - a ground segment consisting of satellite receiving stations called Local User Terminals (LUTs), referred to as LEOLUTs for the LEOSAR system and GEOLUTs for the GEOSAR system, and data distribution nodes called Mission Control Centres (MCCs).









Notes:

COSPAS: Space system for the search of vessels in distress (Russia).

LEOSAR: Low Earth Orbit satellite system for SAR.

GEOSAR: Geostationary satellite system for SAR.

GOES: Geostationary operational environmental satellite (USA).

MSG: Meteosat second generation satellite (EUMETSAT).

SARSAT: Search and rescue satellite-aided tracking system (Canada, France and USA).

LEOLUT: Local user terminal in a LEOSAR system.

GEOLUT: Local user terminal in a GEOSAR system.

INSAT: Indian geostationary satellite.

# 406-MHz Beacons

- Frequencies in the 406.0 – 406,1 MHz band have been exclusively reserved for distress beacons operating with satellite systems.
- The Cospas-Sarsat 406 MHz beacons have been specifically designed for use with the LEOSAR system to provide improved performance in comparison to the now obsolete 121,5 MHz beacons.
- 406 MHz beacons have specific requirements on the stability of the transmitted frequency, and the inclusion of a digital message which allows the transmission of encoded data such as unique beacon identification.
- Second-generation 406 MHz beacons were introduced in 1997 which allow the transmission in the 406 MHz message of encoded position data acquired by the beacons from global satellite navigation systems such as GPS, using internal or external navigation receivers.
- This feature is of particular interest for GEOSAR alerts which otherwise would not be able to provide position information.



# Tipos de transmisor de localización de emergencia (ELT)

**Transmisor de localización de emergencia (ELT).** Término genérico que describe el equipo que difunde señales distintivas en frecuencias designadas y que, según la aplicación puede ser de activación automática al impacto o bien ser activado manualmente. Existen los siguientes tipos de ELT:

- *ELT fijo automático [ELT(AF)].* ELT de activación automática que se instala permanentemente en la aeronave.
- *ELT portátil automático [ELT(AP)].* ELT de activación automática que se instala firmemente en la aeronave, pero que se puede sacar de la misma con facilidad.
- *ELT de desprendimiento automático [ELT(AD)].* ELT que se instala firmemente en la aeronave y se desprende y activa automáticamente al impacto y en algunos casos por acción de sensores hidrostáticos. También puede desprenderse manualmente.
- *ELT de supervivencia [ELT(S)].* ELT que puede sacarse de la aeronave, que está estibado de modo que su utilización inmediata en caso de emergencia sea fácil y que puede ser activado manualmente por los sobrevivientes.

# Normativa OACI per a ELT

## 1. GENERALIDADES

1.1 El transmisor de localización de emergencia (ELT) que funciona en 406 MHz tendrá la capacidad de transmitir un mensaje digital programado que contiene información sobre el ELT o la aeronave que lo lleva.

1.2 La clave del ELT será única, de conformidad con 1.3, y se registrará ante las autoridades competentes.

1.3 El mensaje digital ELT contendrá el número de serie del transmisor o bien uno de los datos siguientes:

- a) el designador de la entidad explotadora de la aeronave y un número de serie;
- b) la dirección de aeronave de 24 bits;
- c) las marcas de nacionalidad y de matrícula de la aeronave.

1.4 Todos los ELT se diseñarán para funcionar con el sistema COSPAS-SARSAT\* y se aprobarán por tipo.

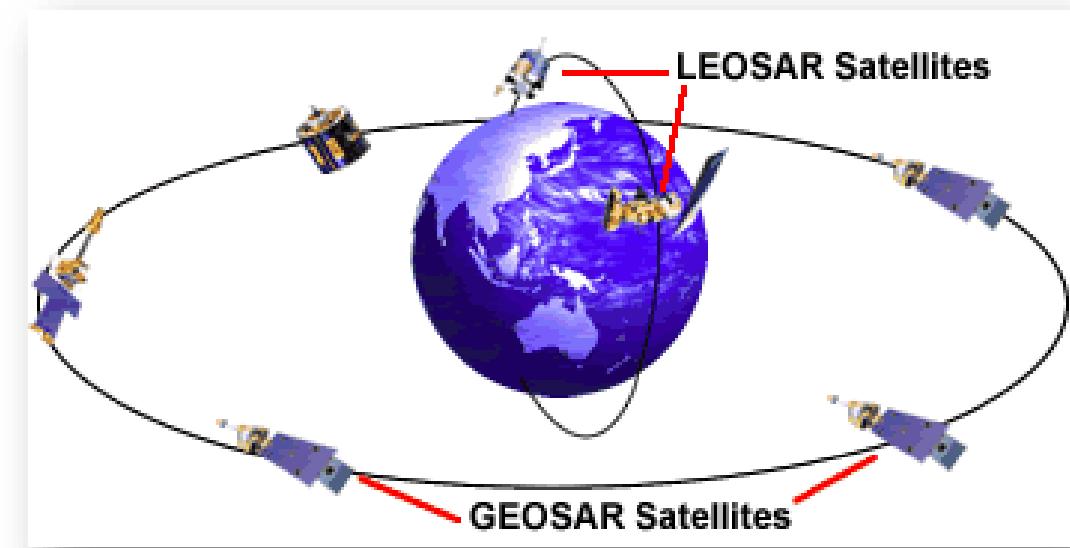
*Nota.— Las características de la señal del ELT pueden confirmarse utilizando la norma de aprobación de tipo de COSPAS-SARSAT (Type Approval Standard C/S T.007).*

*Aplicable a partir del 1 de julio de 2008*

**6.17.7 Recomendación.—** *Todos los aviones deberían llevar un ELT automático.*

# LEOSAR System

- The Cospas-Sarsat LEOSAR system uses polar-orbiting satellites and, therefore, operates with basic constraints which result from non-continuous coverage provided by LEOSAR satellites.
- The use of low-altitude orbiting satellites provides for a strong Doppler effect in the up-link signal thereby enabling the use of Doppler positioning techniques.
- The LEOSAR system operates in two coverage modes, namely local and global coverage.



# LEOSAR System

## LEOSAR Local Mode

- When the satellite receives beacon signals, the on-board Search and Rescue Processor (SARP) recovers the digital data from the beacon signal, measures the Doppler frequency shift and time-tags the information.
- The result of this processing is formatted as digital data which is transferred to the satellite downlink for transmission to any LEOLUT in view. This data is also simultaneously stored on the spacecraft for later transmission and ground processing in the global coverage mode.
- The diagram to the left depicts a LEOSAR satellite orbiting the Earth and its instantaneous field of view is indicated by the red circle. In this example the beacon located in the Northern Atlantic is within the local coverage area of the LEOLUT located on the north west coast of Africa whereas the beacon located in Antarctica is not.
- In addition to the local mode provided by the SARP instrument, a repeater can also provide a local mode of operation. The difference between the SARP and the repeater is that the SARP performs some of the processing onboard the satellite, whereas the repeater simply reflects the beacon signal to the Earth, thereby requiring additional processing on the ground.

## LEOSAR Global Mode

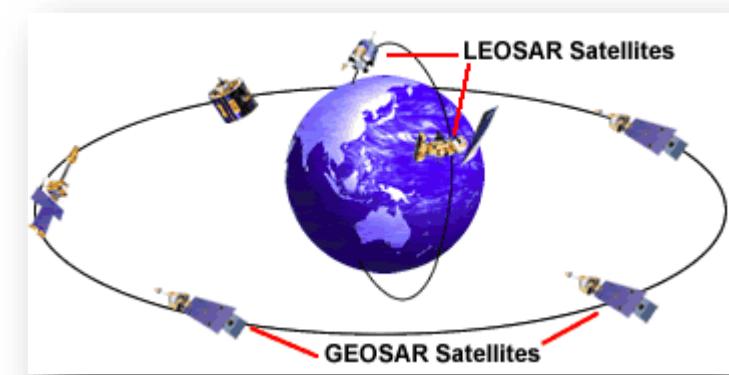
- The 406-MHz SARP system provides global coverage by storing data derived from onboard processing of beacon signal, in the spacecraft memory unit. The content of the memory is continuously broadcast on the satellite downlink. Therefore, each beacon can be located by all LEOLUTs which track the satellite (even for LEOLUTs which were not in the footprint of the satellite at the time the beacon was detected by the satellite). This provides the global coverage and introduces ground segment processing redundancy.

The diagram to the right depicts a LEOSAR satellite orbiting the Earth in the direction of the north pole. The blue circle represents the satellite field of view at a point in the recent past when the satellite was over the southern Atlantic Ocean. At that point in time the satellite detected the beacon in Antarctica, however, since there were no LEOLUTs in its field of view, a distress alert could not be generated at that time. Nevertheless, the satellite continued to transmit the processed data associated with this distress beacon. When the LEOLUT located on the north west coast of Africa came into the view of the satellite, this LEOLUT received the beacon information and generated a distress alert.

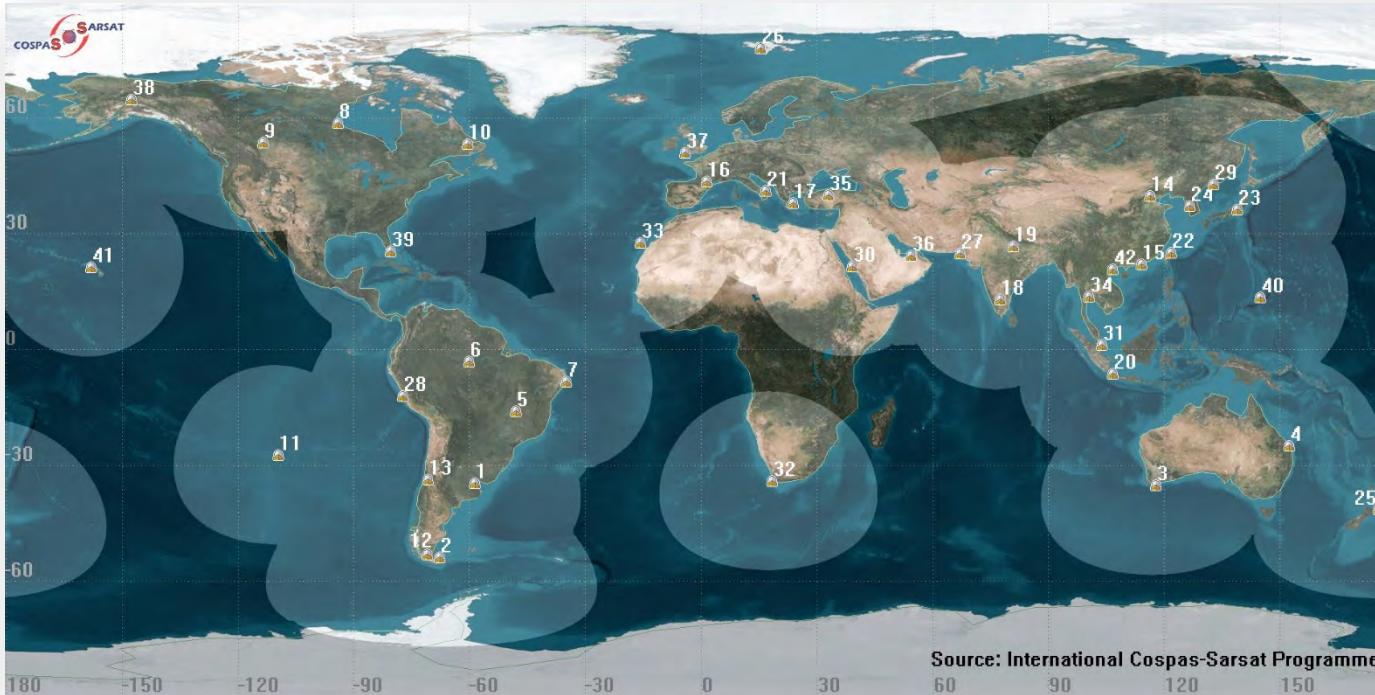
- The global mode may also offer an additional advantage over the local mode in respect of alerting time. As the beacon message is recorded in the satellite memory by the first satellite pass which detected the beacon, the waiting time is not dependent upon the satellite achieving simultaneous visibility with the LEOLUT and the beacon. Consequently, the time required to produce alerts could be considerably reduced.

# GEOSAR System

- Cospas-Sarsat has demonstrated that the current generation of Cospas-Sarsat beacons could be detected using search and rescue instruments on board geostationary satellites.
- The GEOSAR system consists of repeaters carried on board various geostationary satellites and the associated ground facilities called GEOLUTs which process the satellite signal.
- Geostationary satellites orbit the Earth at an altitude of 36,000 km, with an orbit period of 24 hours, thus appearing fixed relative to the Earth at approximately 0 degrees latitude (i.e. over the equator). A single geostationary satellite provides GEOSAR uplink coverage of about one third of the globe, except for polar regions. Therefore, three geostationary satellites equally spaced in longitude can provide continuous coverage of all areas of the globe between approximately 70 degrees North and 70 degrees South latitude.
- Since GEOSAR satellites remain fixed relative to the Earth, there is no Doppler effect on the received frequency and, therefore, the Doppler positioning technique cannot be used to locate distress beacons. To provide rescuers with position information, the beacon location must be either:
  - acquired by the beacon though an internal or an external navigation receiver and encoded in the beacon message, or
  - derived from the LEOSAR system Doppler processing.

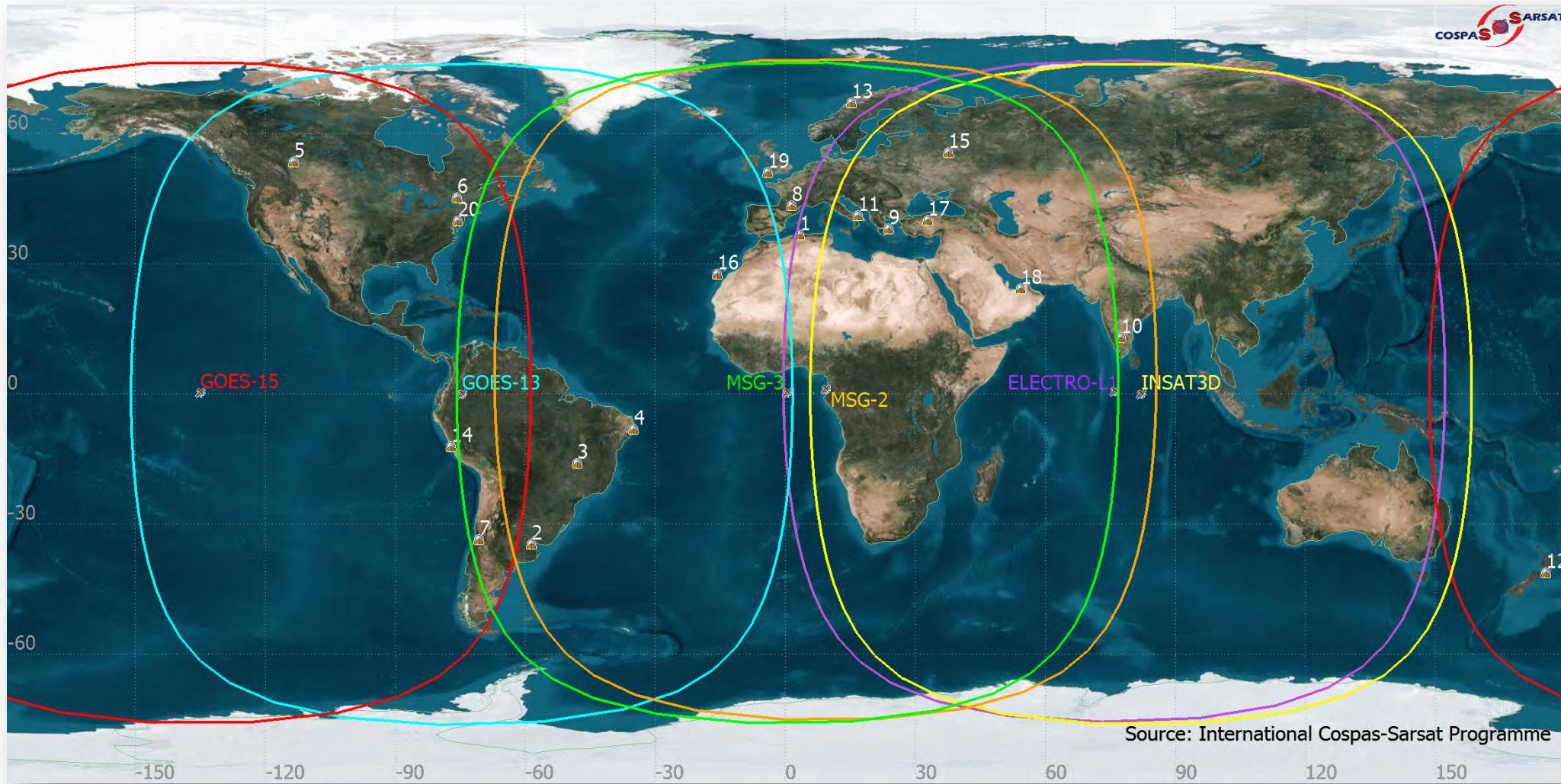


# LELOUT's



1-	EL PALOMAR, ARGENTINA	22-	KEELUNG (ITDC) *
2-	RIO GRANDE, ARGENTINA	23-	GUNMA, JAPAN
3-	ALBANY, AUSTRALIA	24-	SEJONG, KOREA (R. of)
4-	BUNDABERG, AUSTRALIA	25-	WELLINGTON, NEW ZEALAND
5-	BRASILIA, BRAZIL	26-	SPITSBERGEN, NORWAY
6-	MANAUS, BRAZIL	27-	KARACHI, PAKISTAN
7-	RECIFE, BRAZIL	28-	CALLAO, PERU
8-	CHURCHILL, CANADA	29-	NAKHODKA, RUSSIA
9-	EDMONTON, CANADA	30-	JEDDAH, SAUDI ARABIA *
10-	GOOSE BAY, CANADA	31-	SINGAPORE
11-	EASTER ISLAND, CHILE	32-	CAPE TOWN, SOUTH AFRICA
12-	PUNTA ARENAS, CHILE	33-	MASPALOMAS, SPAIN
13-	SANTIAGO, CHILE	34-	BANGKOK, THAILAND *
14-	BEIJING, CHINA (P.R. of) *	35-	ANKARA, TURKEY *
15-	HONG KONG, CHINA *	36-	ABU DHABI, UAE
16-	TOULOUSE, FRANCE *	37-	COMBE MARTIN, UK
17-	PENTELI, GREECE	38-	ALASKA, USA *
18-	BANGALORE, INDIA	39-	FLORIDA, USA *
19-	LUCKNOW, INDIA	40-	GUAM, USA *
20-	JAKARTA, INDONESIA	41-	HAWAII, USA *
21-	BARI, ITALY	42-	HAIPHONG, VIETNAM

# GEOLUT's



# Bibliografia

- OACI, Anexo 12, “Búsqueda y Salvamento”.
- OACI, Anexo 10, “Telecomunicaciones aeronáuticas”, Volumen III, “Sistemas de comunicaciones”.
- OACI, Anexo 6, “Operación de Aeronaves”, Parte I, “Transporte aéreo internacional. Aviones”.

# PULSED RADAR

Jordi Berenguer

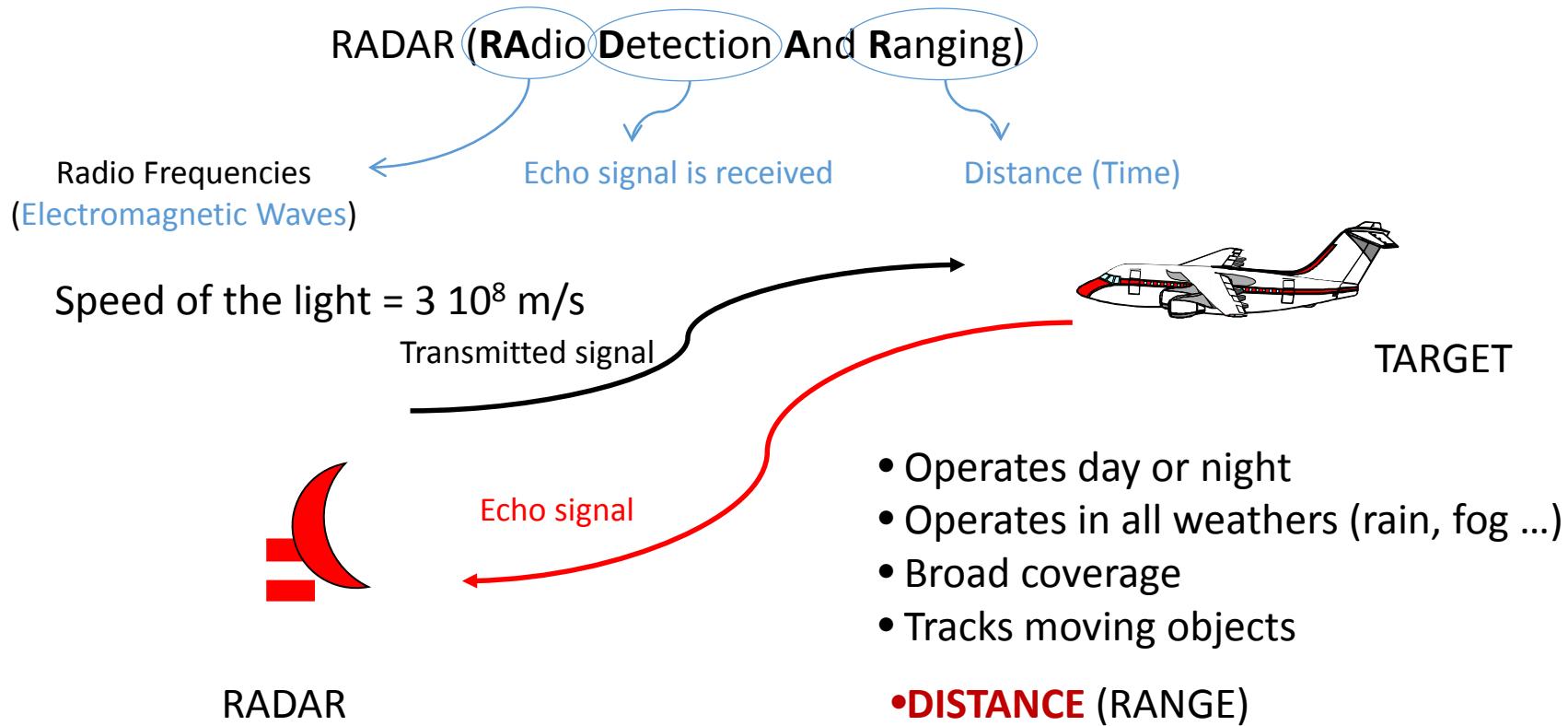


UNIVERSITAT POLITÈCNICA DE CATALUNYA

BARCELONATECH

Departament de Teoria del Senyal  
i Comunicacions

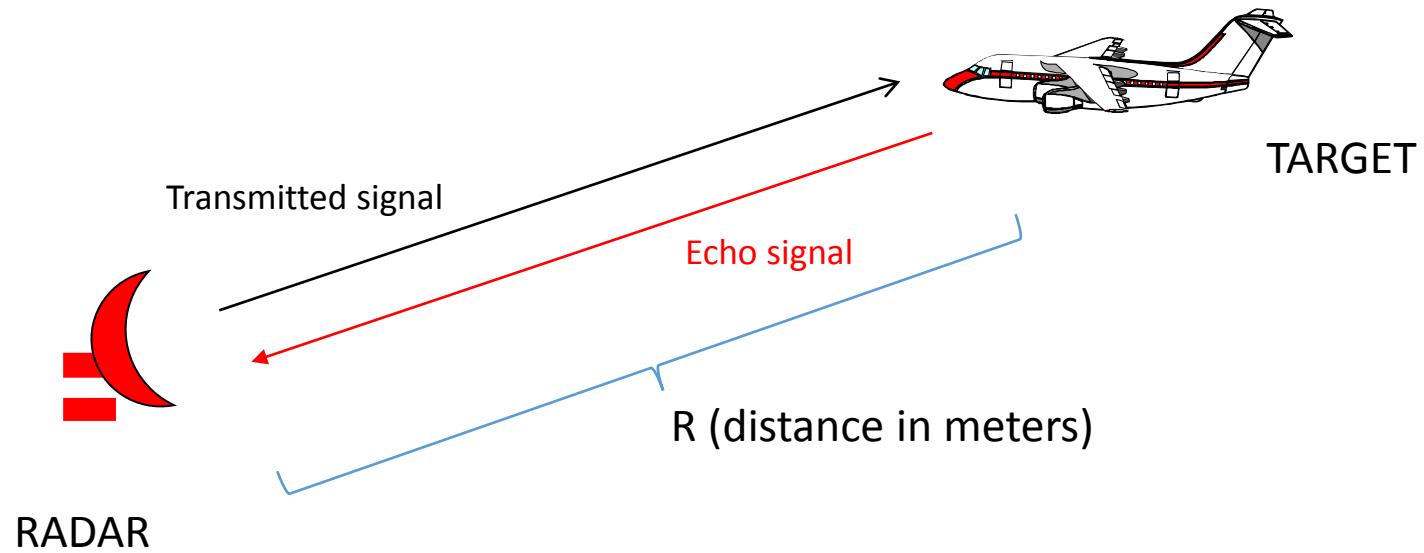
# State the principles of Radar



A SYSTEM THAT USES REFLECTED RADIO SIGNALS

# State the principles of Radar

RADAR (RAdio Detection And Ranging)



Speed of light,  $c = 3 \cdot 10^8$  m/s

DISTANCE

$$R = \frac{c \cdot T_T}{2}$$

# Frequency Bands

Established by the International Telecommunications Union (ITU)



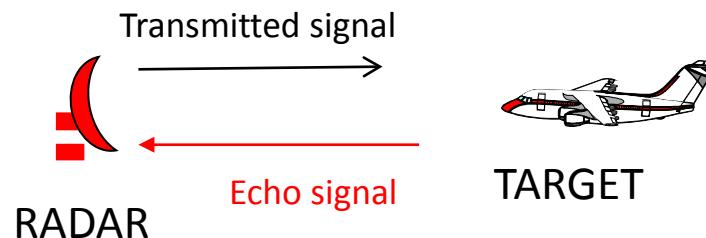
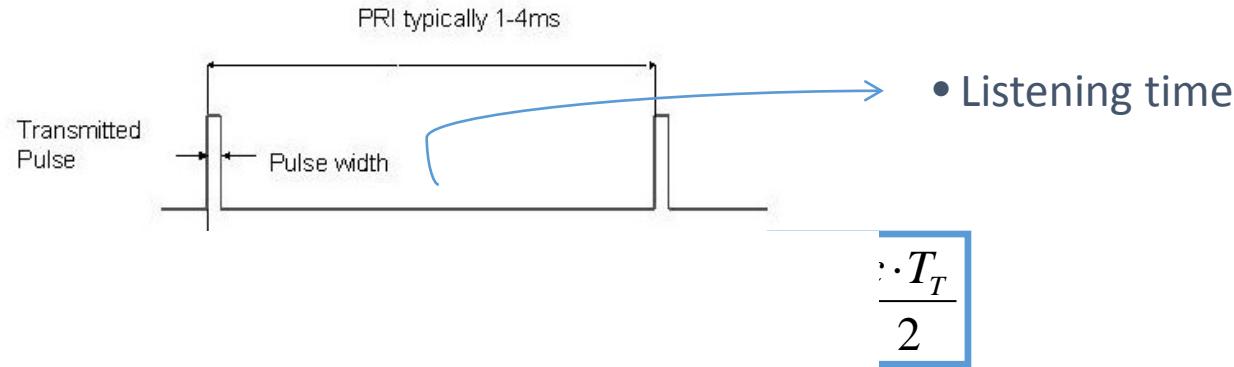
Denomination	Acronym	Frequencies	Wavelength
Very Low Frequency	VLF	3 kHz - 30 kHz	100 km - 10 km
Low Frequency	LF	30 kHz - 300 kHz	10 km - 1 km
Medium Frequency	MF	300 kHz - 3 MHz	1 km - 100 m
High Frequency Aeronautical communications (HF, VHF), and radionavigation Very High Frequency aids (ILS, VOR, NDB, ...)	HF	3 MHz - 30 MHz	100 m - 10 m
Ultra High Frequency RADAR Super High Frequency	VHF	30 MHz - 300 MHz	10 m - 1 m
Extremely High Frequency	UHF	300 MHz - 3 GHz	100 cm - 10 cm
	SHF	3 GHz - 30 GHz	10 cm - 1 cm
	EHF	30 GHz - 300 GHz	10 mm - 1 mm



# Primary Surveillance RADAR: Basics

## Transmitting signal (Pulsed signal)

- Pulsed signal: short pulses/very high power



Characteristics:

T: Pulse repetition Time (PRT)

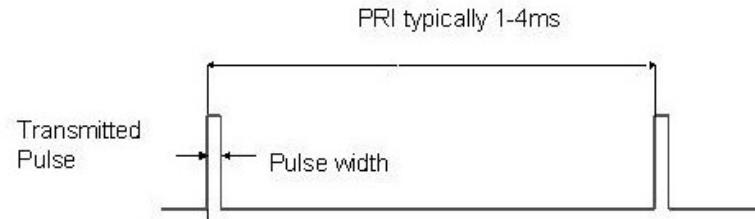
1/T= Pulse repetition Frequency (PRF)

$\tau$ : Pulse width

# Primary Surveillance RADAR: Basics

## Transmitting signal (Pulsed signal)

- Pulsed signal: short pulses/very high power



Mathematical formulation of a Train of pulses

$$\tilde{x}(t) = A \cdot \prod \left( \frac{t}{\tau} \right)$$

$$x(t) = A \cdot \sum_{n=-\infty}^{\infty} \prod \left( \frac{t-nT}{\tau} \right) = \sum_{-\infty}^{+\infty} c_n e^{jn\omega t} = \sum_{-\infty}^{+\infty} c_n e^{jn\frac{2\pi}{T}t}$$

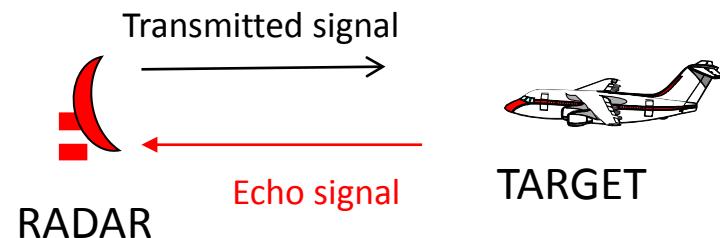
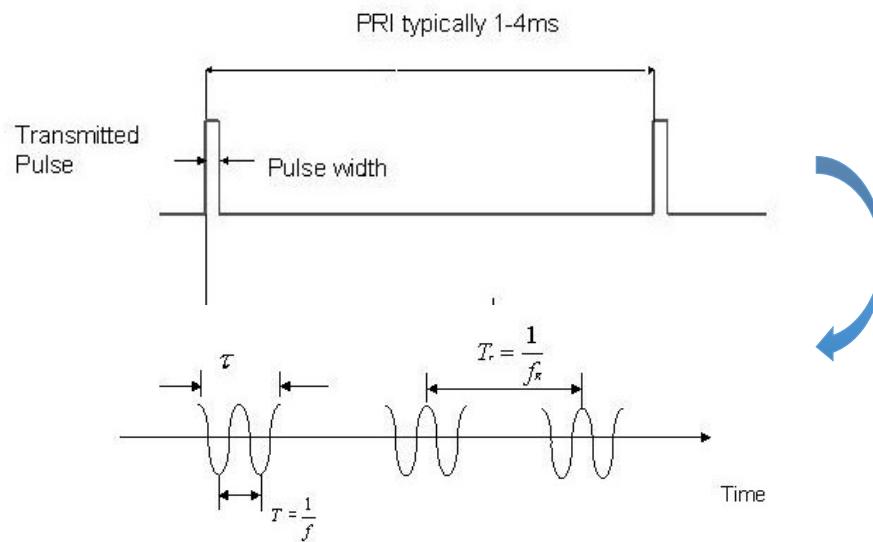
$$c_n = \frac{1}{T} \int_0^T \tilde{x}(t) e^{-jn\omega t} dt = \frac{A}{T} \int_0^\tau e^{-jn\omega t} dt = A \frac{\tau}{T} \frac{\sin(n\omega\tau/2)}{n\omega\tau/2} = A \frac{\tau}{T} \text{sinc}\left(n \frac{\tau}{T}\right)$$

Characteristics:

T: Pulse repetition Time (PRT) (period)  
1/T= Pulse repetition Frequency (PRF)  
τ: Pulse width

# Primary Surveillance RADAR: Basics

## Transmitting signal



Needs to be modulated in frequency, otherwise cannot be transmitted

### Characteristics:

T: Pulse repetition Time (PRT)

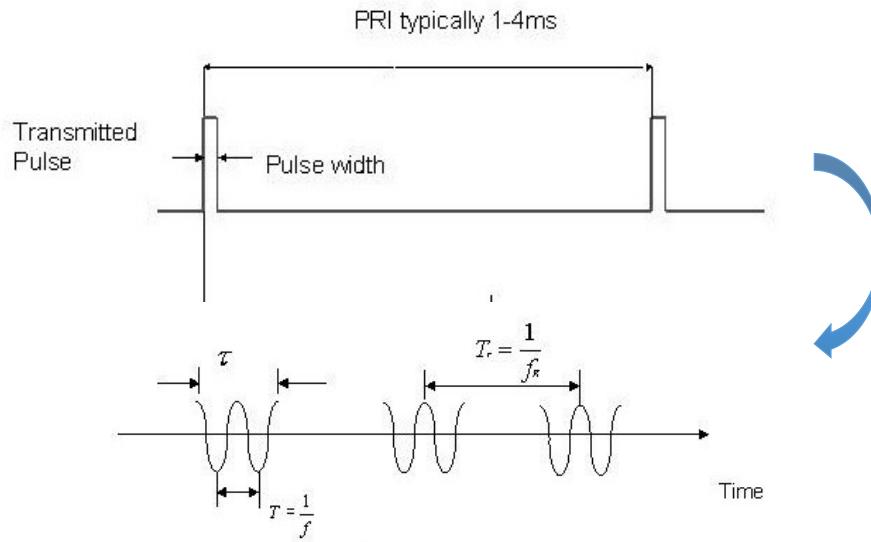
$1/T$ = Pulse repetition Frequency (PRF)

$\tau$ : Pulse width

$f_0$ : operating frequency

# Primary Surveillance RADAR: Basics

## Transmitting signal



Needs to be modulated in frequency, otherwise cannot be transmitted

### Characteristics:

T: Pulse repetition Time (PRT)

1/T= Pulse repetition Frequency (PRF)

$\tau$ : Pulse width

$f_0$ : operating frequency

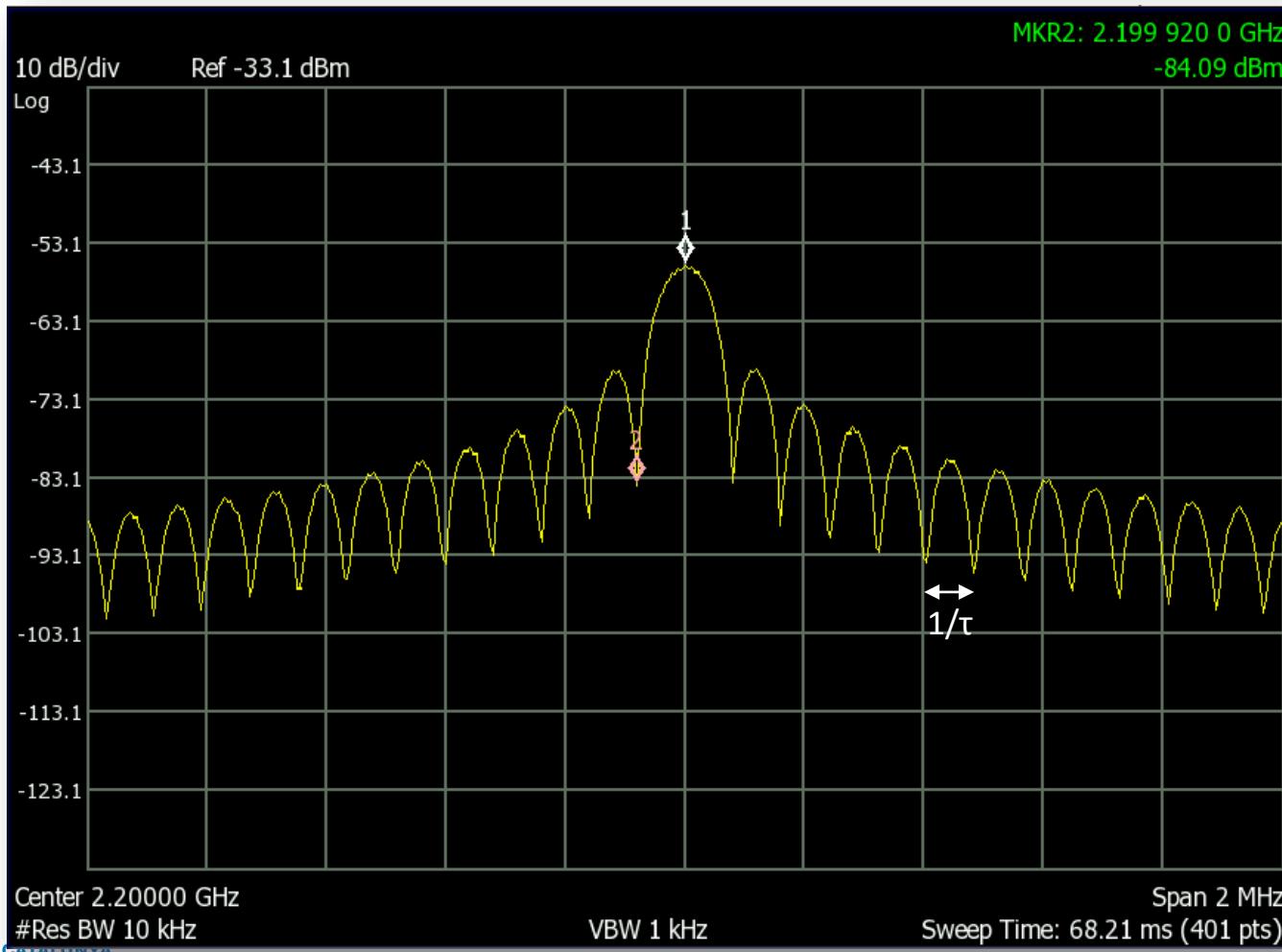
- Mathematical formulation of a Train of pulses modulated a  $f_0$

$$y(t) = \cos(2\pi f_0 t)$$

$$x(t) = A \cdot \sum_{n=-\infty}^{\infty} \prod \left( \frac{t - nT}{\tau} \right) \cdot \cos(2\pi f_0 t)$$

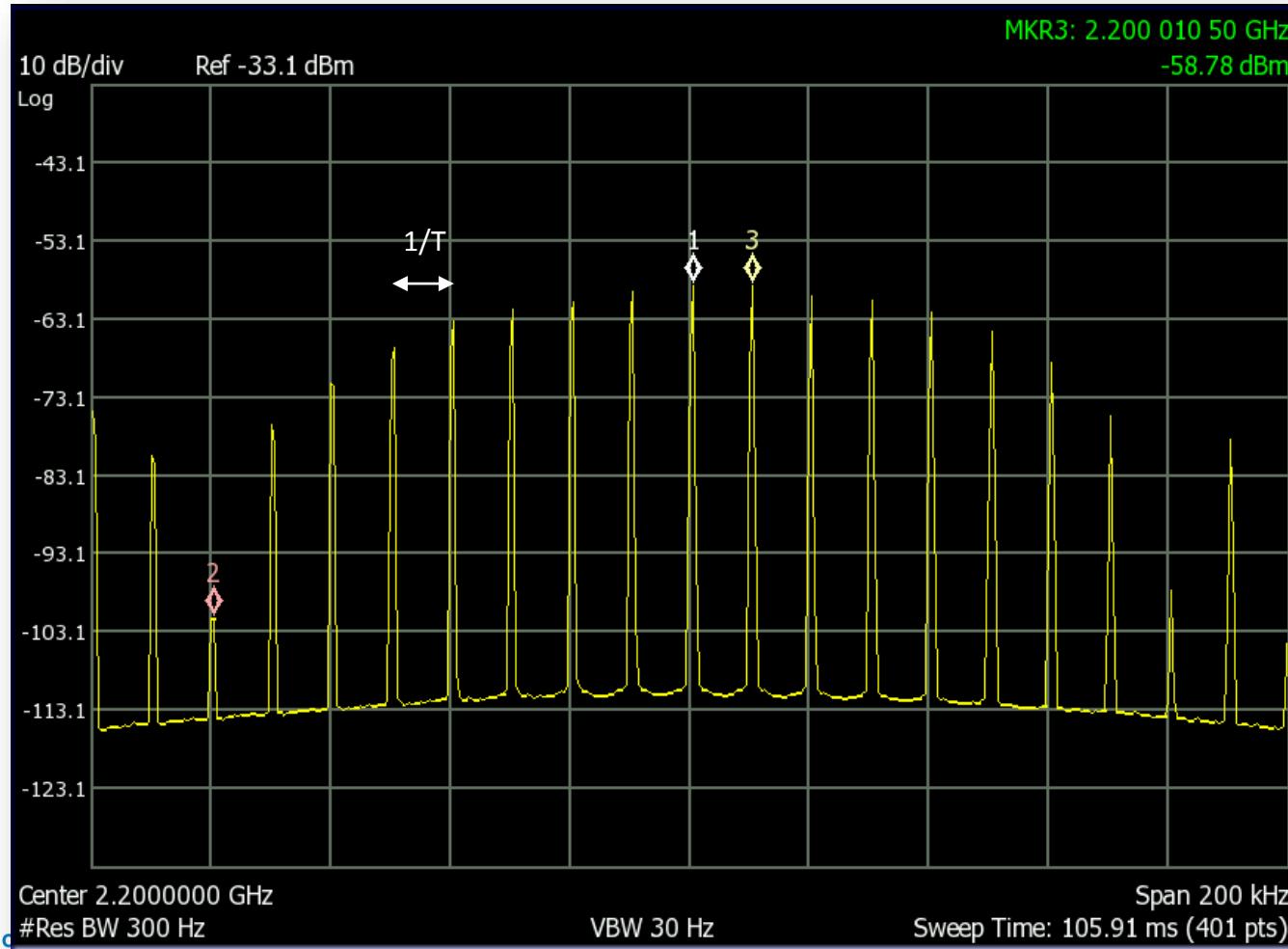
# Primary Surveillance RADAR: Basics

Frequency spectrum of a transmitted pulsed signal



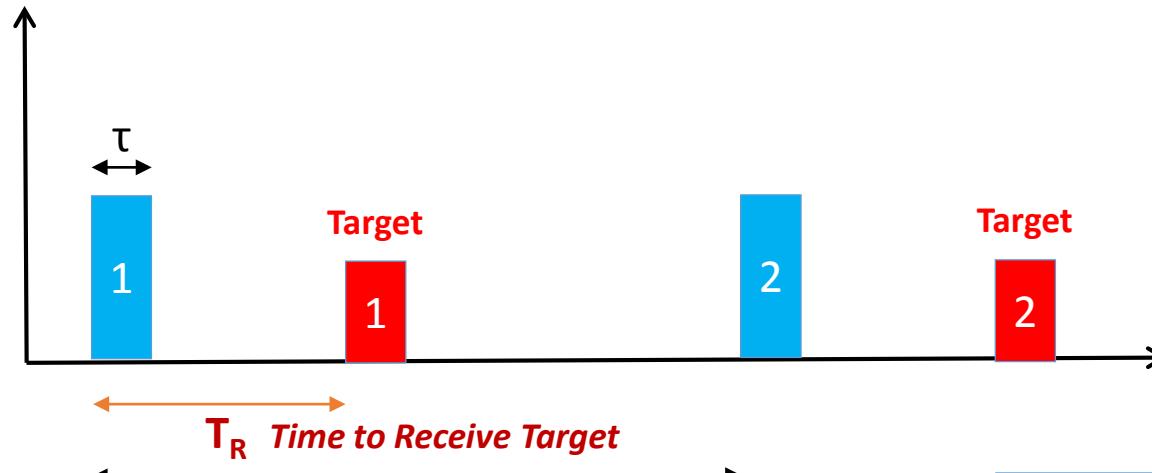
# Primary Surveillance RADAR: Basics

Frequency spectrum of a transmitted pulsed signal

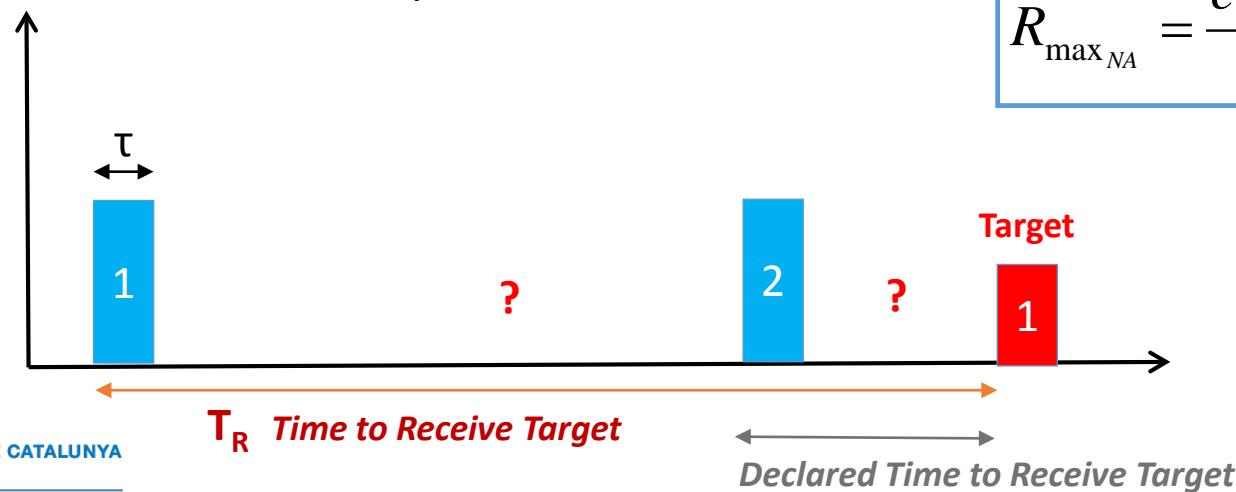


# Primary Surveillance RADAR: Basics

## Range Ambiguity

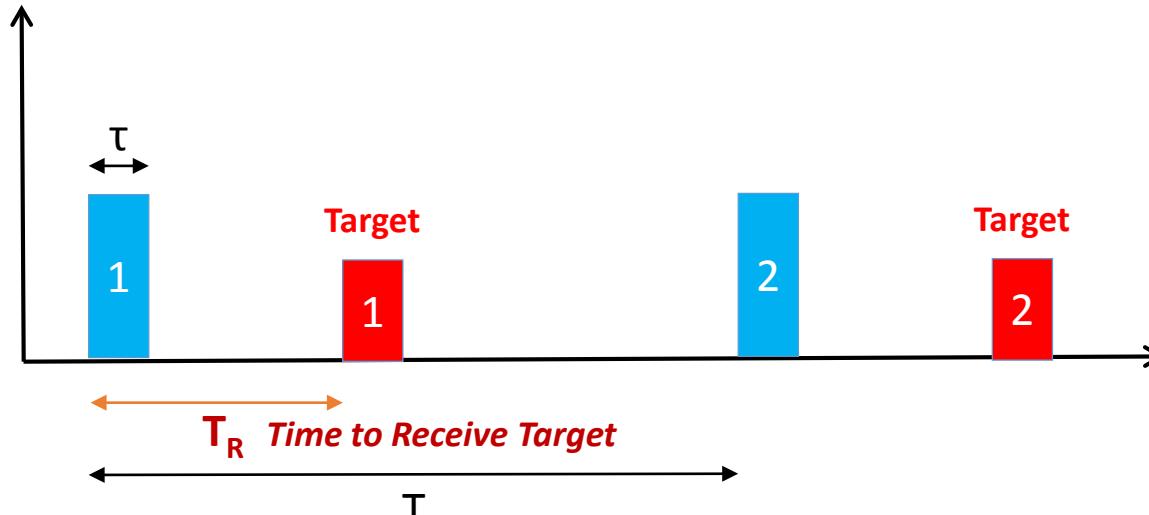


$$R_{\max_{NA}} = \frac{c \cdot T}{2} = \frac{c}{2 \cdot PRF}$$

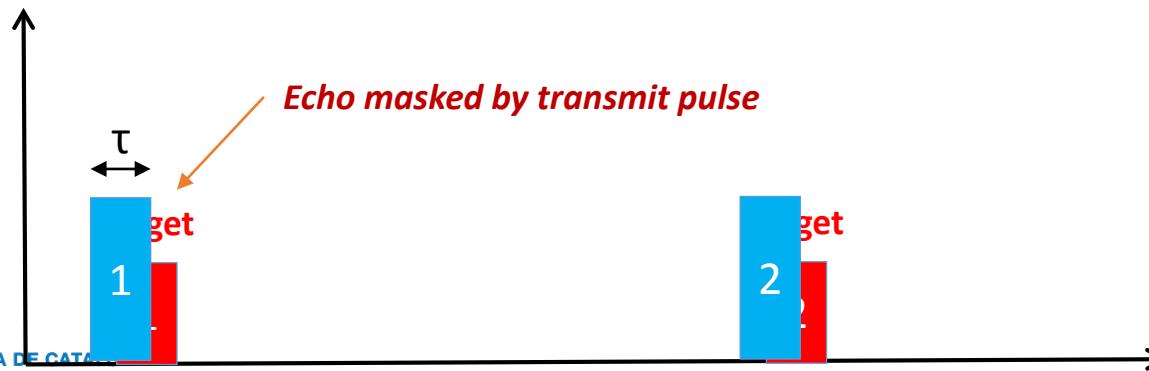


# Primary Surveillance RADAR: Basics

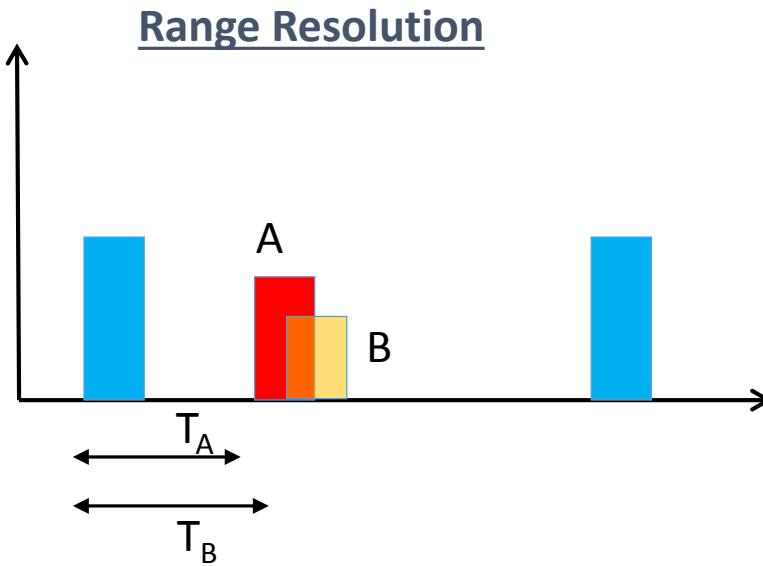
Minimum Range (blind range)



$$R_{blind} = \frac{c \cdot \tau}{2}$$



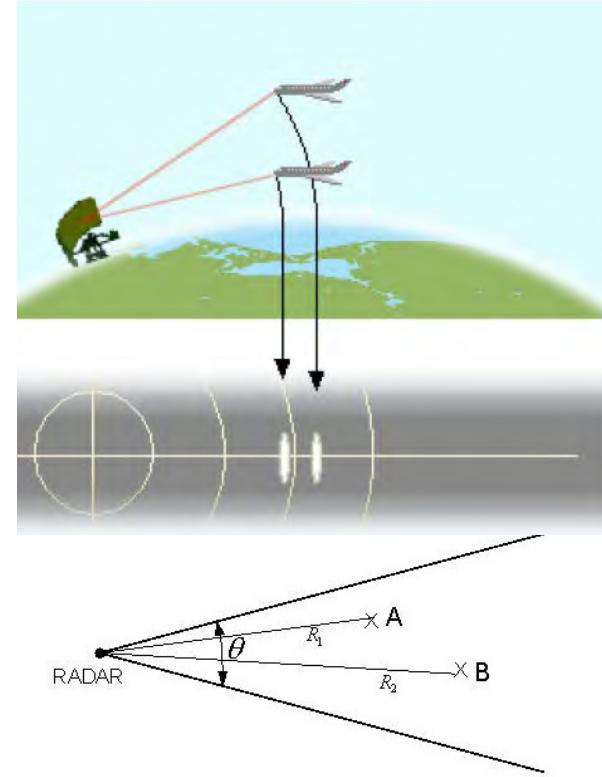
# Primary Surveillance RADAR: Basics



$$T_A = \frac{2R_A}{c}$$

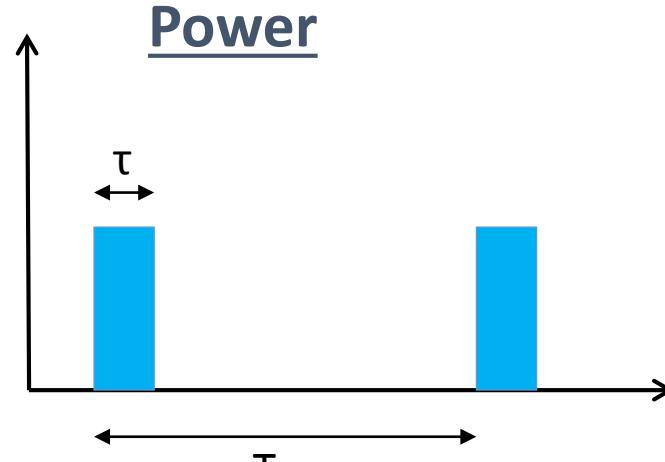
$$T_B = \frac{2R_B}{c}$$

$$\tau < T_B - T_A = \frac{2R_B}{c} - \frac{2R_A}{c} = \frac{2(R_B - R_A)}{c} = \frac{2}{c} \Delta R$$



$$\Delta R = \delta_z = \frac{c \cdot \tau}{2}$$

# Primary Surveillance RADAR: Basics



In dB's

$$dB = 10 \cdot \log\left(\frac{P_1(W)}{P_2(W)}\right)$$

$$dBW = 10 \cdot \log\left(\frac{P_1(W)}{1W}\right)$$

$$dBm = 10 \cdot \log\left(\frac{P_1(W)}{1mW}\right) = dBW + 30dB$$

- Duty cycle:

$$DC = \frac{\tau}{T}$$

- Peak power [W]:

$$P_t$$

- Average power [W]:

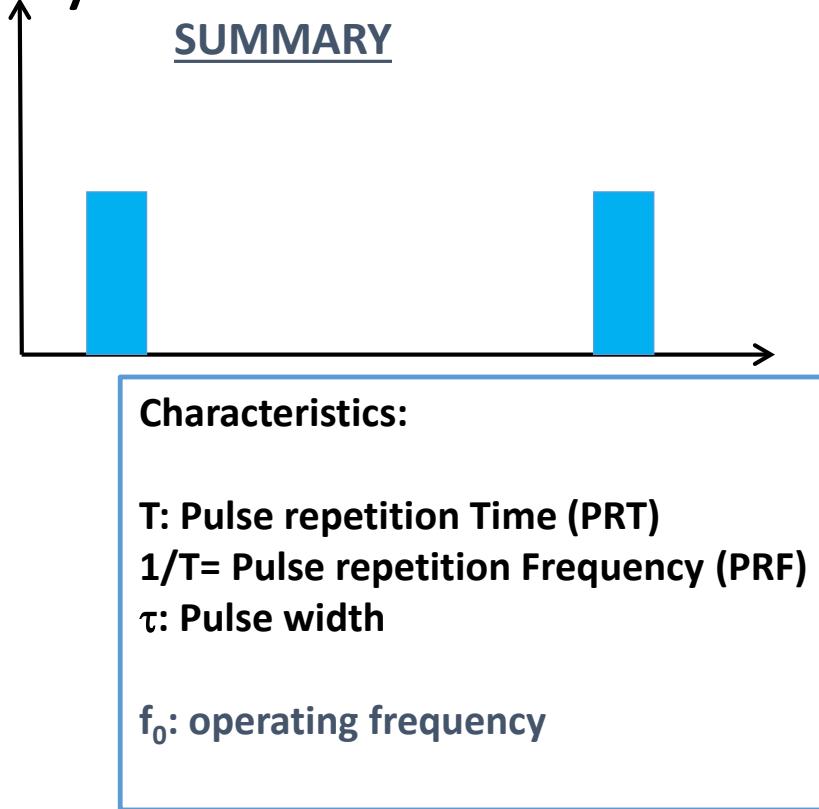
$$P_{av} = \frac{1}{T} \int_{-T/2}^{+T/2} |x(t)|^2 dt = \frac{P_t \cdot \tau}{T}$$

$$= P_t \cdot DC$$

- Pulse energy [J]:

$$E_1 = P_t \cdot \tau$$

# Primary Surveillance RADAR: Basics



- Peak power:  $P_t$
- Medium power:  $P_{av} = P_t \cdot DC = P_t \cdot \tau / T$
- Duty cycle:  $DC = \tau / T$

## Range

$$R = \frac{c \cdot T_R}{2}$$

## Maximum Unambiguous Range

$$R_{\max_{NA}} = \frac{c \cdot T}{2} = \frac{c}{2 \cdot PRF}$$

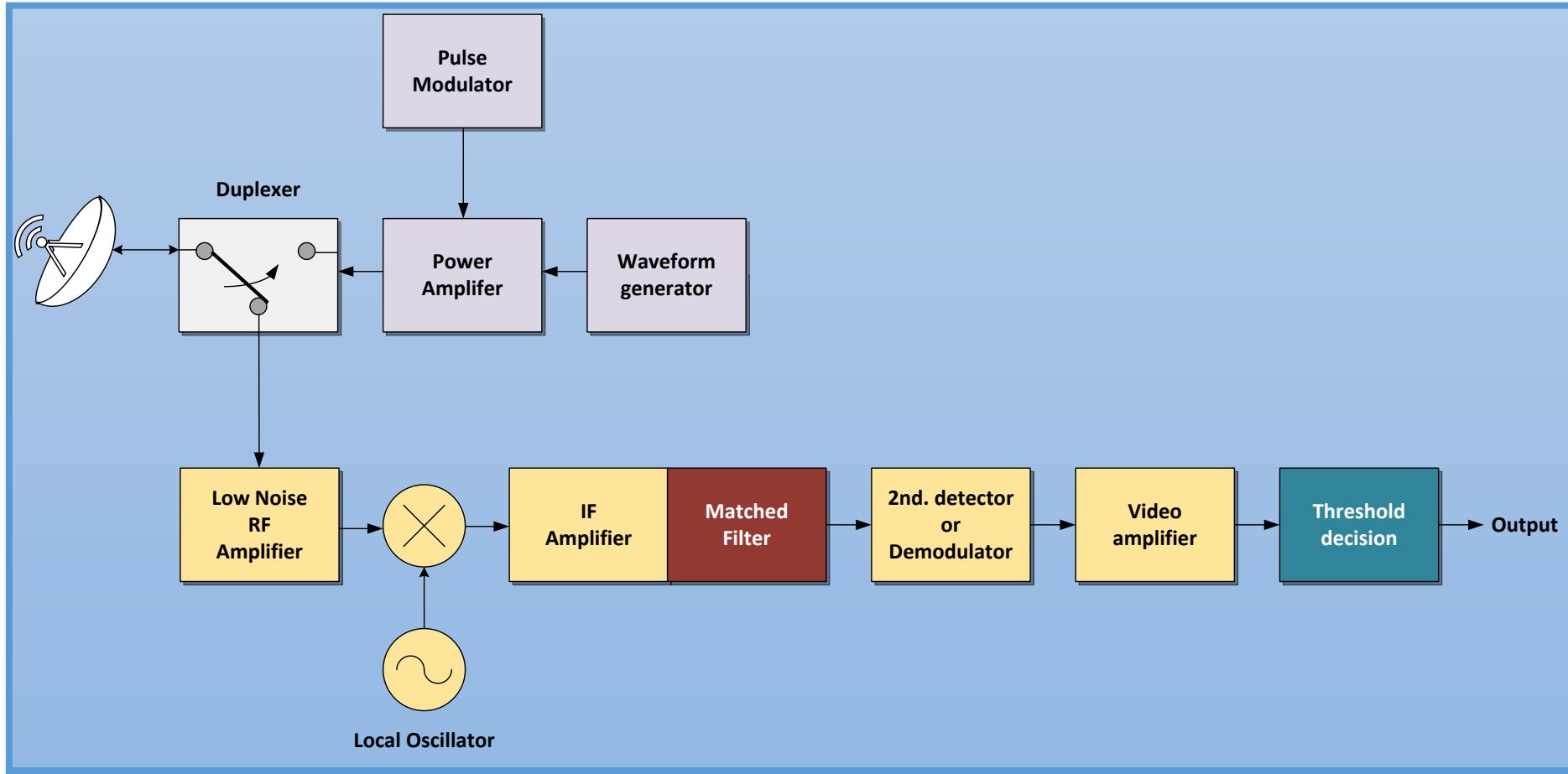
## Range Resolution

$$\Delta R = \delta_z = \frac{c \cdot \tau}{2}$$

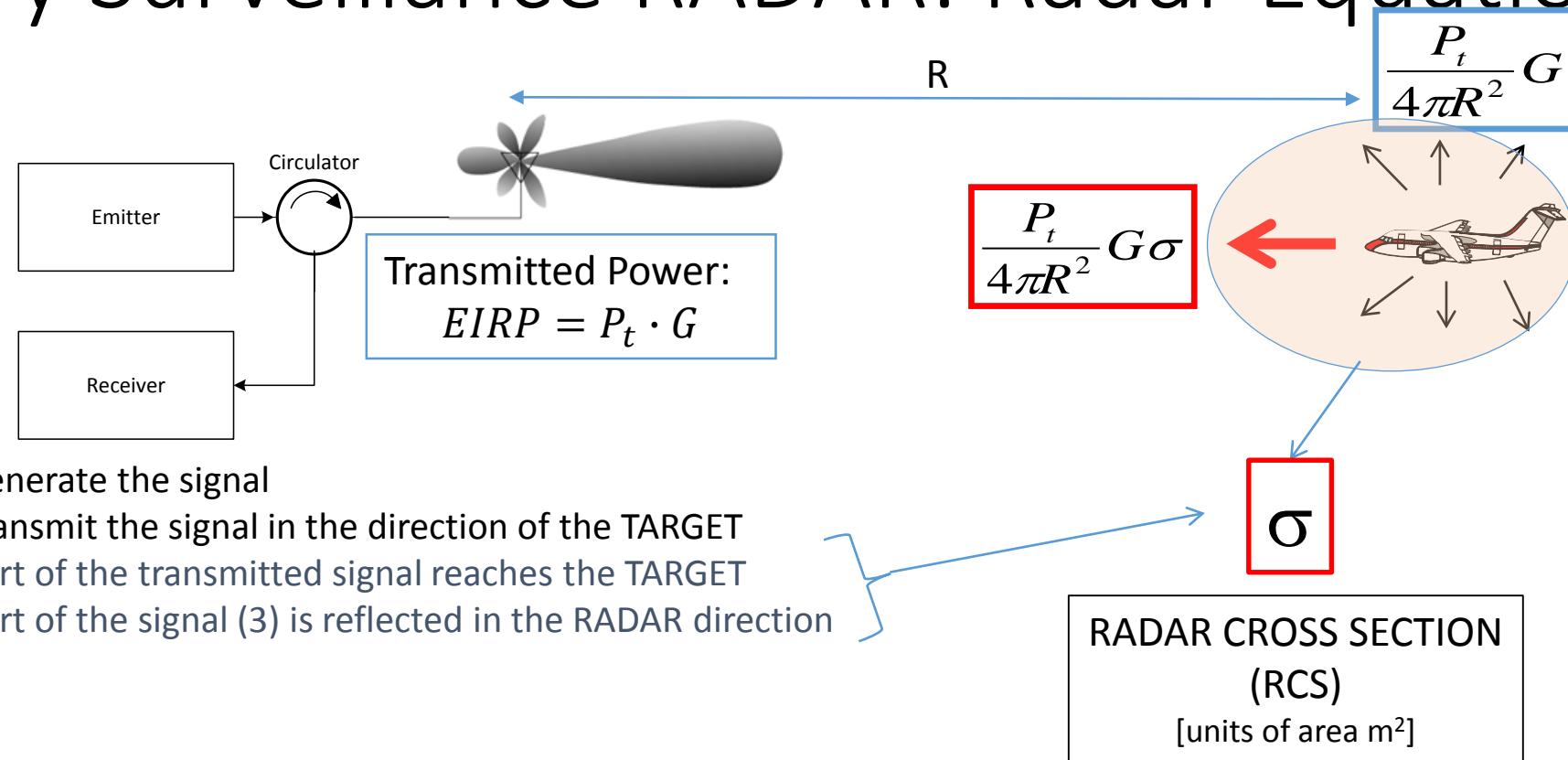
## Minimum Range (blind range)

$$R_{ciega} = \frac{c \cdot \tau}{2}$$

# Pulsed Radar Block Diagram



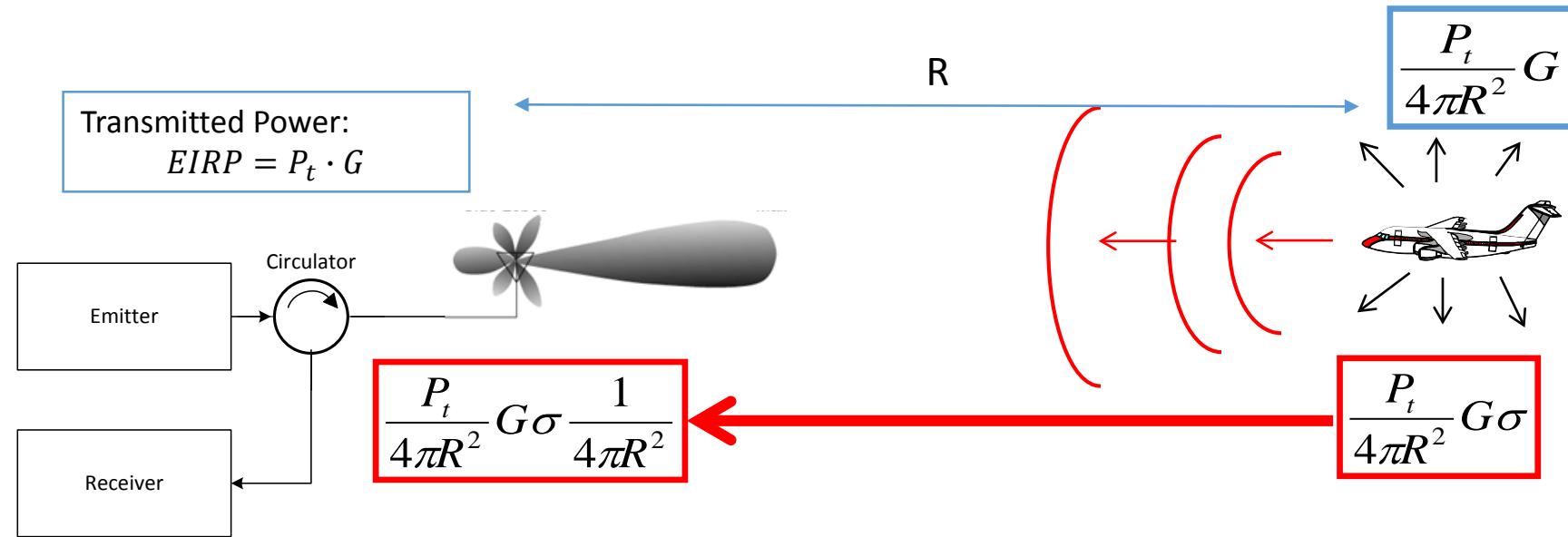
# Primary Surveillance RADAR: Radar Equation



$$\frac{P_t}{4\pi R^2} G \sigma$$

Amount of power reflected to the RADAR direction

# Primary Surveillance RADAR: Radar Equation

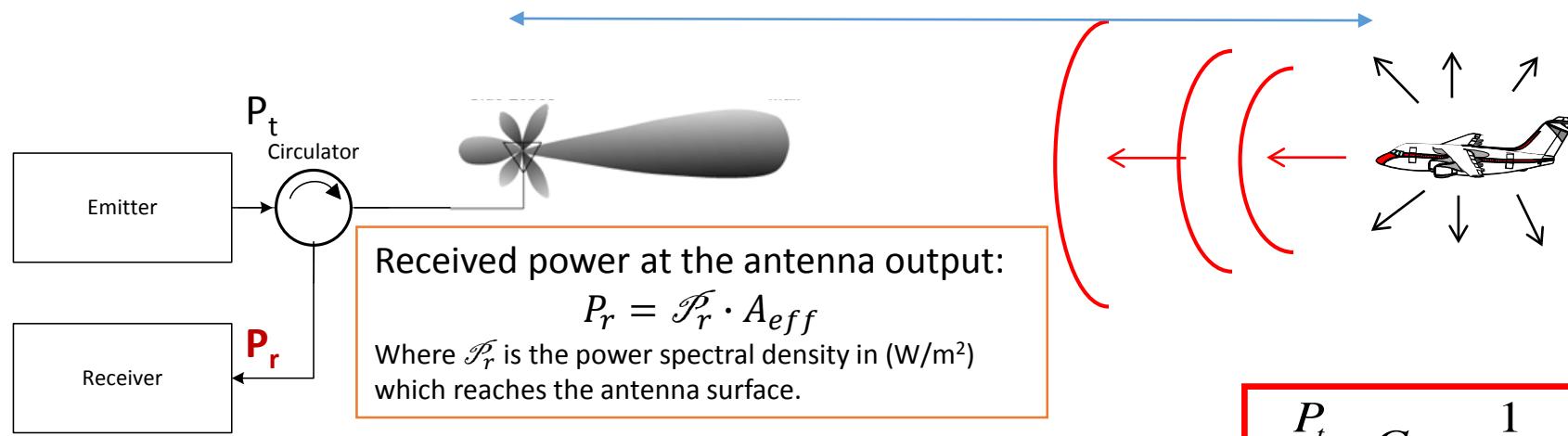


- 1- Generate the signal
- 2- Transmit the signal in the direction of the TARGET
- 3- Part of the transmitted signal reaches the TARGET
- 4- Part of the signal (3) is reflected in the RADAR direction
- 5- Part of the signal (4) is captured by the antenna

$$\frac{P_t}{4\pi R^2} G \sigma \frac{1}{4\pi R^2} = \frac{P_t \cdot G \cdot \sigma}{(4\pi)^2 R^4}$$

Power density ( $\text{W/m}^2$ ) of the reflected signal that reaches the antenna

# Primary Surveillance RADAR: Radar Equation



- 1- Generate the signal
- 2- Transmit the signal in the direction of the TARGET
- 3- Part of the transmitted signal reaches the TARGET
- 4- Part of the signal (3) is reflected in the RADAR direction
- 5- Part of the signal (4) is captured by the antenna

$$\frac{P_t}{4\pi R^2} G \sigma \frac{1}{4\pi R^2}$$

$A_{eff}$  ( $\text{m}^2$ ): capacity of the antenna to capture the energy, related with  $G$  through the equation:

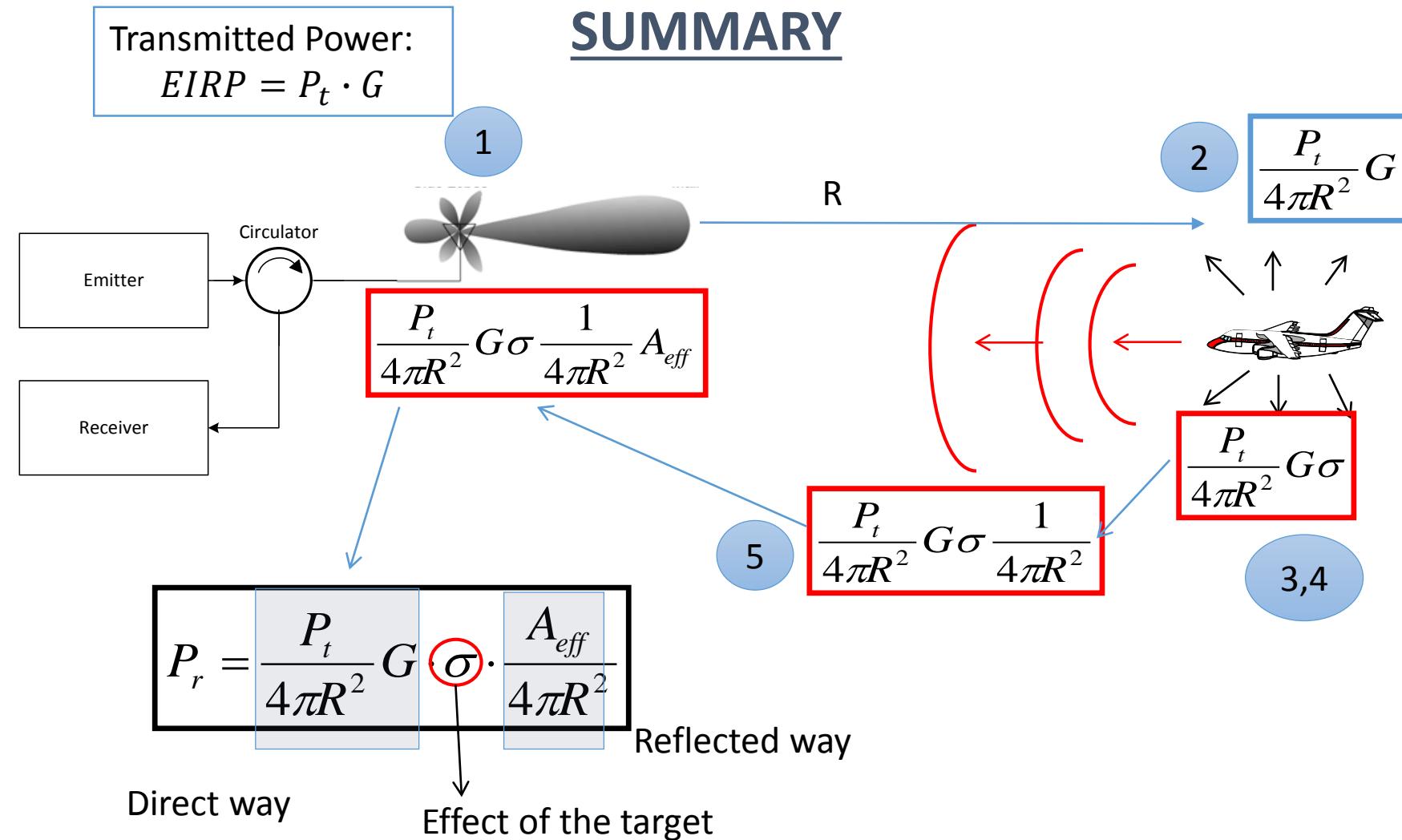
$$\frac{G}{A_{eff}} = \frac{4\pi}{\lambda^2}$$

Being  $\lambda$  the wavelength of the electromagnetic wave

$$P_r = \frac{P_t}{4\pi R^2} G \sigma \frac{A_{eff}}{4\pi R^2} = \frac{P_t G \sigma A_{eff}}{(4\pi)^2 R^4} = \frac{P_t G^2 \sigma \lambda^2}{(4\pi)^3 R^4} = \frac{P_t \sigma A_{eff}^2}{4\pi \lambda^2 R^4}$$

# Primary Surveillance RADAR: Radar Equation

## SUMMARY



# Primary Surveillance RADAR: Radar Equation

## SUMMARY & Conclusion

**Simplified Radar Equation:**

$$P_r = \frac{P_t}{4\pi R^2} G \sigma \frac{A_{eff}}{4\pi R^2} = \frac{P_t G \sigma A_{eff}}{(4\pi)^2 R^4} = \frac{P_t G^2 \sigma \lambda^2}{(4\pi)^3 R^4} = \frac{P_t \sigma A_{eff}^2}{4\pi \lambda^2 R^4}$$

We assume the transmitter and receiver are co-located

The range of the target to the Radar is obtained as:

$$R^4 = \frac{P_t G \sigma A_{eff}}{(4\pi)^2 P_r}$$

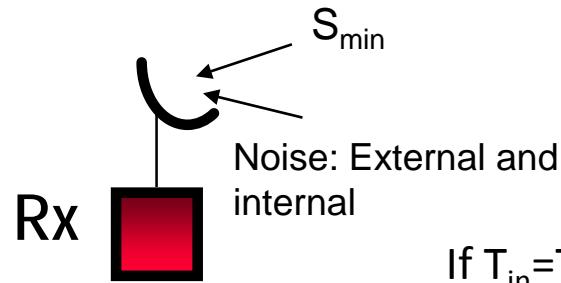
And the maximum range of the Radar is obtained when the received power equals the minimum detectable signal  $S_{min}$ , that is,  $P_r=S_{min}$ , then:

$$R_{max}^4 = \frac{P_t G \sigma A_{eff}}{(4\pi)^2 S_{min}}$$



# Noise and interference

## Radar Equation



$$R_{\max}^4 = \frac{P_t G \sigma A_{\text{eff}}}{(4\pi)^2 S_{\min}}$$

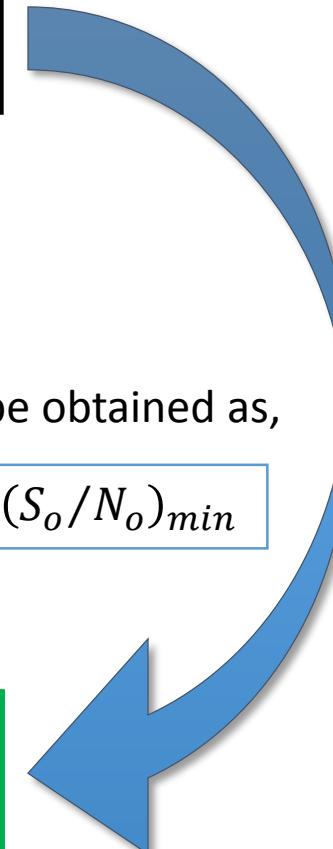
If  $T_{\text{in}}=T_0$ , then,  $(S/N)_{\text{in}} = F(S/N)_{\text{out}}$

then the minimum signal detectable can be obtained as,

$$S_{\min} = (S/N)_{\text{out min}} \cdot N_{\text{in}} \cdot F = kT_0 BF (S_o/N_o)_{\min}$$

Finally we obtain for the radar equation,

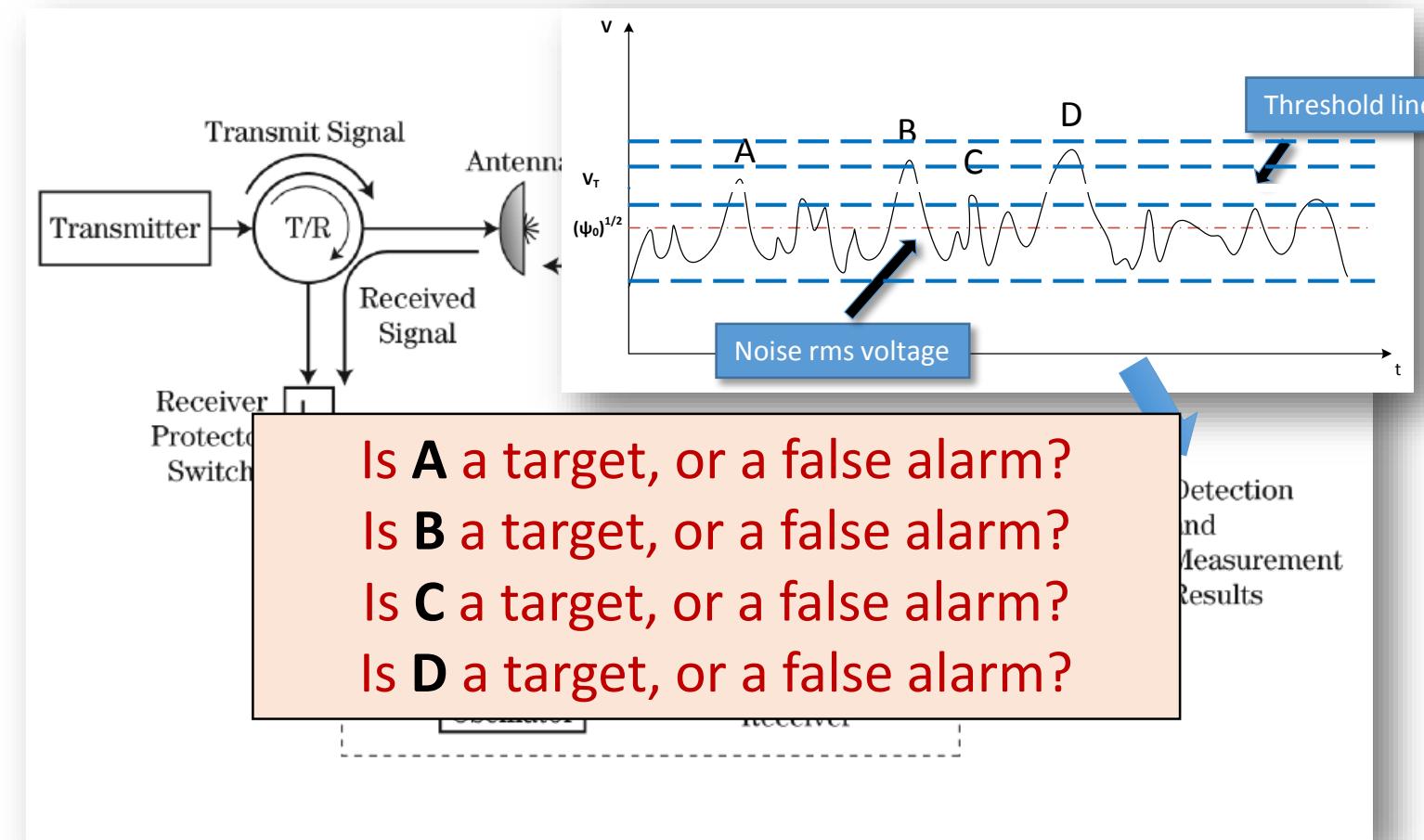
$$R_{\max}^4 = \frac{P_t G \sigma A_{\text{eff}}}{(4\pi)^2 k T_0 B F (S_o/N_o)_{\min}}$$



# False Alarm and Probability of Detection



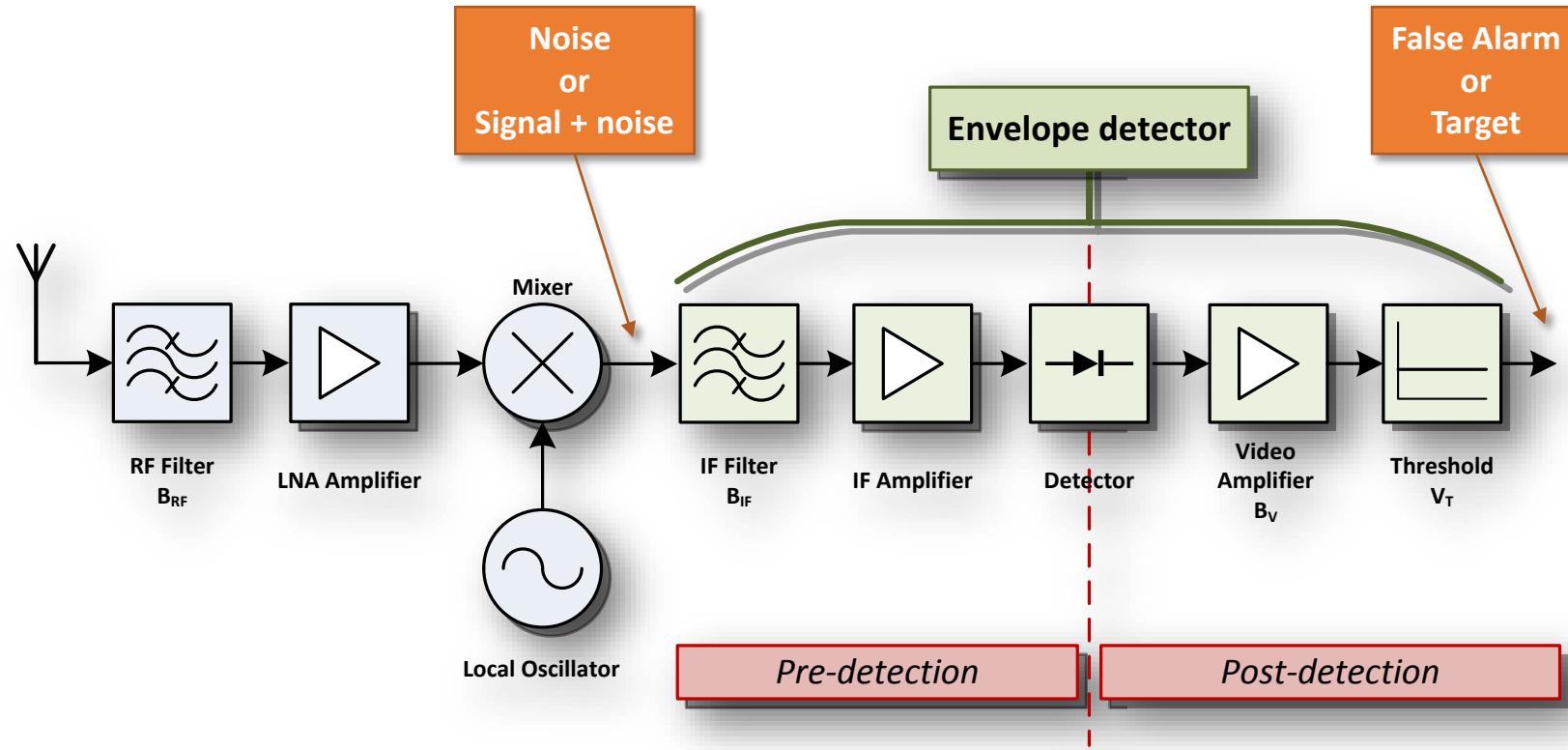
# False Alarm and Probability of Detection



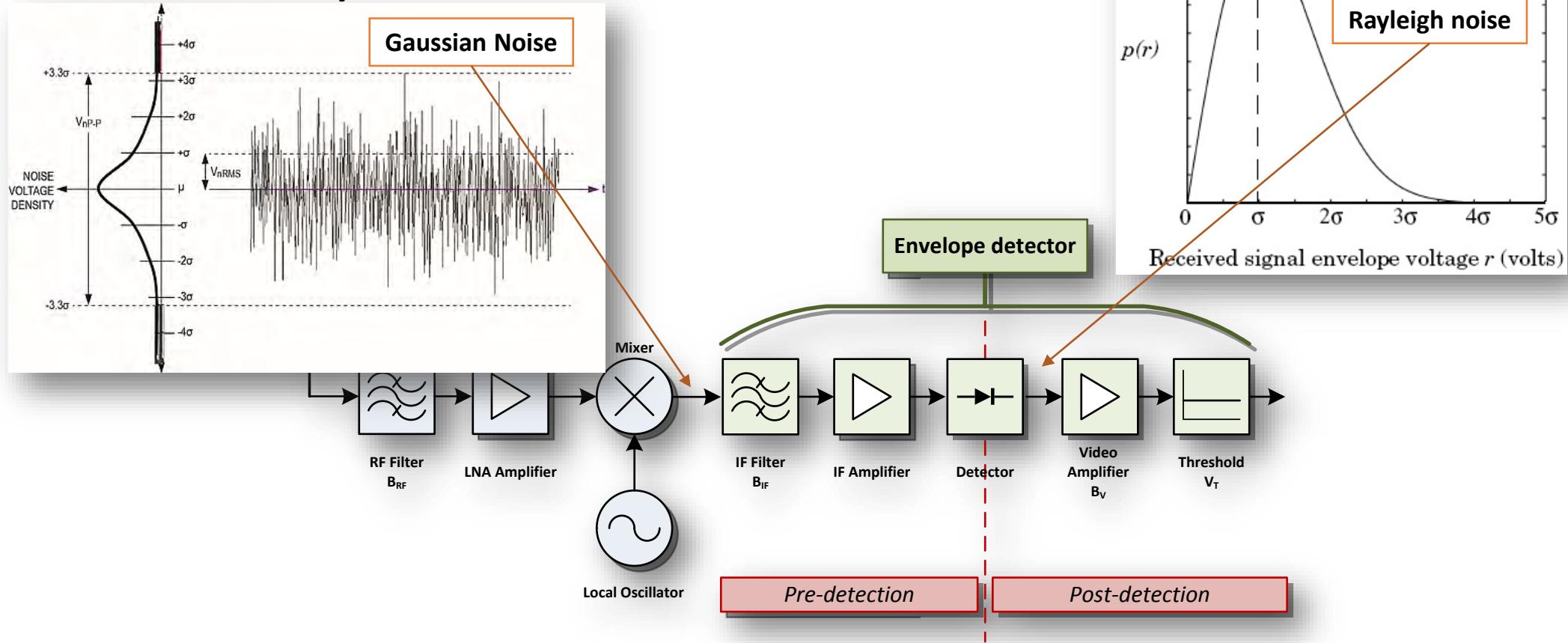
# False Alarm and Probability of Detection

- **False Alarm** occurs when:
  - There is only noise at the input of the detector.
  - And at the output, the noise level it is above of the threshold detection.
  - Thus providing a target (false) indication.
- **Detection** occurs when:
  - There is signal and noise at the input of the detector.
  - And at the output, the signal level it is above the threshold detection.
  - Thus providing a target (true) indication.

# Radar detector



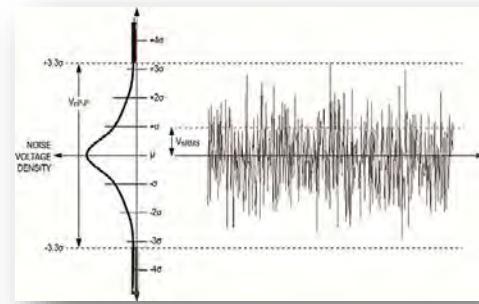
# Probability of False Alarm



# Probability of False Alarm

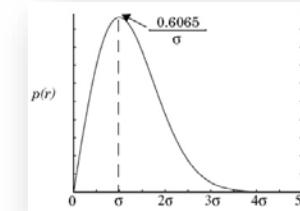
White noise with a Gaussian density function

$$p(v) = \frac{1}{\sqrt{2\pi\psi_0}} e^{-\left(\frac{v^2}{2\psi_0}\right)}, \text{ being } \psi_0 = N_0 = kTB$$



White noise with a Rayleigh density function

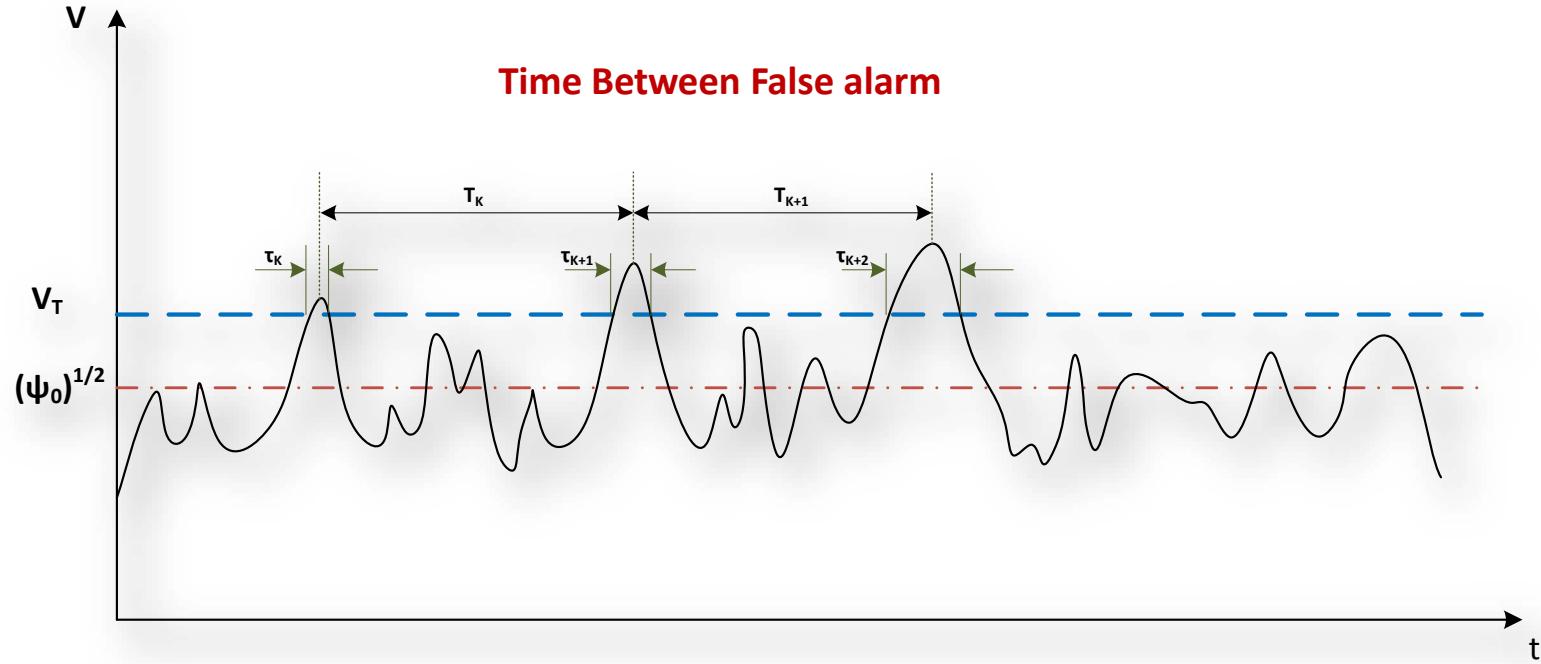
$$p(R) = \frac{R}{\psi_0} e^{-\left(\frac{R^2}{2\psi_0}\right)}$$



The False Alarm probability:

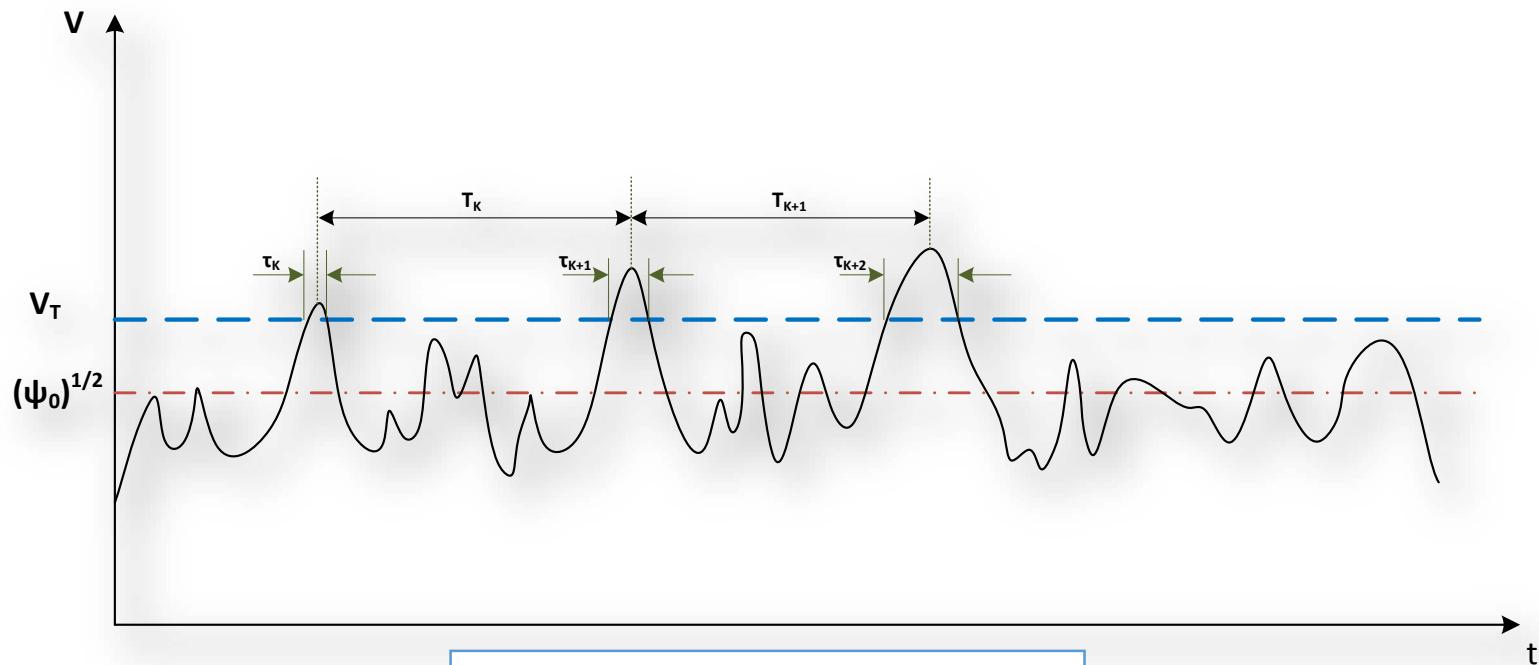
$$P_{FA} = \mathcal{P}(V_T < R < \infty) = \int_{V_T}^{\infty} p(R)dR = e^{-\left(\frac{V_T^2}{2\psi_0}\right)}$$

# Time of false alarm



$$T_{FA} = \lim_{N \rightarrow \infty} \frac{1}{N} \sum_{k=1}^N T_k$$

# Probability of false alarm

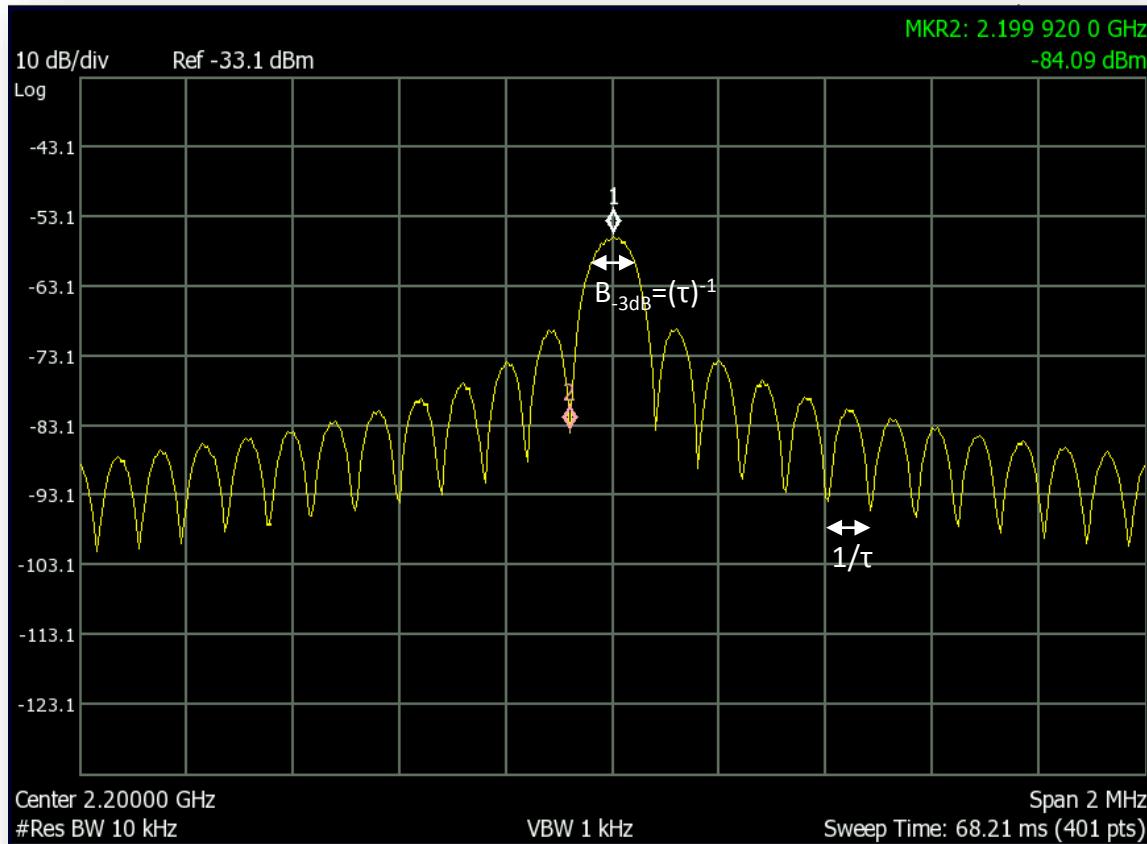


$$P_{FA} = \frac{\sum_{k=1}^N t_k}{\sum_{k=1}^N T_k} = \frac{\langle t_k \rangle}{\langle T_k \rangle} = \frac{\langle t_k \rangle}{T_{FA}}$$

And considering that  $\langle t_k \rangle \approx \frac{1}{B_{IF}}$

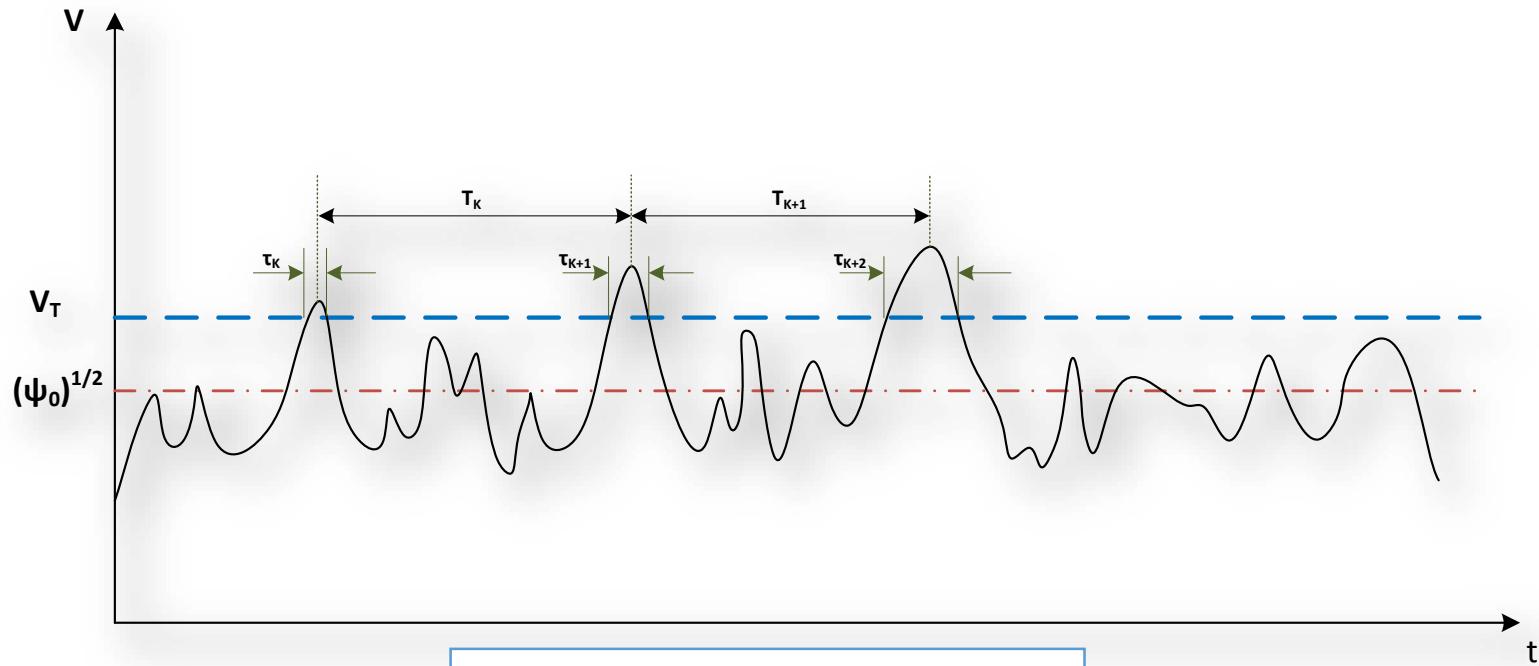
$$P_{FA} = \frac{1}{T_{FA} B_{IF}}$$

# Bandwidth considerations



Considering that  
 $B_{-3dB} \cong \frac{1}{\tau}$

# Probability of false alarm

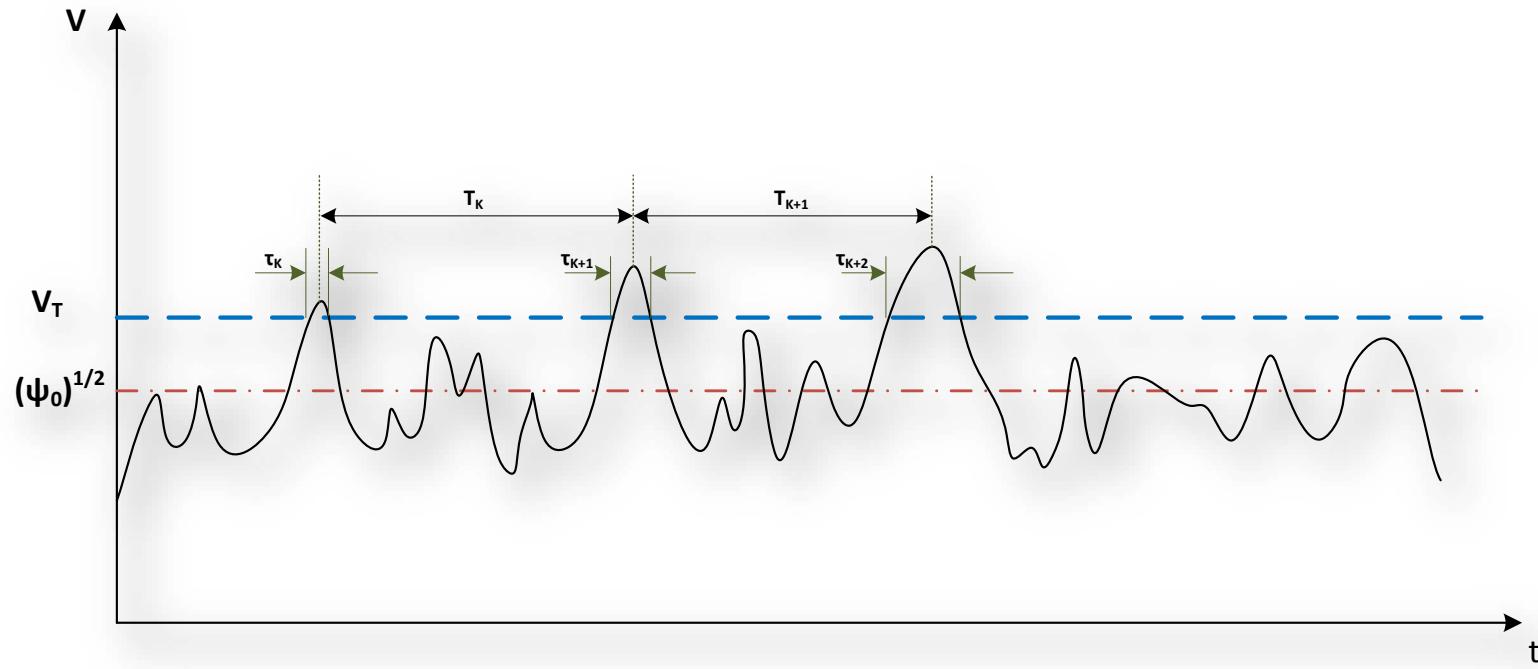


$$P_{FA} = \frac{\sum_{k=1}^N t_k}{\sum_{k=1}^N T_k} = \frac{\langle t_k \rangle}{\langle T_k \rangle} = \frac{\langle t_k \rangle}{T_{FA}}$$

And considering that  $\langle t_k \rangle \cong \frac{1}{B_{IF}} = \frac{1}{B}$

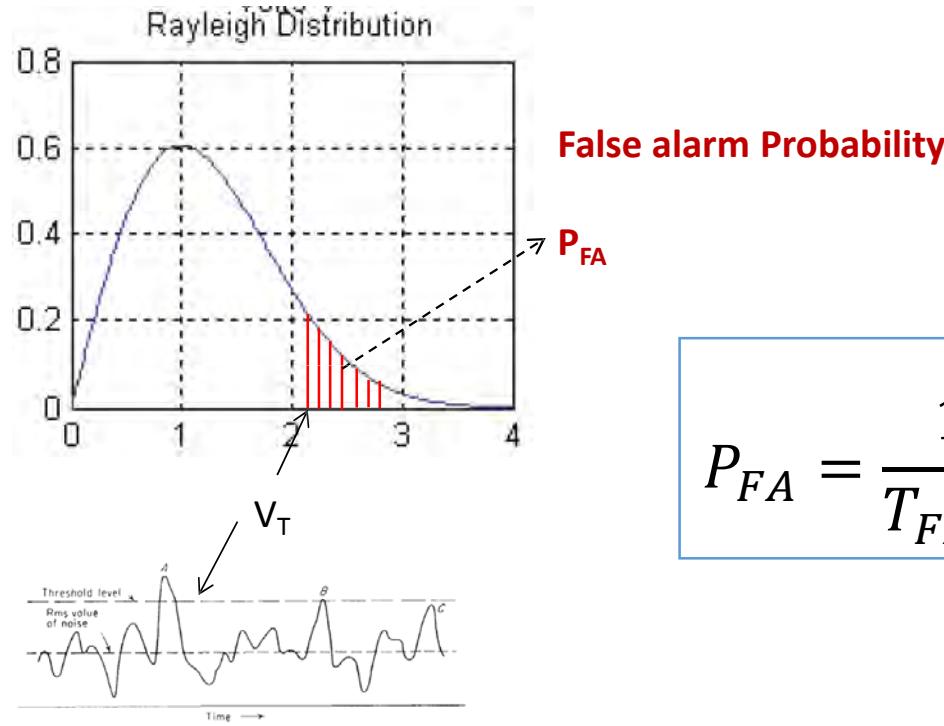
$$P_{FA} = \frac{1}{T_{FA}B}$$

# Probability of false alarm



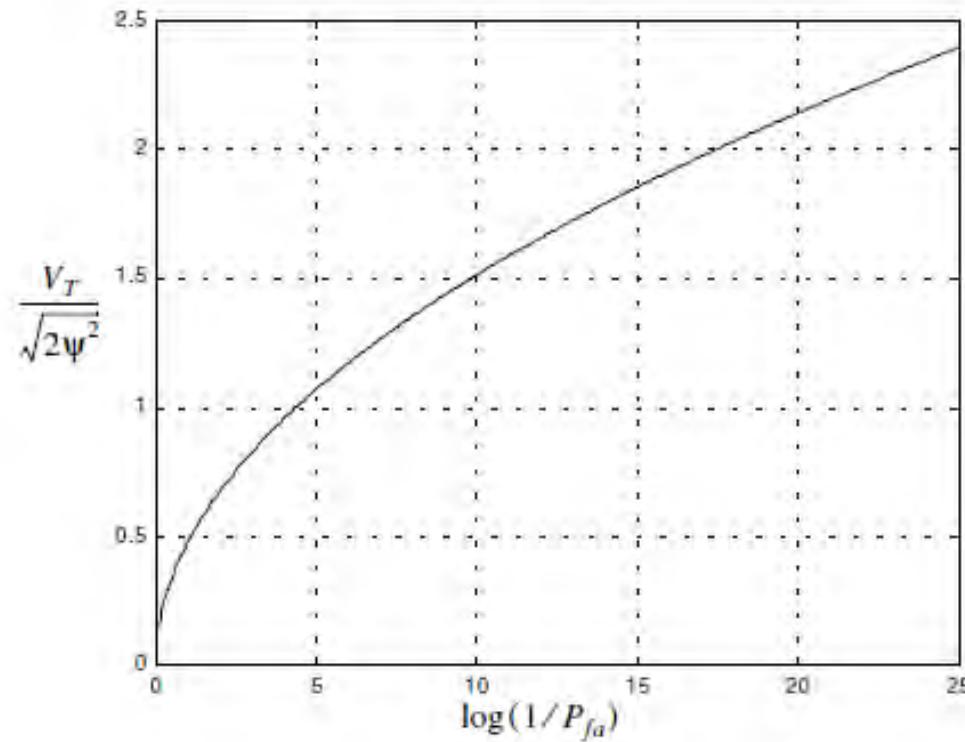
$$T_{FA} = \frac{1}{P_{FA}B_{IF}} = \frac{1}{B_{IF}} e^{\left(\frac{V_T^2}{2\Psi_0}\right)}$$

# Probability of False Alarm



$$P_{FA} = \frac{1}{T_{FA}B} = e^{-\left(\frac{V_T^2}{2\psi_0}\right)}$$

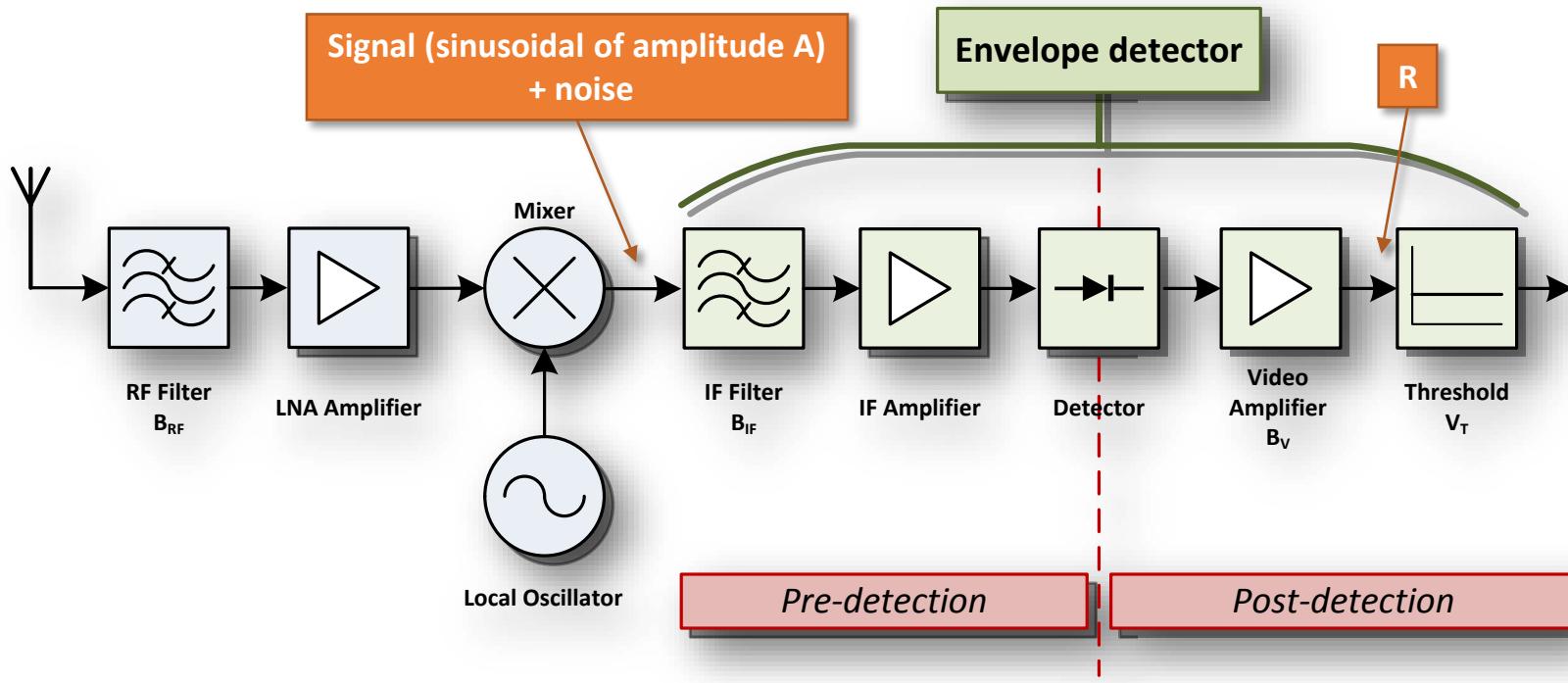
# Probability of False Alarm



$$P_{FA} = \frac{1}{T_{FA}B} = e^{-\left(\frac{V_T^2}{2\psi_0}\right)}$$



# Probability of Detection



Density function of the envelope at the video filter output (Rice function):

$$p_s(R) = \frac{R}{\psi_0} \exp\left(-\frac{R^2 + A^2}{2\psi_0}\right) I_0\left(\frac{R \cdot A}{\psi_0}\right)$$

$I_0$  : Zero order, modified Bessel function.

# Probability of Detection

$$P_D = \int_{\sqrt{2\psi_0 \ln(P_{FA})^{-1}}}^{\infty} \frac{R}{\psi_0} \exp\left(-\frac{R^2 + A^2}{2\psi_0}\right) I_0\left(\frac{RA}{\psi_0}\right) dR$$

No analytical solution available

Relating the amplitude A and the  $\psi_0$  to the (S/N),

$$S = A_{rms}^2 = \frac{A^2}{2}; \quad \text{and} \quad N = kTB = \psi_0$$

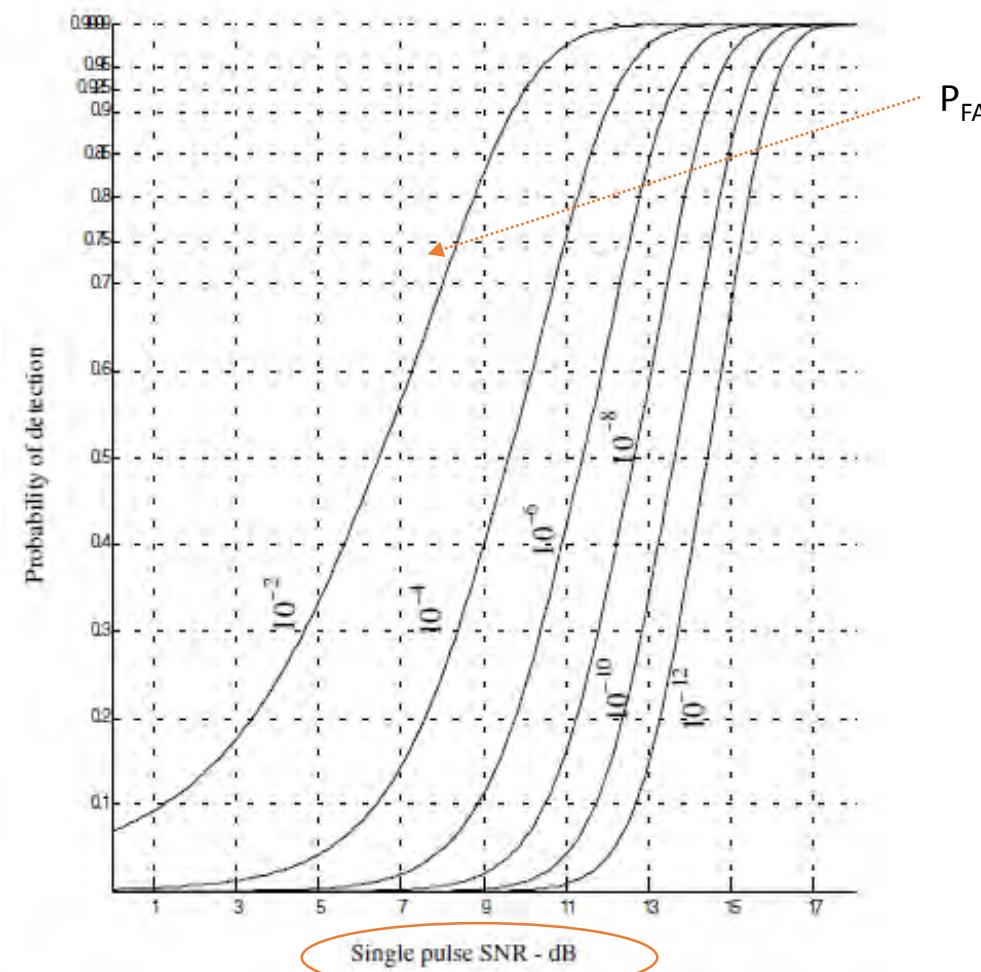
Then,

$$\left(\frac{A^2}{\psi_0}\right) = 2(S/N)$$

Finally, the  $P_D$  is related to the one pulse  $(S/N)_1$ , and to the  $\left(\frac{V_T^2}{2\psi_0}\right)$ ,  
and the  $P_{FA}$  is related only to the  $\left(\frac{V_T^2}{2\psi_0}\right)$  ratio



# Probability of Detection



# Probability of Detection

Empirical equation from Albersheim:

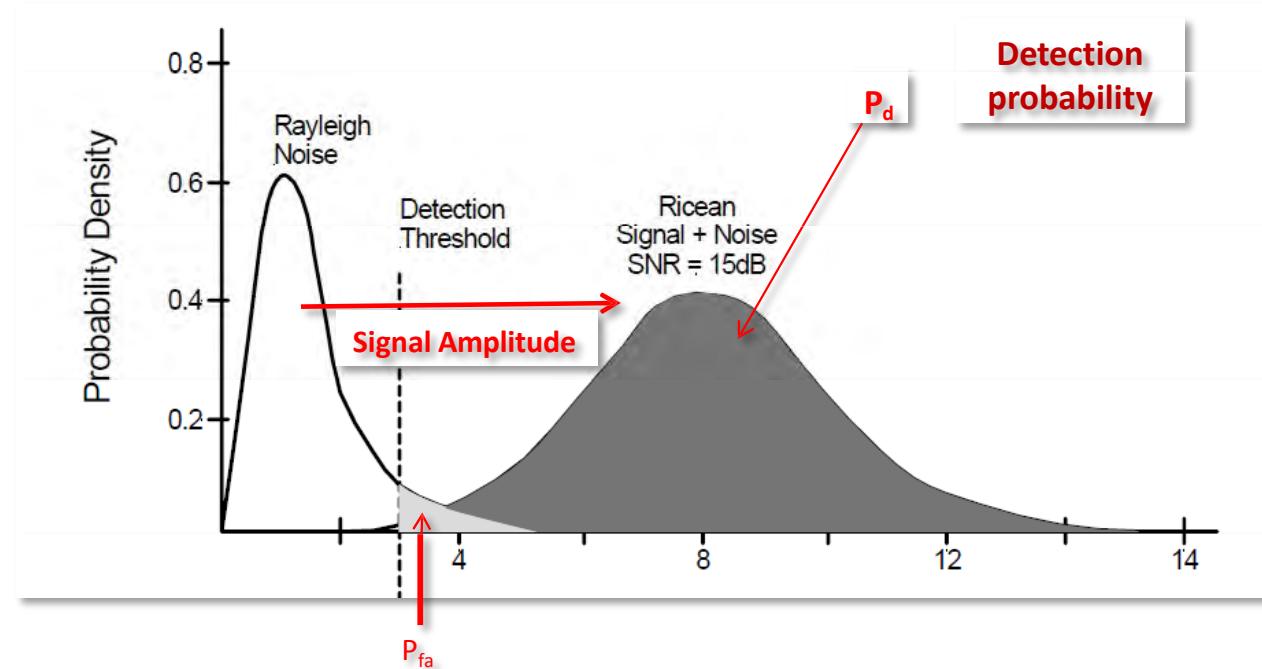
$$(S/N)_{1\text{linear}} = A + 0,12 \cdot A \cdot B + 1,7 \cdot B$$

With

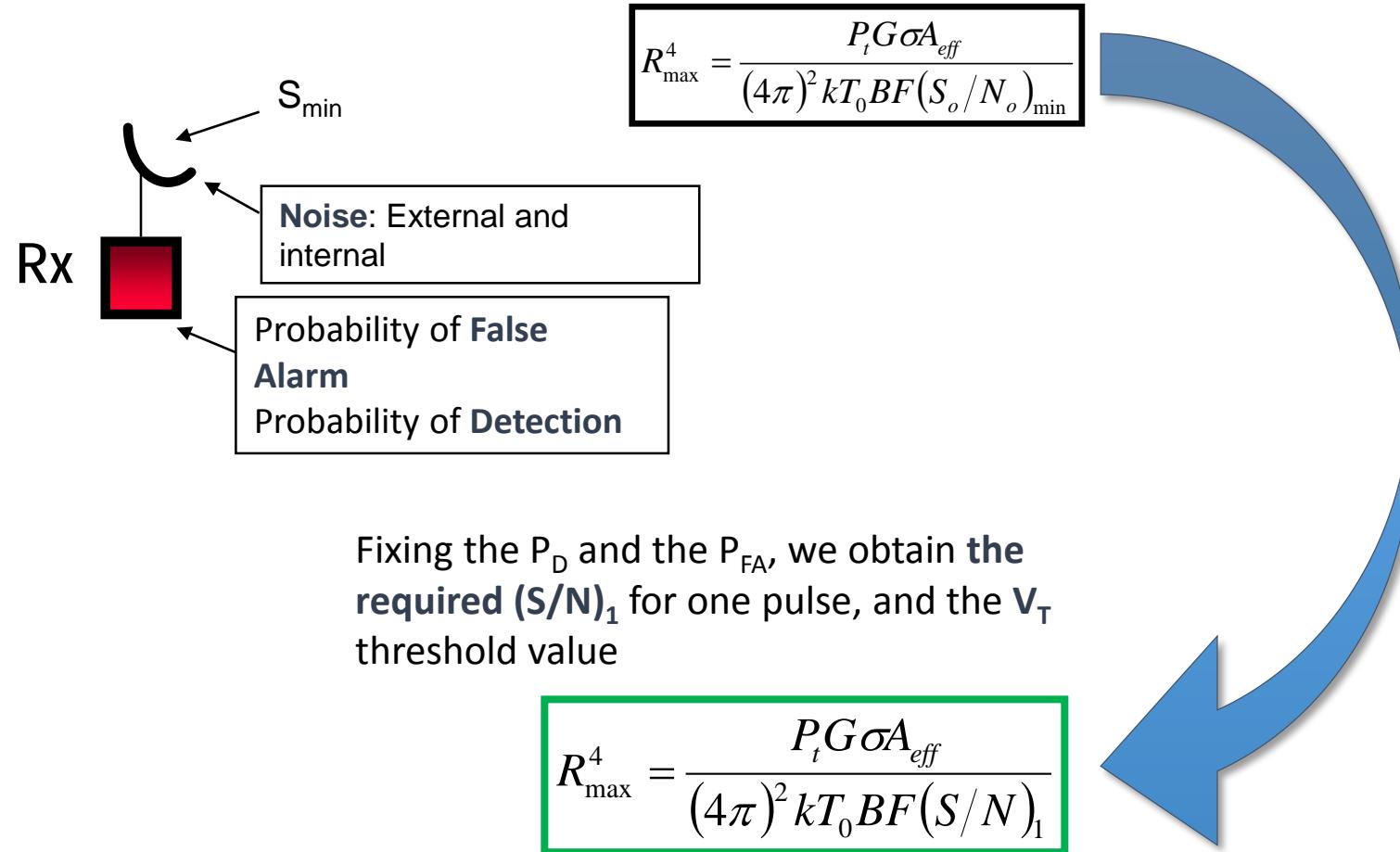
$$A = \ln\left(\frac{0,62}{P_{FA}}\right); \quad \text{and} \quad B = \ln\left(\frac{P_D}{1-P_D}\right)$$



# False Alarm & Detection probability



# Radar equation with $P_D$ , $P_{FA}$ and Noise



Fixing the  $P_D$  and the  $P_{FA}$ , we obtain the required  $(S/N)_1$  for one pulse, and the  $V_T$  threshold value

# Pulse integration



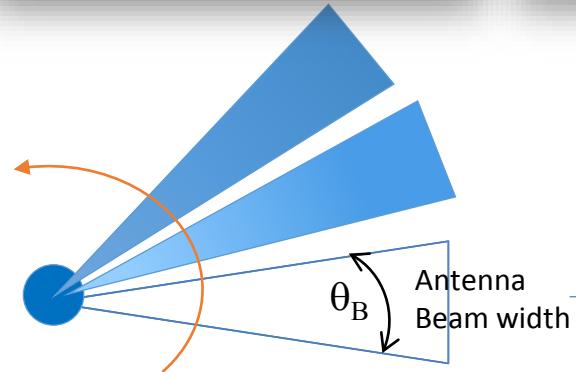
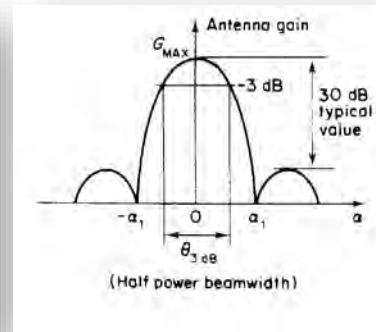
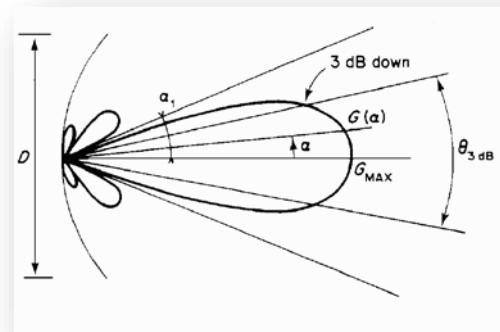
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# Hits per scan



RADAR  
Antenna, with an  
angular rotation  
speed of  $\omega_r$  (rpm)



Target observation time:

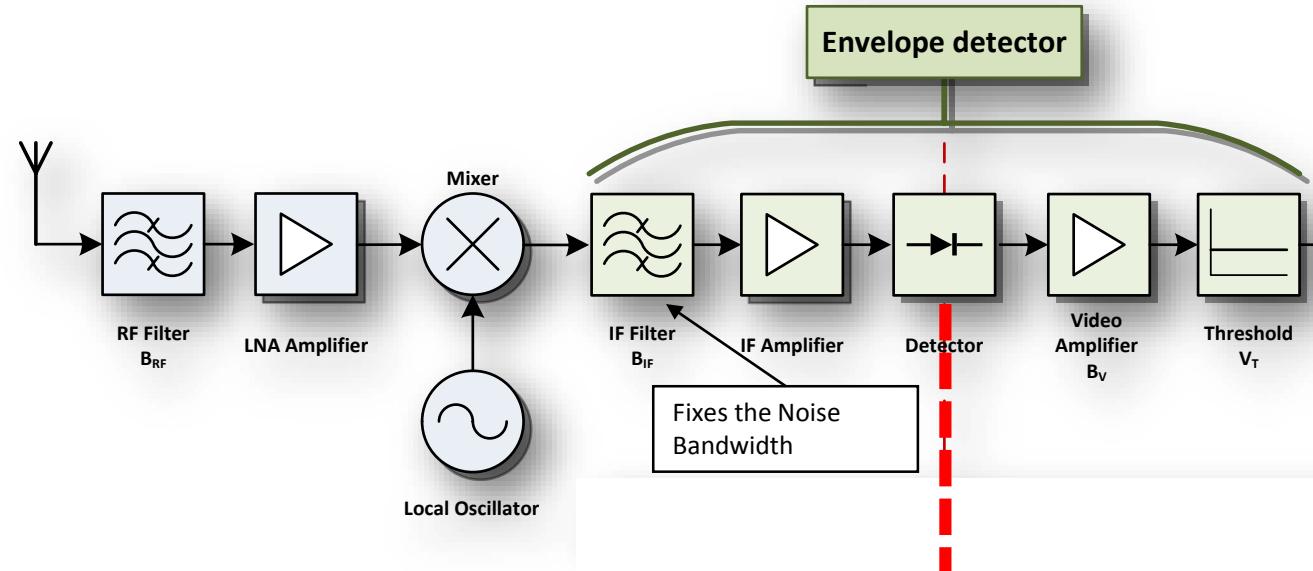
$$t_{obs} = \frac{\theta_B(^{\circ})}{\omega_r} \cdot \frac{60''}{360^{\circ}} = \frac{\theta_B(^{\circ})}{6 \cdot \omega_r}$$

Number of pulses received from the target per scan:

$$n = \frac{t_{obs}}{T} = \frac{\theta_B(^{\circ})}{6 \cdot \omega_r} \cdot PRF \quad (\text{hits/scan})$$

# Pulse integration

A pulse Integrator is an improvement technique by using multiple received pulses.

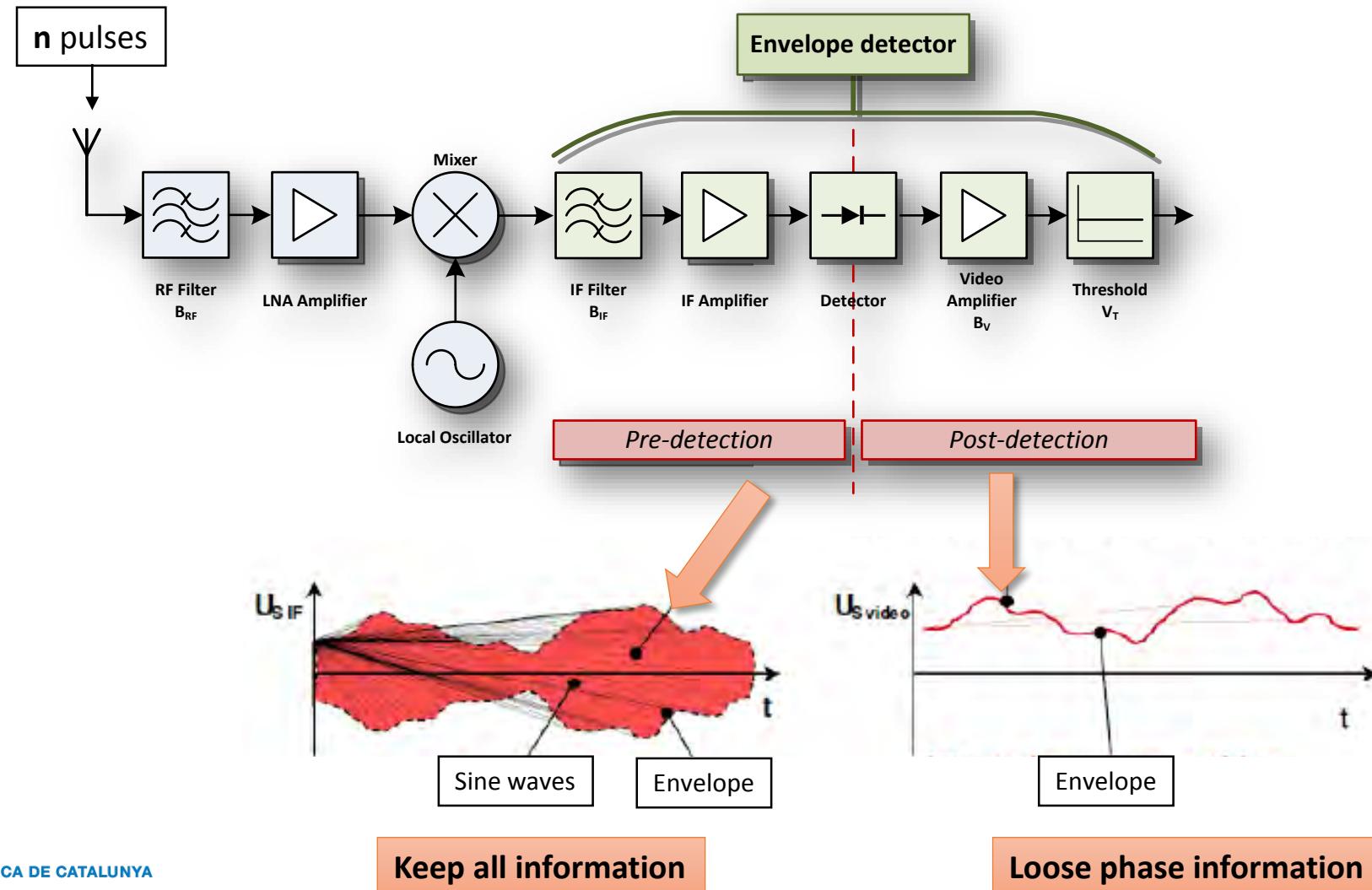


Depending on the location of the pulse Integrator in the signal processing chain, this process is referred to as:

Coherent integration (Pre-detection)

Incoherent integration (Post-detection)

# Pulse integration



# Pulse integration

Integrating pulses increases the (S/N).

That means that for the same  $R_{\max}$ , the required (S/N) is less than without pulse integration.

$$(S/N)_n \geq \frac{1}{n} (S/N)_1 \text{ (linear)}$$

If coherent:

$$(S/N)_n = \frac{1}{n} (S/N)_1$$

If incoherent

$$(S/N)_n > \frac{1}{n} (S/N)_1$$

Maximum of efficiency



# Pulse Integration evaluation

## Efficiency of integration

$$E_i(n) = \frac{(S/N)_1}{n \cdot (S/N)_n}$$

$$E_i(n) \leq 1$$

## Improvement integration factor

$$I_i(n) = n \cdot E_i(n) = \frac{(S/N)_1}{(S/N)_n}$$

$$I_i(n) \leq n$$

## Number of equivalent integrated pulses

$$n_{eq} = n \cdot E_i(n)$$

If coherent integration,  $n_{eq} = n$   
If incoherent integration,  $n_{eq} < n$

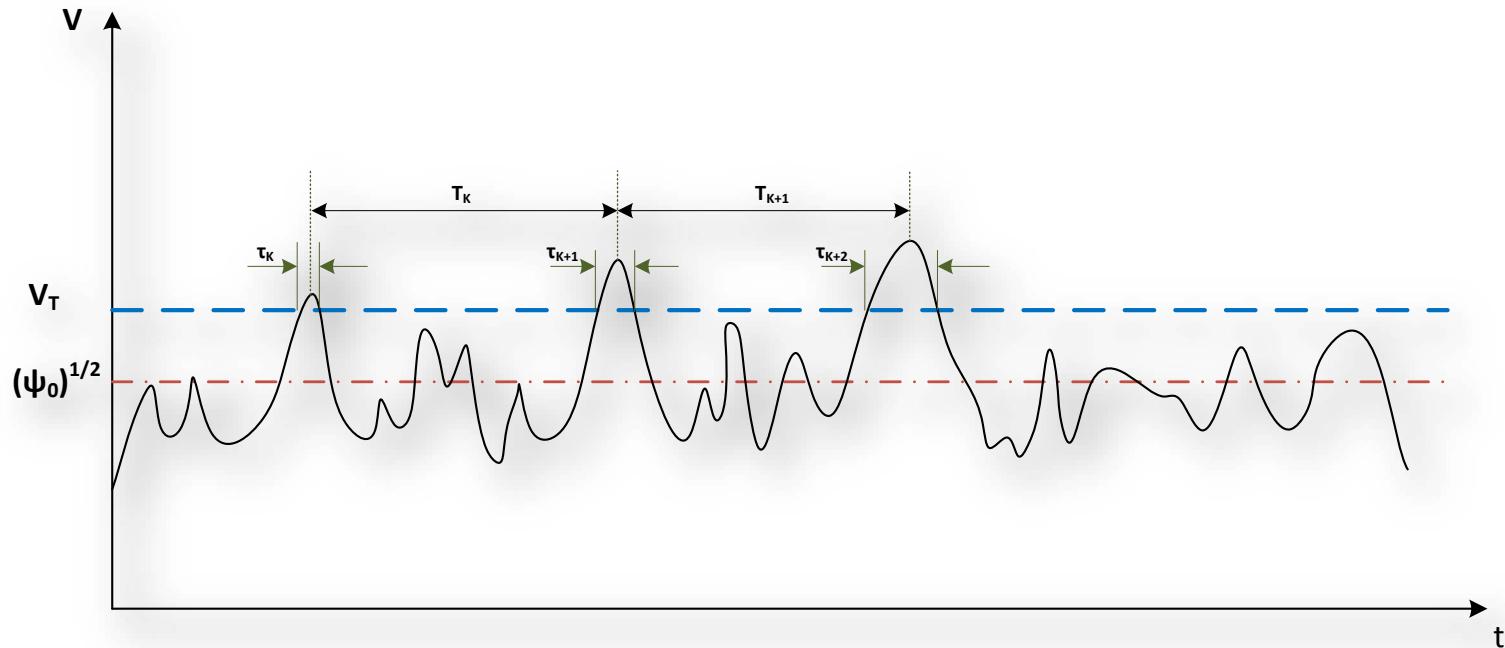
## Integration losses

$$L_i(n) (dB) = -10 \log E_i(n)$$

$$L_i(n) \geq 0 dB$$



# False-alarm number



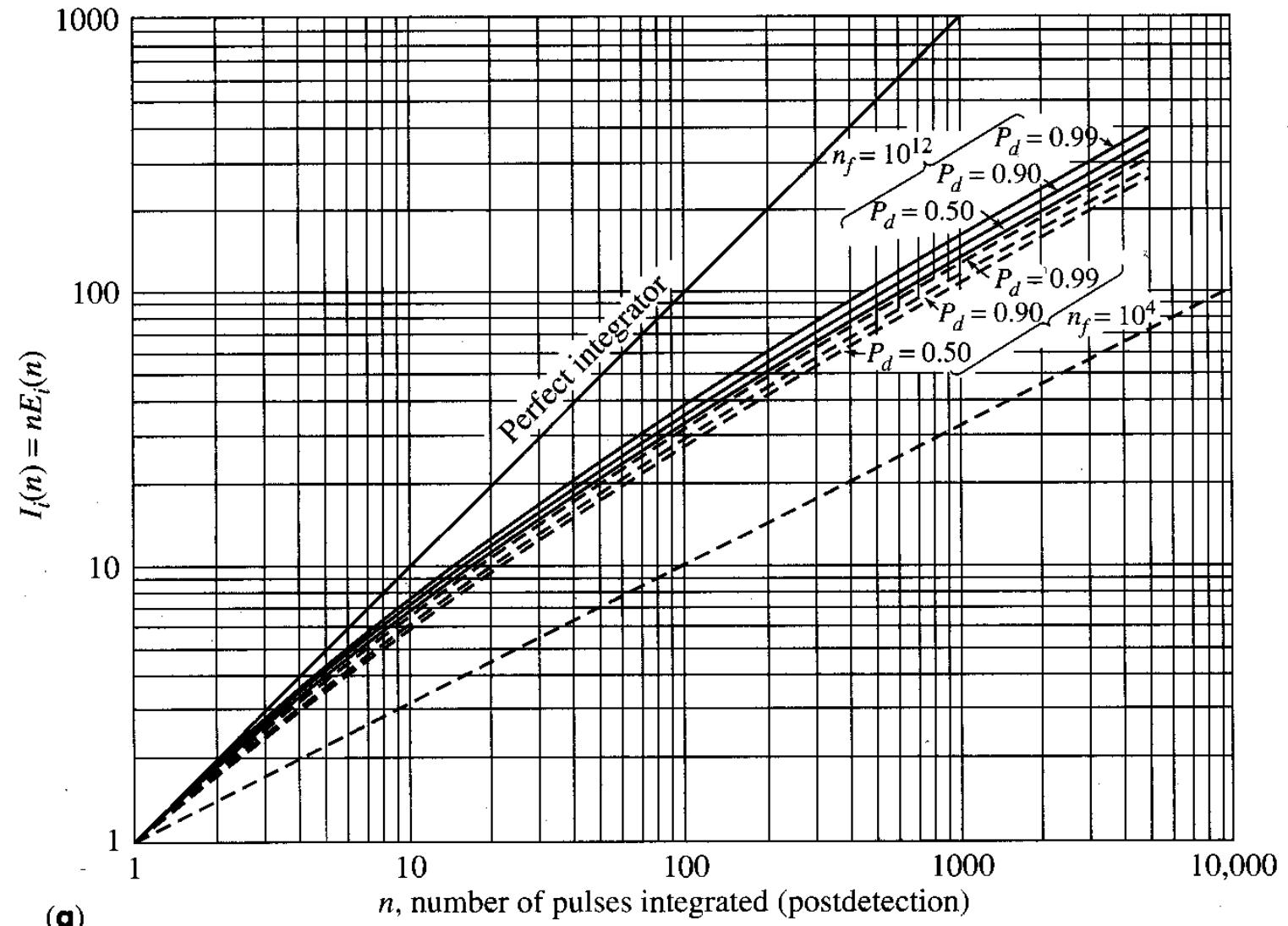
The false-alarm number  $n_f$ , is defined as the average number of possible decisions between false alarms events:

$$n_f = \frac{T}{\tau} \cdot PRF \cdot T_{FA} = \frac{T_{FA}}{\tau}$$

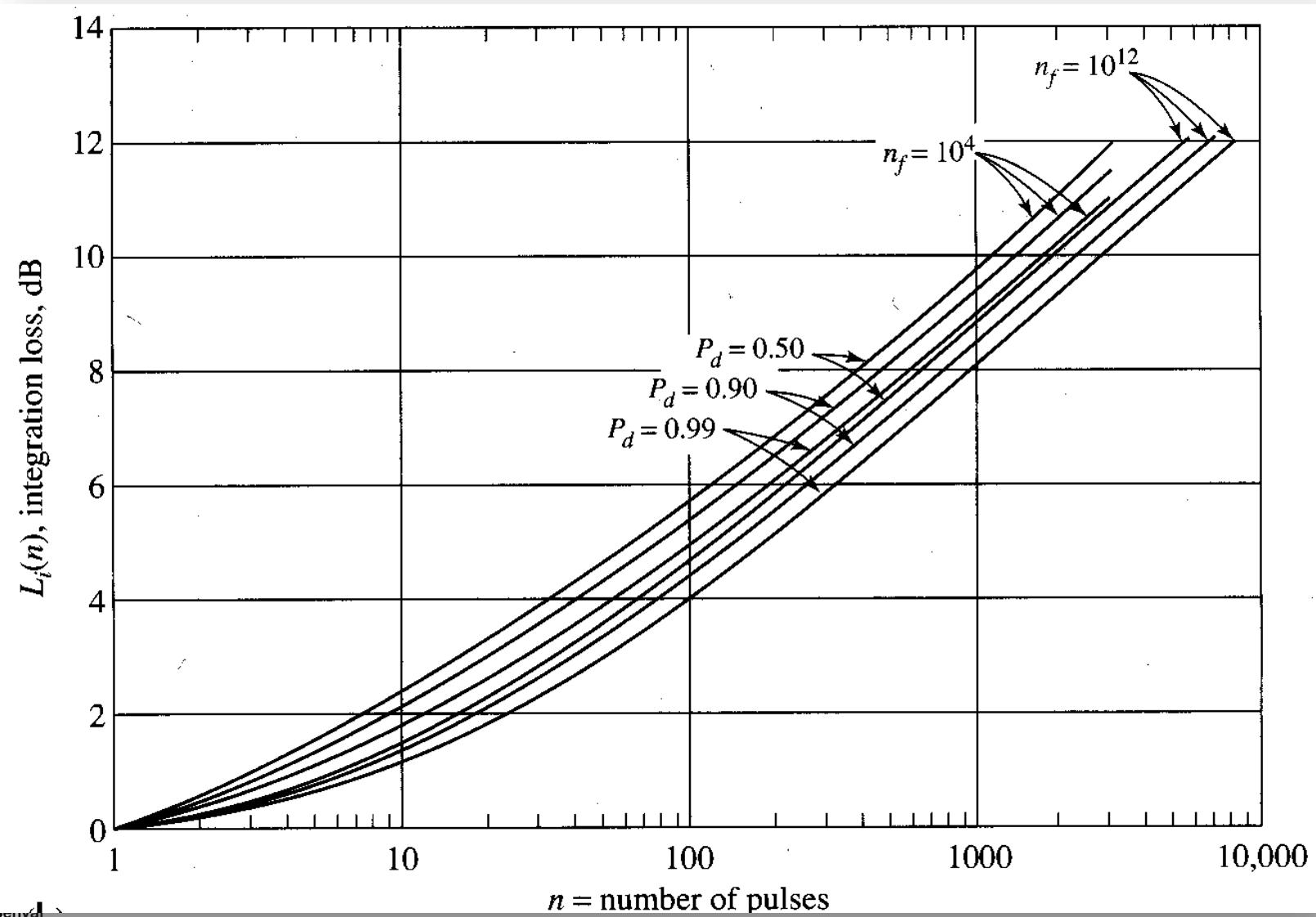
If  $\tau \cong \frac{1}{B}$ , then  $P_{FA} = (T_{FA}B)^{-1}$ , and

$$n_f = \frac{1}{P_{FA}}$$

# Improvement integration factor



# Integration losses



# Empirical expressions

**Empirical expression for the Improvement factor, from Peebles:**

$$[I_i(n)]_{dB} = 6,79 \left(1 + 0,235P_D\right) \left(1 - \frac{\log P_{FA}}{46,6}\right) \log(n) \left[ [1 - 0,14 \log(n) + 0,01831(\log(n))^2] \right]$$

**Empirical expression for the  $(S/N)_n$  in dB, from Albersheim:**

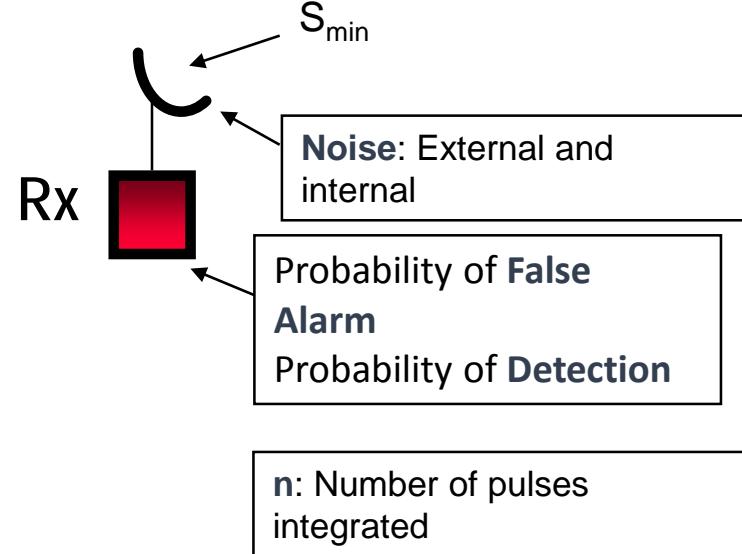
$$(S/N)_{n_{dB}} = -5 \log(n) + \left(6,2 + \frac{4,54}{\sqrt{n + 0,44}}\right) \cdot \log(A + 0,12 \cdot A \cdot B + 1,7 \cdot B)$$

with

$$A = \ln\left(\frac{0,62}{P_{FA}}\right); \quad \text{and} \quad B = \ln\left(\frac{P_D}{1-P_D}\right)$$

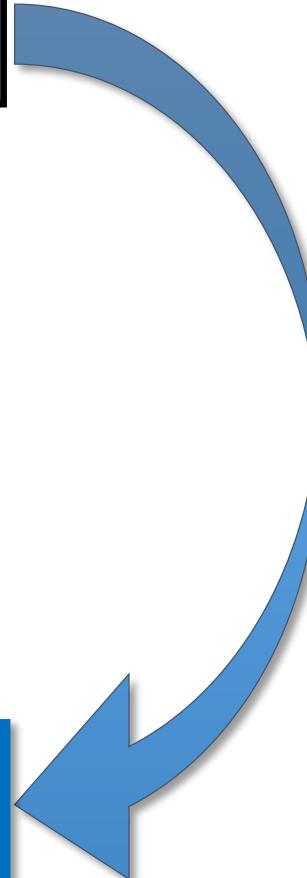


# Radar equation with pulse integration



$$R_{\max}^4 = \frac{P_t G \sigma A_{eff}}{(4\pi)^2 k T_0 B F(S/N)_1}$$

$$R_{\max}^4 = \frac{P_t G \sigma A_{eff}}{(4\pi)^2 k T_0 B F(S/N)_n} = \frac{P_t G \sigma A_{eff} n E_i(n)}{(4\pi)^2 k T_0 B F(S/N)_1}$$



# RADAR TRANSMITTER



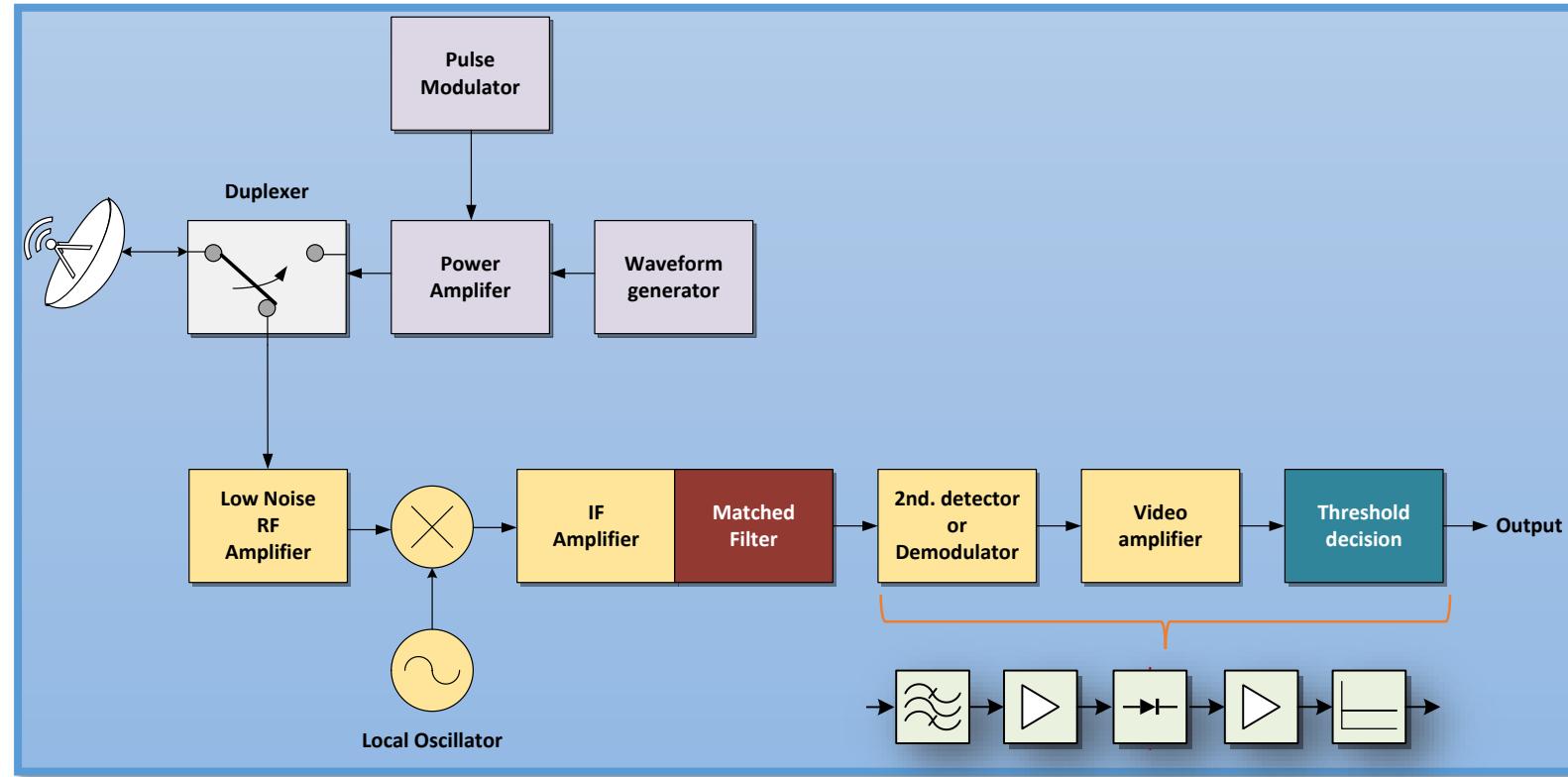
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# Block Diagram of a Pulsed Radar



# The RADAR Transmitter

- Generates high power RF radiation which illuminates targets.
- Includes three basic elements:
  - The Power Amplifier (PA).
  - The Pulse Modulator (PM).
  - Power Supply / Continuous Wave Generator.
- Peak powers can range from milliwatts to gigawatts.
- Frequencies can range from MHz to hundred of GHz.
- Can be continuously operated or pulsed.
- Can be a single device or many.



# THE POWER TRANSMITTER

- Can be based in:

- **Power amplifiers:**

- Klystron

- High peak power and high gain
    - Relative Bandwidth: from 8% to 10%
    - Suitable for coherent Radar applications, such MTI (Moving Target Indicators) and Pulsed Doppler Radar.
    - High mass and volume.
    - High voltage and current required.

- Traveling Wave Tubes

- Solid State Power Amplifiers

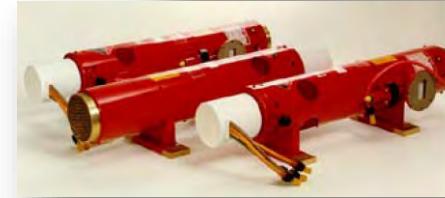
- **Pulsed Power Oscillators:**

- Magnetron

- Poor frequency stability
    - High peak power, but reduced average power.
    - Reduced mass and volume.
    - Can produce out of band and spurious emissions.

- Gyrotron

- The Reflex Klystron (feedback amplifier)



# Radar Antennas



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# Antenna parameters and Basics

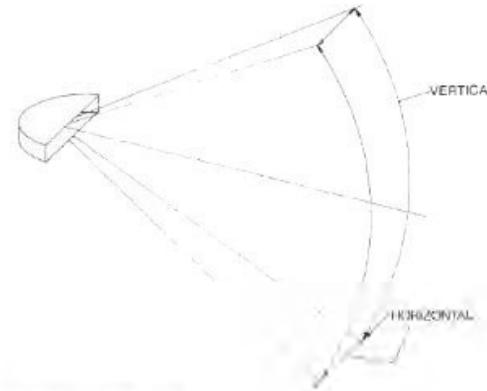


## THE ANTENNA FUNCTIONS:

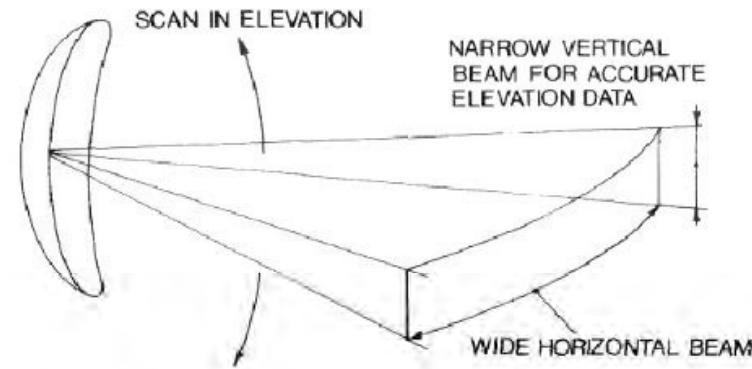
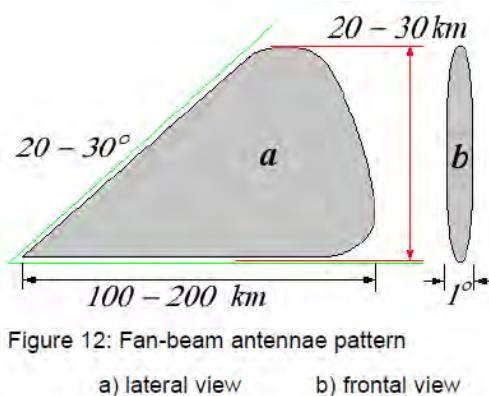
- As a transductor, it transforms an electrical signal into an Electromagnetic wave with an specific space orientation.
- In 2-D Radar Systems, among these functions, it determines the **azimuth angle** of the target.
- In 3-D Radar Systems, it provides the **elevation angle** of the target.

# Typical antenna 2D-Radar patterns

## Fan Beam



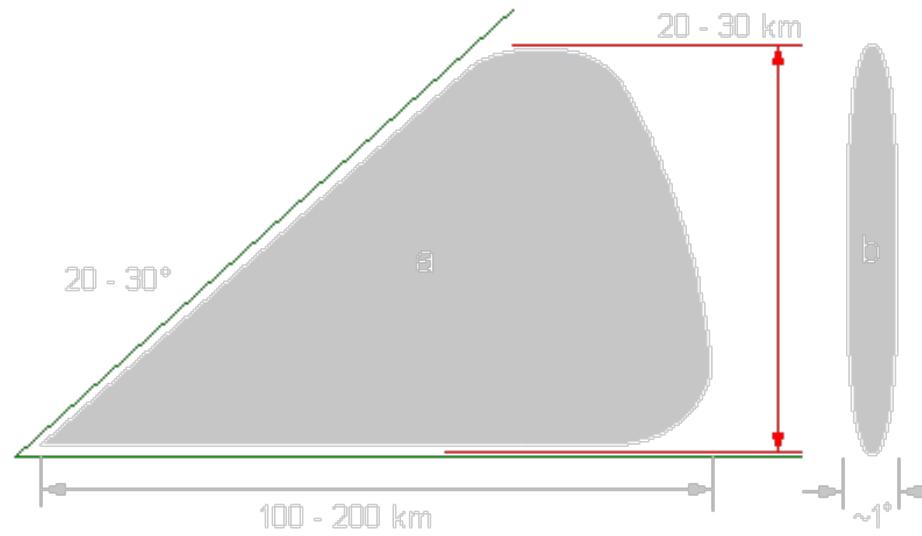
'Cheese' beam form.



A typical height-finder ('orange peel' antenna).

Non symmetric lobe  
Only high resolution in azimuth (not in elevation)  
Only provides  $(r, \phi)$  coordinates.

# FAN-BEAM ANTENNA (2D-Radar)



Fan-beam antennae pattern  
a) lateral view  
b) frontal view

# Stacked antenna pattern (3D-Radar)

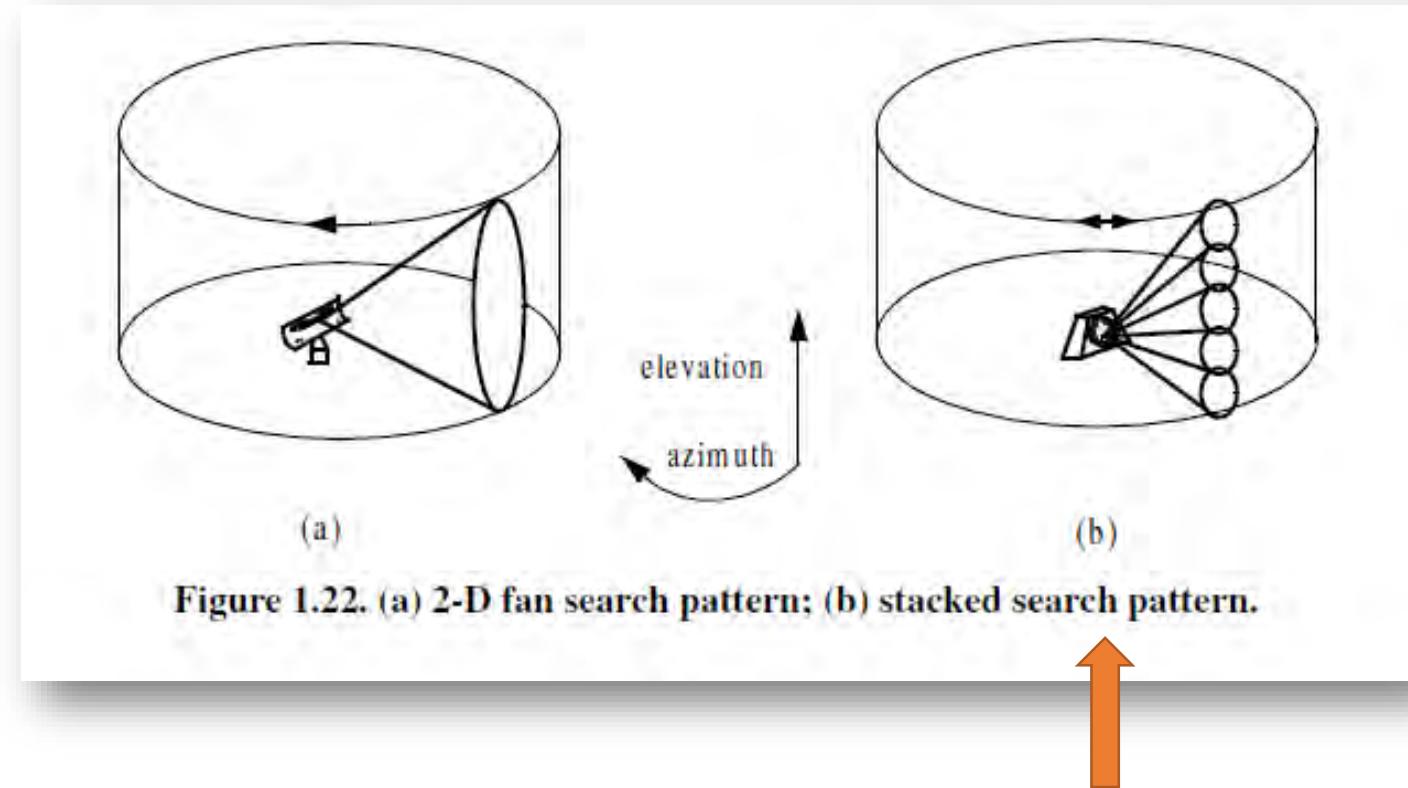


Figure 1.22. (a) 2-D fan search pattern; (b) stacked search pattern.

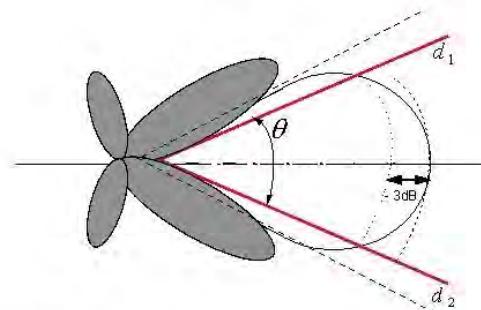
Made with a phased-array antenna.  
Gives high resolution in azimuth and elevation  
Provides  $(r, \theta, \phi)$  coordinates (3-D).  
ATC applications

# Typical radar antenna

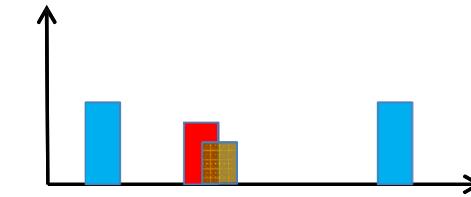


# Uncertain volume

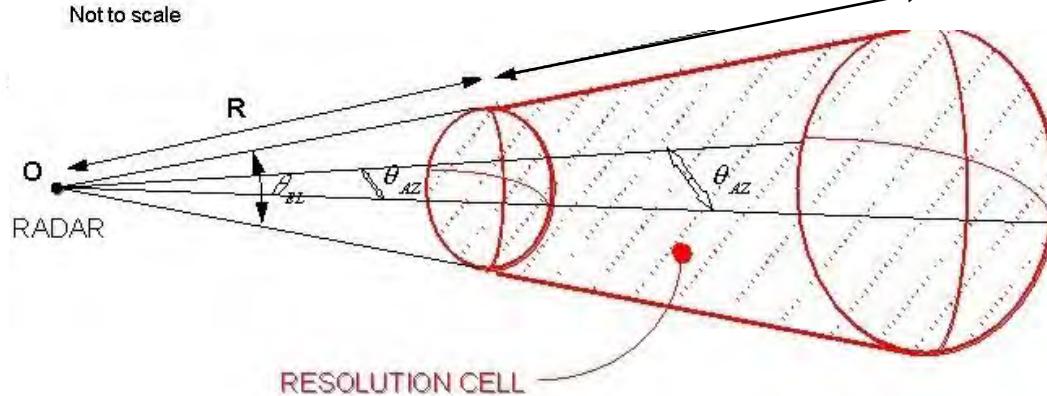
Angular Resolution



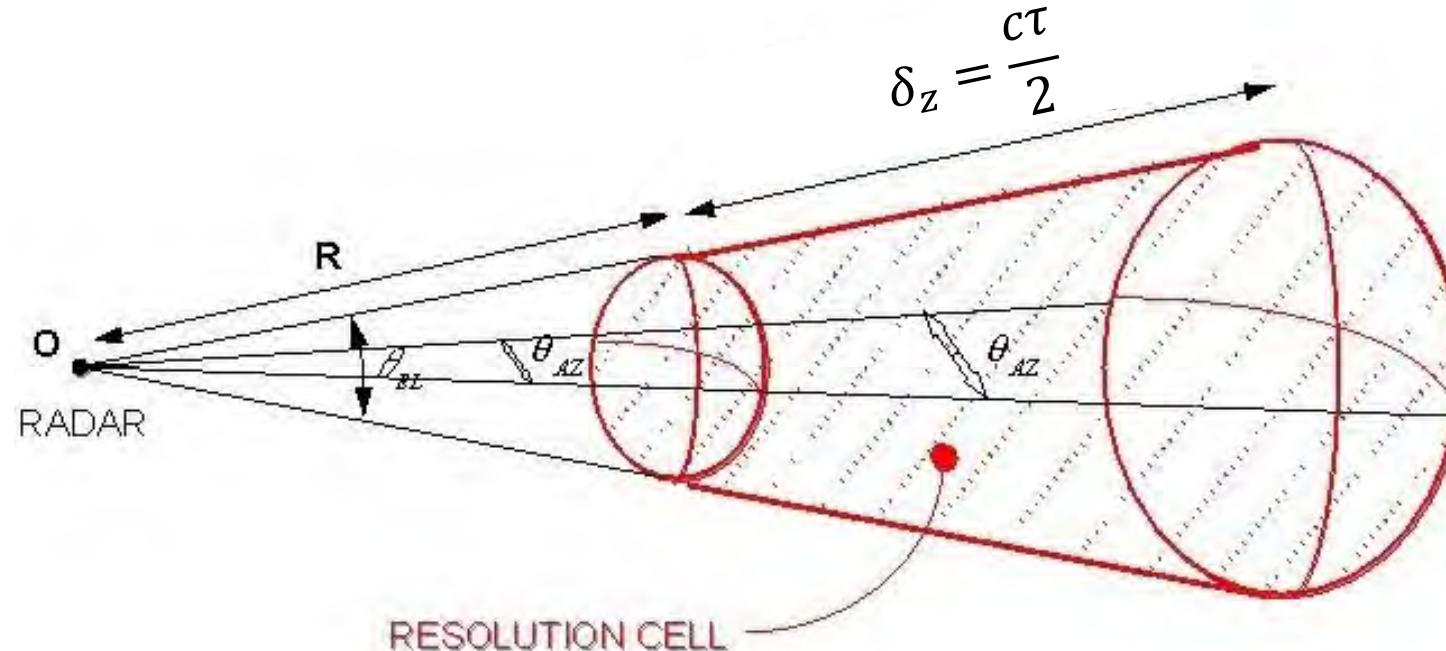
Range Resolution



$$\delta_z = \frac{c\tau}{2}$$



# Uncertain volume



$$V_i = \delta_{\theta_H} \delta_{\theta_V} \delta_z = \theta_H \theta_V R^2 \frac{c\tau}{2} = \theta_H \theta_V R^2 \frac{c}{2B}$$

Beamwidths in azimuth and elevation in radians

Pulse bandwidth

# Radar Cross Section



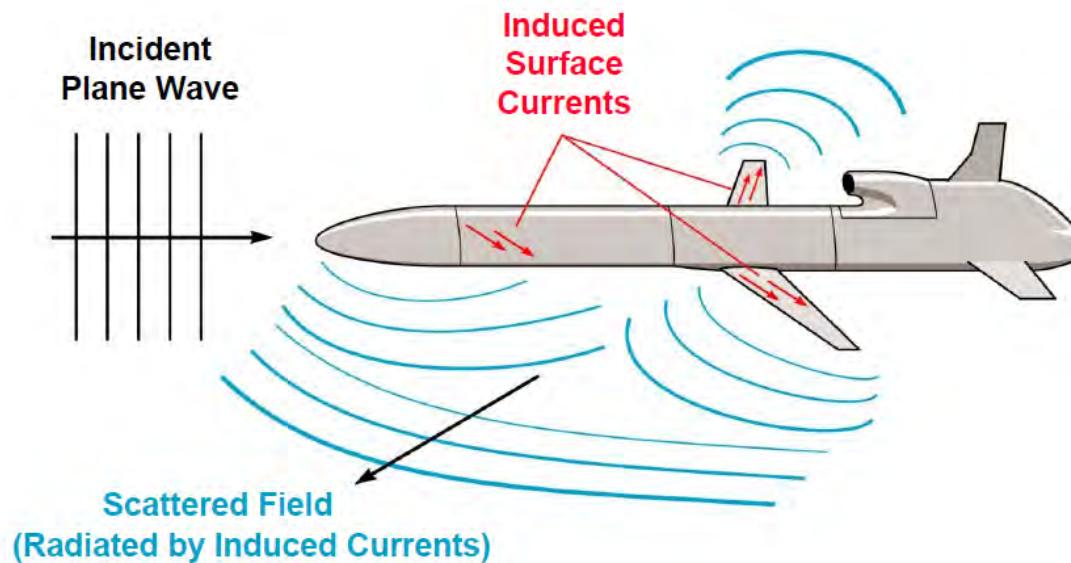
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# RADAR CROSS SECTION



- Two step process to determine scattered fields
  - Determine induced surface currents
  - Calculate field radiated by currents

Courtesy of MIT Lincoln Laboratory  
Used with permission

Dr. Robert M. O'Donnell  
IEEE New Hampshire Section  
Guest Lecturer

**PETER SWERLING**

*March 4, 1929, New York City. - August 25, 2000, California.*

Peter Swerling entered the California institute of technology at the age of 15 and received a B.S. In mathematics three years later in 1947. He went on to take a second undergraduate degree, this time in economics, from Cornell university in 1949,. He then attended the university of California, Los Angeles, where he received an M.A. In Mathematics in 1951 and a Ph.D. in Mathematics in 1955.

While still in graduate school, Swerling worked full-time for Douglas Aircraft Company as a staff member of the newly formed Project RAND. He wrote his landmark report, "Probability of Detection for Fluctuating Targets," for the RAND Corporation (now independent from Douglas Aircraft) in 1954. The paper introduced a set of statistically "fluctuating target" scattering models to characterize the detection performance of pulsed radar systems. Building on the work of Jess Marcum (who statistically subtracted noise from images of steady targets), Swerling accounted for statistical fluctuations of the target itself. The models became known as Swerling Target Models Cases I, II, III, and IV in radar literature.



## PROBABILITY OF DETECTION FOR FLUCTUATING TARGETS



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# SWERLING TARGET FLUCTUATION MODELS

*Developed by Peter Swerling*

## Case I: Scan to Scan Fluctuation (Slow fluctuation) (Rayleigh scatterer). Similar amplitudes from the scattering points.

- The echo pulses received from a target on any scan are of constant amplitude throughout the entire scan, but are uncorrelated from scan to scan.
- The probability density function is:

$$p(\sigma) = \frac{1}{\sigma_{av}} e^{-(\frac{\sigma}{\sigma_{av}})} ; \quad \sigma \geq 0$$

and  $\sigma_{av}$  is the average value of the RCS.

- In this case and **for one pulse**, the probability of detection can be exactly calculated in terms of the average  $\overline{(S/N)_1}$  over all target fluctuations, as:

$$P_D = e^{\frac{-V_T^2}{2\psi_0[1+\overline{(S/N)_1}]}} = (P_{FA})^{\frac{1}{[1+\overline{(S/N)_1}]}}$$



# SWERLING TARGET FLUCTUATION MODELS

*Developed by Peter Swerling*

## Case II: Pulse to Pulse Fluctuation (Fast fluctuation) Similar amplitudes from the scattering points.

- The echo pulses received from a target on any scan are independent from pulse to pulse within the scan, and are uncorrelated from scan to scan.
- The probability density function is the same as Case I:

$$p(\sigma) = \frac{1}{\sigma_{av}} e^{-(\frac{\sigma}{\sigma_{av}})} ; \quad \sigma \geq 0$$

and  $\sigma_{av}$  is the average value of the RCS.



# SWERLING TARGET FLUCTUATION MODELS

*Developed by Peter Swerling*

## Case III: Scan to Scan Fluctuation (Slow fluctuation) One scatterer point much larger than others.

- The echo pulses received from a target on any scan are of constant amplitude throughout the entire scan, but are uncorrelated from scan to scan.
- The probability density function is:

$$p(\sigma) = \frac{4\sigma}{\sigma_{av}^2} e^{-(\frac{2\sigma}{\sigma_{av}})} ; \quad \sigma \geq 0$$

and  $\sigma_{av}$  is the average value of the RCS.

- The target is modelled as one large scatterer together with a number of small scatterers.



# SWERLING TARGET FLUCTUATION MODELS

*Developed by Peter Swerling*

## Case IV: Pulse to Pulse Fluctuation (Fast fluctuation). One scatterer point much larger than others.

- The echo pulses received from a target on any scan are fluctuating from pulse to pulse.
- The probability density function is the same that Case III:

$$p(\sigma) = \frac{4\sigma}{\sigma_{av}^2} e^{-(\frac{2\sigma}{\sigma_{av}})} ; \quad \sigma \geq 0$$

and  $\sigma_{av}$  is the average value of the RCS.

- The target is modelled as one large scatterer together with a number of small scatterers.



# SWERLING TARGET FLUCTUATION MODELS

*Developed by Peter Swerling*

**Case V or Case 0: Non fluctuating target.**



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# THE RADAR EQUATION WITH FLUCTUATING RCS

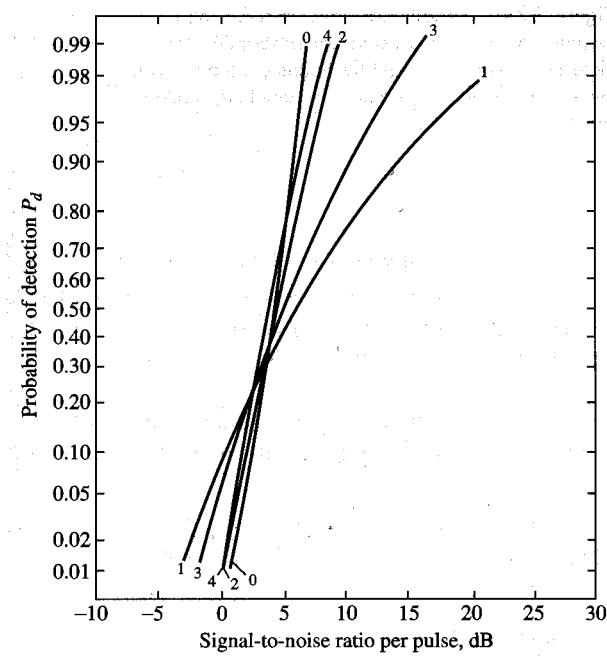
$$R_{max}^4 = \frac{P_t G \sigma_{av} A_{eff}}{(4\pi)^2 k T_0 BF(S/N)_n} = \frac{P_t G \sigma_{av} A_{eff} n E_i(n)}{(4\pi)^2 k T_0 BF(S/N)_1}$$

Fluctuating targets requires a larger S/N than a non fluctuating target to keep the same distance range.



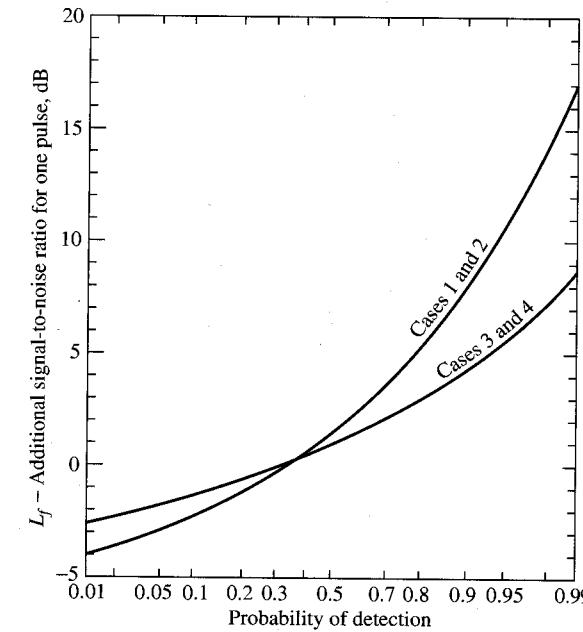
# Probability of detection and SNR in terms of fluctuating targets

**Figure 2.22** Comparison of the detection probabilities for the four Swerling models and the nonfluctuating model, for  $n = 10$  pulses integrated and a false-alarm number  $n_f = 10^8$ .  
[Adapted from Swerling.<sup>40</sup>]



# Additional SNR in terms of fluctuating targets

**Figure 2.23** Additional signal-to-noise ratio required to achieve a particular probability of detection when the target fluctuates according to a Swerling model. The ordinate is sometimes called the *fluctuation loss*,  $L_f$ .



# RADAR EQUATION FOR FLUCTUATING TARGETS

$$R_{max}^4 = \frac{P_t G \sigma A_{eff} n E_i(n)}{(4\pi)^2 k T_0 B F(S/N)_1 L_f}$$



# Tema 5: ELS EQUIPS I ELS SISTEMES RADIOELÈCTRICS AEROPORTUARIS

DOPPLER BASED RADARS

Jordi Berenguer

Novembre 2021



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# Types of Radar

- **Pulsed Radar**
  - Transmits pulses with a high power.
  - Can detect objects, measures range, but not speeds, and has blind and ambiguous ranges.
- **CW radar**
  - Transmits a low power continuous-wave signal.
  - Can detect objects, measures radial velocity from Doppler shift, but cannot measure range.
  - Can be designed in a compact and simple circuitry.
- **Pulsed Doppler Radar**
  - If the phase of the electromagnetic wave is measured, the measurement of the target speed is obtained, but has blind speeds.
  - An **MTI** Radar (**Moving Target Indicator**) is a kind of pulsed Doppler Radar, which removes the echoes from the static clutter.
  - Increases the hardware complexity on the Pulsed Radar.
- **FM-CW radar**
  - Transmits a low power frequency modulated CW signal.
  - Can detect objects, and measures range and radial velocity.

Based on [2]

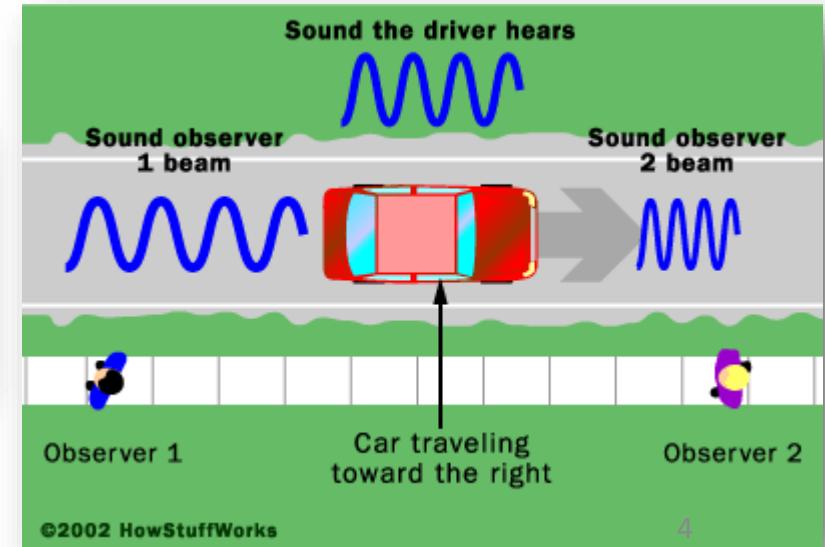
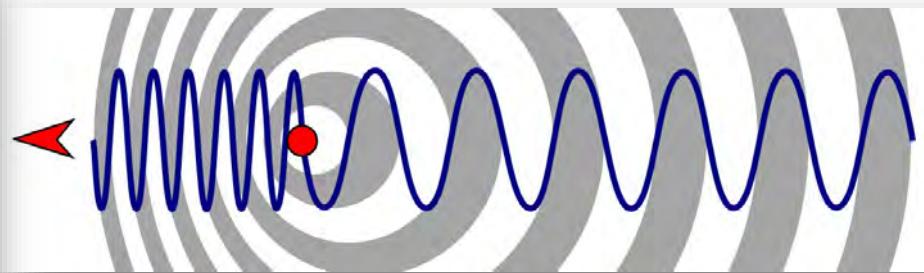
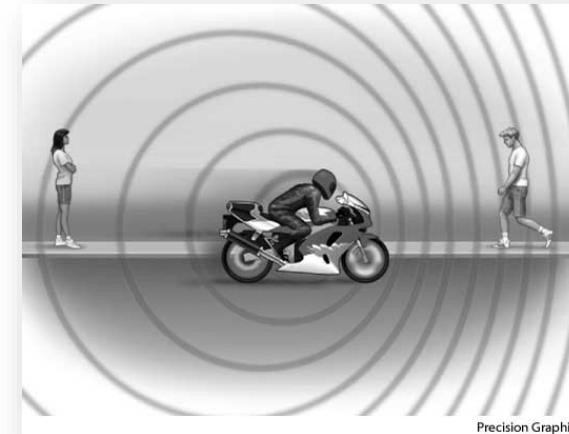
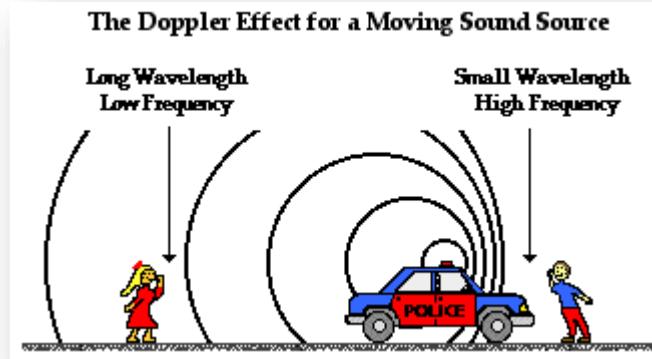


# DOPPLER Effect



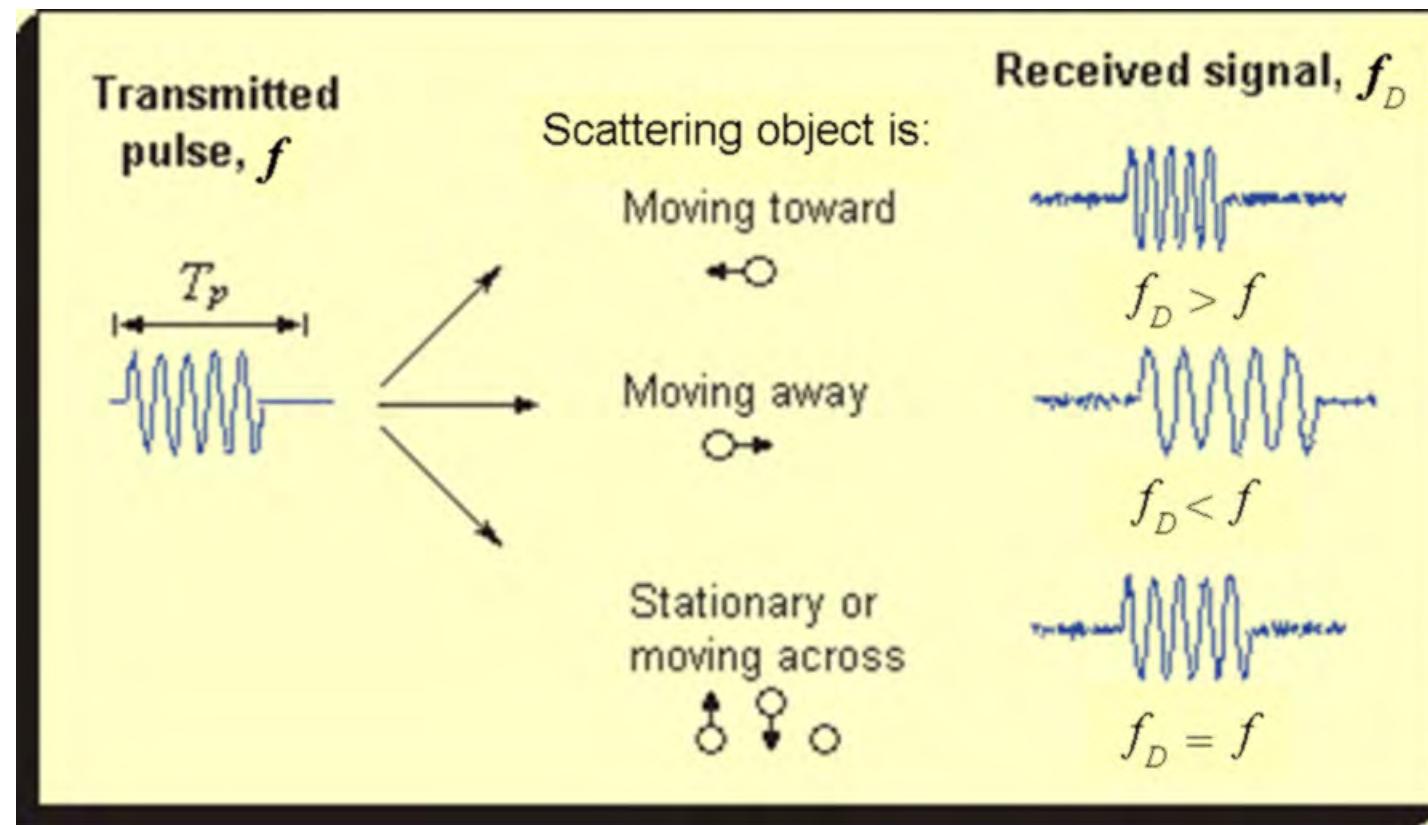
Christian Andreas Doppler  
*Salzburg, 29/XI/1803 – Venezia, 17/III/1853*

# Doppler effect in acoustic waves



# Doppler effect in electromagnetic waves

Doppler Shift: A frequency shift that occurs in electromagnetic waves due to the motion of scatters toward or away from the observer.



# CW Radar

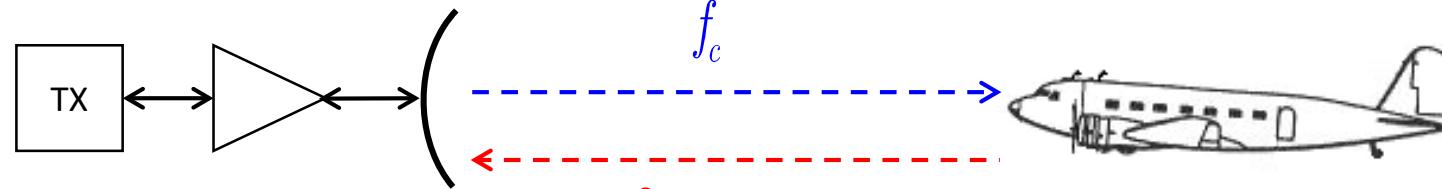
Continuous Wave Radar



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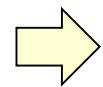
# DOPPLER FREQUENCY SHIFT EFFECT



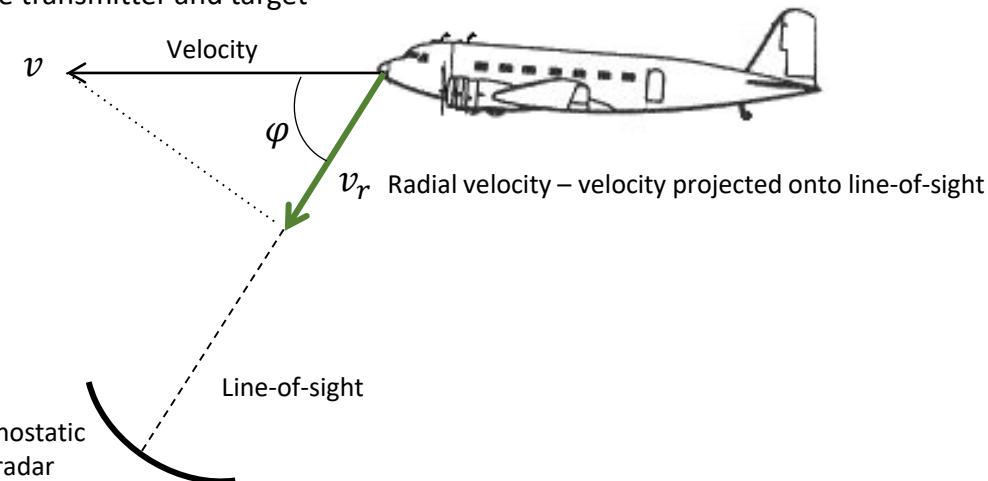
$$f_c + \frac{2v_r}{c} f_c = f_c + f_D$$

The received frequency differs from the transmitted frequency, due to the Doppler effect of the target.

$$v_r = v \cdot \cos \varphi$$

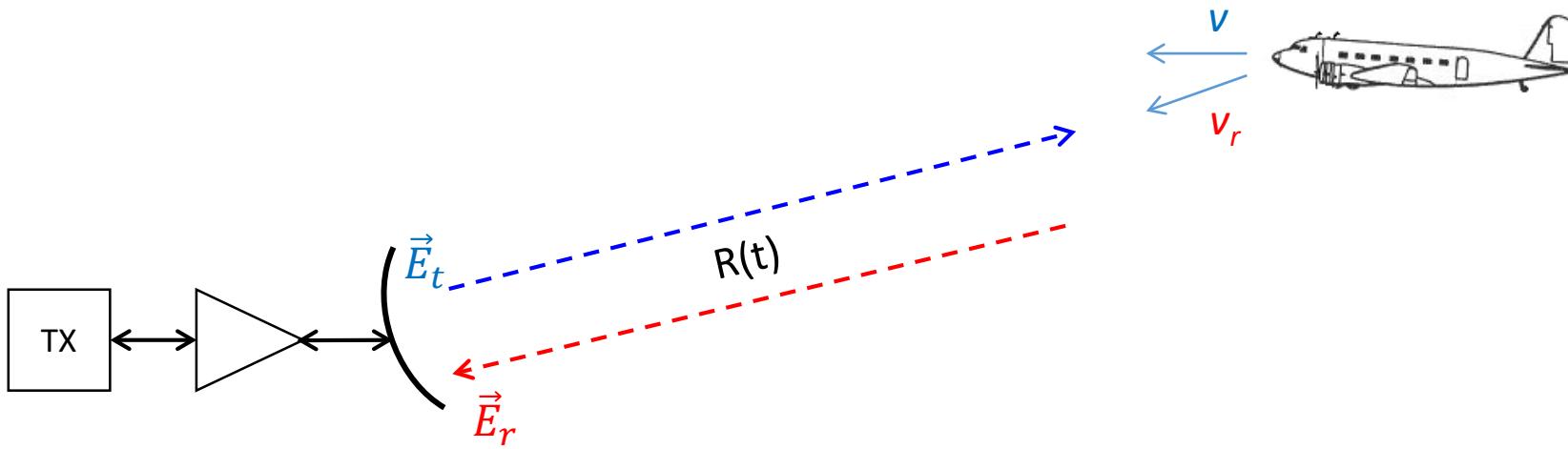


Only is possible the measurement of the relative **radial** of the transmitter and target



**Doppler radar:** A radar that can determine the frequency shift through measurement of the phase change that occurs in electromagnetic waves during a series of pulses.

# DOPPLER FREQUENCY SHIFT EFFECT

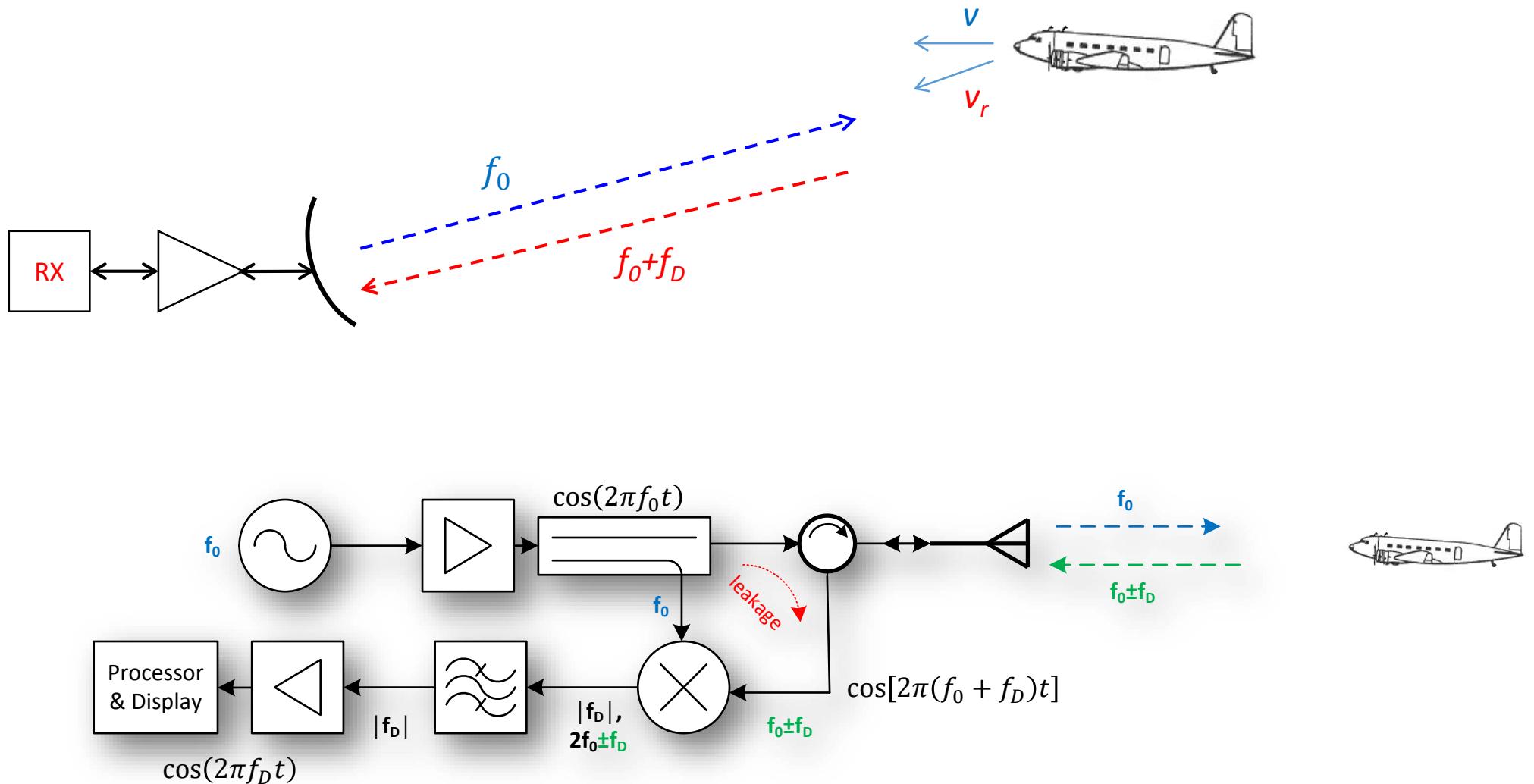


$$\begin{aligned}\vec{E}_t &= Ae^{j\omega_0 t}; \quad \vec{E}_r = A\sigma e^{-j2\beta R(t)}e^{j\omega_0 t} = A\sigma e^{-j\frac{4\pi}{\lambda_0}R(t)}e^{j\omega_0 t} \\ \phi_D &= \phi_t - \phi_r = -2\beta R(t) = -\frac{4\pi}{\lambda_0}R(t) \\ \omega_D &= \frac{d\phi_D}{dt} = -\frac{4\pi}{\lambda_0} \frac{dR(t)}{dt} = -\frac{4\pi}{\lambda_0}v_r \\ f_D &= \frac{\omega_D}{2\pi} = -\frac{2v_r}{\lambda_0} = -\frac{2f_0v_r}{c}\end{aligned}$$

$f_D$  = Doppler frequency  
 $v_r$  = radial velocity  
 $f_0$  = transmission frequency  
 $\lambda_0$  = wavelength  
 $c$  = propagation velocity (light speed)

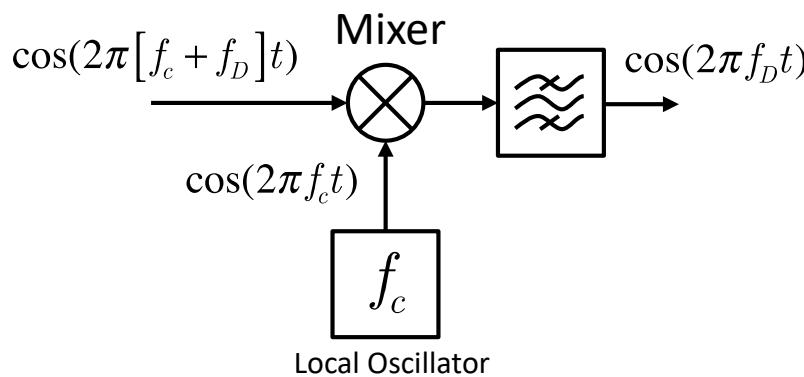
$$f_D = -\frac{2f_0v_r}{c}$$

# HOMODYNE CW RADAR



# HOMODYNE CW RADAR

With a simple receiver, the sign information of the Doppler frequency is lost. Only the target speed is obtained without any information about the sense of the target.



$$\cos([\omega_c + \omega_D]t)\cos(\omega_c t) = \frac{1}{2}\cos(\omega_D t) + \frac{1}{2}\cos([2\omega_c + \omega_D]t)$$

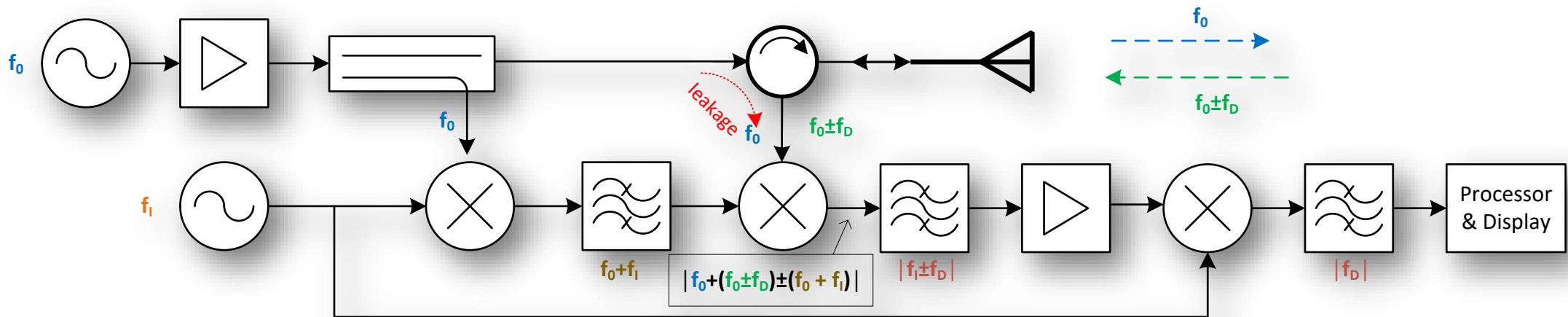
$$\cos([\omega_c - \omega_D]t)\cos(\omega_c t) = \frac{1}{2}\cos(\omega_D t) + \frac{1}{2}\cos([2\omega_c - \omega_D]t)$$



Removed by filtering

There is an ambiguity in target speed, because the signal components at  $f_c+f_D$  and  $f_c-f_D$ , result in the same IF.

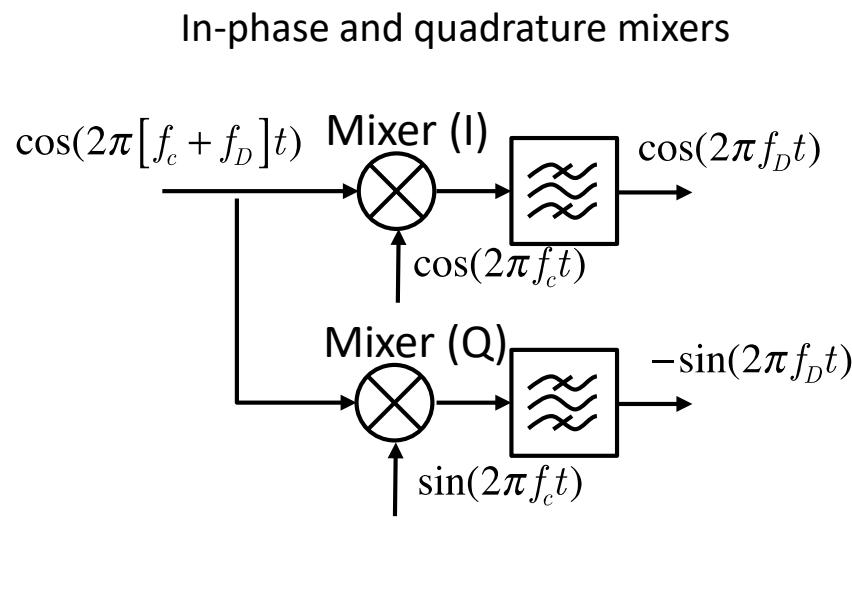
# HETERODYNE CW RADAR



- Improves the sensitivity of the receiver.
- Avoids the leakage problems of the circulator.
- But doesn't detect the sign of the Doppler shift.

# I/Q HOMODYNE CW RADAR (Sign sense)

To solve this ambiguity, the use of a phase/quadrature (I/Q) receiver is required, where the module and phase information is obtained, but increasing the complexity of the receiver.



For the negative Doppler:  $\cos(2\pi[f_c - f_D]t)$

In-phase:  $\cos(2\pi f_D t)$   
Quadrature:  $+\sin(2\pi f_D t)$



Change in sign

$$\hat{f}_D = \tan^{-1}\left(\frac{Q}{I}\right)$$

# NORMALIZED FREQUENCIES BY THE CNAF

Cuadro nacional de atribución de frecuencias (CNAF)

CNAF 2013 (B.O.E. de 9 de mayo 2013, actualizado B.O.E. de 16 de abril 2015)

<http://www.minetur.gob.es/telecomunicaciones/Espectro/Paginas/CNAF.aspx>

## UN - 86 Dispositivos de baja potencia para detección de movimiento y vigilancia

Frecuencia	Potencia (p.i.r.e.)
2400 - 2483,5 MHz	25 mW
9500 - 9975 MHz	25 mW
10,5 - 10,6 GHz	500 mW
17,1-17,3 GHz	400 mW (*)
24,05 - 24,25 GHz	100 mW

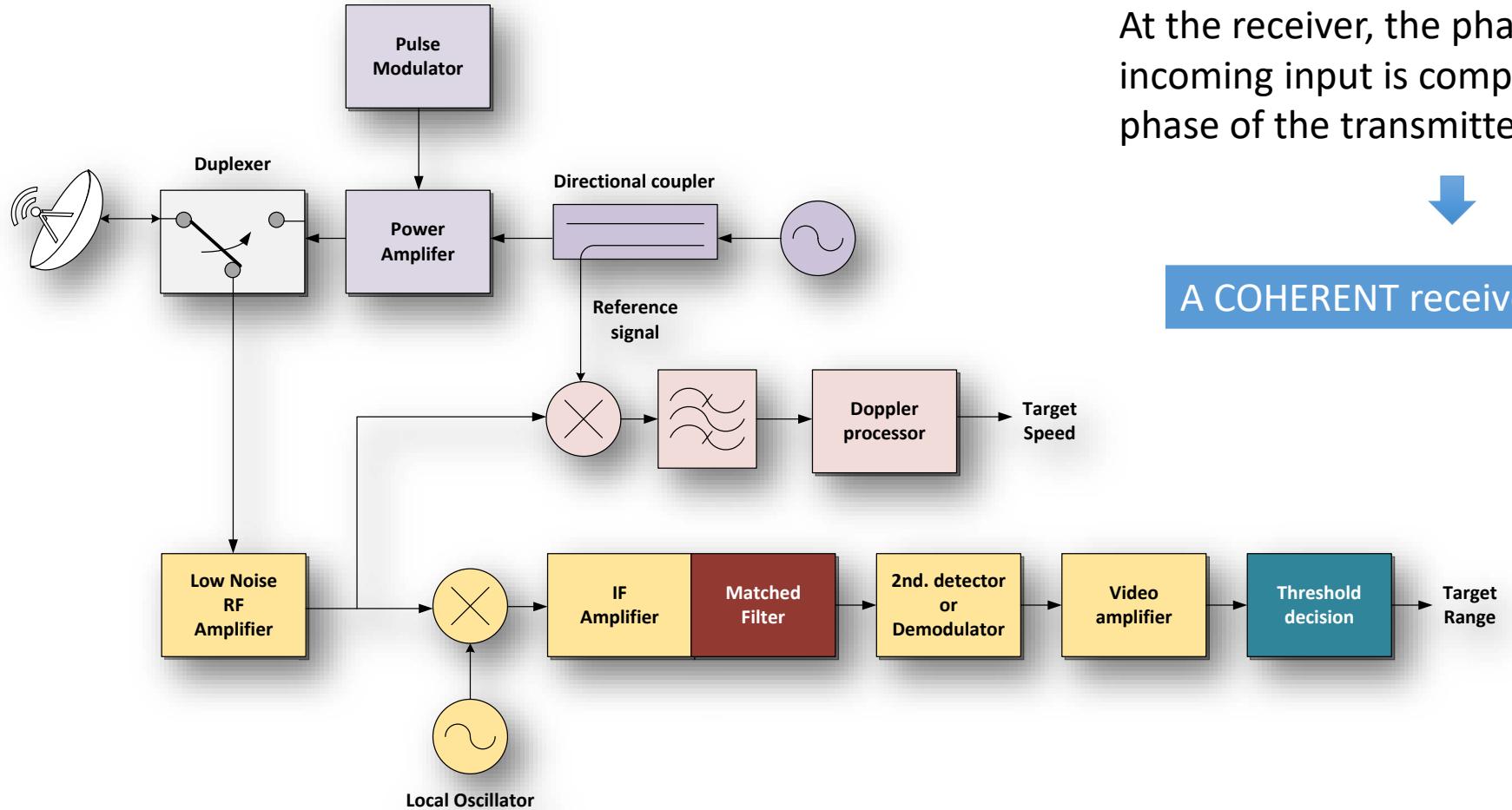


(\*) Utilizando técnicas de acceso al espectro y de mitigación de interferencias con rendimiento al menos equivalente a las normas armonizadas con arreglo a la Directiva 1999/5/CE.

# PULSED Radar with Doppler shift



# PULSE DOPPLER RADAR

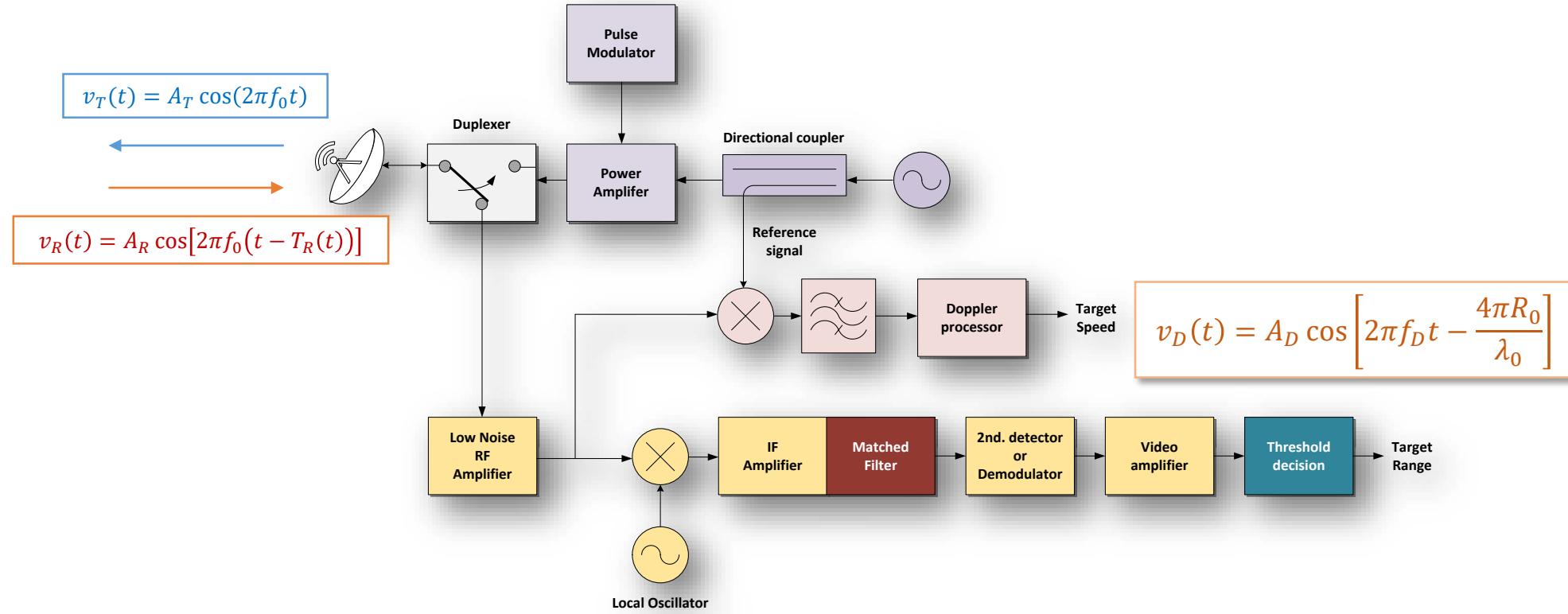


At the receiver, the phase of the incoming input is compared with the phase of the transmitted signal.



A COHERENT receiver is needed

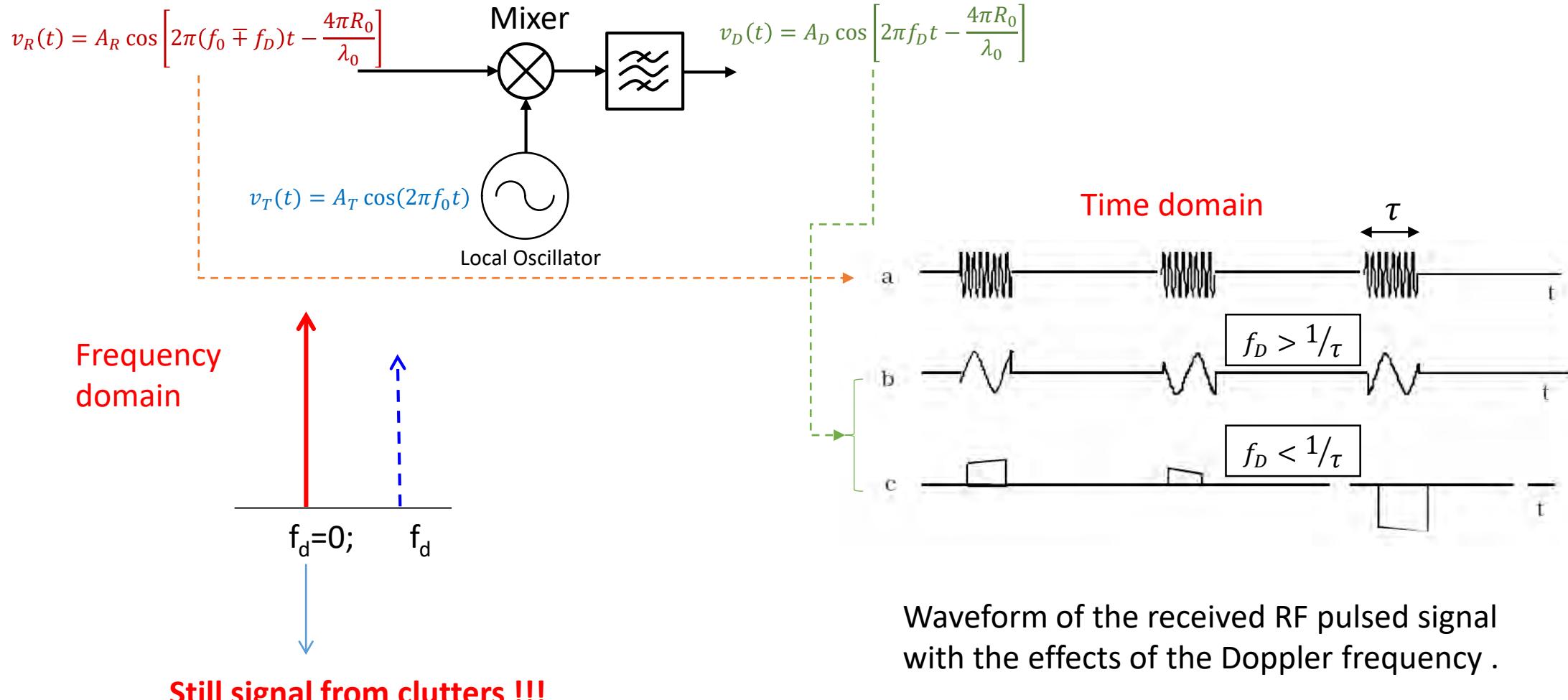
# PULSED DOPPLER RADAR



$$T_R(t) = \frac{2}{c} (R_0 \pm v_r t)$$

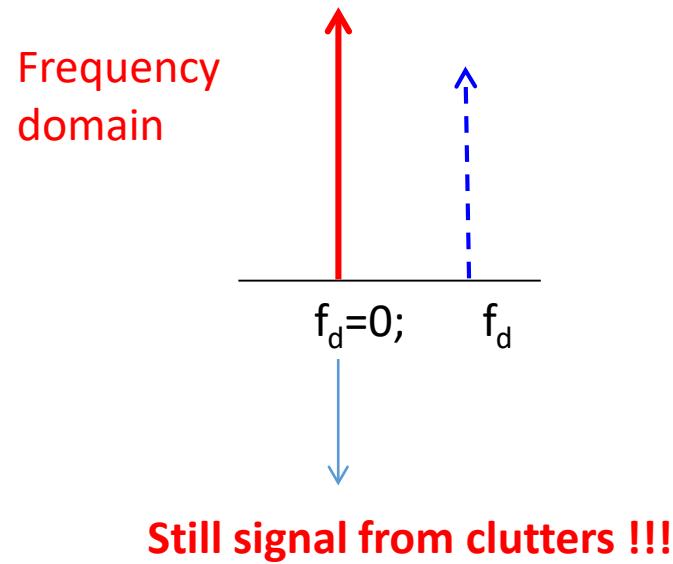
$$v_R(t) = A_R \cos\left[2\pi f_0 \left(1 \mp \frac{2v_r}{c}\right) t - \frac{4\pi f_0 R_0}{c}\right] = A_R \cos\left[2\pi(f_0 \mp f_D)t - \frac{4\pi R_0}{\lambda_0}\right]$$

# PULSE RADAR WITH THE DOPPLER SHIFT EFFECT

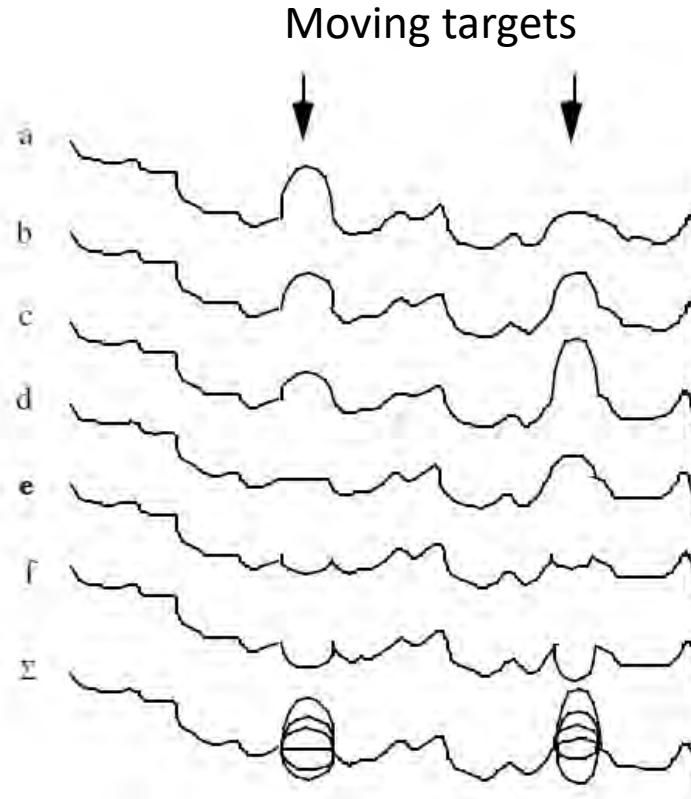


Waveform of the received RF pulsed signal with the effects of the Doppler frequency .

# PULSE RADAR WITH THE DOPPLER SHIFT EFFECT



Time domain



The fixed clutter echoes remain the same from sweep a sweep. After integration, only the moving targets are clearly identified.

# MOVING TARGET INDICATOR (MTI)

Pulsed Radar with Doppler Shift



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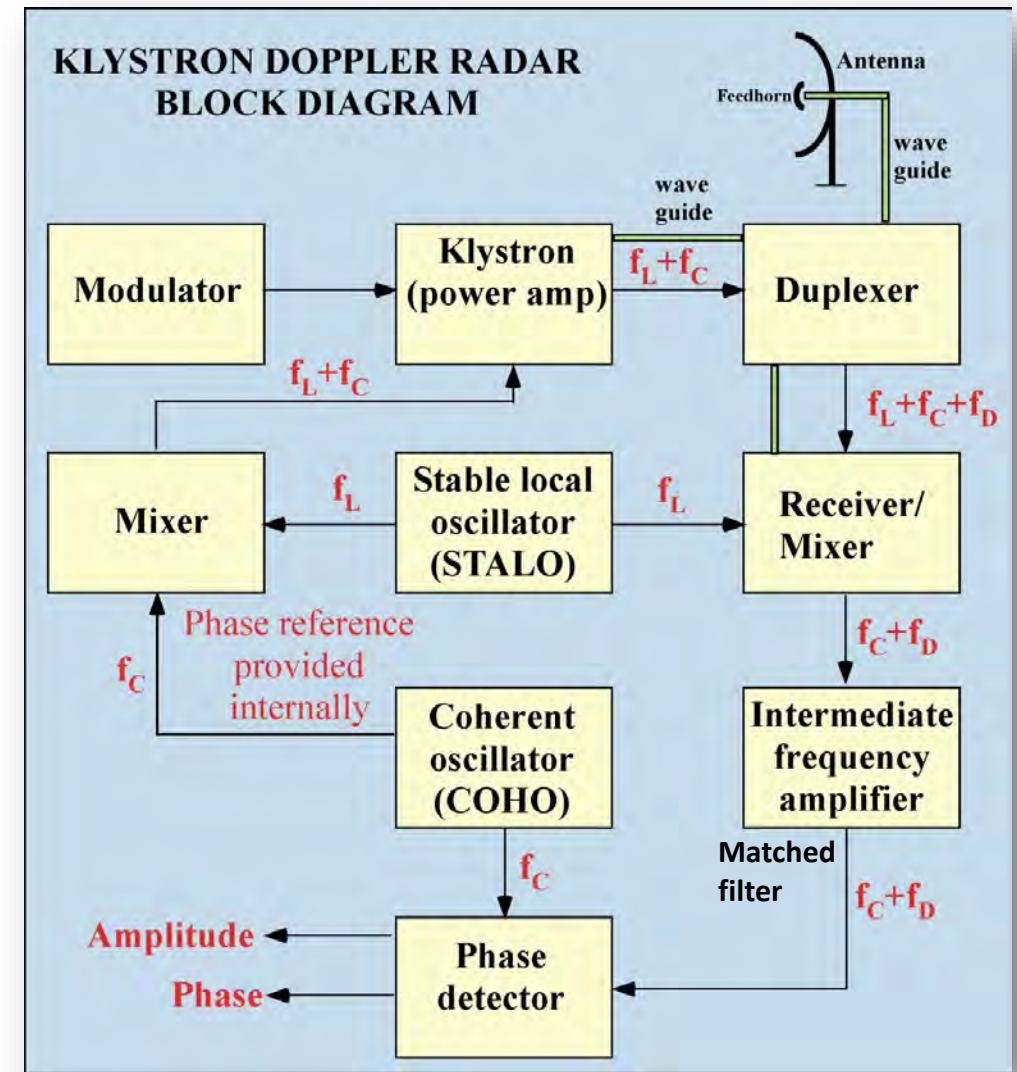
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# MTI RADAR: Block Diagram

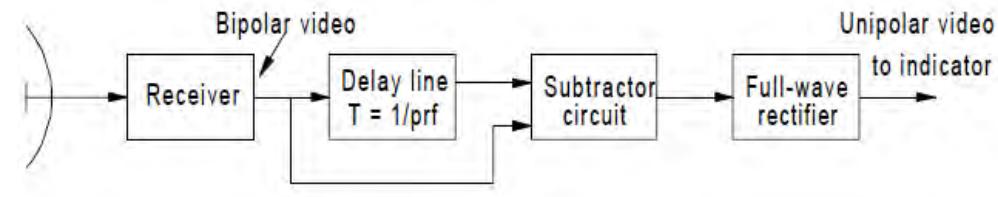
MTI is the process of rejecting fixed or slowly moving clutter while passing echoes from targets moving at significant velocities.

In most cases the MTI is sensitive only to radial components of velocity, but area MTI techniques can provide sensitivity to angular components as well.

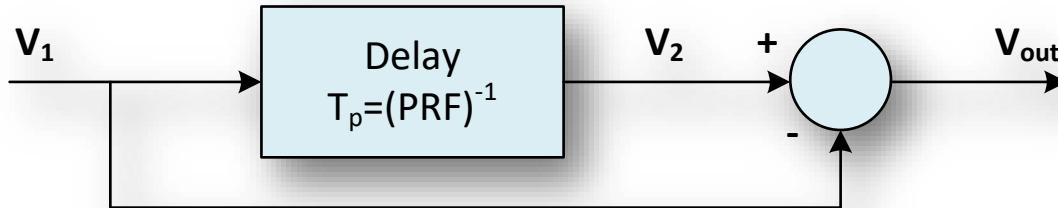


# MTI WITH SINGLE DELAY-LINE CANCELLER

- Implementation in the time domain is based on the fact that the phase of the fixed target echo does not change from pulse to pulse, while that of the moving target changes at a rate corresponding to the Doppler frequency.
- This leads to the delay-line canceler implementation.



# MTI WITH SINGLE DELAY-LINE CANCELLER



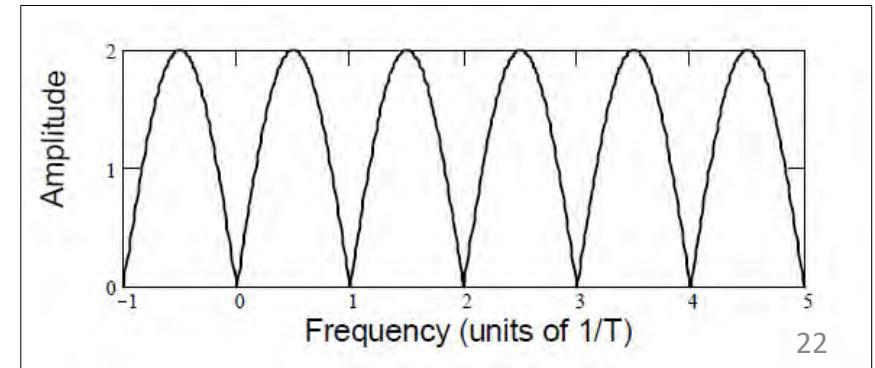
$$V_2 = k \sin[2\pi f_D(t - T_p) - \phi_0]$$

$$V_1 = k \sin(2\pi f_D t - \phi_0), \quad \phi_0 = \frac{4\pi R_0}{\lambda_0}$$

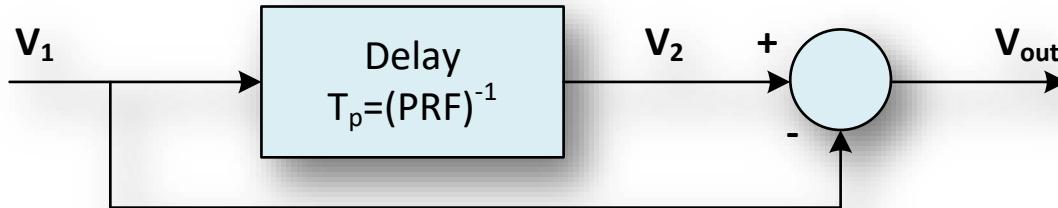
$$V_{out} = 2k \sin(\pi f_D T_p) \cdot \cos[2\pi f_D \left(t - \frac{1}{2}T_p\right) - \phi_0]$$

Transfer function of the single canceller

$$H(f_D) = 2 \sin(\pi f_D T_p)$$



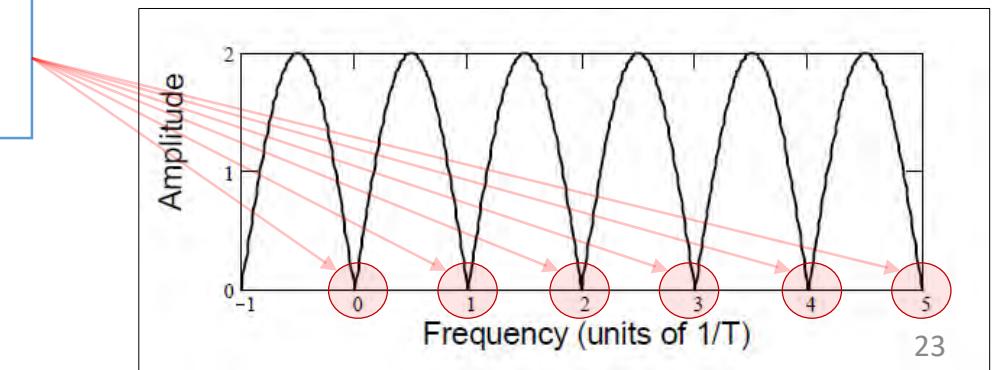
# MTI WITH SINGLE DELAY-LINE CANCELLER



$$H(f_D) = 2 \sin(\pi f_D T_p)$$

- It removes the ideal static clutter echoes  $\delta(0)$ , but the Doppler shifts that are multiples of the PRF are undetectable.
- They are called the **blind speeds**.

$$v_n = \frac{n\lambda_0}{2T_p} = n \frac{\lambda_0}{2} \text{ PRF}; \quad n = 1, 2, 3, \dots$$

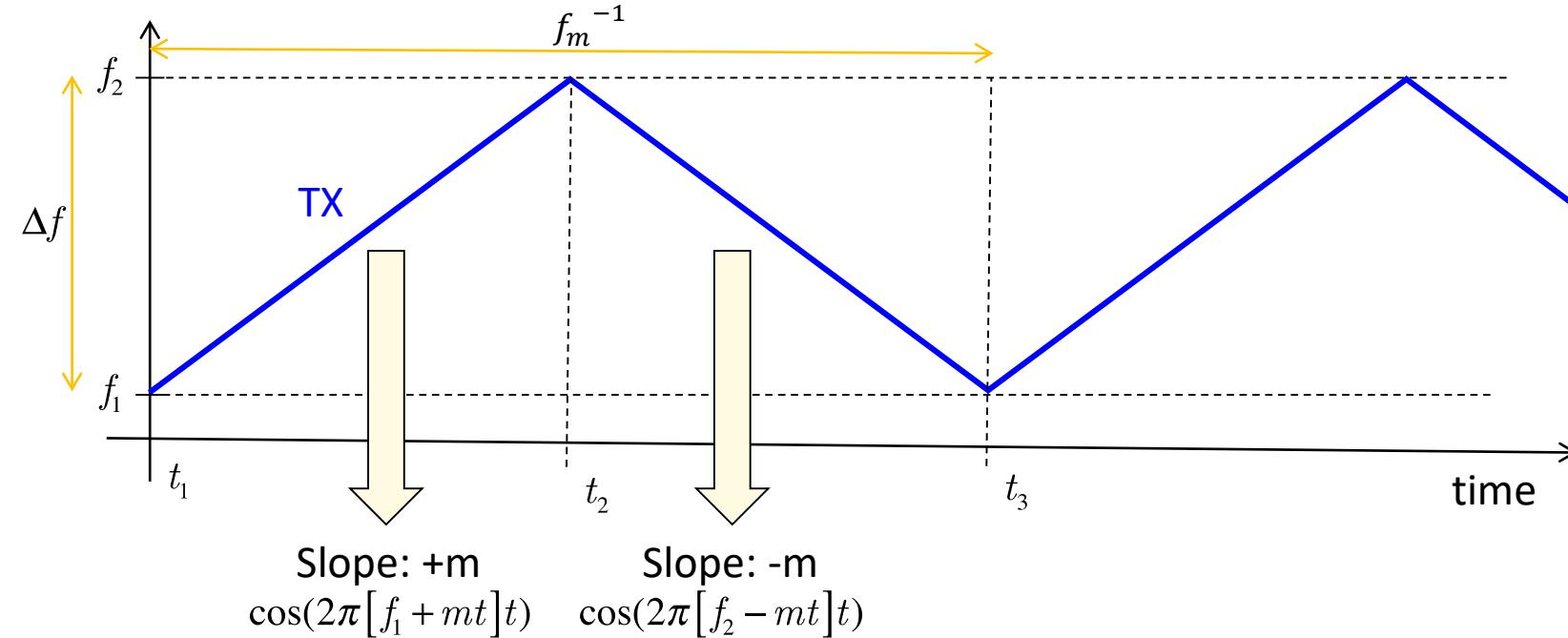


# FM-CW Radar



# FM-CW Radar

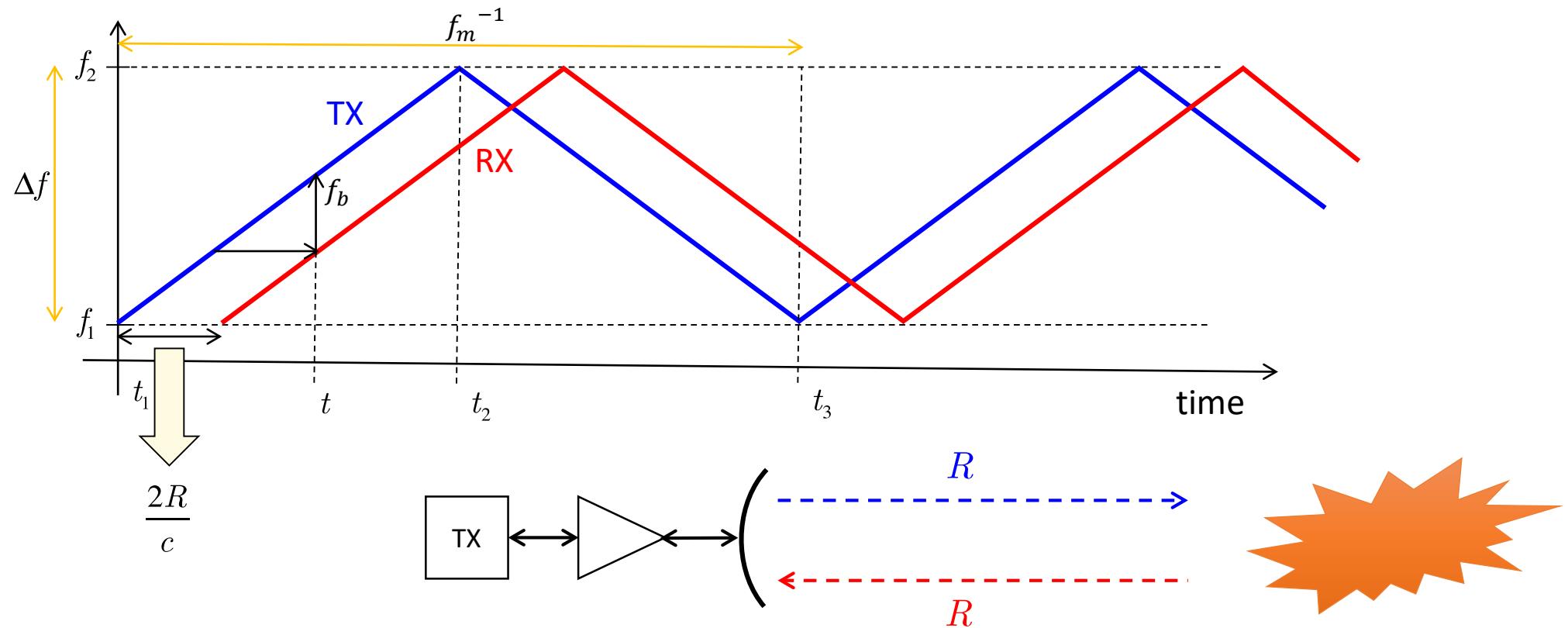
- Frequency modulate a CW signal



$$m = \frac{\Delta f}{(f_m)^{-1}/2} = 2f_m\Delta f$$

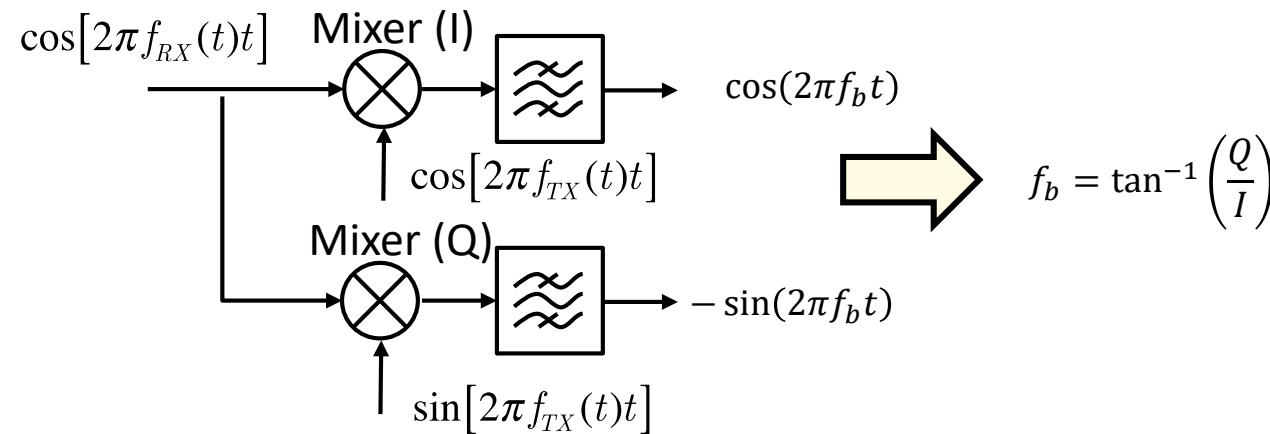
# FM-CW Radar

**Stationary** target at Range ‘R’



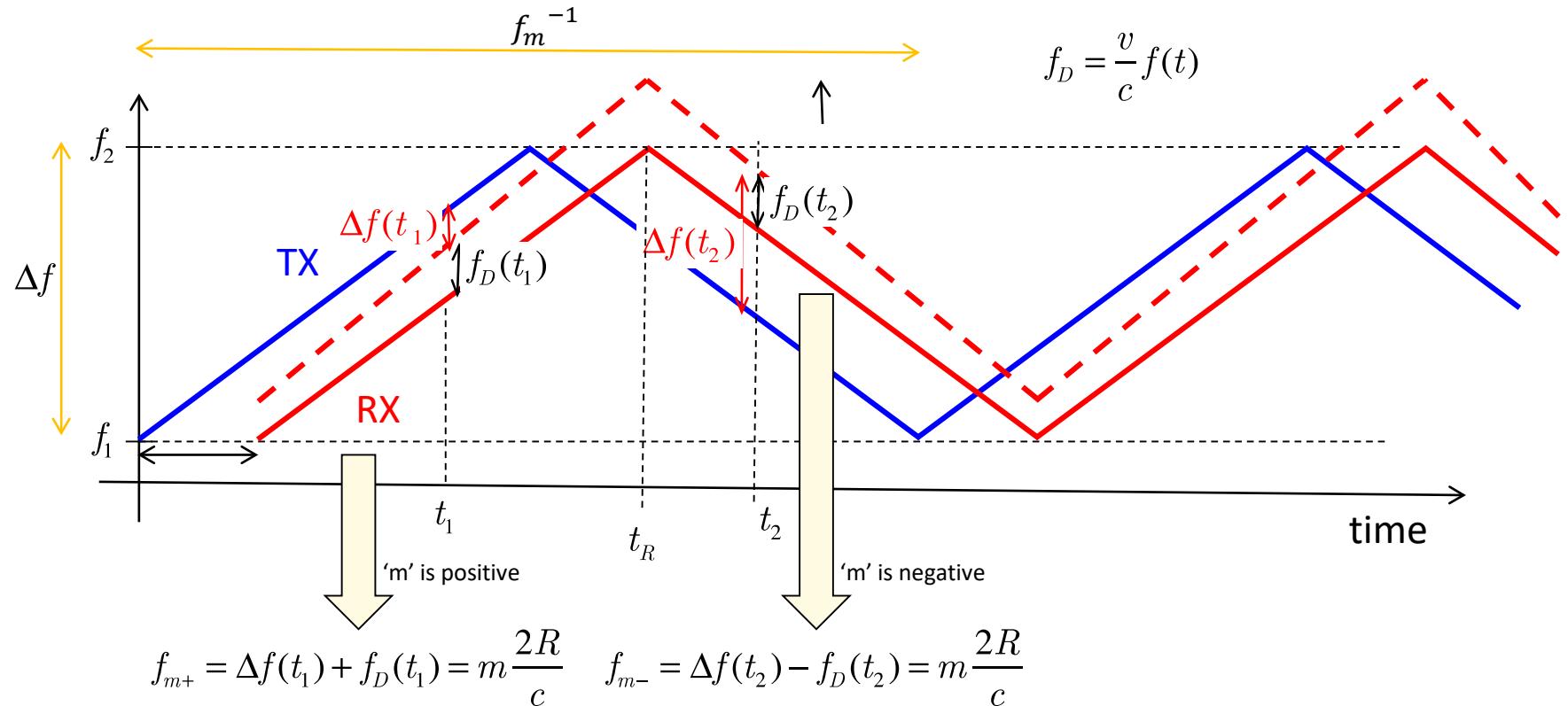
$$m = \frac{f_b}{2R/c} = \frac{f_b c}{2R} \Rightarrow R = \frac{f_b c}{2m} = \frac{f_b c}{4f_m \Delta f}$$

# FM-CW Radar



$$R = \frac{f_b c}{4f_m \Delta f}$$

# FM-CW Radar - Moving target at Range 'R'



If  $t_1$  and  $t_2$  are chosen symmetric with respect to  $t_R$  and the target velocity is constant over that interval:

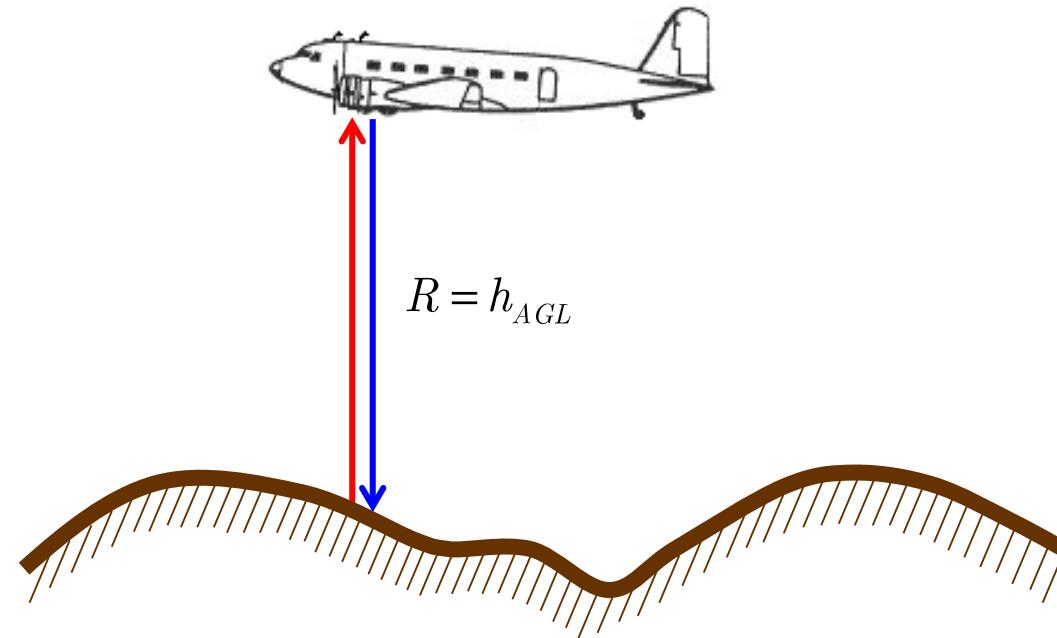
$$f_D(t_1) = f_D(t_2) = f_D \Rightarrow f_D = \Delta f(t_2) - \Delta f(t_1) \text{ and } R = \frac{c[\Delta f(t_2) - \Delta f(t_1)]}{4m}$$

# FM-CW Radar altimeter



# Application: the Radar Altimeter

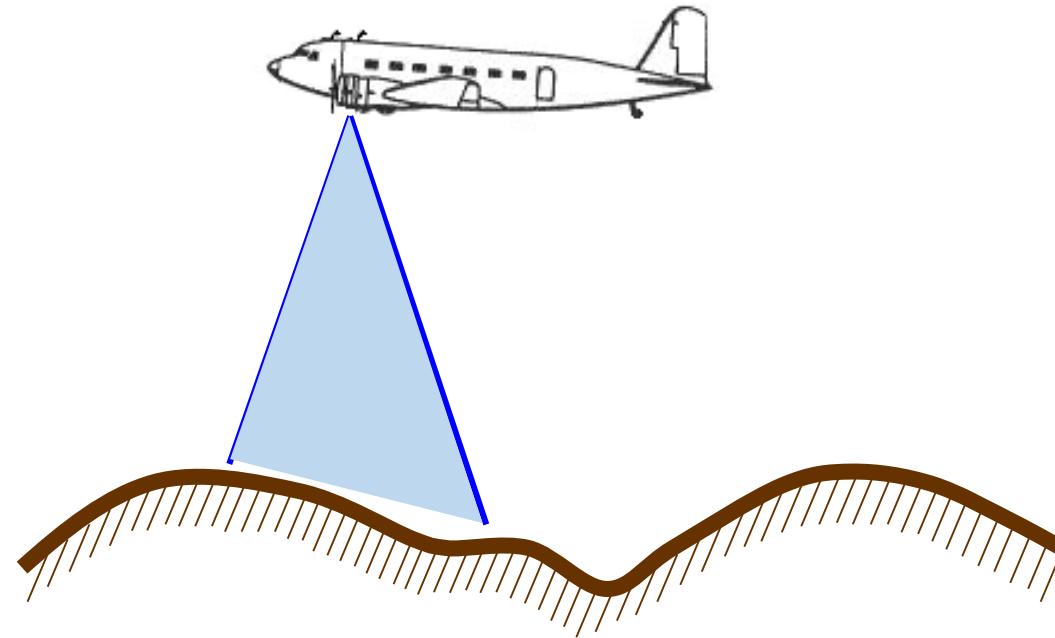
- Measures height ***Above Ground Level (AGL)***



Frequency of operation: 4,2 to 4,4 GHz.

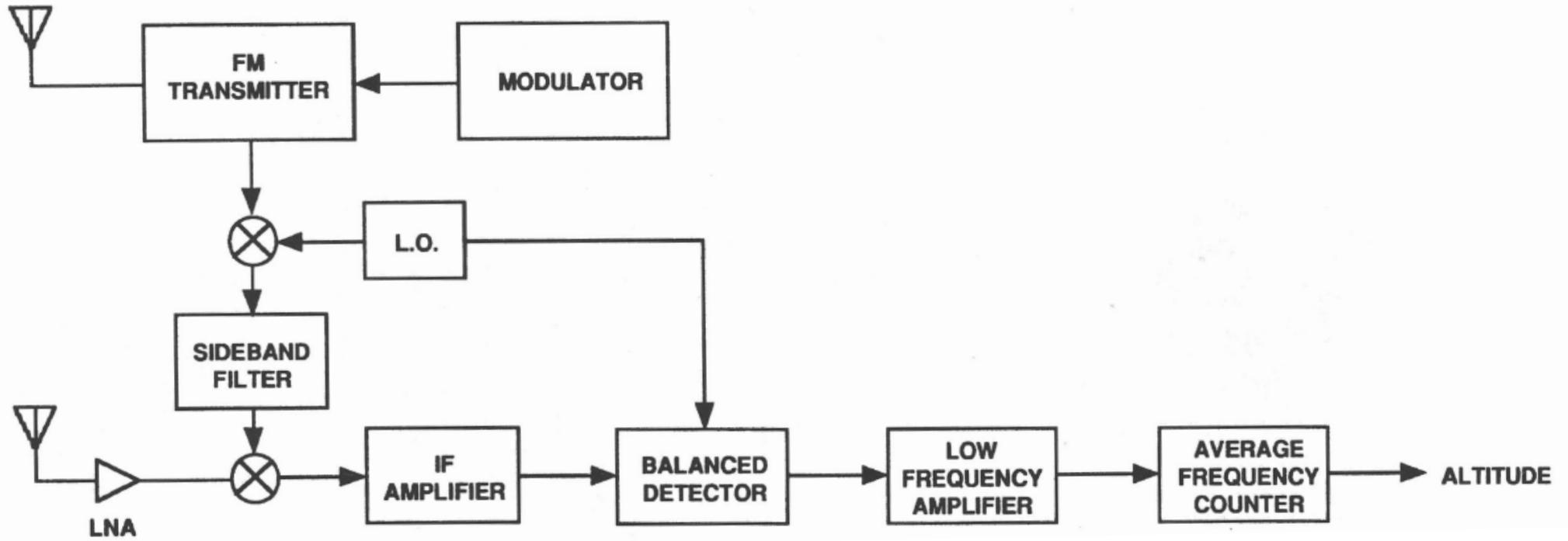
# Radar Altimeter – Effect of Beam-width

- The beam illuminates an area rather than a single point



Frequency of operation: 4,2 to 4,4 GHz.

# FM-CW Radar Altimeter Block Diagram



Frequency of operation: 4,2 to 4,4 GHz.

# Honeywell KRA-405B FM-CW Radar Altimeter

- The KRA-405B radar altimeter (RADALT) is a lightweight, solid-state, airborne altimeter that provides accurate altitude measurements above terrain during various portions of flight. With more than 10,000 produced and sold to date and more than four million service hours, the KRA-405B RADALT has proven to be one of the most reliable and industry proven radar altimeters available.
  - Size: 3.00"W x 3.50"H x 11."L
  - Weight: 3.06 lbs. (unit); 5.36 lbs (system)
  - TSO Compliance: C87/ETSO-2C87
  - Primary Power: 27.5 VDC  $\pm$ 20% at 850 mA (nom); 18 VDC @ 1.2 Amps (max)
  - Temperature: -55 to +70C
  - Altitude range:
    - Tracked: -20 to 2,500 feet (-6.1 to 762.0 m)
    - Accuracy: 3 ft. or  $\pm$ 3% at 0-500 ft. and  $\pm$ 5% at 500-2500 ft.
  - Output: 160 mW nominal, FMCW**
  - Frequency: 4300  $\pm$  15 MHz
  - Modulation Frequency: 100 Hz nominal



# Tema 5:

## ELS EQUIPS I ELS SISTEMES RADIOELÈCTRICS AEROPORTUARIS

Jordi Berenguer

Novembre 2021



UNIVERSITAT POLITÈCNICA DE CATALUNYA  
BARCELONATECH

Departament de Teoria del Senyal  
i Comunicacions

# Secondary Surveillance RADAR (SSR) Air Traffic Control Radar Beacon System

ATCRBS

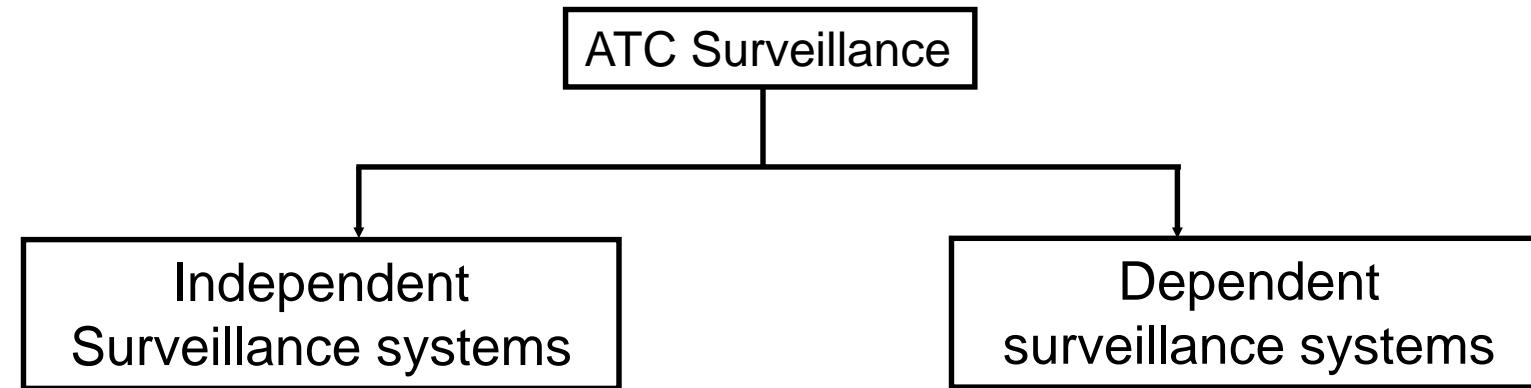


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# Overview

## Surveillance systems

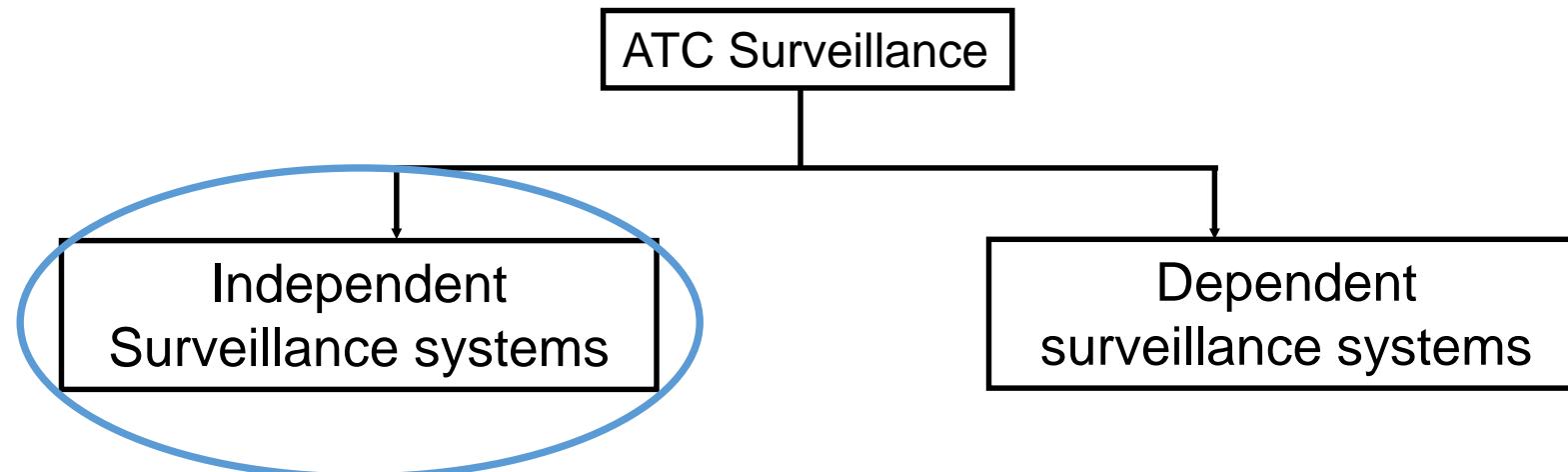


**Independent Surveillance Systems:** The aircraft position is obtained from **ground** equipment, **with** or **without** the aircraft collaboration.

**Dependent surveillance systems:** The aircraft position is obtained from on-board equipment and are transmitted to ground stations.

# Overview

## Surveillance systems

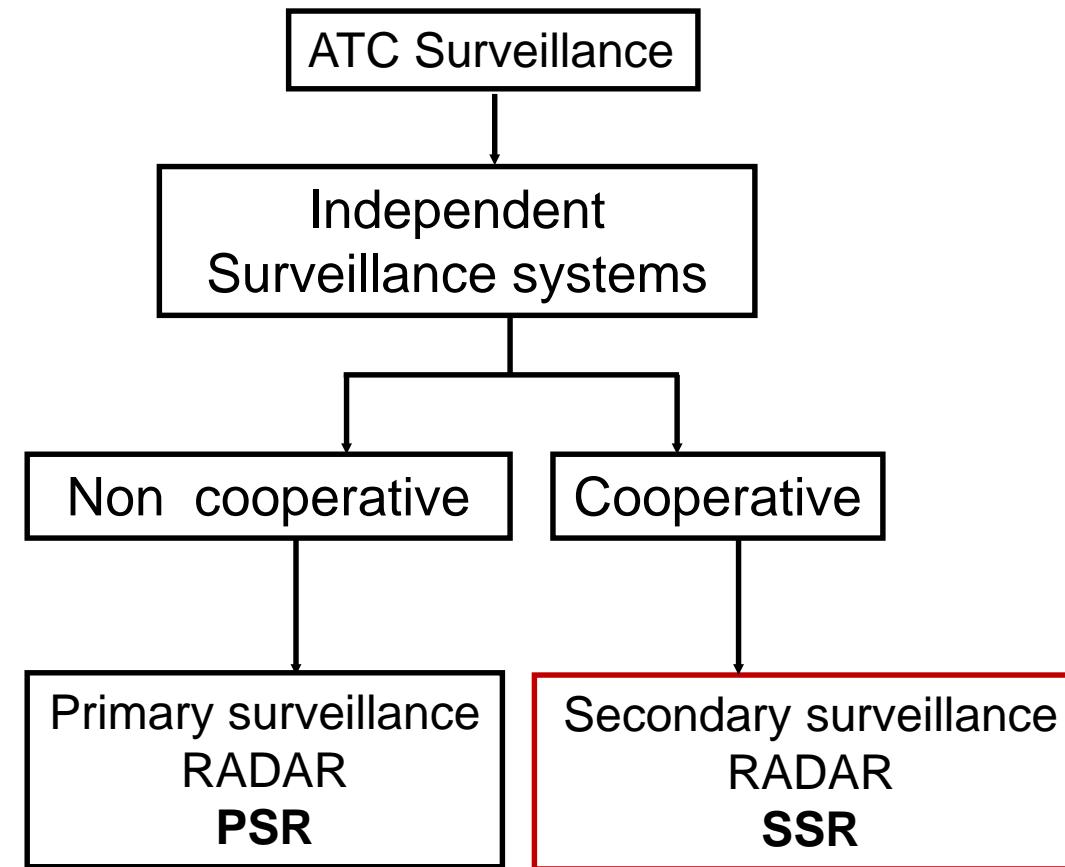


**Independent Surveillance Systems:** The aircraft position is obtained from **ground equipment**, **with** or **without** the aircraft collaboration.

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# Overview

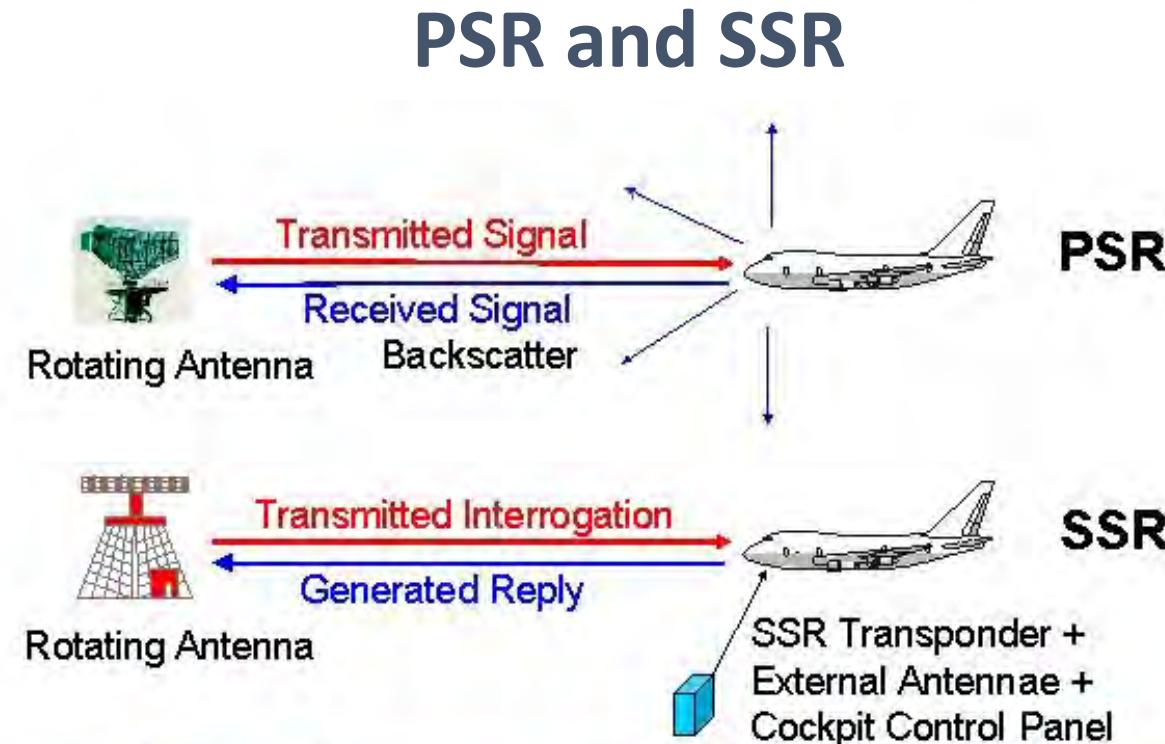
## Surveillance systems



# ATCRBS

- **ATCRBS**, the **Air Traffic Control Radar Beacon System**, is a secondary surveillance radar system developed for use within the air traffic control system for more precise position reporting of planes.
- It is **used in conjunction with the primary radar**, which is used to determine the presence of planes in the airspace.
- ATCRBS **supplements** this positional information with positive **identification and altitude information**, allowing controllers to track each plane more precisely and efficiently.
- Developed in 1956, ATCRBS was the first air route surveillance radar system developed and purchased for the purposes of air traffic control.
- The technology was based closely on that of the military's IFF (Identification Friend or Foe) system.

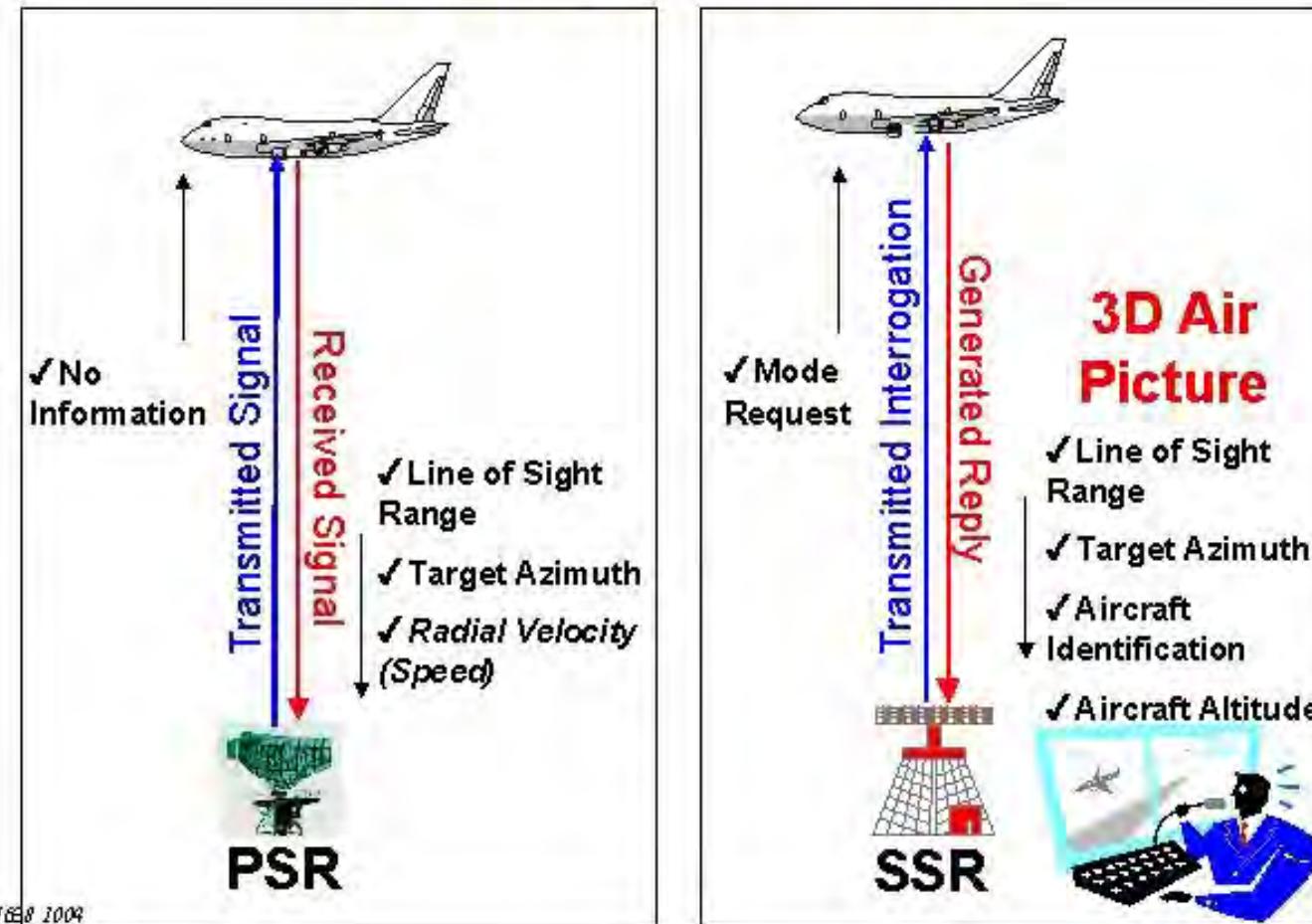
# Working Principle of SSR



Non co-operative versus co-operative Independent Surveillance

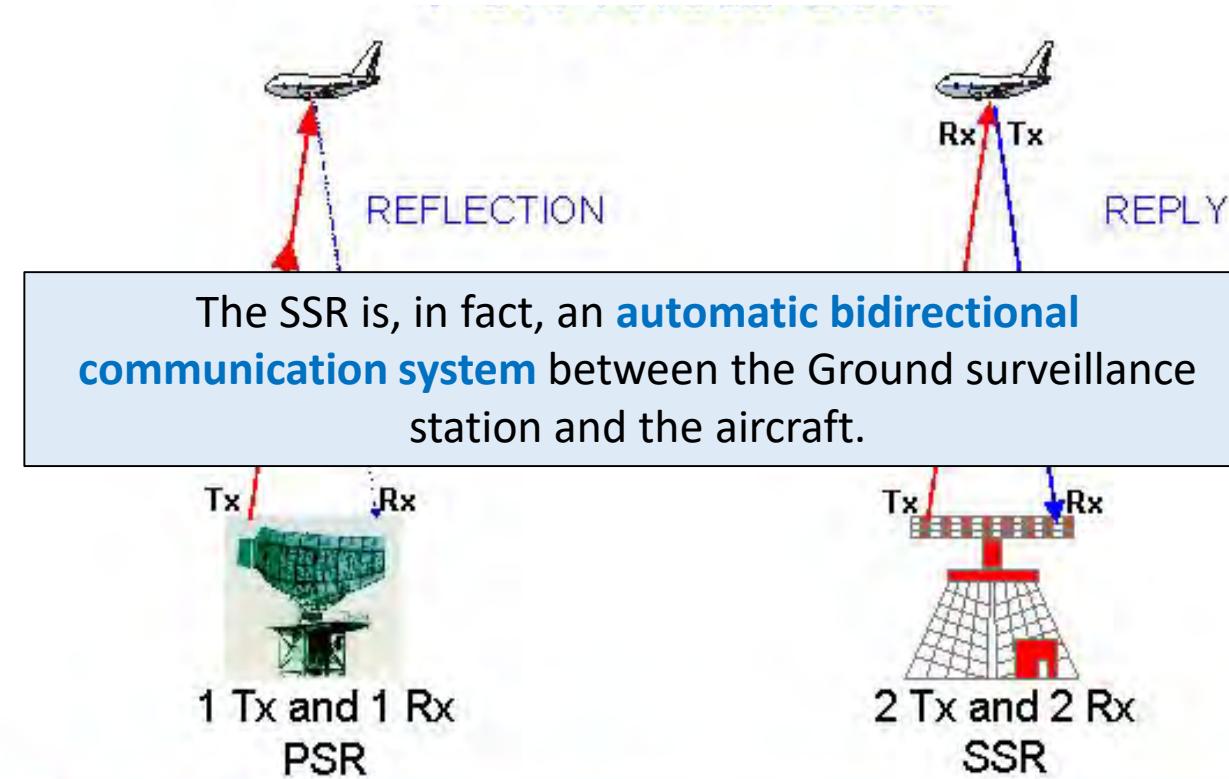
# Working Principle of SSR

## PSR and Classical SSR



# Working Principle of SSR

## PSR and SSR



SSR “round trip” requires 2 successful transmissions and 2 successful receptions BUT each transmission require less power

# Working Principle of SSR

- Primary surveillance radar (PSR) detects and measures the position of an aircraft.
- Secondary surveillance radar (SSR) requests additional information from the aircraft such as **identity** and **altitude**.
- It relies on the aircraft being equipped with a transponder that automatically replies to an interrogation signal.

# Working Principle of SSR

PSR	SSR
Detects everything	Detects only Co-operating Targets
Sees “clutter”	No Clutter
High Transmitting Power	Conventional Transmission Power
Needs Sensitive Receiver <i>(the received signal depends of the target RCS)</i>	Bidirectional communications system. <i>(Good SNR in both senses)</i>
Tracking is more difficult	More unambiguous tracking
<b>Blind to Height</b>	<b>Extracts Altitude</b>
<b>Blind to Identity</b>	<b>Extracts Identity</b>

# Working Principle of SSR

## PRIMARY SURVEILLANCE RADAR (PSR)

- Defined by the radar equation.

$$P_r = \frac{P_t G_T \sigma A_{effR}}{(4\pi)^3 R^4}$$

- The received power is proportional to  $R^4$

## SECONDARY SURVEILLANCE RADAR (SSR)

- Defined by the transmission equation.

$$P_r = \frac{P_t G_T A_{effR}}{4\pi R^2}$$

- The received power is proportional to  $R^2$

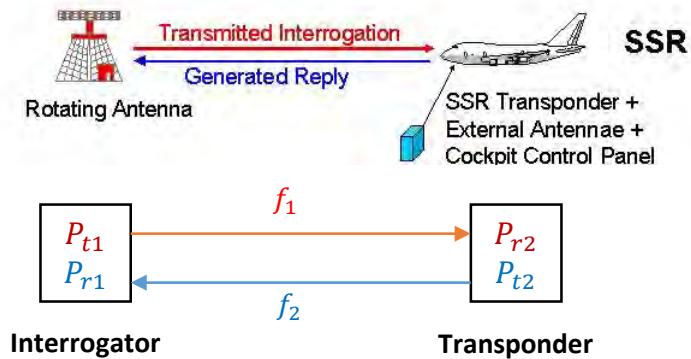
## PSR and SSR differ in many ways:

- Transmission frequencies differ
- Different antennas used (ground and air)
- Bidirectional communication system

# UPLINK –DOWNLINK

## SSR Uplink Range:

The range to which the transponder can go before it ceases to reply to 90% of the interrogations.



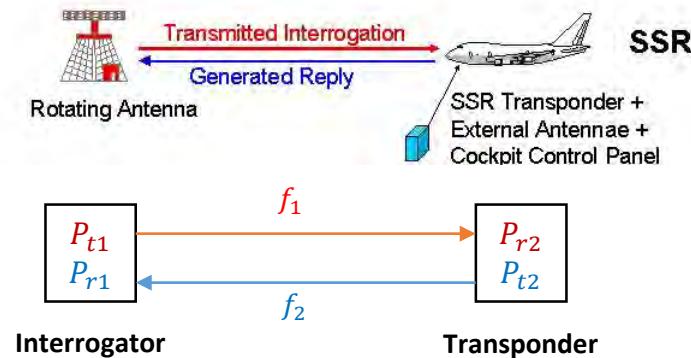
$$R_{t,max}^2 = \frac{P_{t1} G_T A_{effR}}{4\pi P_{r2,min}} = \frac{P_{t1}}{P_{r,2 min}} G_T G_R \left( \frac{\lambda_1}{4\pi} \right)^2$$

$P_{r2,min}$  is the minimum power the on board transponder can receive.

# UPLINK –DOWNLINK

## SSR Down-link Range:

The range to which the transponder can be taken before its reply pulses cease to be detected by the interrogation station.

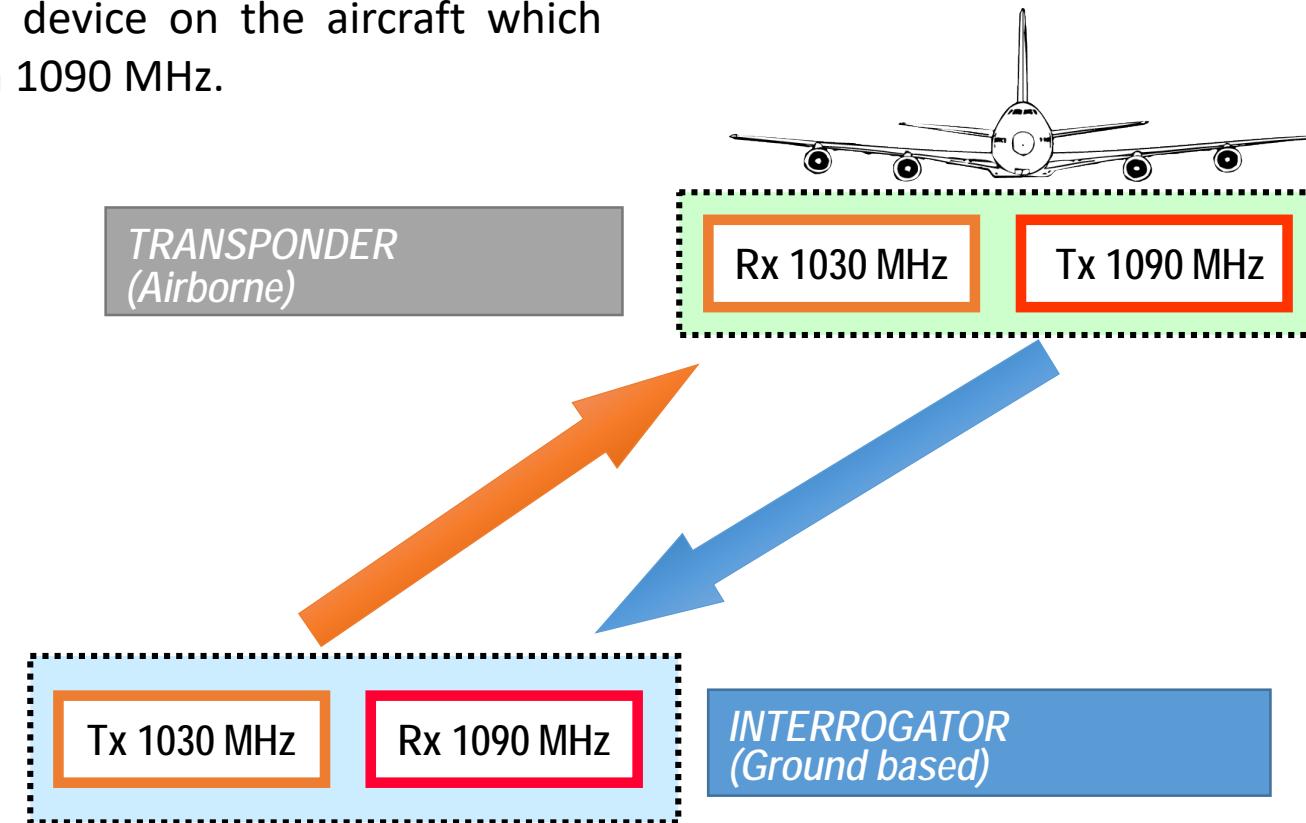


$$R_{i,max}^2 = \frac{P_{t2} G_T A_{effR}}{4\pi P_{r1,min}} = \frac{P_{t2}}{P_{r1,min}} G_T G_R \left( \frac{\lambda_2}{4\pi} \right)^2$$

$P_{r1,min}$  is the minimum power the interrogation station can receive.

# Frequencies SSR

An Interrogator on the ground, transmits a signal on 1030 MHz requesting information from all transponders in range. A transponder is a device on the aircraft which replies to interrogations on 1090 MHz.



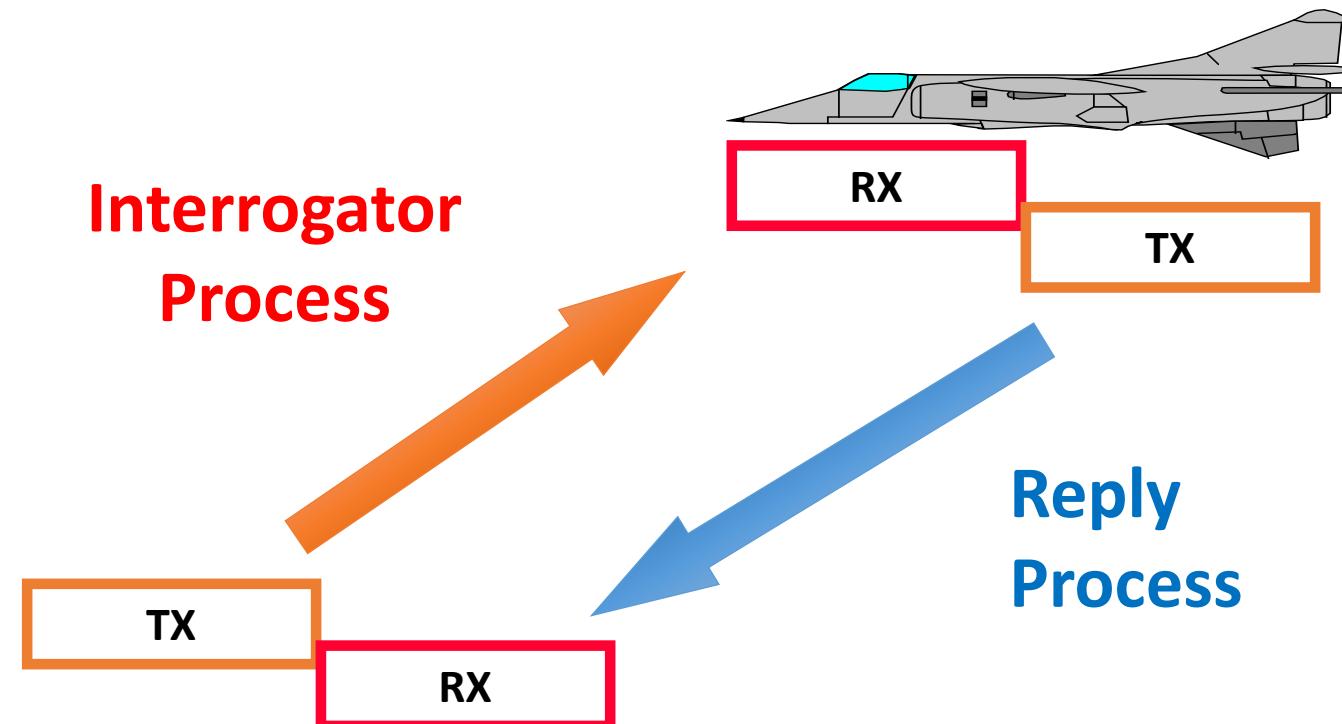
# SSR Code Management



# SSR Code Management: Coding System

Communicating **information** consists of the transmission and reception of pulses.

The method is divided into two processes:



# SSR Code Management: Coding System

Only two modes are used in civil aviation:

**Mode A** for identification

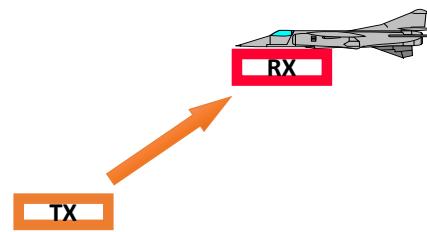
**Mode C** for automatic pressure altitude information

(Modes B and D - research and development)

The ground interrogator and the airborne transponder must be **set to the same mode** in order that the exchange of information may take place.

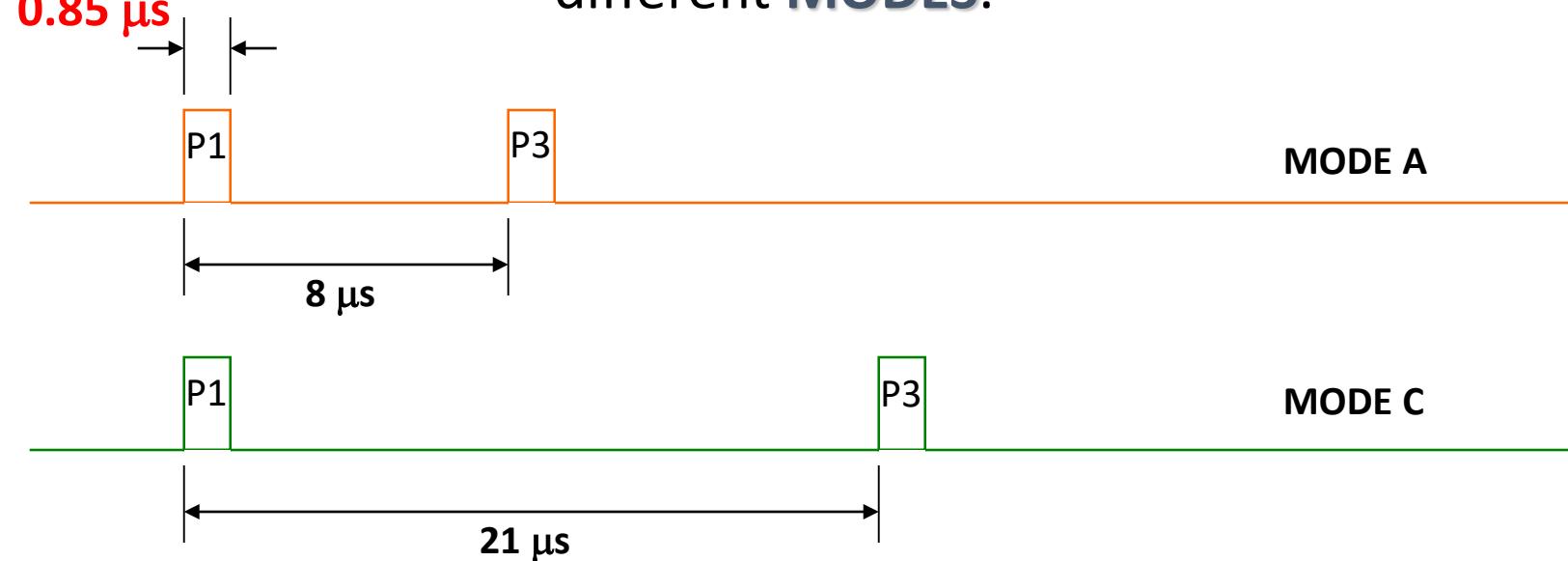


# SSR Code Management: Interrogator process



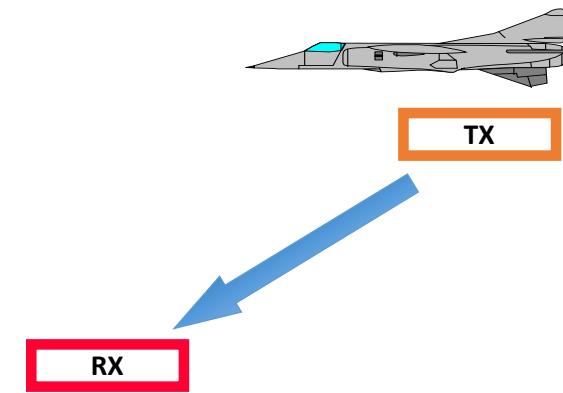
Two pulses with a known spacing are transmitted from the interrogator.

The ground-based interrogations comprise pairs of pulses in different **MODES**.



The interrogator, consists of a pair of pulses of **0,85 μs** long.

# SSR Code Management: Reply process



The aircraft transponder recognizes the time spacing between the two pulses.

The transponder reply, consists of a train of pulses each of which is **0,45 µs** long.

# MODE A: identity

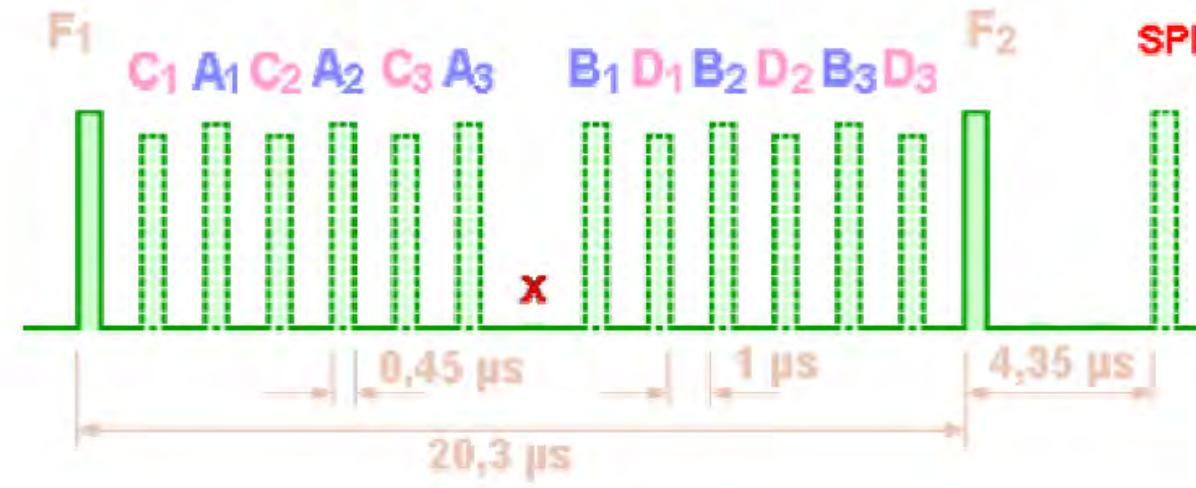
SSR CODE MANAGEMENT



# SSR Code Management: Reply process



# SSR Code Management: Reply process



- **F1** and **F2** always present.
- A, B, C, D coded in **octal format**.
- **SPI**, additional pulse only reply if the pilot is explicitly requested by the ACTO.

# SSR Code Management: Reply process

A binary bit, that is a 0 or a 1, is used to represent data.

How many decimal numbers can be represented by three binary bits?

3 Binary Bits	Decimal
0 0 0 =	0
0 0 1 =	1
0 1 0 =	2
0 1 1 =	3
1 0 0 =	4
1 0 1 =	5
1 1 0 =	6
1 1 1 =	7

There are no other combinations of the 3 binary bits - hence only decimal 0 to 7 can be represented by 3 binary bits.

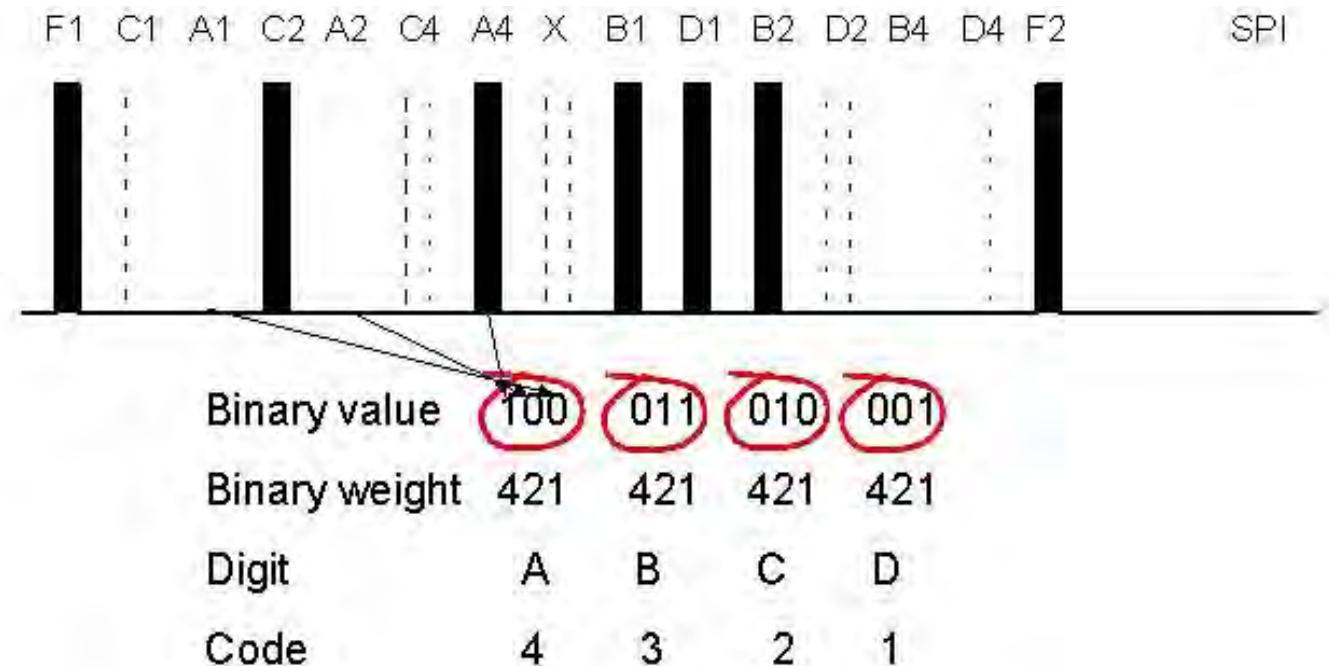
That is why there are no squawk codes containing the decimal numbers 8 and 9.

# SSR Code Management: Reply process

Squawk code 4321 can be represented by combinations of 3 binary bits as:

1 0 0      0 1 1      0 1 0      0 0 1

**These are the 12 information pulses**



## SSR Code Management: Reply process

Therefore, the number of possible combinations  
is  $2^{12} = 4096$ .

Hence there are 4096 discrete squawk codes.

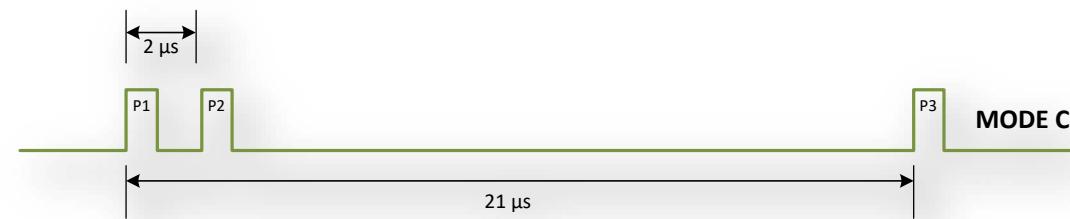


### LIMITATION

(Overcome with Mode S)

# MODE C: ALTITUDE

SSR CODE MANAGEMENT



# SSR Code Management: Transmission of Altitude

- Aircraft altitude information is the response to an interrogation in **Mode C**.
- The altitude information is transmitted in the form of a response **pulse train** to the ground station.
- This is decoded into a numerical form and provides a direct indication of the vertical position of the aircraft.
- To exclude operational errors during the transmission of vertical position data, reference is solely made to the standard ICAO atmosphere pressure setting of **1013,2 hPa**.
- The process is entirely automatic, the only crew function being a selection of “**ALT ON**” on the transponder control panel.
- Thus, no matter what pressure setting has been selected on the altimeter, the vertical position of an aircraft in response to a Mode C interrogation is **always** given as a **Flight Level**.

# SSR Code Management: Transmission of Altitude

- The altimeter altitude data are sent to an analog-digital converter that automatically encodes it in **increments/decrements of 100 feet** ranging between +126.750 to -1.000 feet, with an uncertainty of  $\pm 50$  ft.
- Only 1278 different combinations** (from the 4096 available) are needed.
- The aircraft altimeters generally have greater accuracy and resolution.
- Although the aircraft altimeters have a greater accuracy and resolution than 100 ft, this kind of encoding is sufficiently accurate to be displayed in the label associated with the plane and presented to the controller, but it's not accurate to specify the vertical rate.

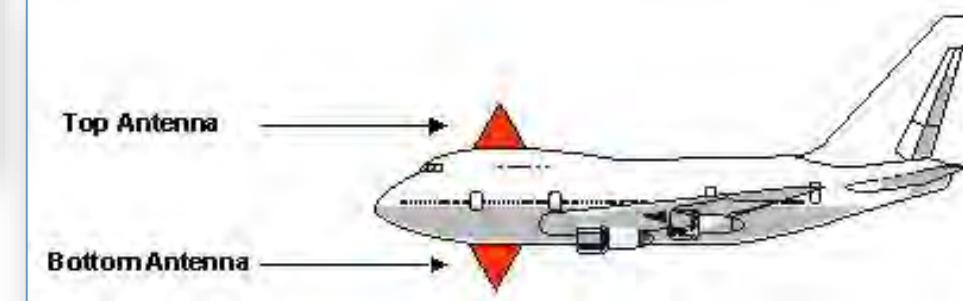
RANGE		PULSE POSITIONS <i>(0 or 1 in a pulse position denotes absence or presence of a pulse, respectively)</i>											
Increments <i>(Feet)</i>		D <sub>2</sub>	D <sub>1</sub>	A <sub>4</sub>	A <sub>3</sub>	A <sub>2</sub>	A <sub>1</sub>	B <sub>1</sub>	B <sub>2</sub>	B <sub>3</sub>	C <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>
88 250	to	88 350	1	1	1	0	1	0	1	0	1	0	0
88 350	to	88 450	1	1	1	0	1	0	1	0	1	1	0
88 450	to	88 550	1	1	1	0	1	0	1	0	0	1	0
88 550	to	88 650	1	1	1	0	1	0	1	0	0	1	1
88 650	to	88 750	1	1	1	0	1	0	1	0	0	0	1

# SSR Transponder Antennas



If the aircraft has only one antenna it is at the bottom of the aircraft.

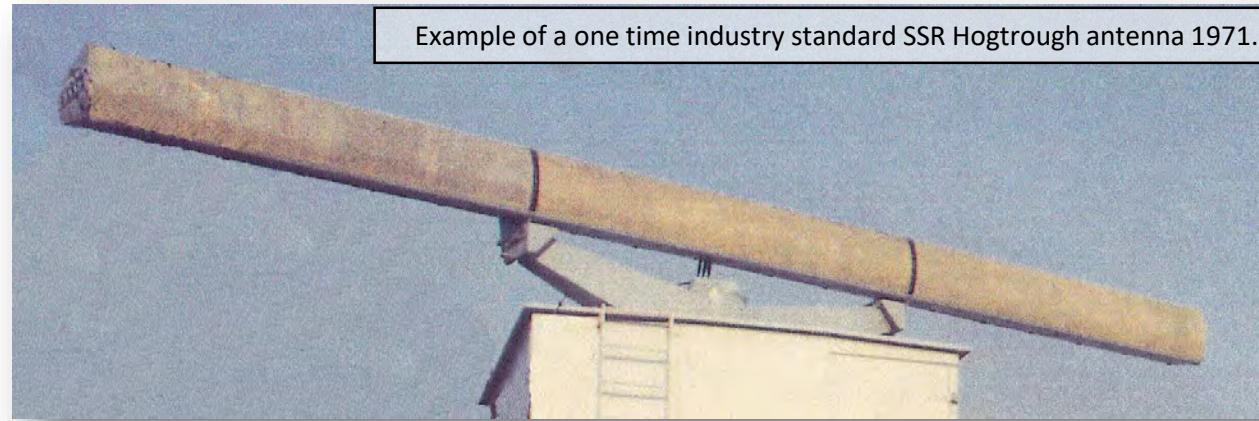
If aircraft are equipped with two antennas (**DIVERSITY**), one on top and one at the bottom, the antenna choice for squitter messages is under control of the **Squitter Antenna Selection (SAS)**.



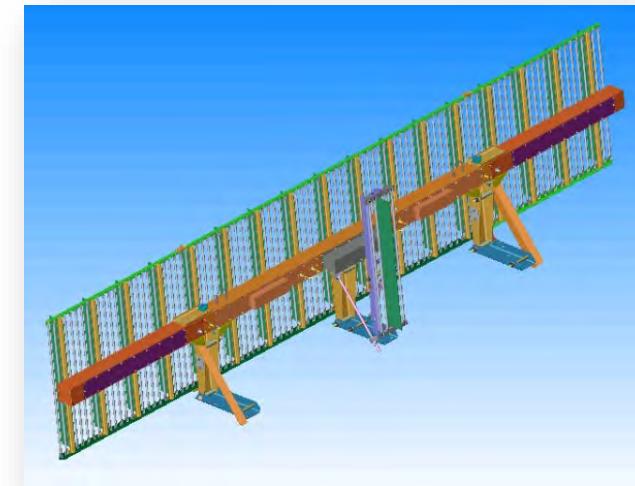
The reply is transmitted by just one antenna, usually that which received a greater power level of the interrogation signal.

In the absence of SAS the default antenna choice is the top antenna. Mode S interrogations/replies are working in diversity.

# SSR Antennas



- Various antenna architectures have been used in SSR systems. Early systems used a so-called “Hogtough” antenna typically about 4 metres in horizontal aperture and 0.5 meters in vertical aperture.
- This resulted in a large vertical beamwidth resulting in heavy ground reflections and resulting inaccuracies.
- Recent designs use a Large Vertical Aperture antenna with a 1.6 meters vertical aperture and resulting narrower vertical beamwidth. This necessitated a vertical array of dipoles suitably fed to produce the desired shape. A five-foot vertical dimension was found to be optimum and this has become the international standard
- SSR antennas are often co-mounted with primary RADAR.



# SSR ANTENNAS

## SSR Interrogator Antenna Types



**Hog Trough**  
(now outdated)

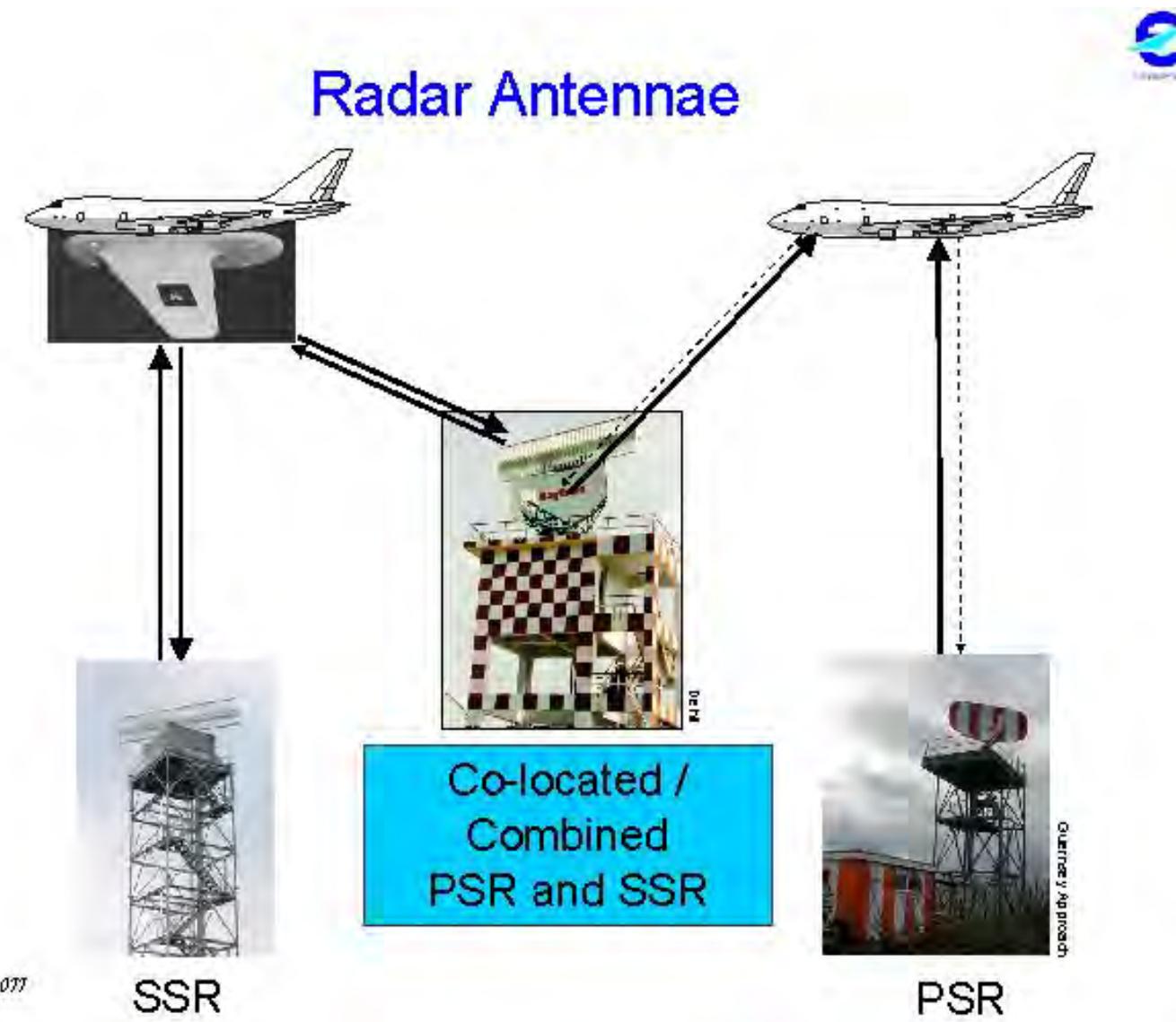


**Flat Plate**  
Antenna



**Planar Array**

# SSR Antennas



# Mode S Selective interrogation

SSR

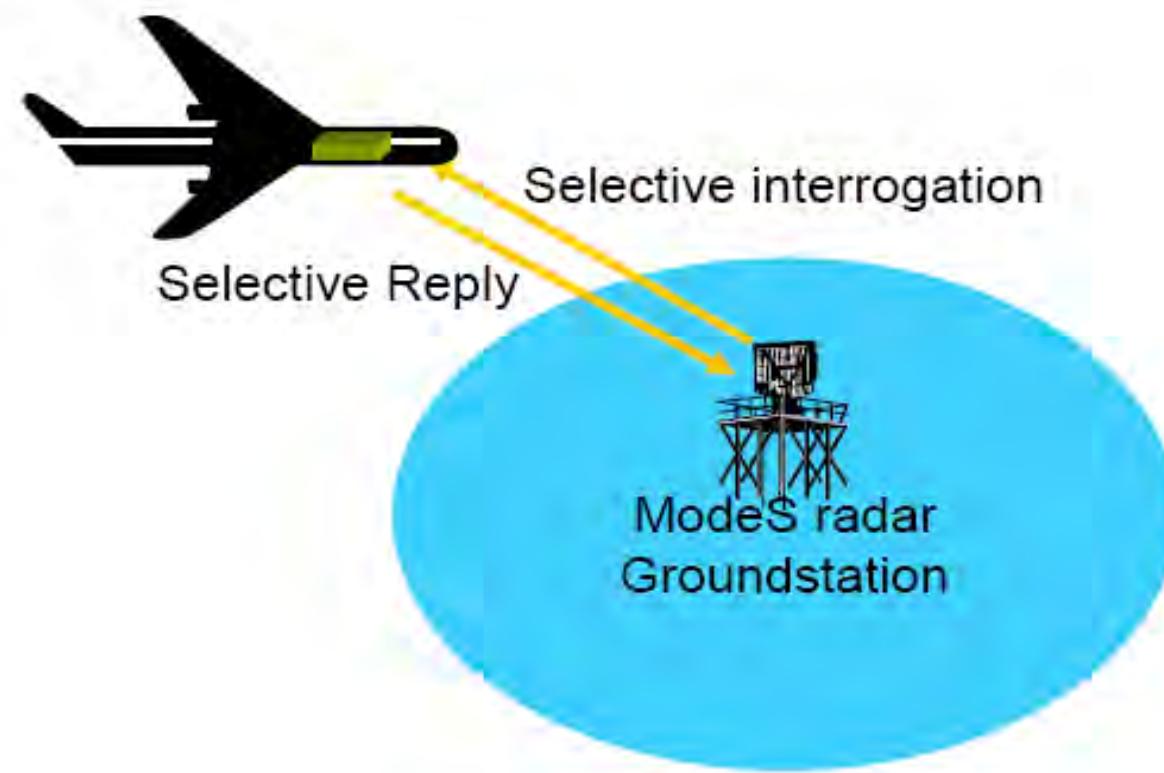


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# Overview: What is available

## Mode S Secondary Surveillance Radar



# What is Mode S?

## Definition

Mode S (Select), which has been standardised by ICAO for many years, is a co-operative surveillance technique for air traffic control.

It employs ground based sensors and airborne transponders. Mode S operates in the same Radio Frequency (1030-1090 MHz) band as conventional SSR systems.

# How does Mode S Work?

- Each Mode S equipped aircraft is assigned a unique address code. Using this discrete addressing system, Mode S compatible with ground radar installations are able to selectively interrogate a specific aircraft via its ICAO address code (*24 bits, provides 16.777.216 addresses*), even in high-density situations.
- This significantly improves the ability of ATC to monitor and direct the aircraft, as well as the others around it.
- Sizeable unallocated blocks of codes have been reserved for different ICAO regions and over 3 million codes are as yet unallocated to any State or region.

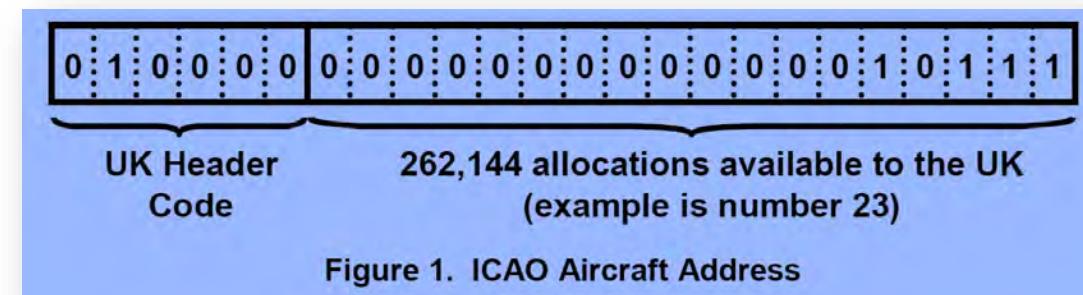


Figure 1. ICAO Aircraft Address

- Figure 1 illustrates an example of a code that would have been allocated by the UK. If the first 6 bits of the address are 010000 then this signifies that the aircraft is registered in the UK.
- The remaining 18 bits comprise 262,144 codes that can be allocated by the UK in whatever manner they choose.
- The length of the header block, and hence codes, varies by State. For example, Austria has a 9-bit header block which means that it has just 32,768 codes available to allocate.

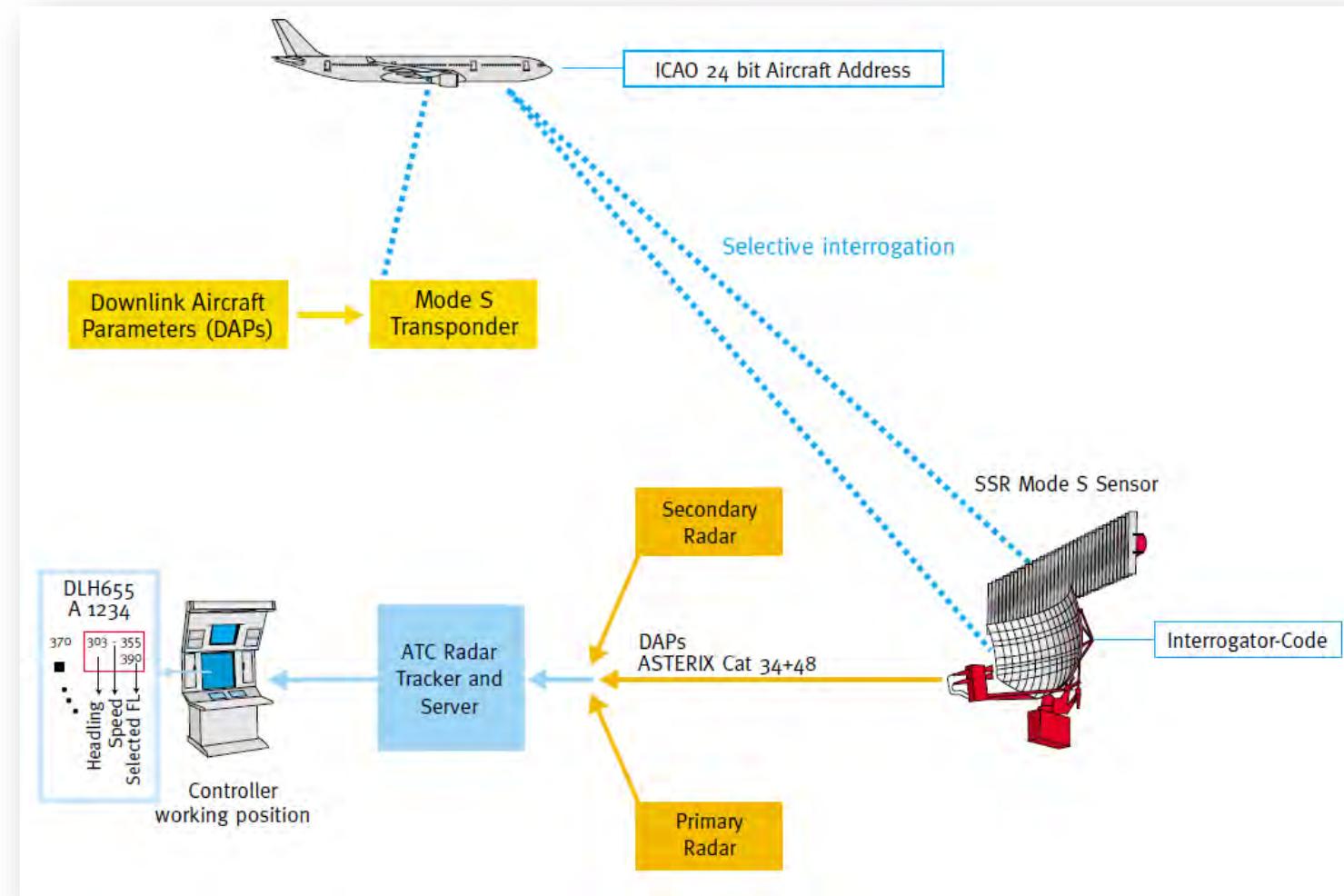
# Benefits of Selective Interrogation

- Using this unique ICAO code, interrogations can be directed to a particular aircraft, and individual replies **unambiguously** identified.
- All exchanges are protected against transmission errors using powerful error detection techniques.
- Mode S **reduces interference in identity and level reporting**, an important consideration in today's increasingly crowded ATC environment.
- The use of selective addressing of aircraft offers technical advantages over conventional secondary surveillance radar, such as reducing **FRUIT** and **garble**, hence providing higher integrity radar tracks.
- Mode S also offers a **data link facility**, which will be used to enhance safety, improved aircraft **surveillance and reporting accuracy**, by providing **Downlink Aircraft Parameters (DAPS)** such as aircraft speed, magnetic heading and level to Air Traffic Controllers and their systems, and:
  - Level coded in 25 ft increments.
  - Indication whether aircraft is airborne or on the ground.
  - Aircraft Identification (**call sign or registration mark**) used for Elementary Surveillance, in order to have a direct correlation with the ground flight plan.

# SSR Mode S Attributes

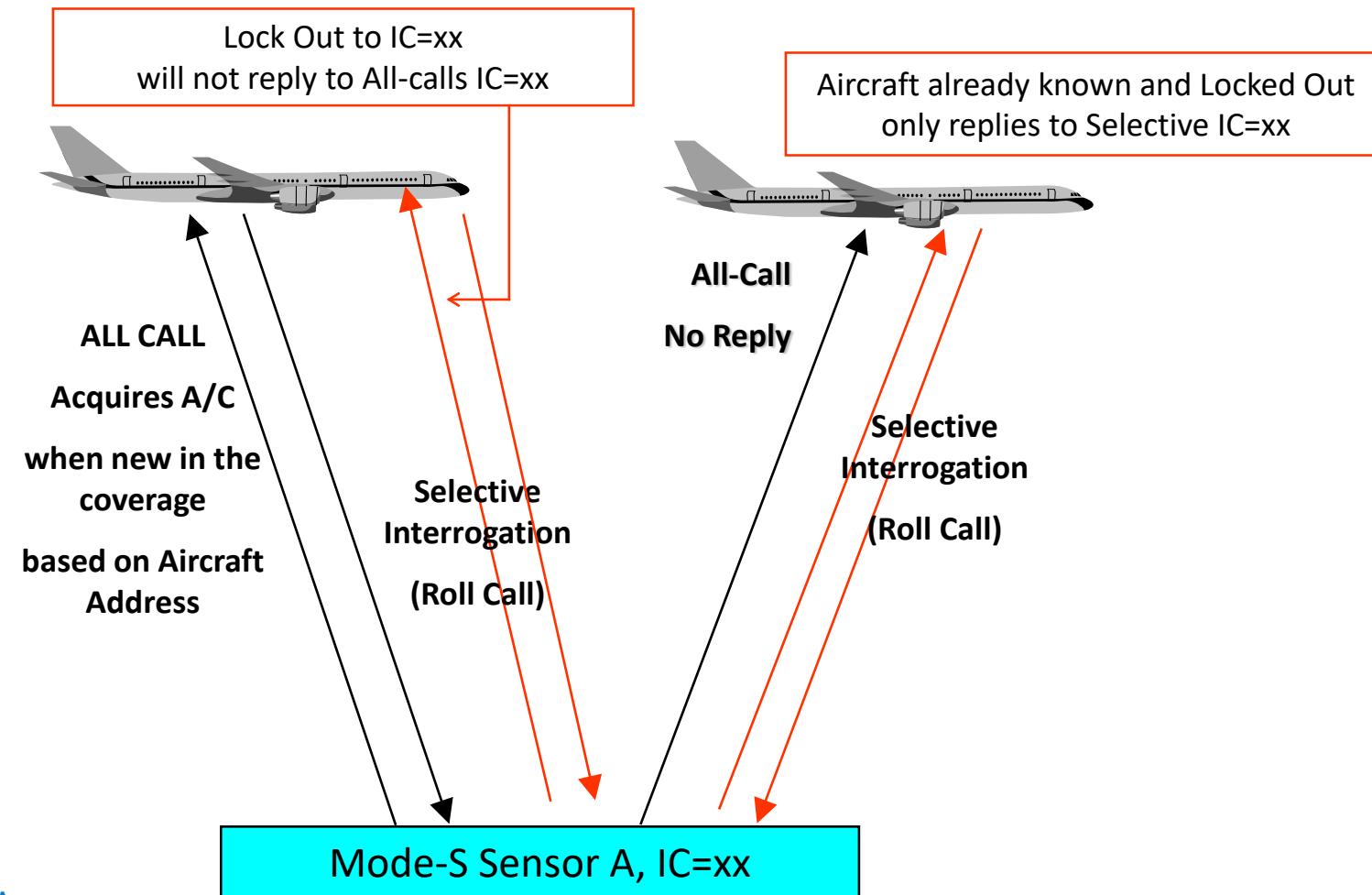
- a) The selective address capability **eliminates garbling situations** which may occur in high traffic density areas and will enhance the general reliability of SSR information.
- b) The **coding of altitude data in 25-foot increments** improves the ability of ground systems to monitor and predict the movement of aircraft in the vertical plane.
- c) The data link capability, associated with transponder Level 2 and above, **permits the ground system to acquire automatically aircraft call signs**, thus overcoming the problems connected with SSR code allocation and assignment, code/call sign correlation, radar identification and transfer procedures.
- d) The data link capability also permits the ground system **to acquire automatically certain airborne data** which improve the ground tracking of aircraft, thus ensuring that the required level of safety is maintained when improved radar separation minima can be used.
- e) Electronic scanning techniques **may permit the renewal rate of information** on each aircraft to be **selectively adapted** according to ATC needs.

# How does MODE-S work?



# How does MODE-S work?

## Mode-S Selective Interrogation Principle

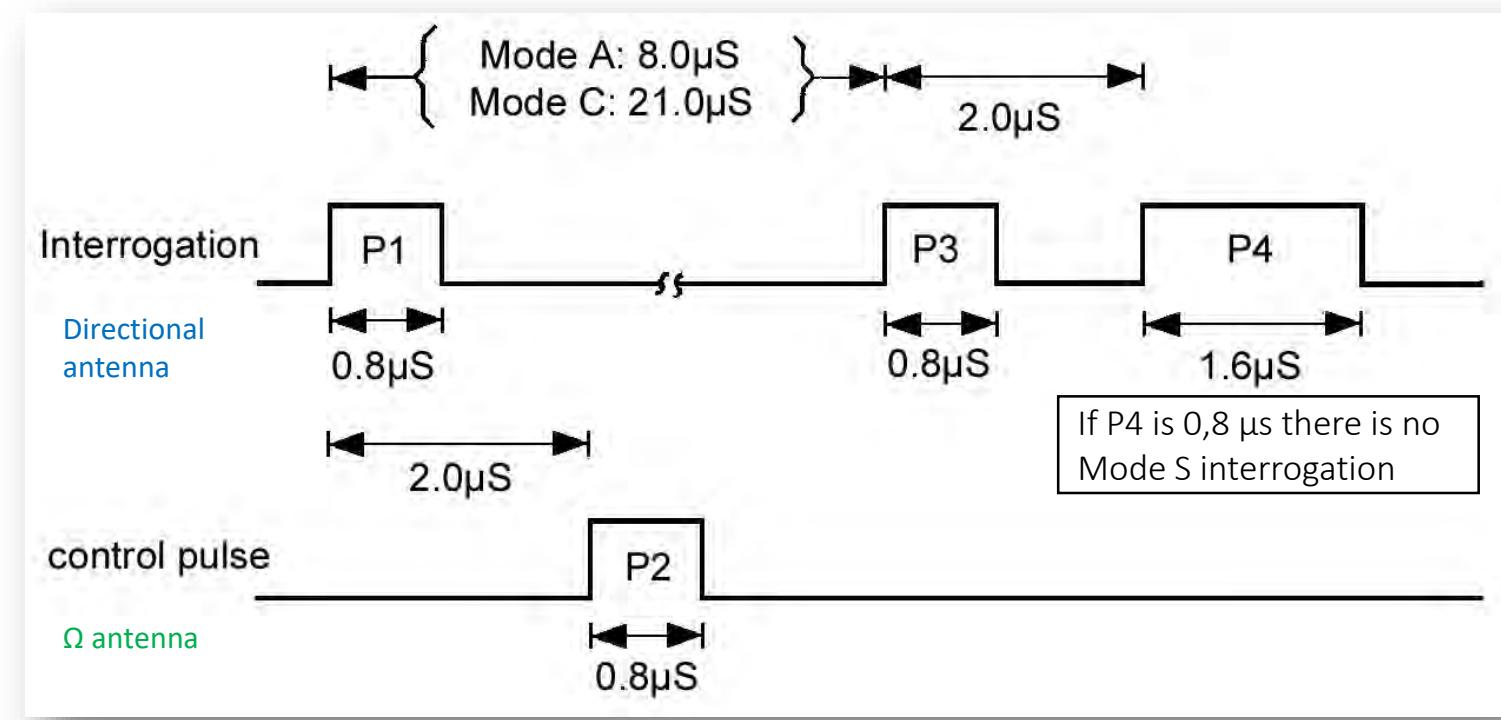


# SSR Mode S Interrogation types

- **ATCRBS all call:**
  - This interrogation consists of P1, P3 and a **0.8 µs P4 pulse**.
  - P2 SLS is transmitted as normal.
  - All ATCRBS transponders reply with the 4096 identification code for mode A interrogations and altitude data for mode C.
  - **Mode S transponders do not reply** on this interrogation.
- **ATCRBS/mode S all call:**
  - This interrogation is identical to the former except **P4 is 1.6 µs long**.
  - **ATCRBS transponders reply with the 4096 code or altitude data** as per the ATCRBS all call.
  - **Mode S transponders reply with a special code**, which contains the identity and the aircraft's discrete address.
- **Mode S discrete interrogation:**
  - This interrogation is directed at a specific mode S transponder-equipped aircraft.
  - The interrogation consists of P1, P2 and P6. P2 is transmitted via the directional antenna and hence is the same amplitude as P1 and P3.
  - This effectively **suppresses ATCRBS transponders from replying**.
  - **P6 is actually a DPSK data block** that contains either a **56-bit or 112-bit message**.
  - The DPSK modulation produces a **spread-spectrum signal**, which has **immunity to interference**.

# Interrogation types

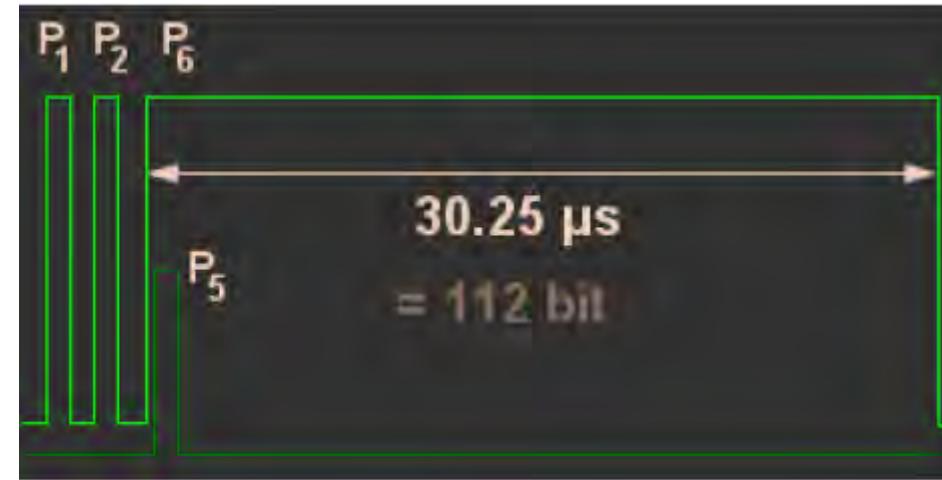
## Up-link (Ground/aircraft)



Mode S interrogation, **ATCRBS all call**

# How does MODE-S work?

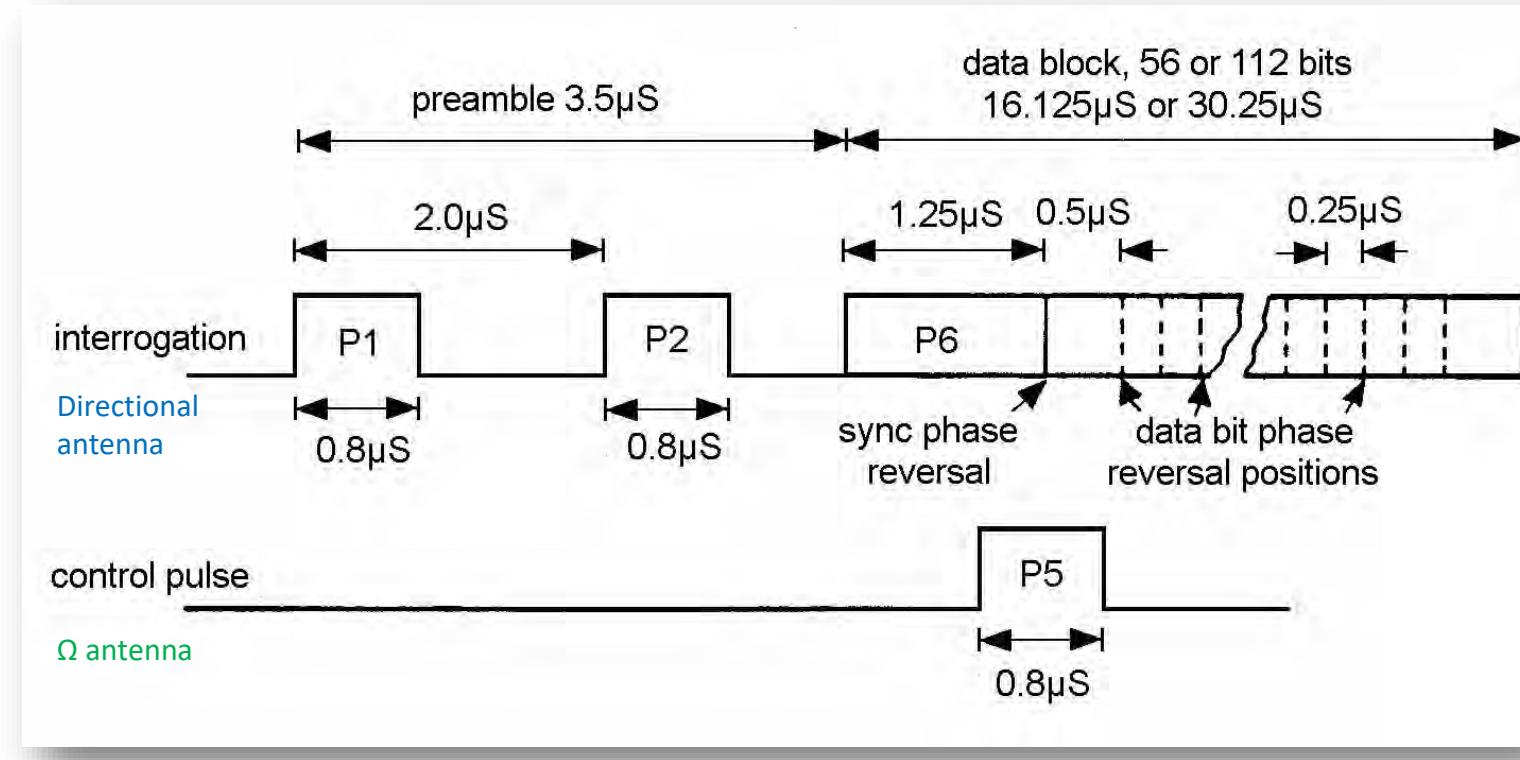
## Up-link (Ground/aircraft)



- P<sub>1</sub>, P<sub>2</sub> Check the compatibility
- P<sub>6</sub> – Modulates the interrogation
- The interrogation happens about 50 Hz PRF.
- Frequency: 1030 MHz
- Modulation: Differential Phase-Shift Keying (DPSK)
- Data rate: 4 Mbps

# Interrogation types

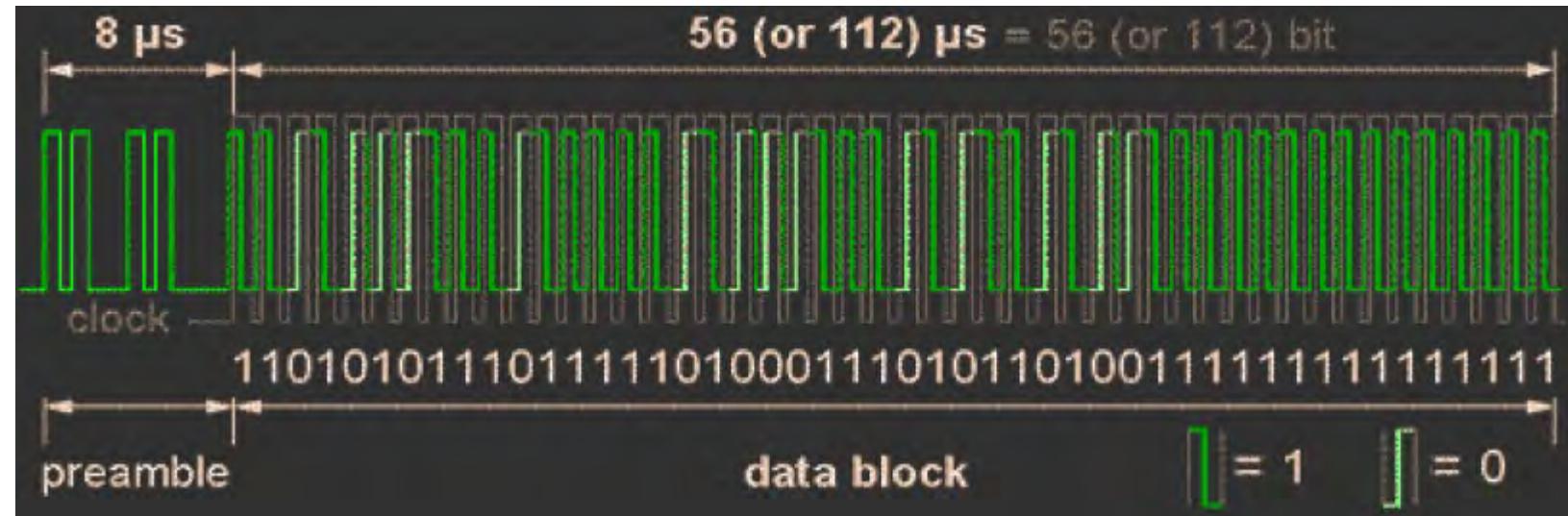
## Up-link (Ground/aircraft)



Mode S interrogation, short and long.

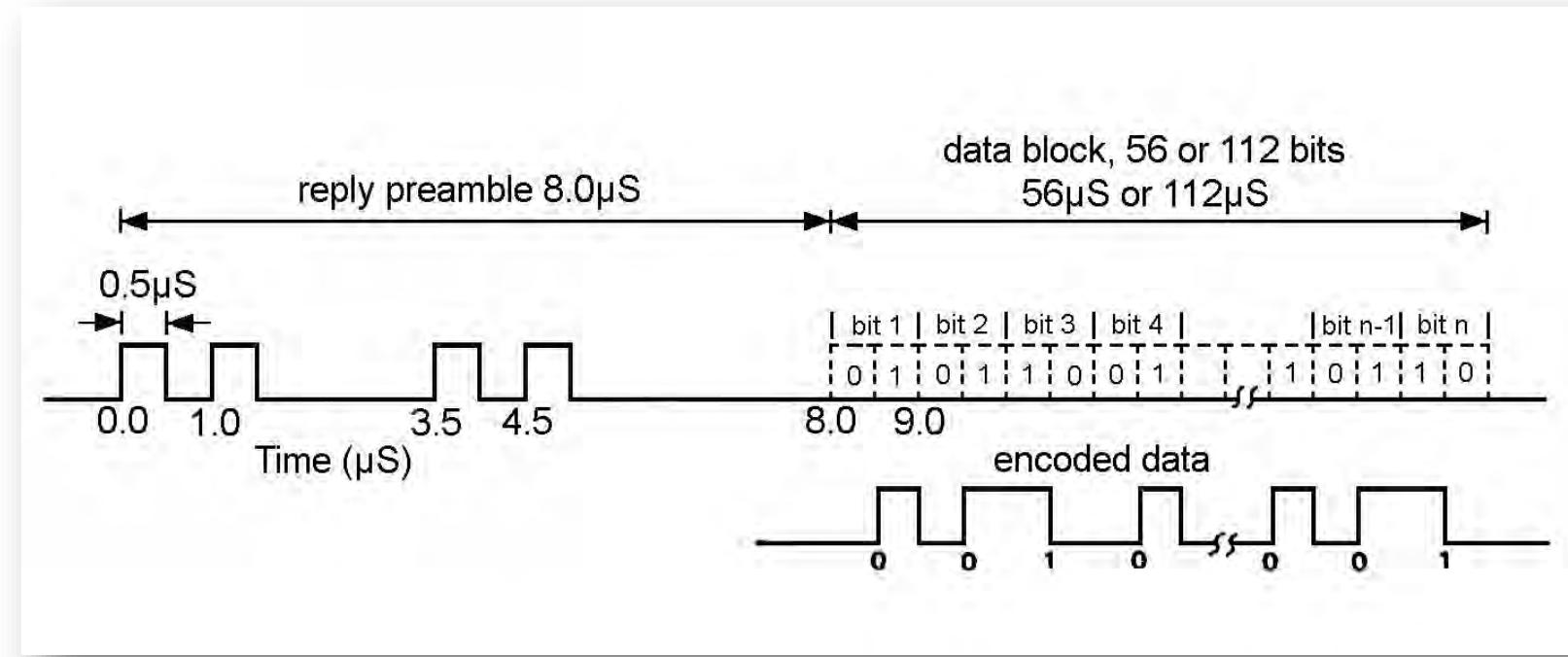
# How does MODE-S work?

Down-link (aircraft/Ground)



- The reply is returned 128  $\mu$ s after reception.
- The reply is transmitted on 1090 MHz and uses a 56-bit or 112-bit PPM transmission.
- Spacing between pulses 1  $\mu$ s
- Synchronization + information
- Frequency: 1090 MHz
- Modulation: Pulse Position (PPM)
- Data Rate: 1 Mbps

# Reply Format

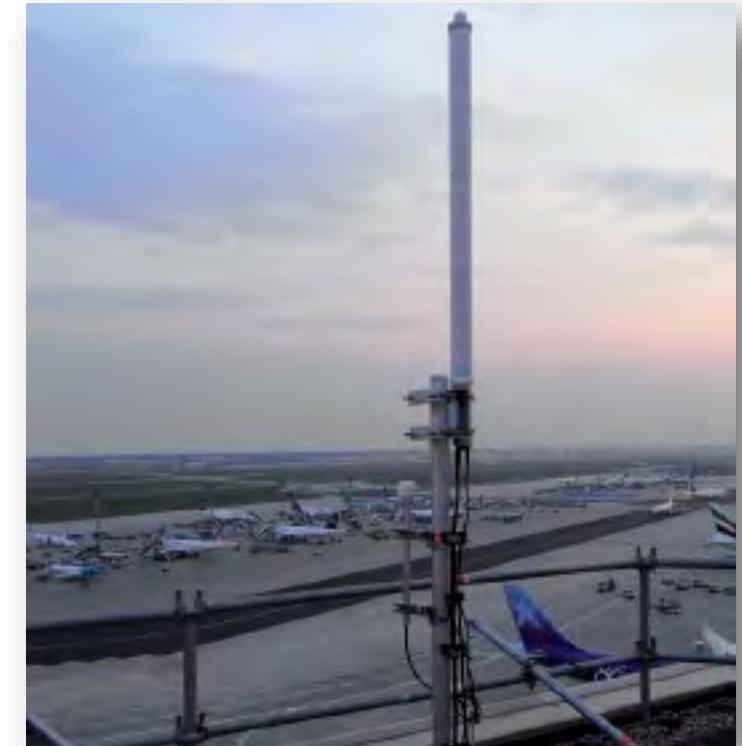


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- Frequency: 1090 MHz
- Modulation: Pulse Position (PPM)
- Data Rate: 1 Mbps

# Wide Area Multilateration (MLAT) Systems

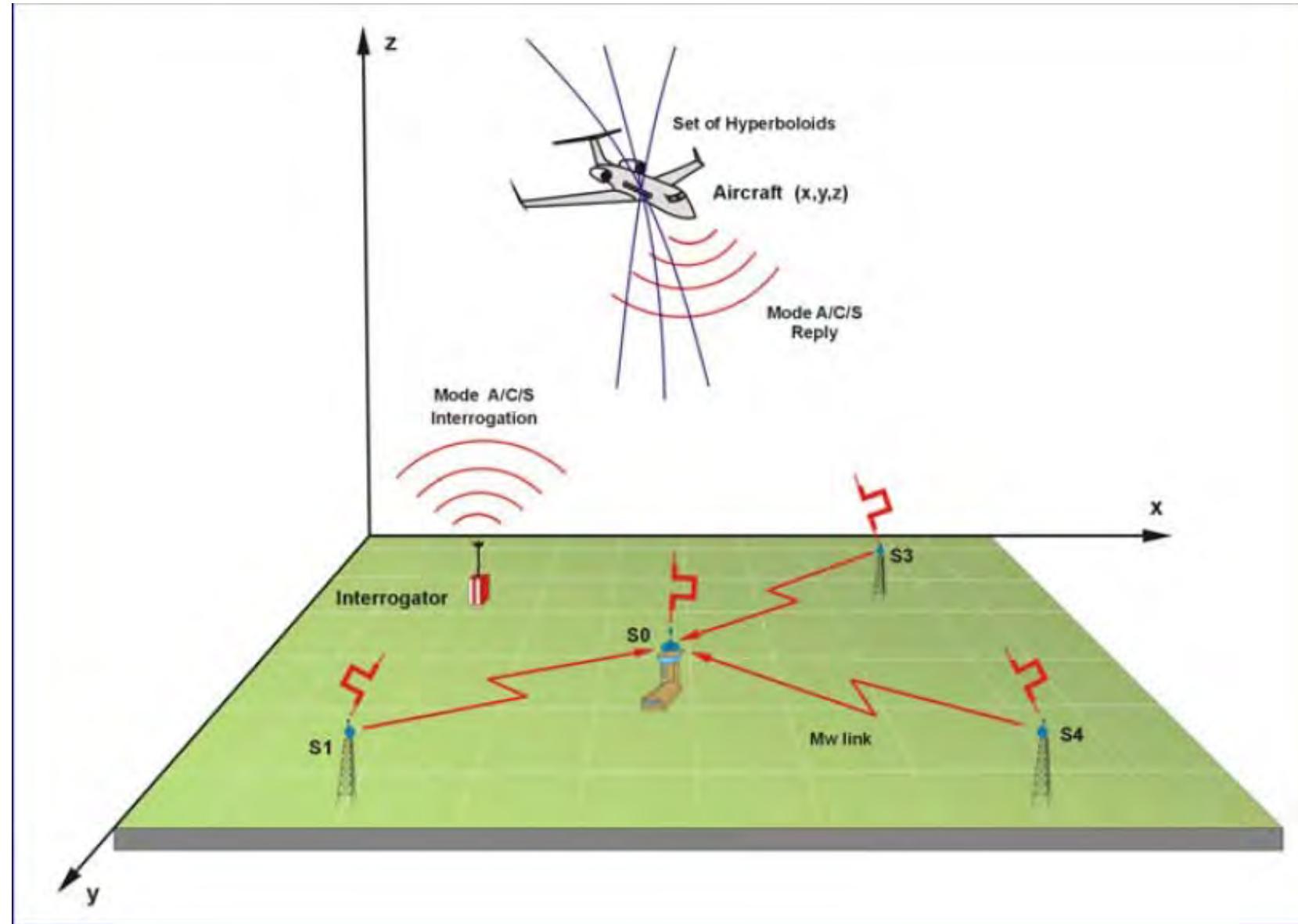
# MULTILATERACIÓ vs. RADAR

- En un radar primari/secundari el temps de rotació de l'antena és de 4 a 12 segons per volta, de forma que l'actualització de la pantalla del controlador es realitza cada 4 o 12 segons.
- A més poden aparèixer zones d'ombra, degut a problemes de propagació de les ones electromagnètiques.
- El sistema de multilateració consisteix en instal·lar de forma estratègica diferents estacions receptors terrestres en la proximitat de l'aeroport, o de la seva àrea terminal, que escolten les rèpliques a les interrogacions del SSR local.
- Les respostes arriben als receptors amb diferents diferències de temps, de forma que al processar-ho es pot determinar la ubicació precisa de l'emissor.
- Permet l'actualització gairebé instantània de la informació en la pantalla del controlador.



# What is Multilateration

- A **multilateration** system consists of a **number of antennas receiving a signal from an aircraft** and a **central processing unit** calculating the aircraft's position from **the time difference of arrival (TDOA)** of the signal at the different antennas.
- The **TDOA between two antennas** corresponds, mathematically speaking, with a **hyperboloid** (in 3D) on which the aircraft is located.
- When **four antennas** detect the aircraft's signal, it is possible to estimate the 3D-position of the aircraft by calculating the **intersection of the resulting hyperbolas**.
- **When only three antennas are available**, a 3D-position **cannot be estimated directly**, but if the **target altitude is known** from another source (e.g. from Mode C or in an SMGCS environment) **then the target position can be calculated**. This is usually referred to as a 2D solution. It should be noted that the use of barometric altitude (Mode C) can lead to a less accurate position estimate of the target, since barometric altitude can differ significantly from geometric height.
- **With more than four antennas**, the extra information can be used to either **verify the correctness of the other measurements** or to calculate an **average** position from all measurements which should have an overall **smaller error**.



# Measurement system

- It consists of a system able to:
  - Calculate the Time Difference of Arrival (TDOA): The difference in relative time that a transponder signal from the same aircraft (or ground vehicle) is received at different receivers.
  - Synchronize all the receivers.
- Systems of TDOA calculation:
  - Cross Correlation Data Flow
  - TOA (Time of Arrival) System
- Synchronization methods
  - Common clock systems
  - Distributed clock systems
    - Transponder Synchronized Systems
    - GNSS Synchronized Systems
      - Standalone GNSS Synchronization.
      - Common View GNSS Synchronization.

# Types of MLAT Systems

- Passive:
  - Consists only of receivers
  - It is dependent on other sources to trigger a transmission from an aircraft.
  - The update rate will depend on other surveillance sources.
  - No transmission frequency license is required for the installation and use of the system.
  - There is no increase in the number of interrogations or replies caused by the system.
  - Suitable for:
    - Busy areas with a high volume of ACAS (Aircraft Collision Avoidance System) equipped traffic
    - Areas with existing MSSR surveillance infrastructure
    - Areas where Mode S use is mandatory
- Active:
  - Has one or more transmitting antenna in order to interrogate.
  - It is not dependent on other sources to trigger a transmission from an aircraft.
  - Can provide a high update rate if required.
  - is much simpler than an MSSR interrogator.
    - A rotating antenna is not required.
    - An omni-directional or sectored antenna is used.
    - The power level of the interrogation can be limited to provide a shorter range than for equivalent MSSR surveillance.
  - A short range interrogator can be used to acquire low level aircraft on approach that fall below the coverage of existing MSSR systems, or in terminal area surveillance.
  - Directional antennas are another method of excluding certain areas.

# MLAT Systems based in SSR Transponders

- An SSR receiver in an MLAT system might have a problem to distinguish between a Mode A and a Mode C reply.
- A **limitation** of the SSR antenna signal is the **line-of-sight visibility** that is **required** between the transponder and the ground receiver.
  - When the path is obscured by e.g. a building, the signal strength will degrade very strongly.
- The **maximum range** of an SSR signal is about **250 NM** (depending on the sensitivity of the receiver), but especially in regions with high density traffic interference problems may limit the useful range.
- **Mode S Squitter:**
  - An aircraft equipped with a Mode S transponder emits a signal, called **Acquisition Squitter**, approximately **once per second**.
  - The acquisition squitter consists of a **Mode S All-call reply** containing the **24-bit technical address** of the aircraft.
  - The high update rate makes them very useful for a passive MLAT system.
- **Mode S Extended Squitter**
  - Is agreed to be the first global Datalink for international commercial flight.
  - It makes use of the Mode S transponder to emit periodically, with a **frequency** up to about **6 Hz**, the **aircraft's 24-bit technical address** accompanied by either **aircraft state information or callsign**.
  - Just as with Acquisition Squitter, the high update rate is ideal for a passive MLAT system.

# Aplicacions de la multilateració

- Control de superfície de l'aeroport
  - Àrea terminal
  - Wide area
- Monitoratge de precisió de les pistes
- Monitoratge en altura
- Gestió ambiental
- Operacions aeroportuàries

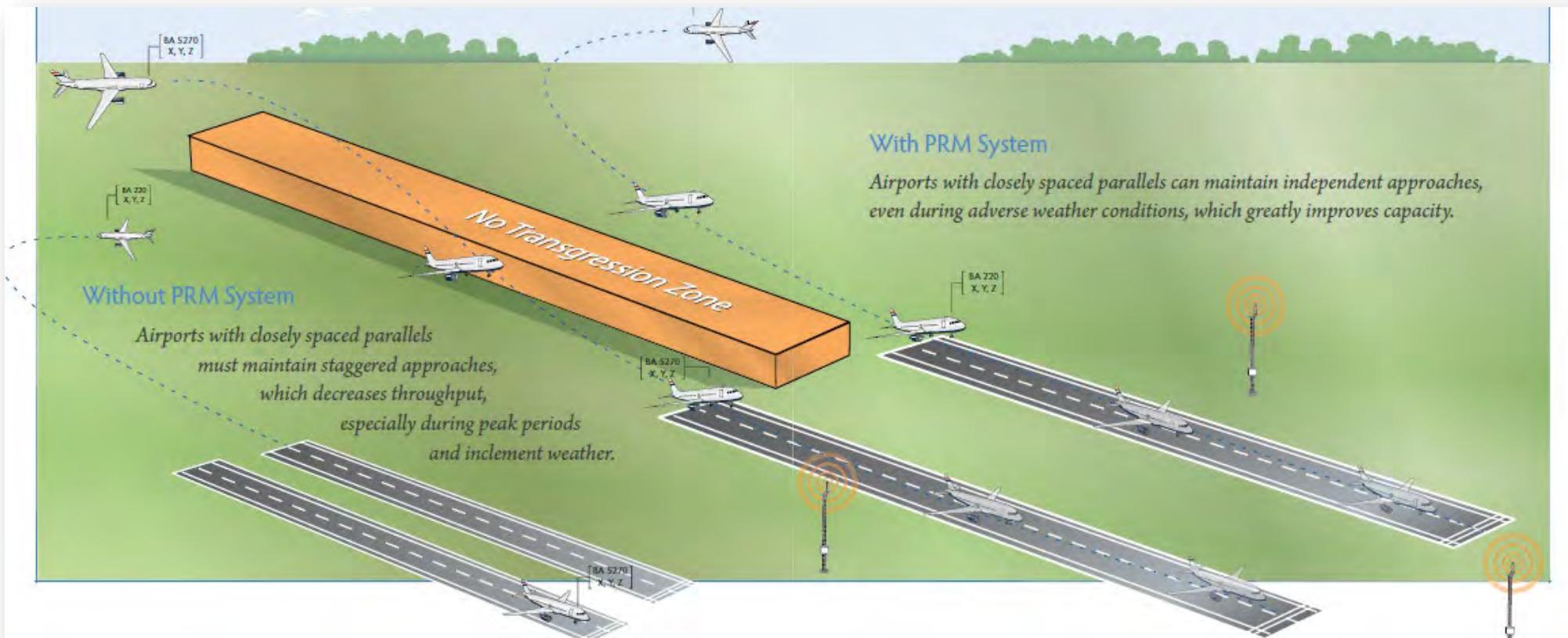
# Control de superfície de l'aeroport

- Inicialment desenvolupat amb finalitats militars.
- Element vital pel sistema A-SMGCS (*Advanced Surface Movement Guidance and Control Systems*) desplegat a molts aeròports.
- La multilateració permet:
  - Visió clara de tota l'àrea, sense zones d'ombra i/o ocultes.
  - Millora la precisió i la discriminació de blancs.
  - Immune a la situació meteorològica.
  - Permet la identificació unívoca de vehicles.
  - Permet identificar a vehicles de pista equipats amb squitters de Mode S.



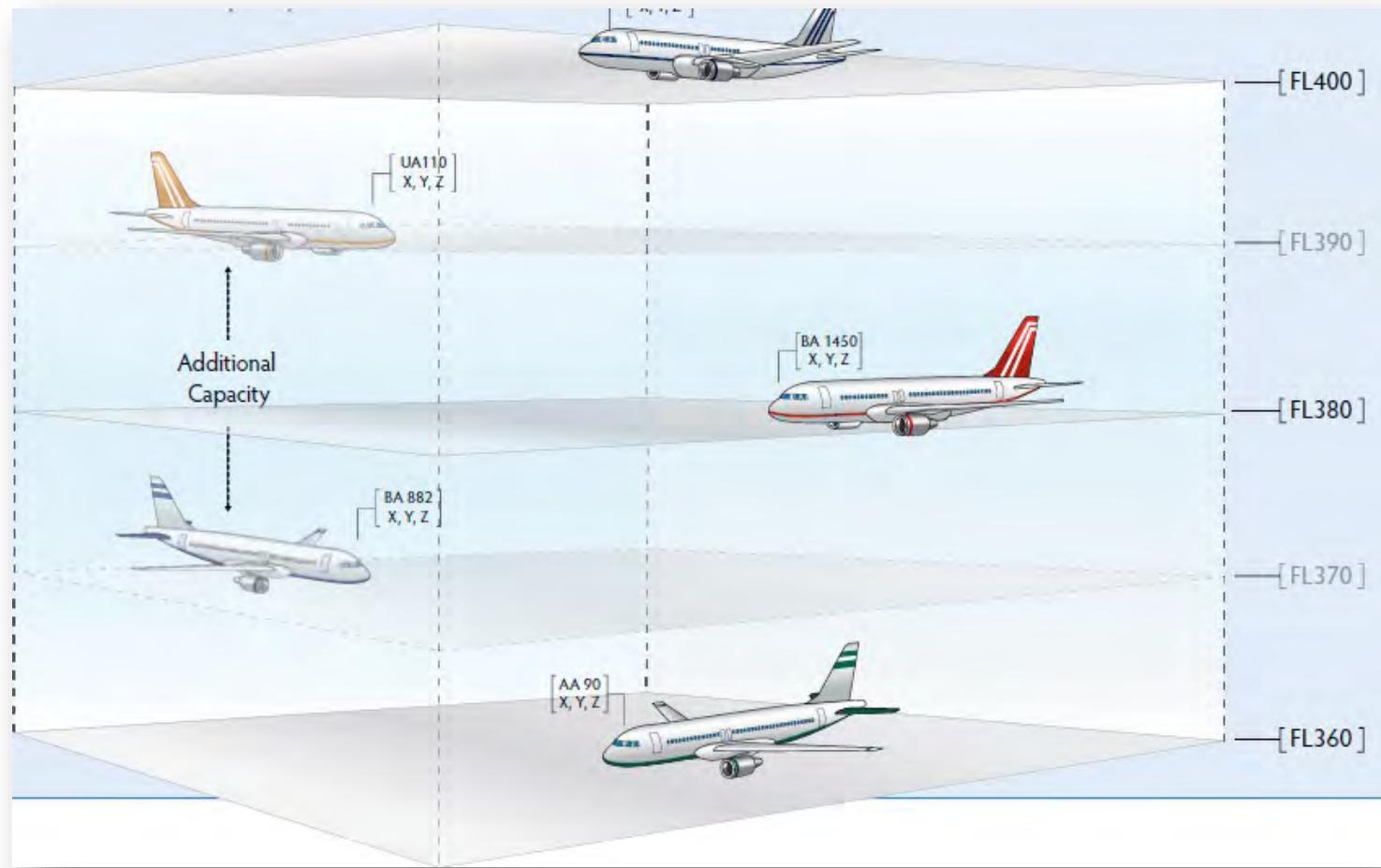
# Monitoratge de precisió de les pistes

- Pistes massa junes i condicions meteorològiques adverses, suposen reduir el temps de throughput.
- La solució era la instal·lació de sistemes PRM (Precision Runway Monitor), apte per pistes separades 3000 ft, però equipament costós.
- La multilateració permet guanys de més del 30% en el throughput en hores punta i amb condicions meteorològiques adverses.



# Monitoratge en altura

- Per altures de més de 29.000 ft es requereix una separació vertical de 1.000 ft, mentre que per altures inferiors 29.000 ft, la separació passa a ser de 2.000 ft, degut a la falta de precisió del altímetres baromètrics.
- Als anys 1990, amb la introducció del sistema **RVSM (Reduced Vertical Separation Minima)** en la tecnologia dels altímetres, es va permetre una separació vertical de 1.000 ft fins a 40.000 ft d'altitud, requerint però tasques periòdiques i costoses de manteniment de l'aeronau.
- La multilateració permet el sistema **HMU (Height Monitoring Unit)** a grans altures i amb un equipament barat.



# Gestió mediambiental

- Permet fer el registre de la trajectòria seguida per cadascuna de les aeronaus, i veure si ha produït algun episodi de contaminació, tant de tipus acústic, com de qualsevol altre mena.



# Operacions aeroportuàries

- Permet fer una gestió eficaç del sistema **CDM** (**Collaborative Decision Making**) per a la planificació i optimització dels horaris, fent una millor gestió en l'assignació de portes i de l'organització dels moviments de rampa.

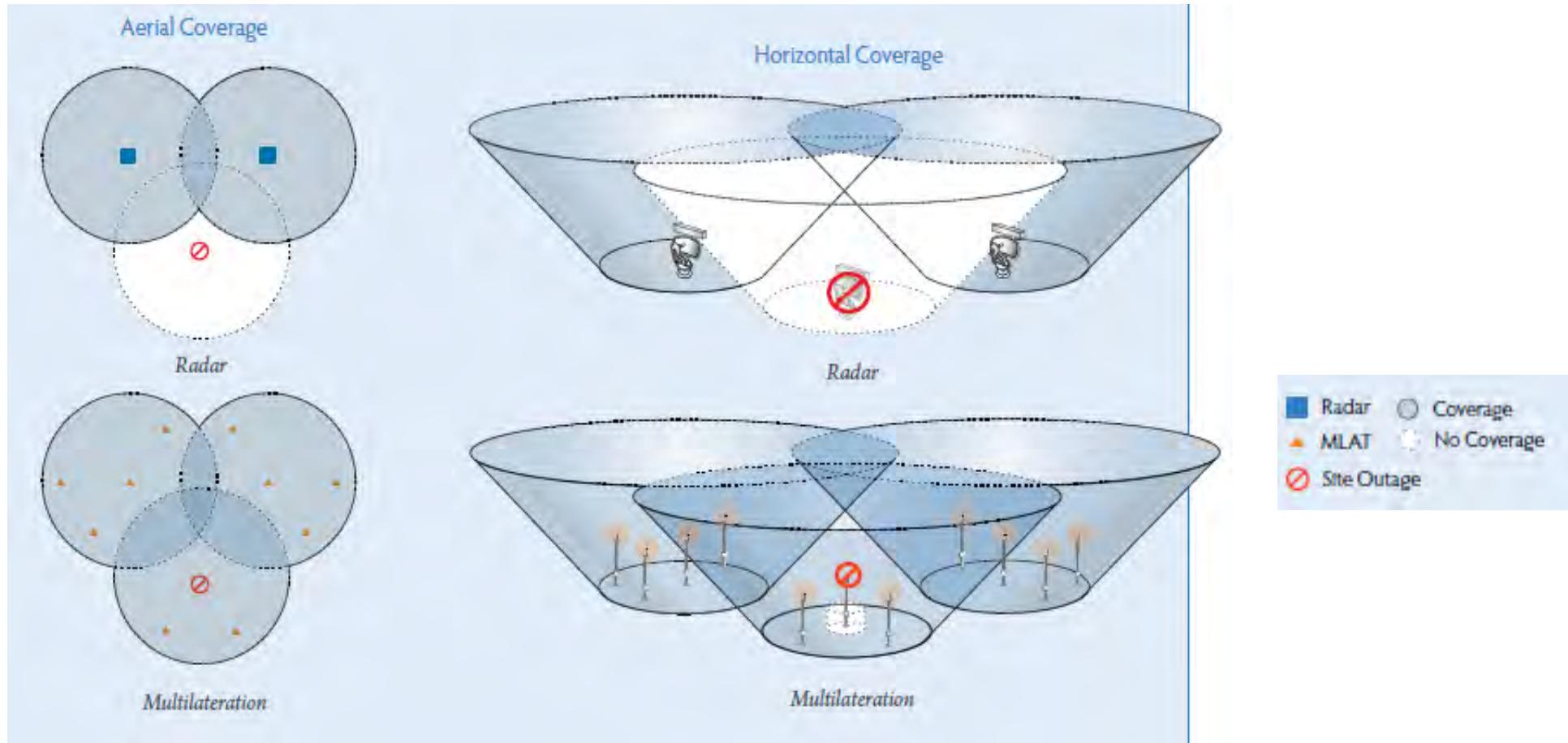
## What is Airport Collaborative Decision Making (A-CDM)?

A-CDM is the timely exchange of information between operational users and suppliers of services at airports and the network manager. Following initial success at Munich Airport in 2007, the A-CDM Action Plan was launched by EUROCONTROL and airport industry body ACI EUROPE one year later. Over 30 airports in Europe are at various stages of implementing A-CDM, with progress reported in November each year.

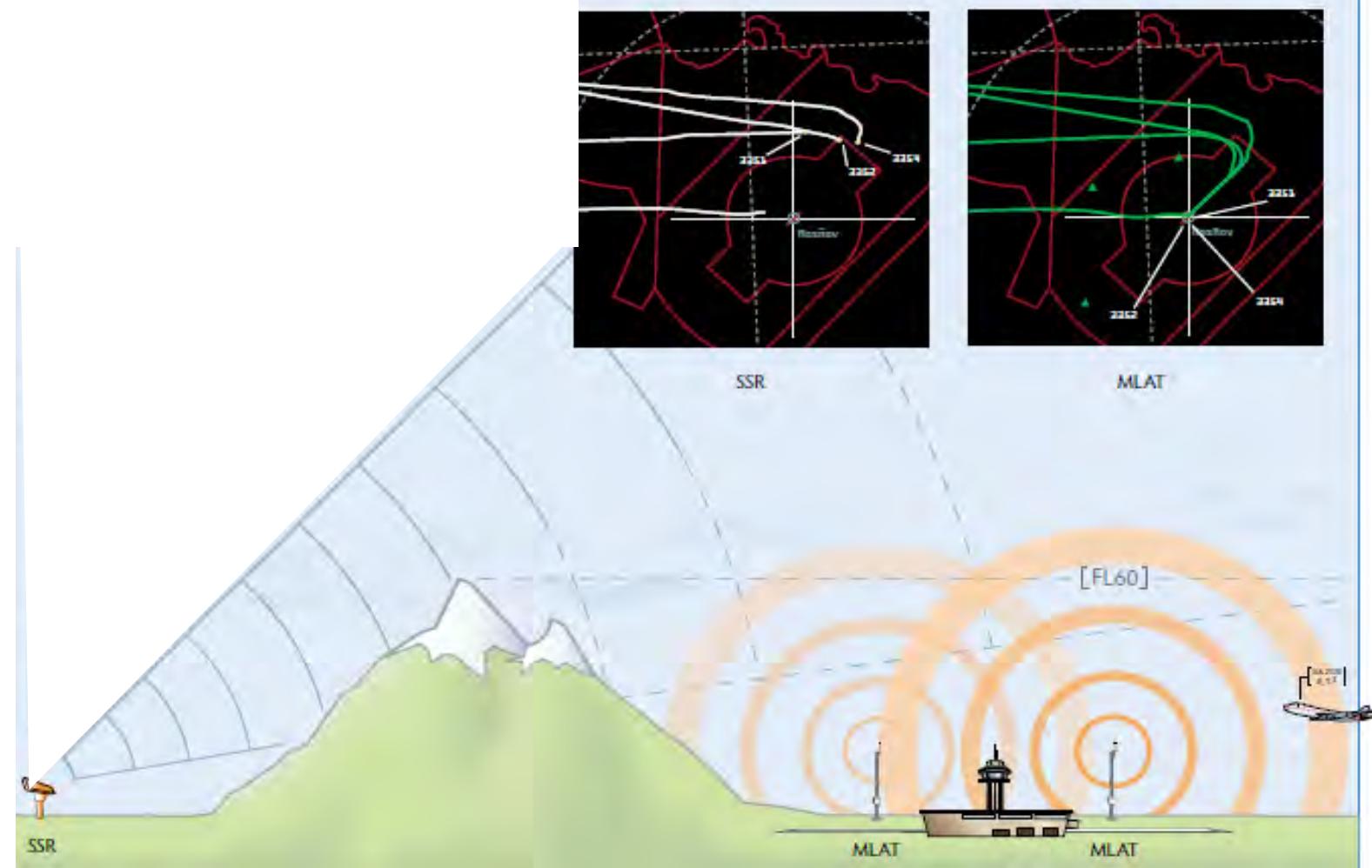
The benefits of participating in A-CDM start with enhanced accuracy and better predictability of arrival and departure information. Flight punctuality and network efficiency improve as airport partners' work together to optimise aircraft turnaround, reduce runway taxi-ing times and make the most of existing airport capacity. Harmonised CDM applications at airports are key for aircraft operators to fully benefit from A-CDM.



# Cobertura comparativa PSR vs MLAT



# Permet suprimir les zones d'ombra



# Tema 5:

## ELS EQUIPS I ELS SISTEMES RADIOELÈCTRICS AEROPORTUARIS

Jordi Berenguer  
Novembre 2021



UNIVERSITAT POLITÈCNICA DE CATALUNYA  
BARCELONATECH

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# DME + ILS

Distance Measurement Equipment  
Instrument Landing System



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# Distance Measurement Equipment

DME



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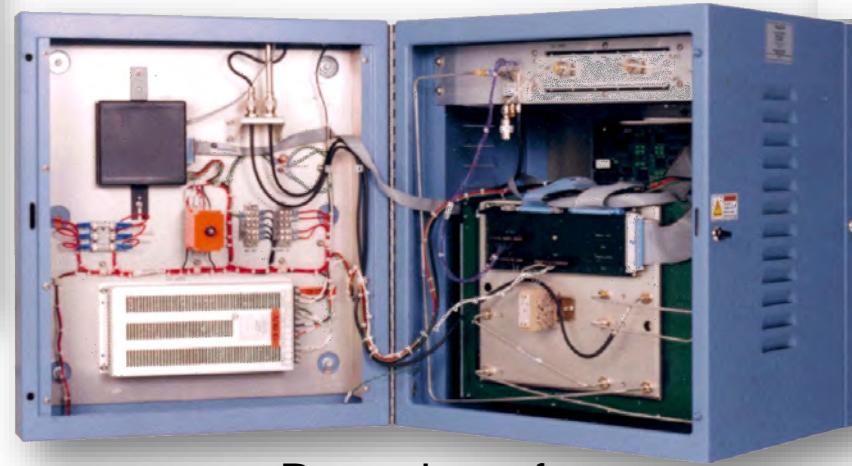
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# Distance Measuring Equipment (DME)





Antenna and shelter



Rear view of  
LPDME wall unit



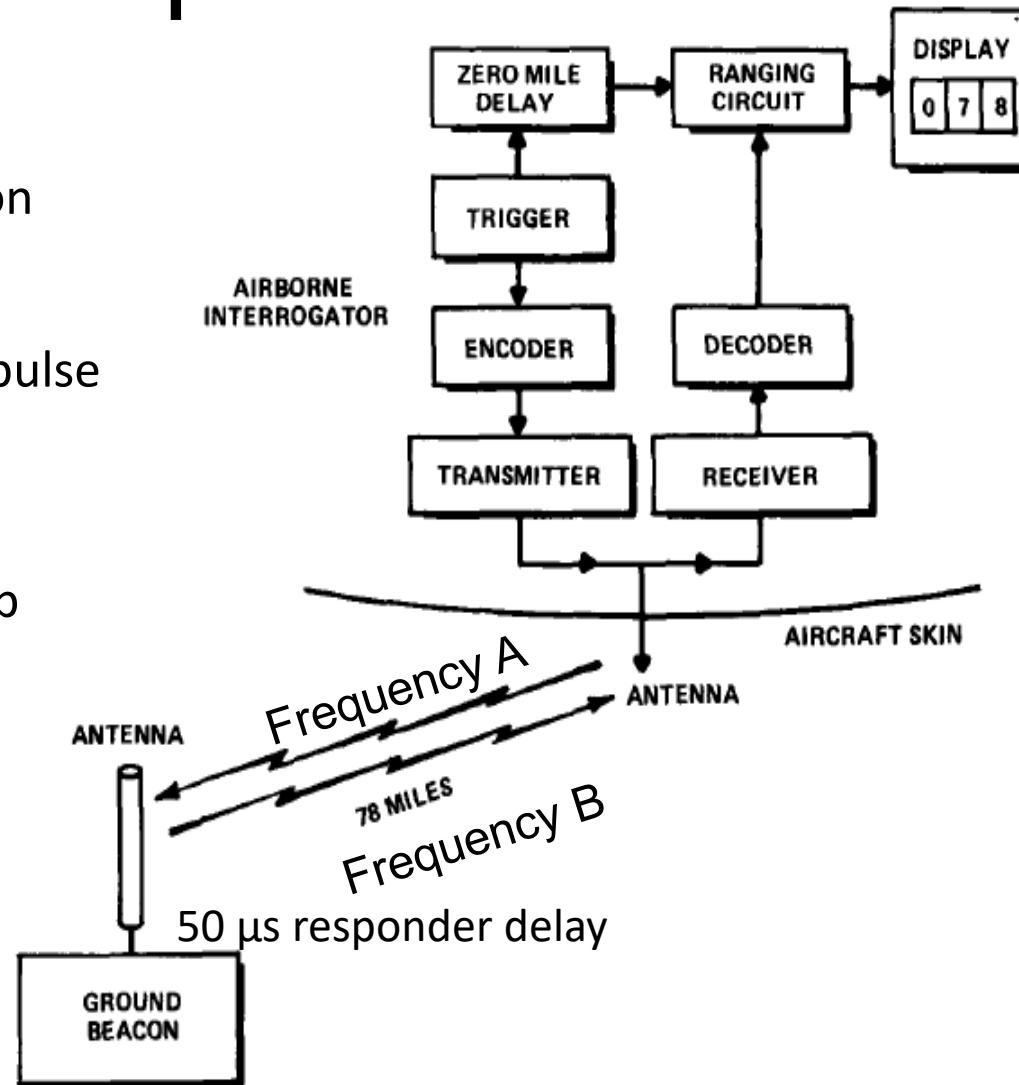
Front view of  
LPDME wall unit

# DME Operation Principle

**Interrogator** (Airplane) transmits pulse pair on frequency A.

**Transponder** (DME ground station) receives pulse pair, adds 50  $\mu$ s delay, transmits pulses on frequency B.

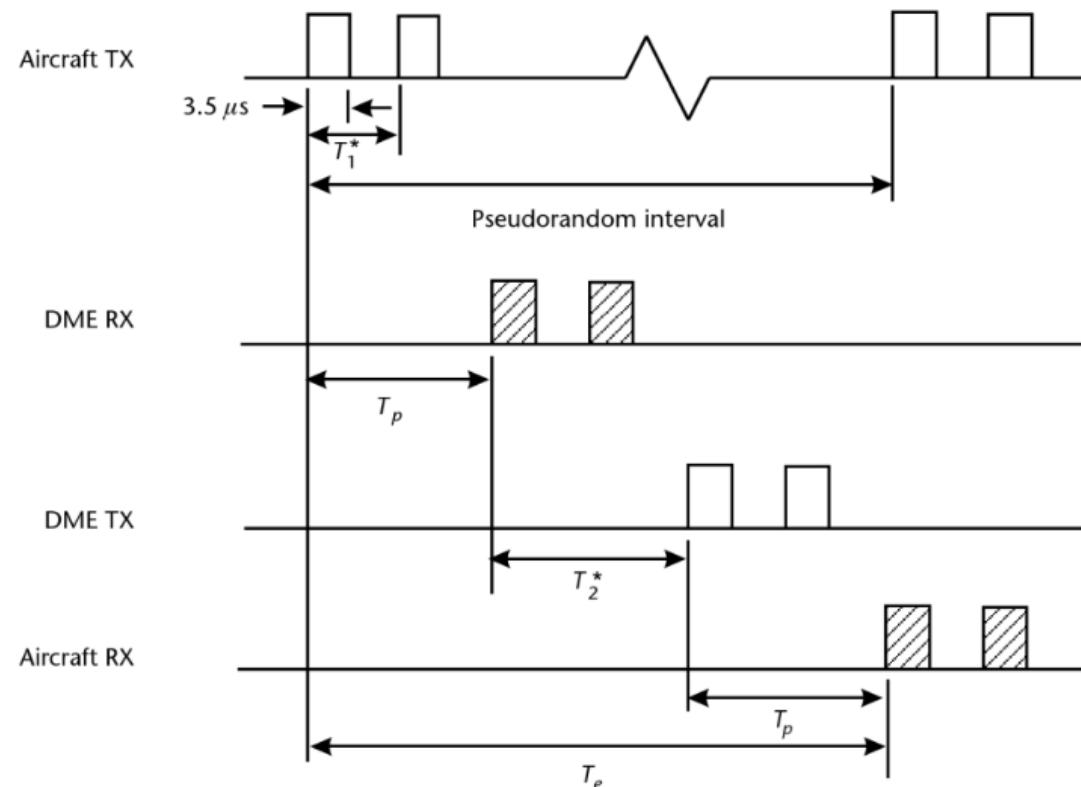
Airplane receives pulses, measures round-trip delay, calculates **slant range**



# Principi de funcionament

1. L'interrogador emet un parell de polsos de durada 3,5  $\mu\text{s}$  separats 12  $\mu\text{s}$  en Mode-X o 36  $\mu\text{s}$  en Mode-Y.
  1. Aquesta seqüència d'interrogació la pot tornar a emetre utilitzant un interval pseudoaleatori diferent per a cada interrogador.
  2. El parell de polsos s'emet en una mitjana de 30 parells/segon.
2. Quan el transpondedor rep el parell de polsos, aplica un retard de 50  $\mu\text{s}$  en Mode-X o de 56  $\mu\text{s}$  en Mode-Y, en retornar la resposta, utilitzant una freqüència de transmissió 63 MHz per sota de la utilitzada per l'interrogador.
3. L'interrogador rep la resposta i mesura el temps de retard restant-li els 50 o els 56  $\mu\text{s}$  de retard introduïts pel DME, de la forma:

$$\text{Slant range} = \frac{T_e - T_2}{2} c$$



	X mode	Y mode
$T_1^*$	12 $\mu\text{s}$	36 $\mu\text{s}$
$T_2^*$	50 $\mu\text{s}$	56 $\mu\text{s}$

Figure 2.20 DME pulse timing.

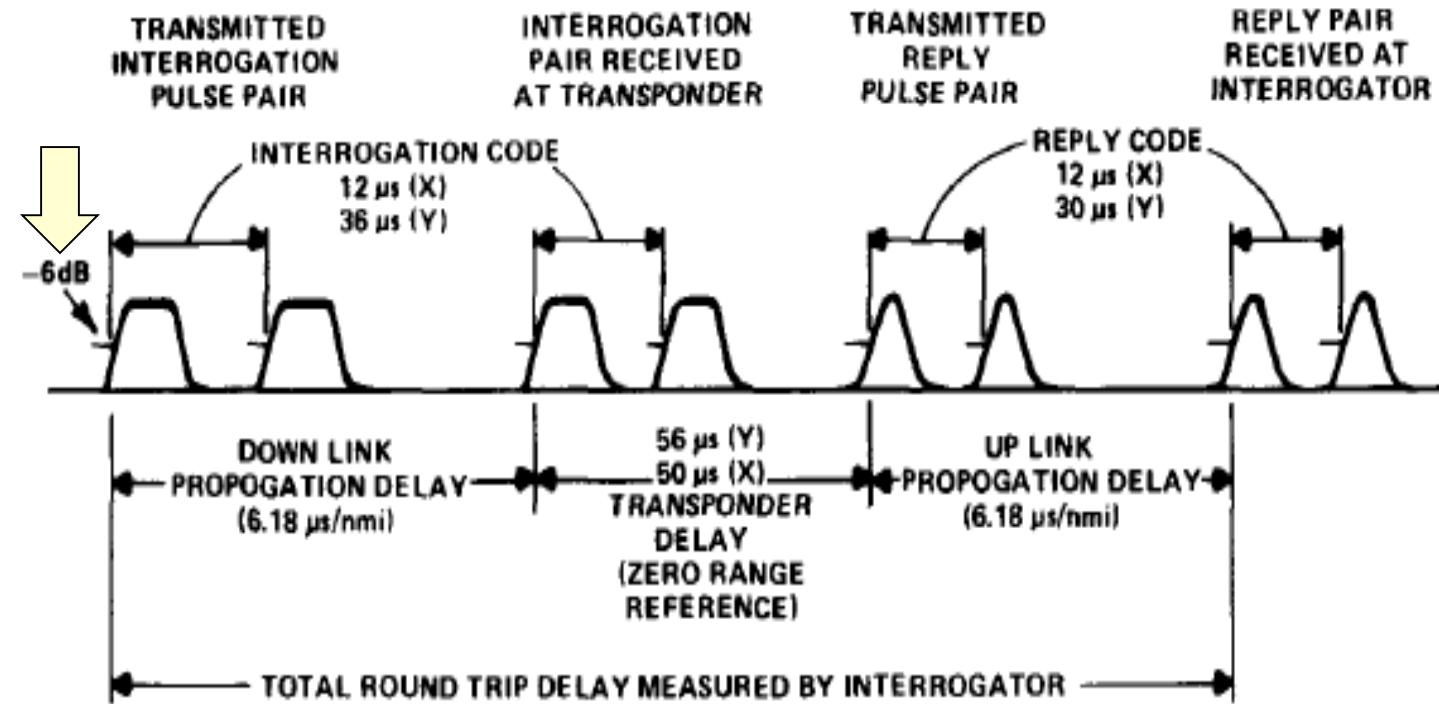
# DME Operation Principle

- DME transponder ID
  - Via Morse code @ 1350 Hz
- DME is interrogating system:
  - Limited capacity: 100-200 users
- DME provides “slant range,” not ground distance
  - Difference depends on altitude

# DME frequency assignment

- 960-1215 MHz (L-band)
  - Direct Line-Of-Sight
  - For example: 5000 ft, flat terrain: approximately 60 nmi, rough terrain: 30-40 nmi
- 1 MHz channels between 962-1213 MHz
- 126 channels, determined by
  - Interrogation frequency
  - Reply frequency
  - Difference between Interrogation & reply = 63 MHz = Intermediate Frequency (IF) of DME/TACAN equipment
  - Pulse code (X or Y)

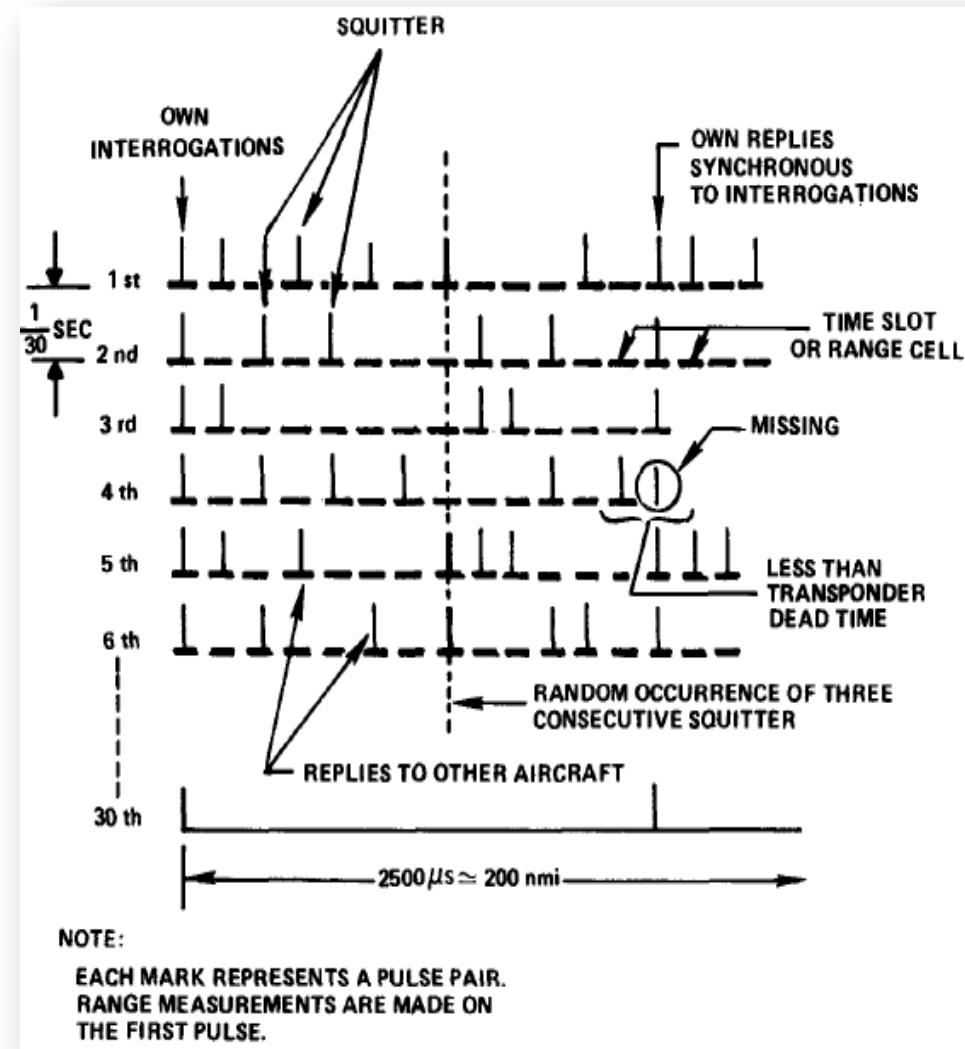
# DME Round-trip Delay Measurement



*$\frac{1}{2}$  amplitude point (6 dB below peak) of first pulse is reference point for time measurements*

# DME search process

- Each interrogator (airplane) transmits its DME pulses at a random time.
- During search, airplane sends out high number (max 150) pulse pairs/sec.
- Detect those replies with a statistically relevant constant time difference.
- Determine slant range and slant range rate.



# DME Tracking

- Approximate slant range and slant range rate known from Search.
- “Track” the received pulses by the predicted slant range.
- Switch to 5-25 pulse pairs/sec.

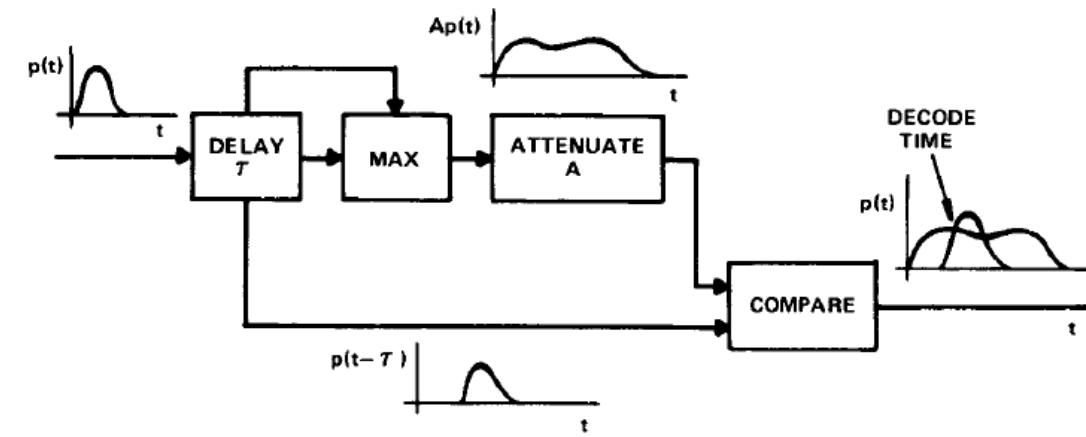
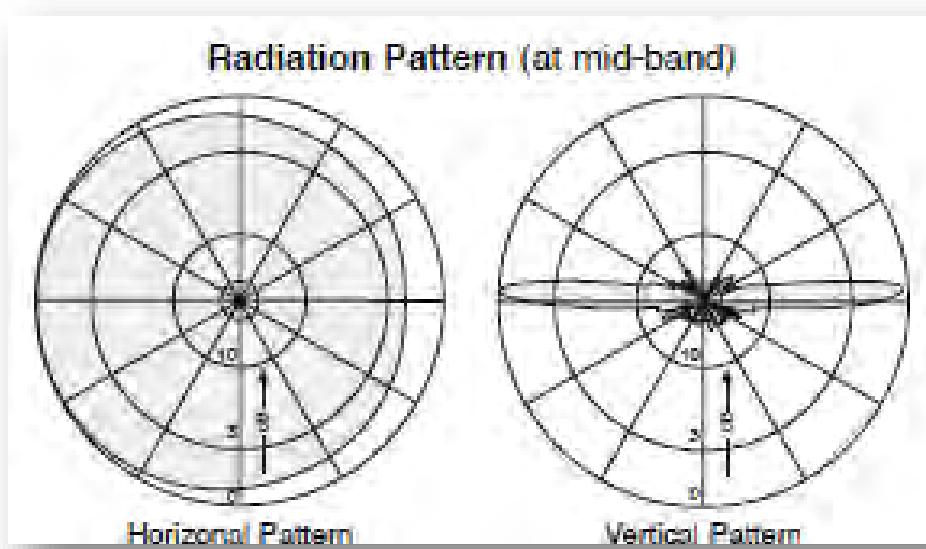


FIG. 66. The  $\frac{1}{2}$ -amplitude find circuit.

# DME antenna



**D.M.E. Omnidirectional Gain Antenna**  
**960 – 1215 MHz**  
**715 986, 722 394**

**KATHREIN**  
 Antennen · Electronic

The antenna consists of a number of identical, decoupled half-wave dipoles, phase-feeding cables and transformer. Each dipole is mounted onto a central supporting brass tube. The horizontal pattern is obtained by the circular characteristic of the single dipole, the vertical pattern varying phase and distance of the single dipoles. All metal parts are DC grounded and, therefore, widely immune to damage from lightning. The top of the antenna is fitted with a dual obstruction light (type no. 715 986). Two antenna monitor probes are located inside the fiberglass tube. All feedlines and monitor cables descend inside the supporting brass tube.

Type No.	715 986	722 394
Obstruction light	Yes	No
Input (antenna/monitors)	N female	
Connector position	Bottom	
Frequency range	960 – 1215 MHz	
Bandwidth	255 MHz	
VSWR	< 1.8 (antenna input)	
Gain	9 ±0.5 dBi	
Impedance	50 Ω	
Horizontal pattern	Omnidirectional: Deviation from omni better ±1.5 dB	
Vertical pattern up tilt	3 ±0.5°	
Coupling attenuation	25 ±3 dB (antenna/monitor probes)	
R. F. peak power	10 kW, modulated as per ICAO recommendation	
Polarization	Vertical	
Temperature range	-40 to +80 °C ambient	
Weight	28 kg	21 kg
Wind load	400 N (at 150 km/h with 12 mm radial ice)	270 N (at 150 km/h with 12 mm radial ice)
Max. wind velocity	150 km/h (incl. 12 mm radial ice)	200 km/h
Radome diameter	86 mm	

**Material:** Dipoles, decoupling elements, supporting tube and transformer: High quality brass.  
 Base: Weather-resistant aluminum.  
 Radome: Fiberglass, colour: Grey.  
 All screws and nuts: Stainless steel.

**Mounting:** To pipes of 60 – 62 mm OD by means of mounting clamps, supplied.

**Grounding:** The antenna is DC grounded by a cross section of 98 mm<sup>2</sup> brass.



# Instrument Landing System

ILS



UNIVERSITAT POLITÈCNICA DE CATALUNYA  
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Departament de Teoria del Senyal  
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# ILS: Instrument Landing System

- ILS has never been blamed for an aircraft accident during normal ILS operation: A perfect safety record.
- About 1500 ILS in use (1097 in USA, 2008),
  - 100 airports CAT-III,
  - 117.000 aircraft with ILS (1996)

# Categories ILS

- Cat I
  - Cèl·lules de 200 ft (60,96 m), 0,5 nmi (926 m) de visibilitat
- Cat II
  - Cèl·lules de 100 ft (30,48 m), 1200 ft (365,76 m) de Runaway visual range (RVR)
- Cat IIIa
  - Cèl·lules de 100 ft (30,48 m), RVR > 700 ft (213,36 m)
- Cat IIIb
  - Cèl·lules de 50 ft (15,24 cm), RVR de 150 ft (45,72 m)

1 nmi = 1852 m  
1 ft = 30,48 cm



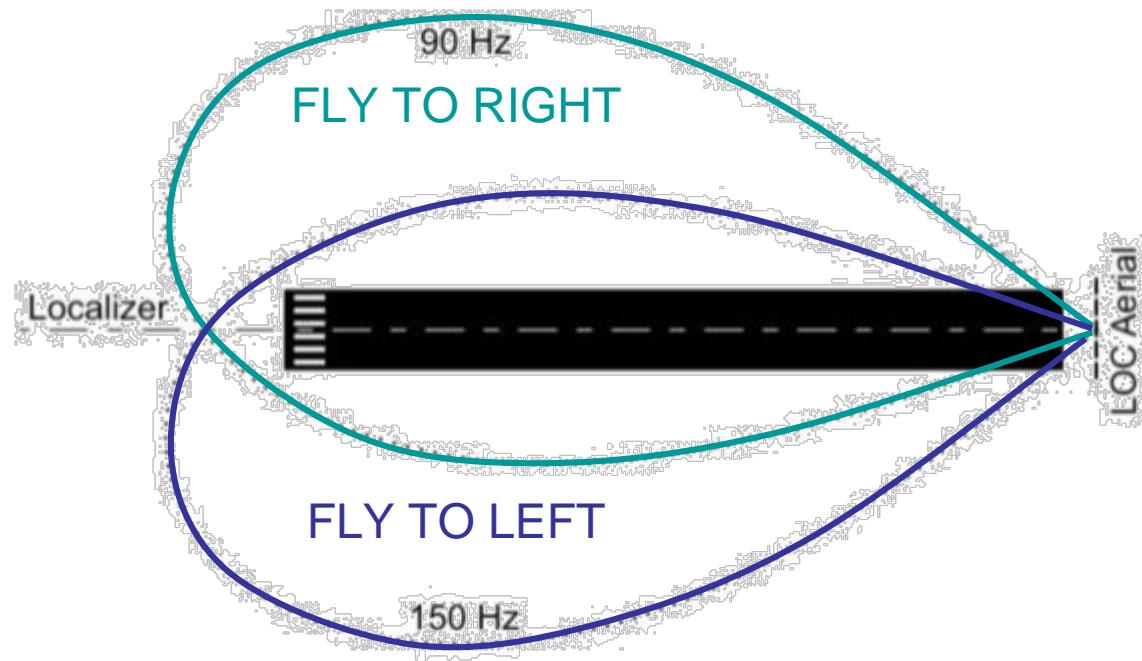
# ILS: Instrument Landing System

- History ILS and autoland:
- 1939: first commercial usage of ILS
- 1947: civil aviation CAT-I
- 1959: program started aiming at CAT IIIa autoland in early 1970s
- 1962: flight test program started at Hatfield
- 1965: CAT I certification of autoflare: world first autoflare in passenger operation
- 1966: First autoland in development aircraft in CAT IIIb conditions
- 1968: CAT II certification for passenger operations
- 1972: CAT IIIa certification for passenger operations
- 1974: CAT IIIb certification for passenger operations
- 1976: CAT IIIc certification

# ILS system components

- **Localizer:**
  - Provides lateral guidance: guides the plane along the center line of the runway
  - Frequency: **108-112 MHz**
  - Range: 25 NM at 10°, 17 NM at 35°
  - Antenna located at the end and on center line of the runway
- **Glide slope:**
  - Provides vertical guidance: guides plane with descent slope of ≈3° to the runway
  - Frequency: **329.3-335.0 MHz**
  - Antenna located besides runway near threshold.
- **Monitors:**
  - Detect ILS failure
  - When failure: shutdown ILS (CAT I/II) or switch to backup (CAT III)
- **Marker beacons:**
  - Located along approach path
  - Outer marker:
    - 4NM,
    - Morse-style dashes of 400 Hz tone modulation; 2 points/s ( $h=400$  m)
  - Middle marker:
    - 3500 ft;
    - Morse-style dot-dash of 1300 Hz tone modulation; 2 points/s ( $h=55$  m)
  - Inner marker:
    - 1000-1500 ft;
    - Morse-style dots of 3000 Hz tone modulation; 6 points/s ( $h=20$  m)
  - Frequency: **75 MHz**
- **DME (optional)**
  - Takes over function of marker beacons

# ILS Localizer



Localizer  
(Lateral Guidance - VHF Frequencies)

Provides lateral guidance: guides the plane along the center line of the runway  
Frequency: 108-112 MHz  
Range: 25 NM at  $10^\circ$ , 17 NM at  $35^\circ$   
Antenna located at the end of runway, on the center line

# Difference in Depth of Modulation (DDM)

- Reference path defined by static antenna beams (only one path possible)
- A carrier is **amplitude modulated with a 90 Hz and 150 Hz subcarrier**
- Due to the antenna pattern:
  - the 90 Hz signal is dominant on the left side of the runway,
  - the 150 Hz signal on the right side of the runway.
- Deviation from reference path is measured by estimating the **Difference in Depth of Modulation (DDM)**

# Difference in Depth of Modulation (DDM)

## Total signal modulation:

$$M = \frac{A_{150Hz} + A_{90Hz}}{A_{carrier}}$$

$A_{carrier}$ : amplitude of the carrier

$A_{150\text{ Hz}}$ : amplitude of the 150 Hz subcarrier

$A_{90\text{ Hz}}$ : amplitude of the 90 Hz subcarrier

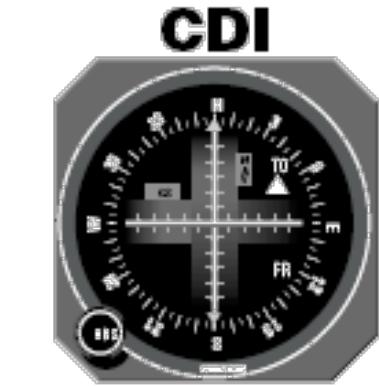
## Difference in Depth of Modulation:

$$DDM = \frac{A_{150Hz} - A_{90Hz}}{A_{carrier}}$$

90 Hz dominant:

At centerline:

150 Hz dominant:

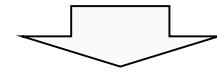


Cross-pointer  
Course Deviation  
Indicator (CDI)

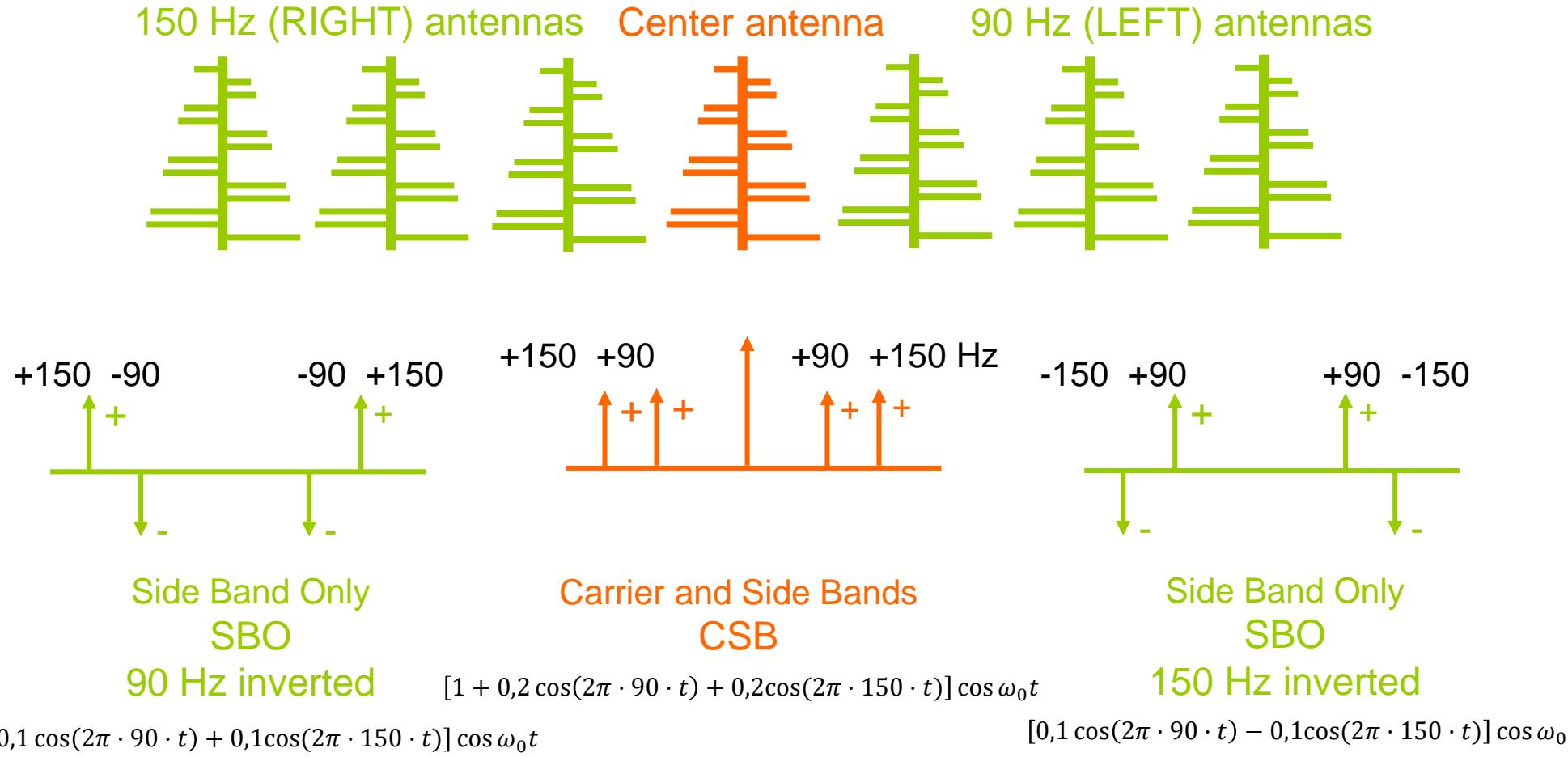
DDM negative → Fly to right

DDM zero → on course

DDM positive → Fly to left



# Localizer Antenna Array



# Localizer Array Radiation Patterns

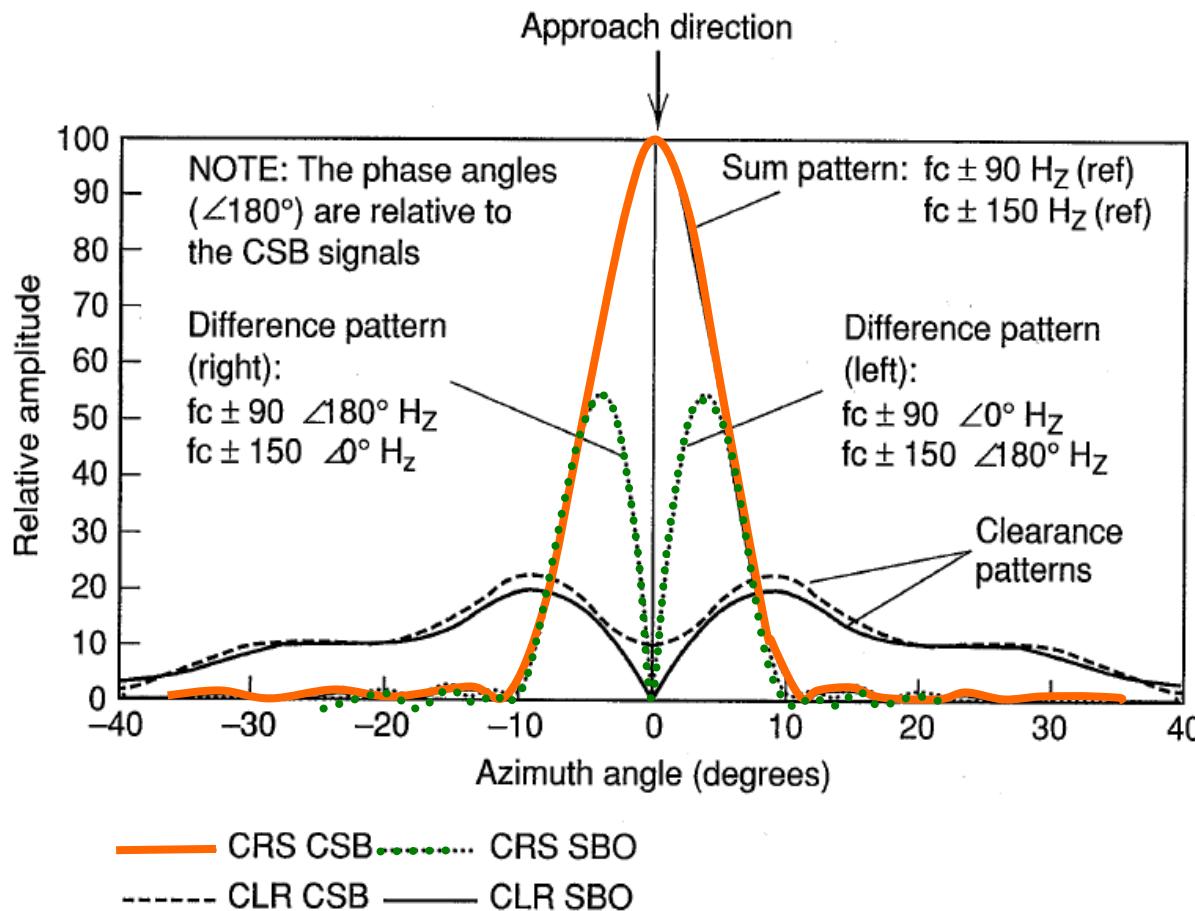


Figure 13.4 Sum and difference radiation patterns for the course (CRS) and clearance (CLR) signals of a directional localizer array.

Full-scale course-deviation readout required at 3-6°

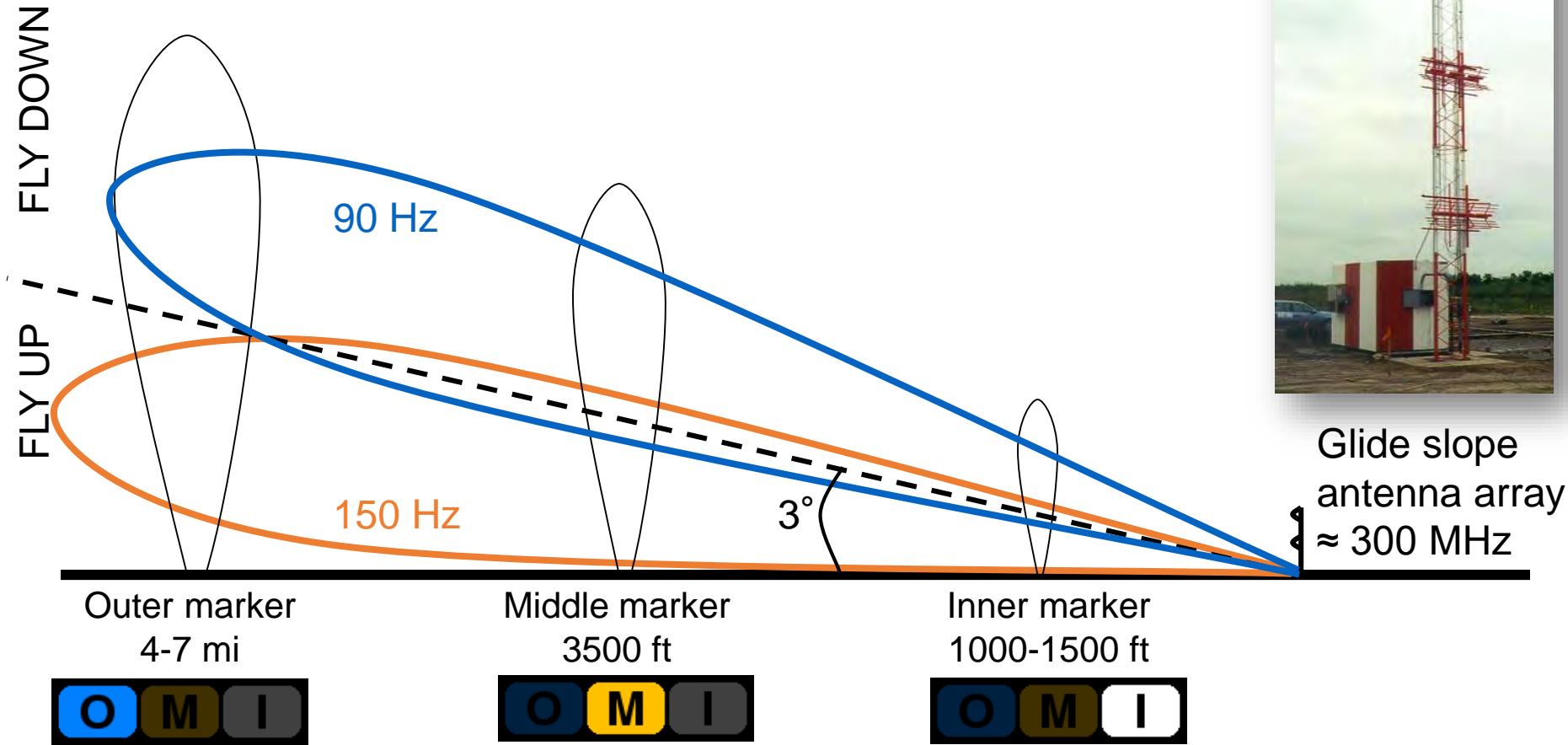
Carrier Side Band (CSB) pattern is narrow (5-10° )

ICAO requires +/-35° coverage to aid acquisition

Solution:

*addition of seconds set of signal: CLR (Clearance), modulated on a different carrier, 8 kHz from CRS (Course) carrier. AM detector in Rx automatically takes strongest*

# ILS Glide Path or Glide Slope



# Marker Beacon Antenna

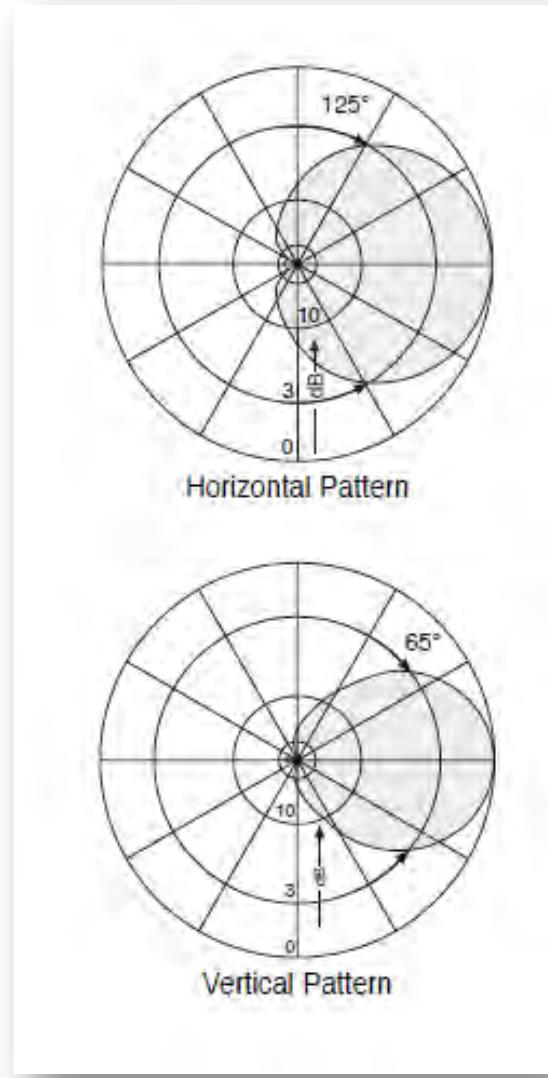
**Marker Beacon Antenna**

74–76
H/V
125°

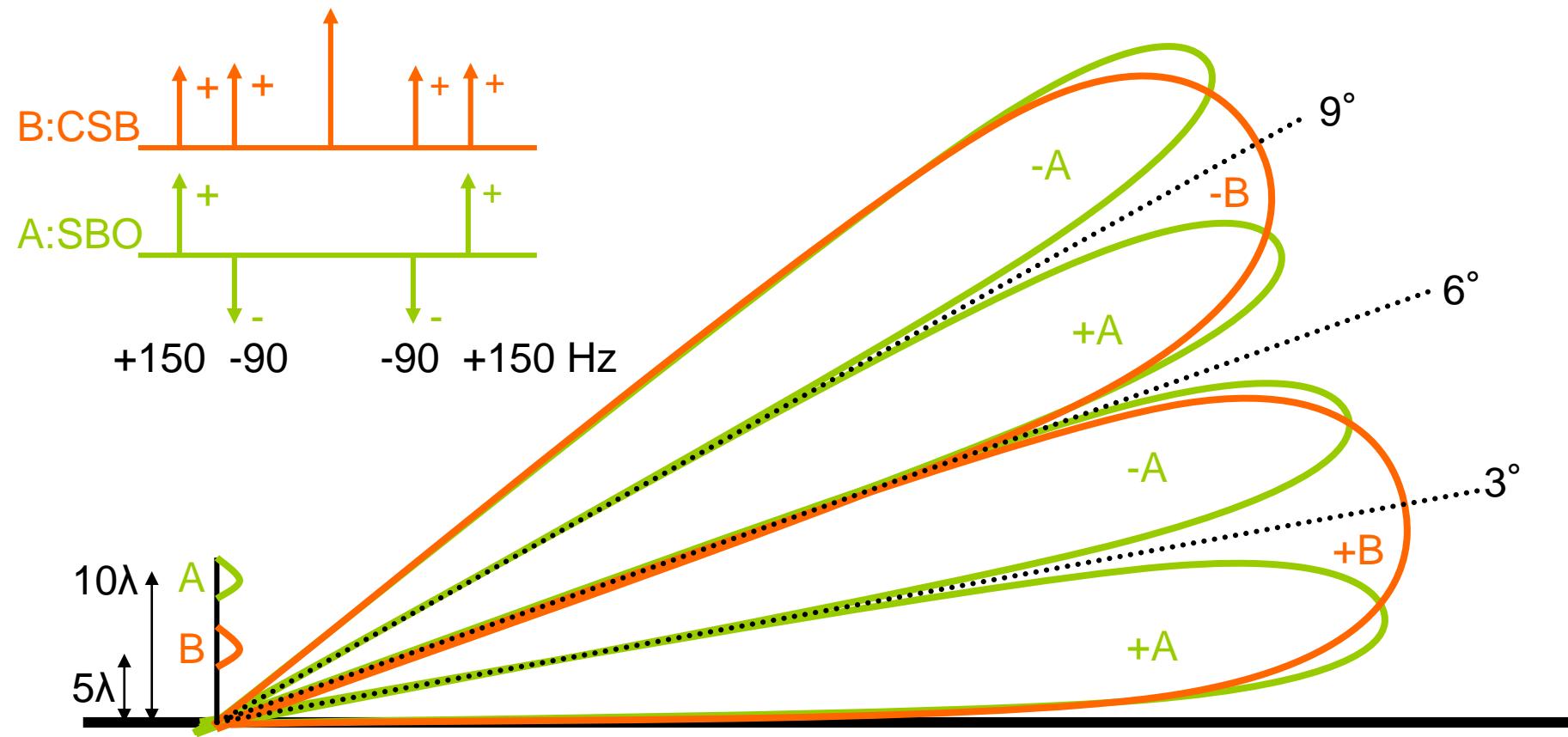
**KATHREIN**  
Antennen · Electronic

**4-unit Yagi**

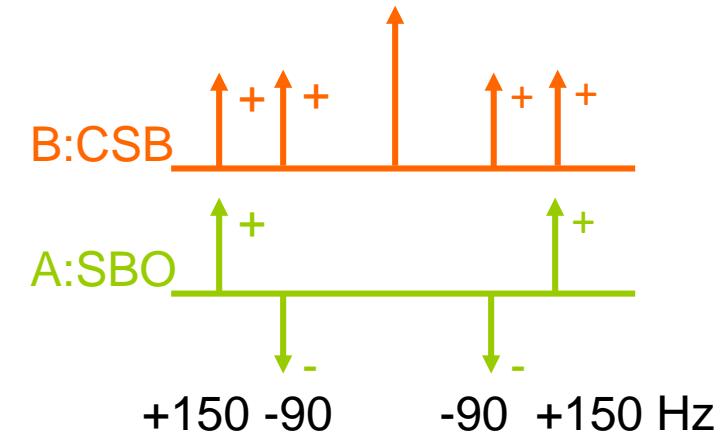
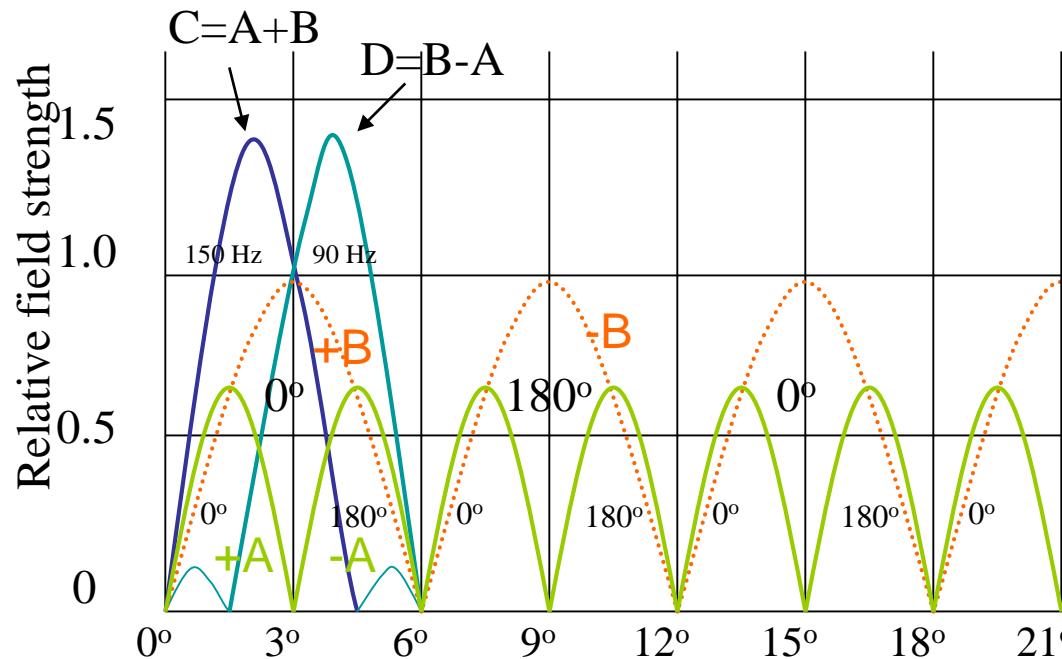
Type No.	800 10228
Frequency range	74 – 76 MHz
Polarization	Horizontal / vertical
Gain	7 dBi
Half-power beam width	H-plane: 125° E-plane: 65°
Impedance	50 Ω
VSWR	< 1.4
Max. power	15 W
Material:	Hot-dip galvanized steel.
Mounting:	Mast: Using the supplied flange 120 x 140 mm. Walls: Using the mounting kit 711 978.
Grounding:	All metal parts of the antenna including the delivered mounting kit are DC grounded.



# ILS Glide Path



# ILS Glide Path



Depth of modulation difference between the 90 and 150 Hz modulation is the measurement. It is very linear throughout the guidance region (around 3°, 1° - 5°).

Vertical Deviation Indicator (VDI) needle at full scale for DDM  $\pm 0.175$  at  $\pm \theta/4$  ( $= \pm 0.75^\circ$  for  $\theta = 3$ )

# Glide path antenna

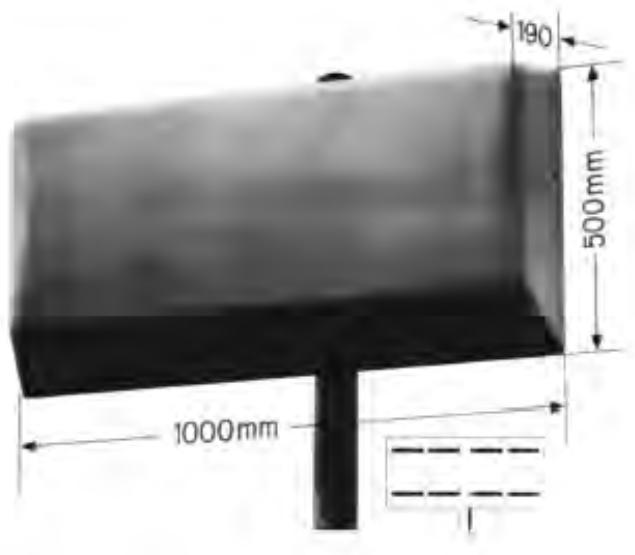
Type No.	714.747
Input	Type N female connector in a weather protective rubber cap directly at the antenna
Frequency range	328 - 335.5 MHz
VSWR	< 1.1
Gain	8.5 dB (ref. to the half wave dipole)
Max. power input (CW)	100 Watts (at 35°C = 95°F ambient)* 60 Watts (at 50°C = 122°F ambient)*
Max. permiss. DC	1 A (between inner and outer conductor)
Polarization	Horizontal
Lightning protection	The antenna is DC grounded by a cross-section of 204 mm <sup>2</sup> (0.32 sq.") aluminum
Scope of supply	Antenna with two weather protective rubber caps for the connector, but without mounting hardware
Material	Heavy duty cast aluminum radiators 35 x 2 mm (1 3/8 x 5/32"), reflector screen of high strength aluminum alloy sheet. Hot dip galvanized steel clamps. All screws and nuts: stainless steel
Mounting (special order)	By means of hot dip galvanized steel clamps K 61 32 5 ... (see reverse side) to pipes of 60 ... 380 mm (2 5/8" ... 15") OD
Net weight	12 kg (26.4 lbs)
Max. exposed area	0.5 m <sup>2</sup> (5.38 ft <sup>2</sup> )
Lateral thrust	72 kp (158 lbs) at 160 km/h = 100 mph
Wind velocity w/o ice	rated (1.65 safety factor)**/survival 220 km/h = 130 mph/270 km/h = 170 mph
1/2" radial ice	160 km/h = 100 mph/250 km/h = 155 mph
Packing	106 x 50 x 25 cm (41.7" x 19.6" x 9.8")

\* antennas for higher powers on request.

\*\* based on the yield point.

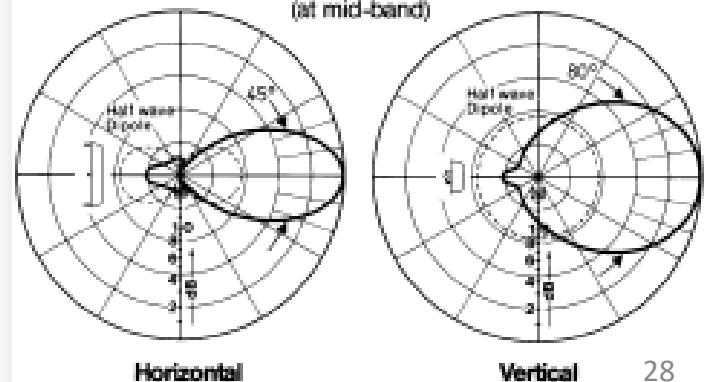
## Glide Path Antenna 328 – 335.5 MHz 714 747

**KATHREIN**  
Antennen · Electronic



Horizontally polarized, 8.5 dB glide path panel, completely enclosed in a rugged, impact-resistant fibreglass radome for maximum protection from heaviest icing, saltwater and corrosive atmosphere. The fibreglass radome keeps the electrical characteristics, even under heaviest icing, nearly constant. The antenna is supplied with a coupler for radiation monitoring.

Radiation Pattern  
(at mid-band)

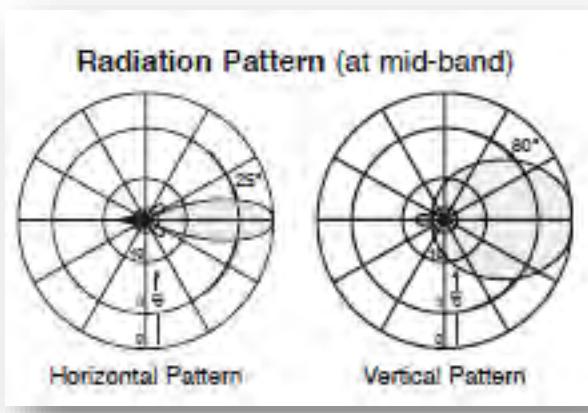


Horizontal

Vertical

28

# Glide path antenna



**Glide Path Antenna**  
328 – 335.5 MHz  
**713 316 B**

**KATHREIN**  
Antennen · Electronic

## RF monitor system integrated

Type No.	<b>713 316 B</b>
Input	Type N female connector
Frequency range	328 – 335.5 MHz
VSWR	< 1.1
Gain	12 dBi
Impedance	50 Ω
Polarization	Horizontal
Half-power beam width	H-plane: 80° / E-plane: 25°
Max. power input (CW)	60 W (at 50 °C ambient temperature)
Max. current (DC)	1 A (between inner and outer conductor)
Weight	19 kg
Max. exp. area	1.0 m <sup>2</sup>
Lateral thrust	1450 N at 160 km/h
Max. wind velocity	200 km/h (incl. 1/2 radial ice)
Width/height/depth	2000 / 500 / 190 mm
Packing size	2100 x 510 x 260 mm

Material:  
Dipole system: Cast aluminum.  
Reflector: Weatherproof aluminum.  
Radome: Fiberglass (white).  
All screws and nuts: Stainless steel.

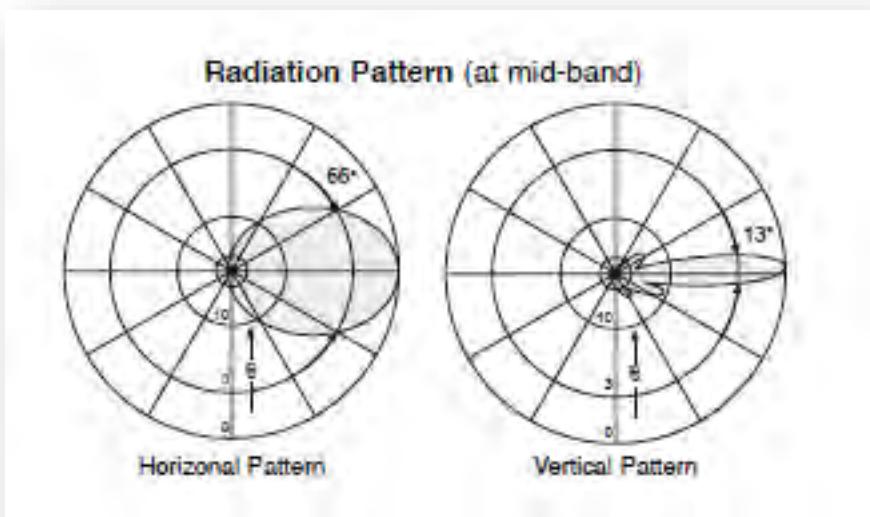
Scope of supply:  
Antenna with two weather protective rubber caps for the connectors, but without mounting hardware.



# DME-ILS colocation antenna

**Directional Antenna  
960 – 1215 MHz  
716 405**

**KATHREIN**  
Antennen · Electronic

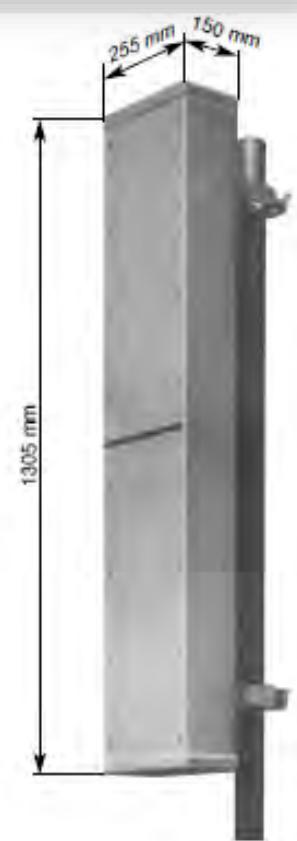


The directional antenna 716 405 has been specially designed for DME ground beacons and particularly for DMS-ILS colocation. The antenna provides a pattern with a cosecant-squared shaping. The antenna is equipped with two monitoring probes inside.

Type No.	716 405
Inputs (antenna and monitoring probes)	N female connector (protected by a rubber cap)
Connector positions	Rearside
Frequency range	960 – 1215 MHz
VSWR	< 1.6 (antenna input)
Gain (ref. $\lambda/2$ dipole)	14 dBd
Impedance	50 Ω
Coupling attenuation	$25 \pm 3$ dB (antenna/monitoring probes)
Beam tilt	+4° $\pm 0.5$ °
R. F. peak power	10 kW; duty cycle 2%
Polarization	Vertical
Temperature range	-30 to +60 °C ambient
Weight	12 kg
Wind load	600 N (at 160 km/h)
Max. wind velocity	200 km/h (incl. $1/2$ radial ice)
Packing size	1420 x 360 x 250 mm
Height/width/depth	1305 / 255 / 150 mm

**Material:** Radiators: Brass. Reflector screen: High strength aluminum alloy sheet. Cover: Fiberglass.  
Clamps: Hot dip galvanized steel.  
All screws and nuts: Stainless steel.

**Mounting:** To pipes of 40 – 95 mm OD by means of mounting clamps, supplied. Clamps for thicker masts see second page.



# Tema 5:

## ELS EQUIPS I ELS SISTEMES RADIOELÈCTRICS AEROPORTUARIS

Jordi Berenguer  
Novembre 2021



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Departament de Teoria del Senyal  
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# VOR

VHF Omnidirectional Range

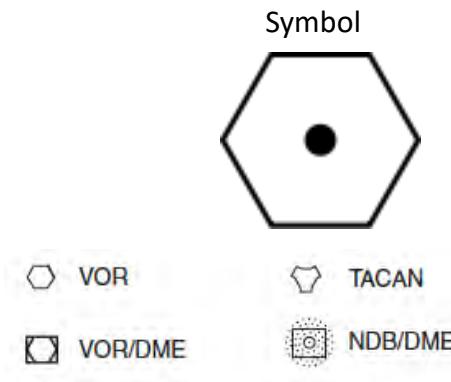


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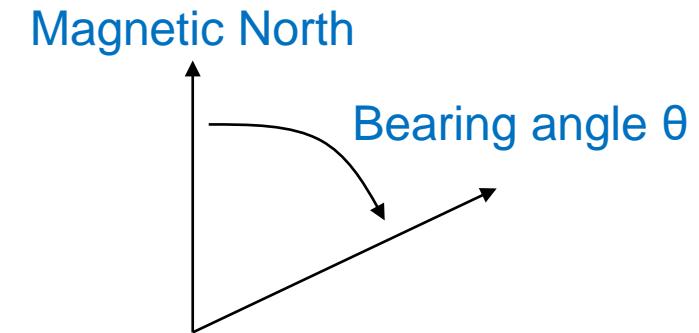
# Very-High Frequency Omni Range (VOR)

- NOW US and International standard
  - 108 MHz - 118 MHz
- Principle:
  - Phase offset between a reference signal and a rotating signal measures the angle
- VHF, no sky-wave contamination
- Signal structure, FM AM Sub-carrier
- Antennas
  - Transmitting antenna = ref + rotating
  - Phase locked signals
- VOR and Doppler VOR



# Very-High Frequency Omni Range (VOR)

- To encode the bearing angle in space
  - Transmit a reference angle (same phase in all directions).
  - Transmit a variable angle in space (phase dependent on the bearing  $0 - 360^\circ$ ).
- Cannot just transmit the variable angle, since aircraft does not have an absolute reference
- Angular guidance:
  - lateral accuracy is dependent on distance to the VOR station.
- True bearing or offset from desired bearing.
- Simplest pilot guidance is with a needle: Course Deviation Indicator (CDI).

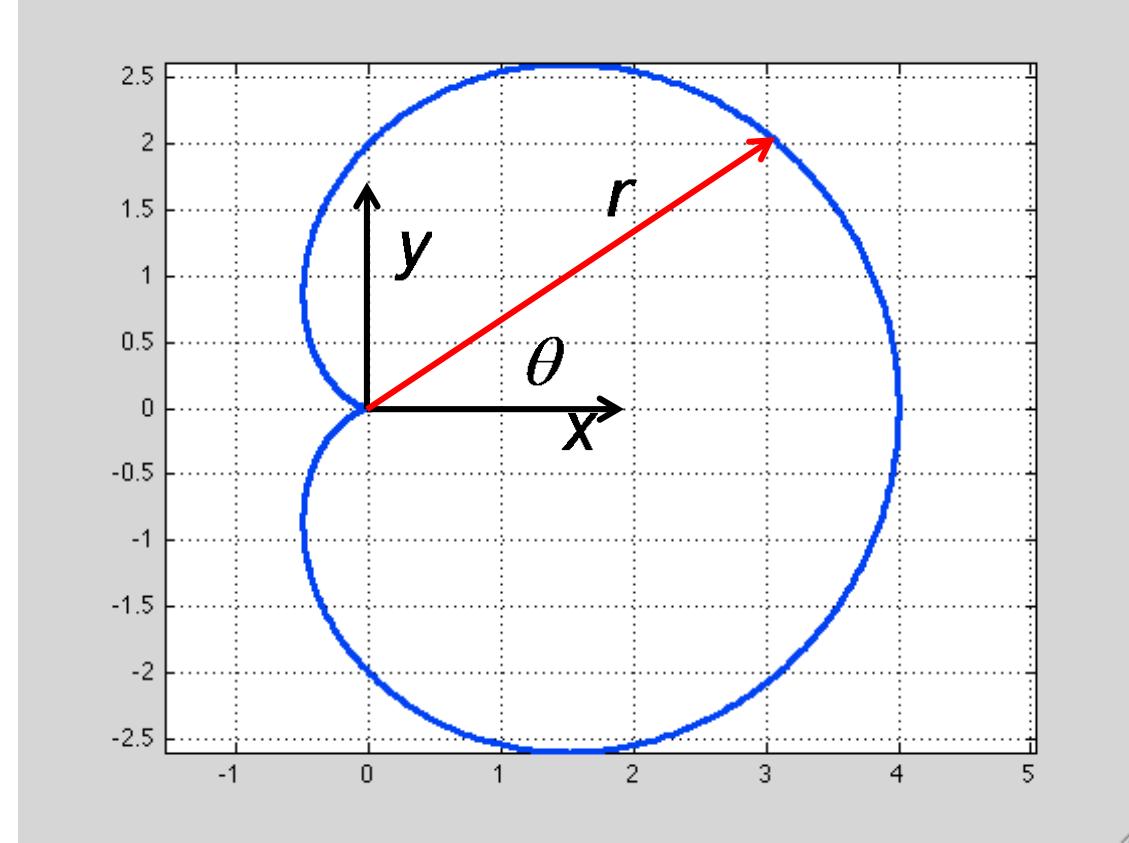


# Cardioid – Some Mathematics

$$x = 1 + 2 \cos \theta + \cos 2\theta$$

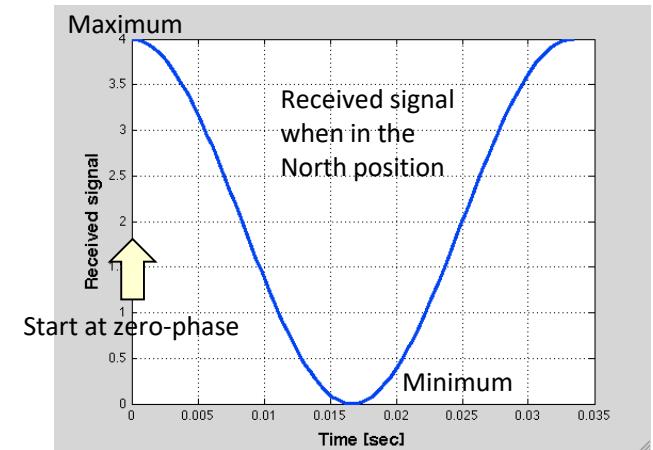
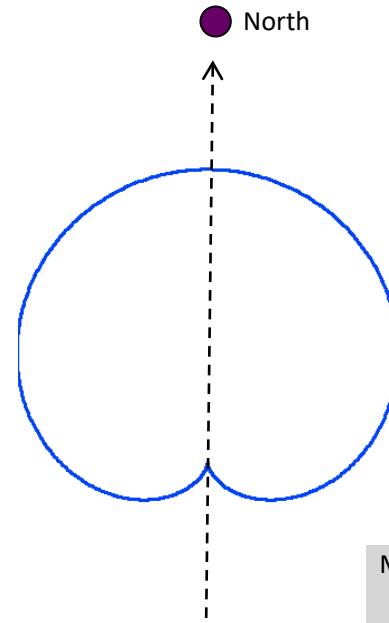
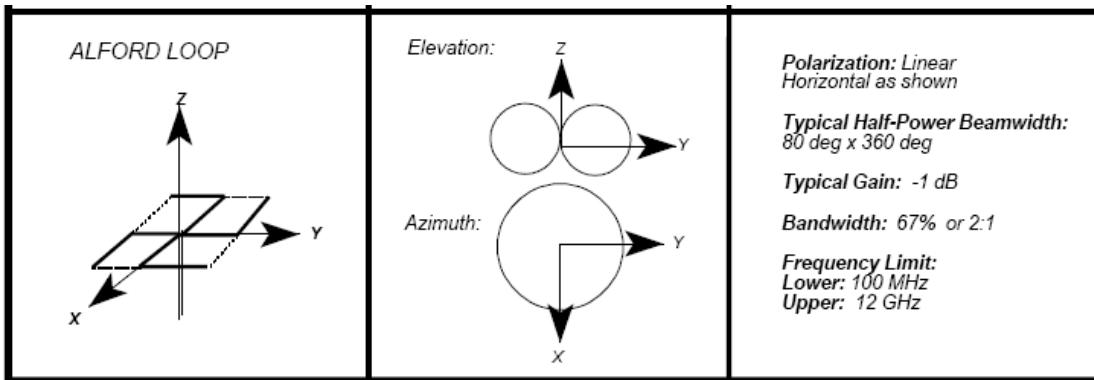
$$y = 2 \sin \theta + \sin 2\theta$$

$$r = 2(1 + \cos \theta)$$

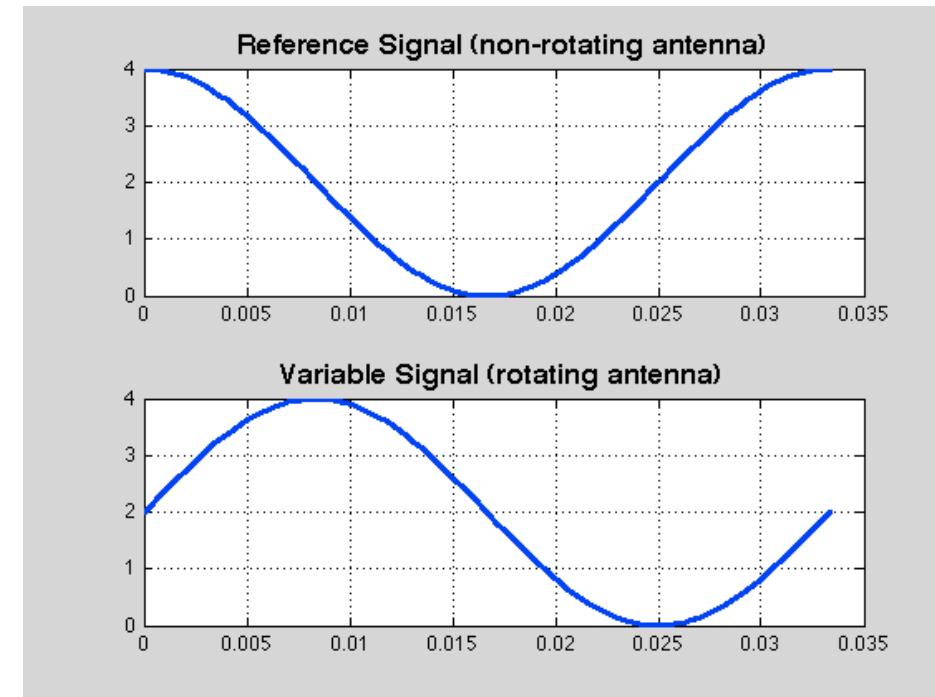
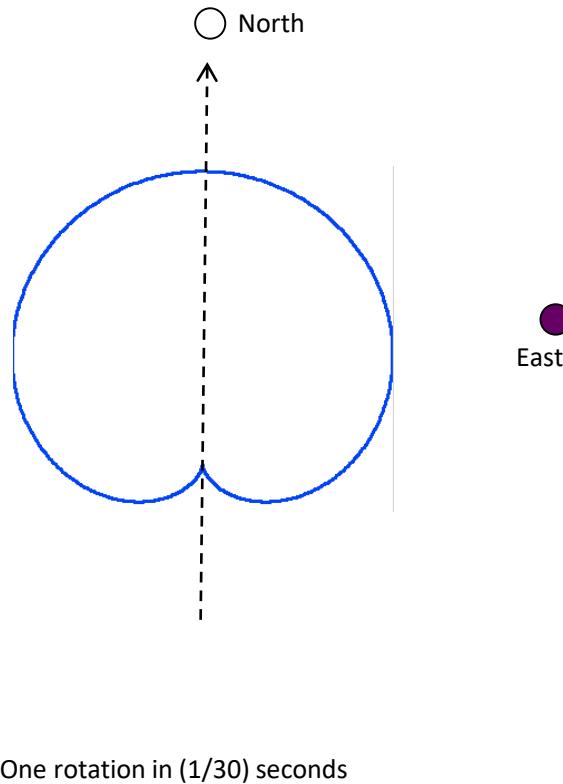


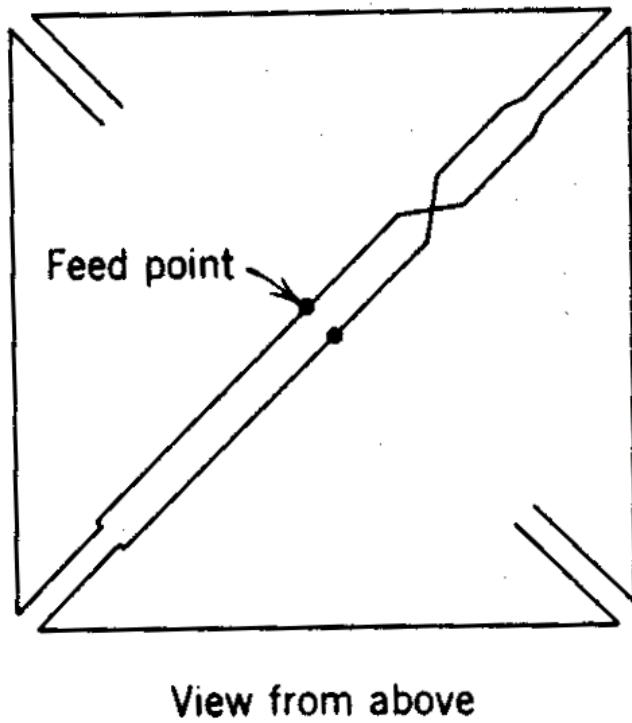
# Conventional VOR Transmitter Antenna

- Omni-directional antenna
  - Fixed
  - Transmitting a reference tone at 30 Hz **frequency modulated** onto a sub-carrier at 9960 Hz.
- Cardioid-pattern antenna
  - Rotating (physically or electrically) at **30 rotations per second**
  - Consisting of four Alford loops

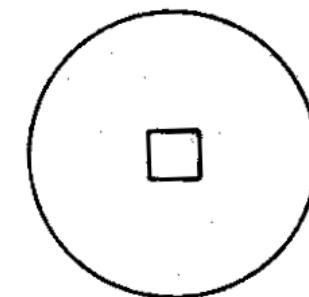


# Conventional VOR Transmitter Antenna

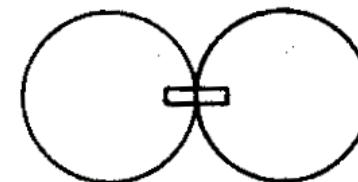




Antenna patterns



Horizontal



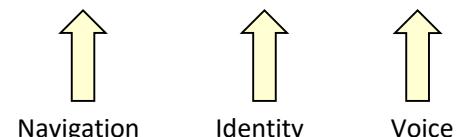
Vertical

**Figure 4.14** Alford loop.

# Conventional VOR Signal Structure

- Variable phase (dependent on bearing) signal generated by rotating Cardioid antenna (30Hz);
- Tone at 9960Hz frequency modulated by 30Hz reference signal;
- Identity tone at 1020Hz (Morse code modulated);
- Optionally, voice.

$$s(t) = [1 + m(t) + i(t) + v(t)] \cos(2\pi f_c t)$$



$$f_c = 108 - 118 \text{ MHz}$$

$$\cos(\omega_c t) = \cos(2\pi f_c t)$$

# VOR Signal Structure - Navigation

Navigation part only:

$$m(t) = 0.3\cos(\omega_m t + \theta) + 0.3\cos\left\{\int_0^t \omega_{sc} + \omega_d \cos(\omega_m t) dt\right\}$$

Modulation index  
 Variable phase  
 Due to rotating cardioid pattern  
 Bearing

$$\omega_{sc} = 2\pi(9960) \text{ rad/s}$$

$$\omega_m = 2\pi(30) \text{ rad/s}$$

$$\omega_d = 2\pi(480) \text{ rad/s}$$

$$m(t) = 0.3\cos(\omega_m t + \theta) + 0.3\cos\left\{\omega_{sc}t + \frac{\omega_d}{\omega_m} \sin(\omega_m t)\right\}$$

sub-carrier  
 Reference phase  
 16

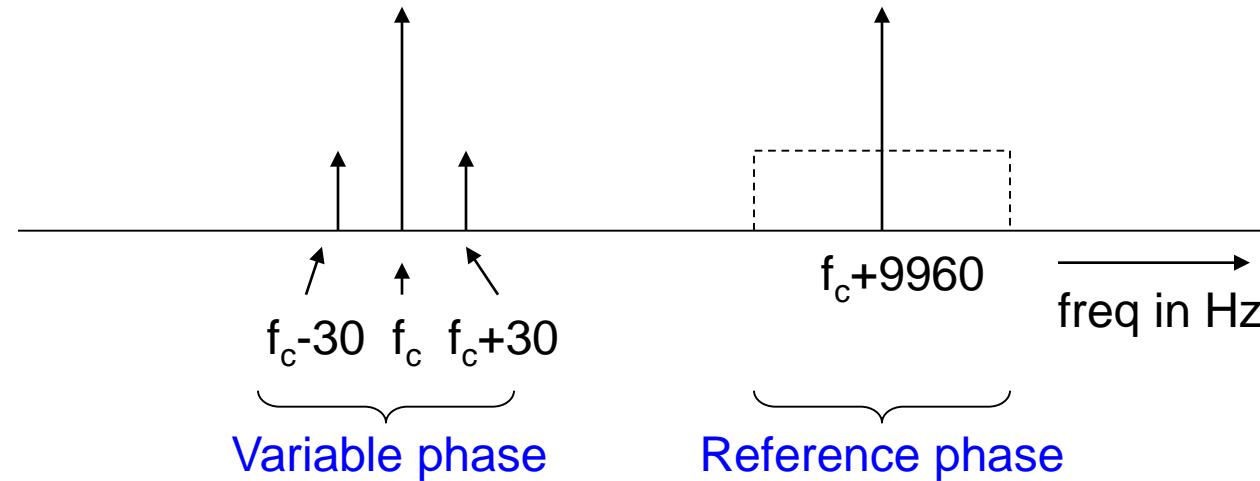
The 30-Hz variable phase is *amplitude-modulated* onto the carrier frequency (108-118 MHz).

The 30-Hz reference phase is *frequency modulated* onto a sub-carrier at 9960 Hz.

The sub-carrier is *amplitude-modulated* onto the carrier frequency.

*The VOR radial is determined by taking the phase-difference between the 30 Hz variable phase and the 30 Hz reference phase as received at the aircraft.*

# VOR Spectrum – Navigation Part Only



Instantaneous frequency:  $\frac{1}{2\pi} \frac{d\phi(t)}{dt} = f_{sc} + f_d \cos(\omega_m t) = 9960 \pm 480 \text{Hz}$

$$m(t) = 0.3 \cos(\omega_m t + \theta) + 0.3 \cos \left\{ \underbrace{\omega_{sc} t + \frac{\omega_d}{\omega_m} \sin(\omega_m t)}_{\phi(t)} \right\}$$

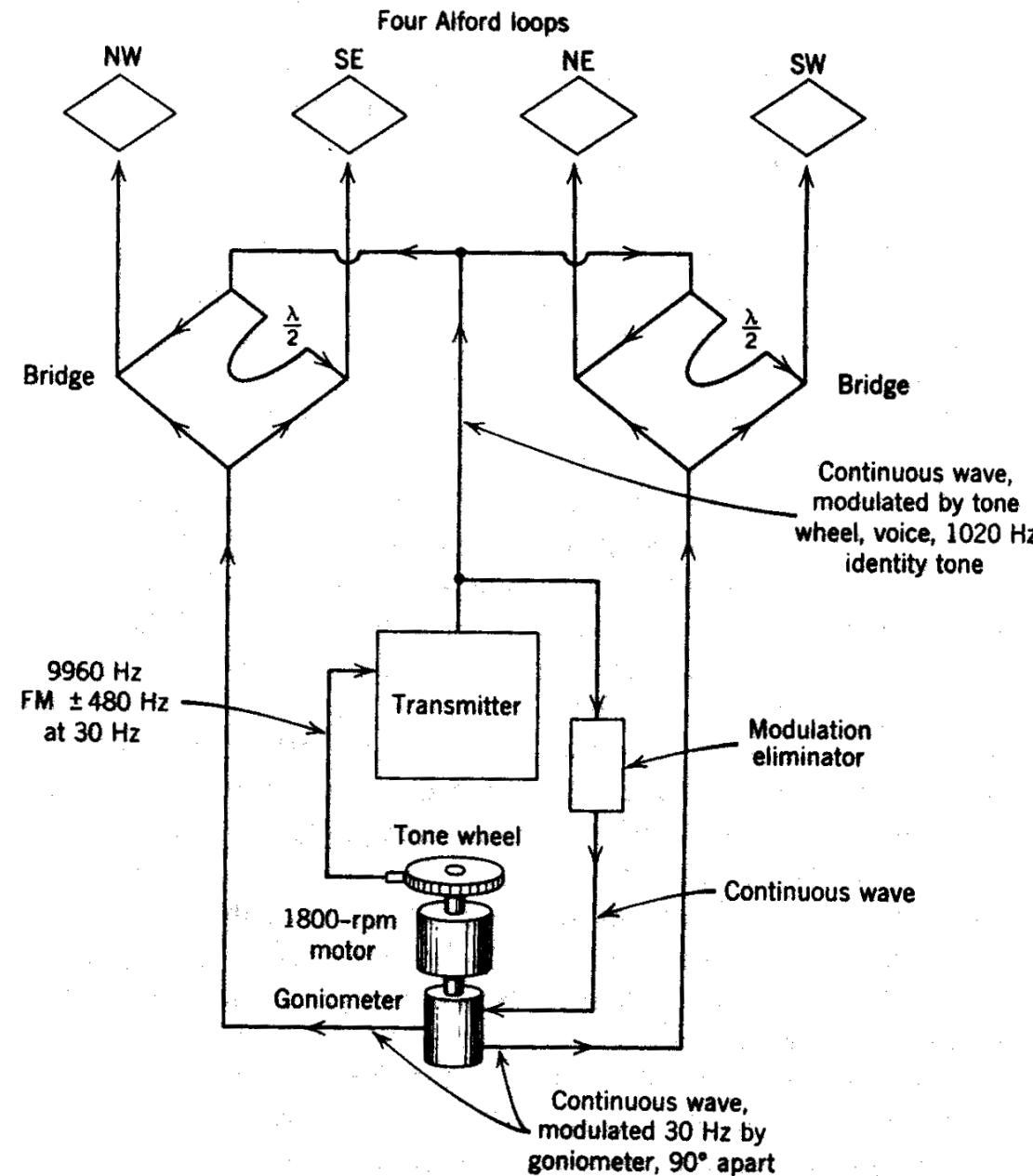


Figure 4.15 VOR block diagram.

# VOR Receiver

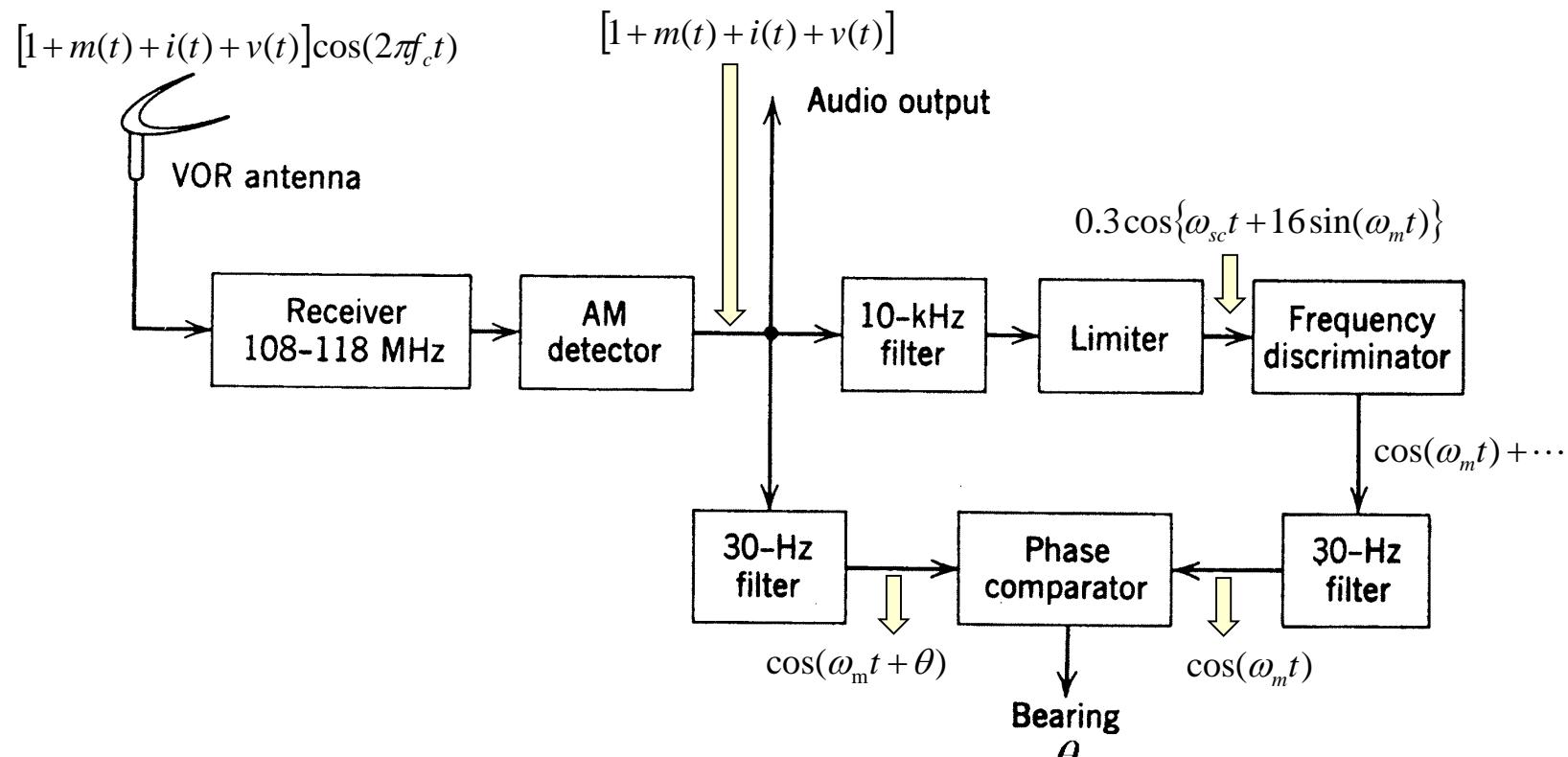
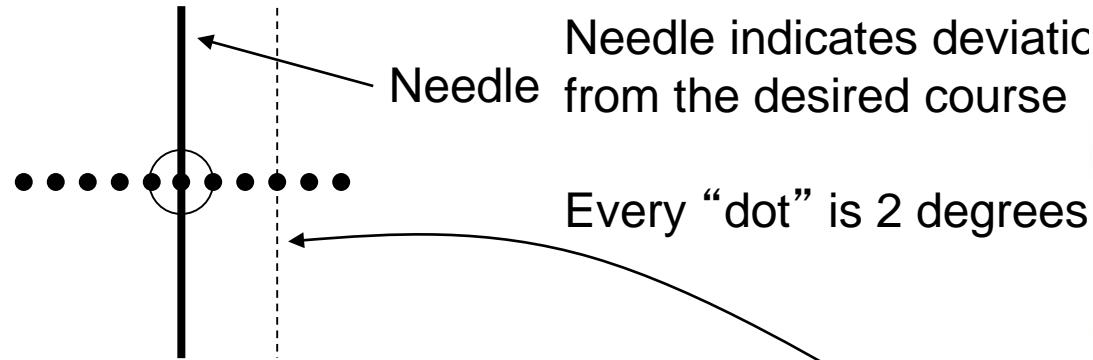


Figure 4.16 VOR receiver.

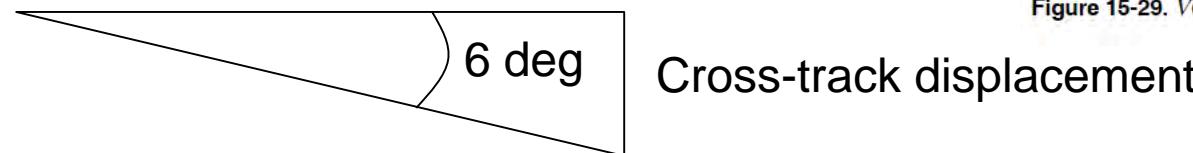
From [5]

# Course Deviation Indicator (CDI)



Example: 3 dots of course deviation corresponds to 6 degrees

Top-view: 10 nmi



$$\text{Cross-track displacement} = 10 \text{ nmi} \times \sin(6 \text{ deg}) = 1 \text{ nmi}$$

At a distance of 1 nmi from the VOR station, each dot corresponds to  $1 \text{ nmi} \times \sin(2 \text{ deg}) = 0.035 \text{ nmi} (212 \text{ ft})$

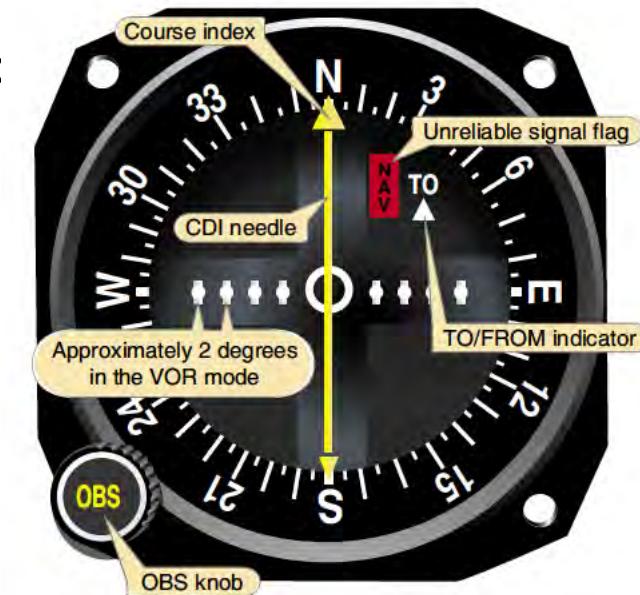


Figure 15-29. VOR indicator.

From [6]

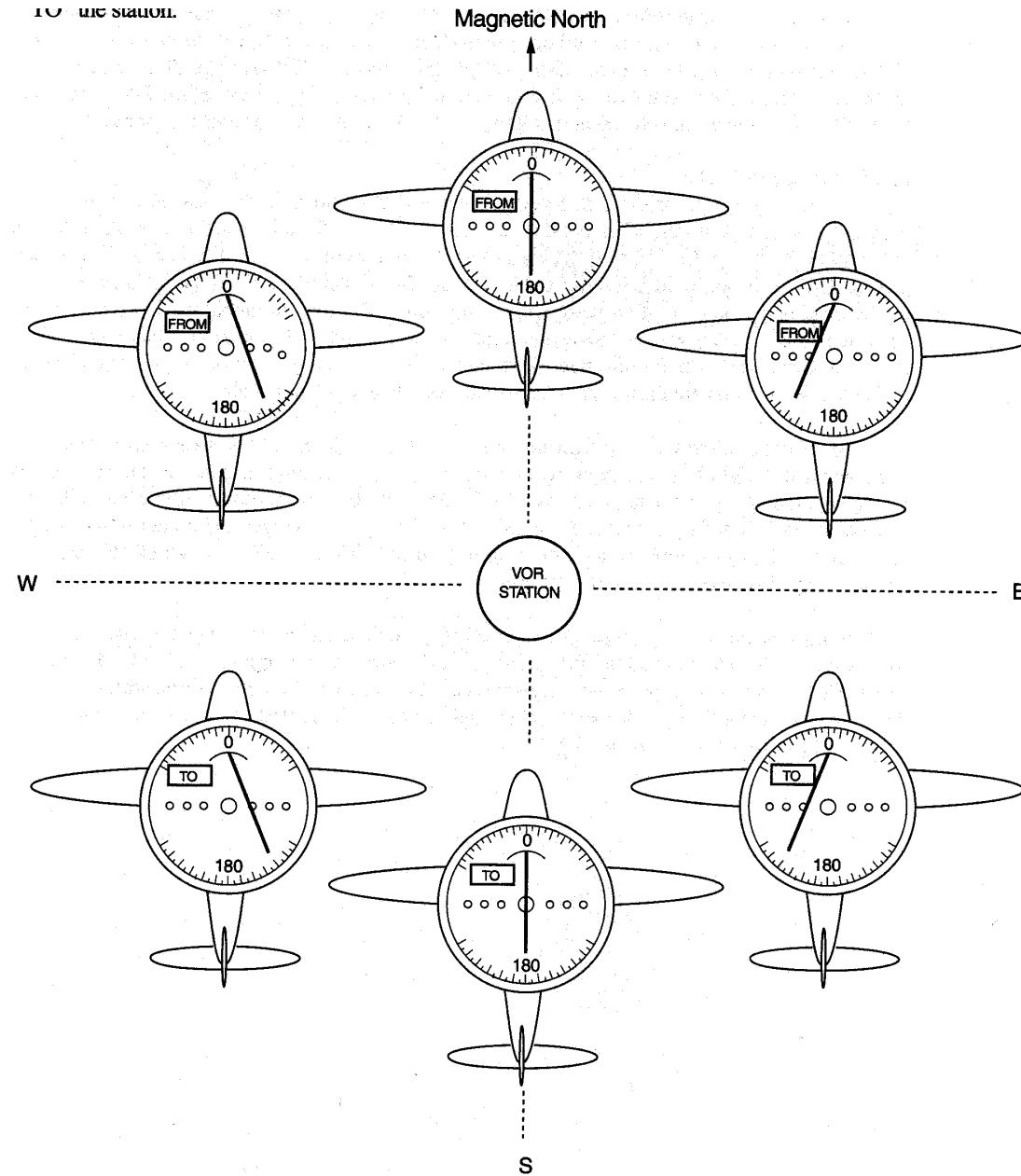


Figure 2.8 VOR Indicator for locations around the VOR station

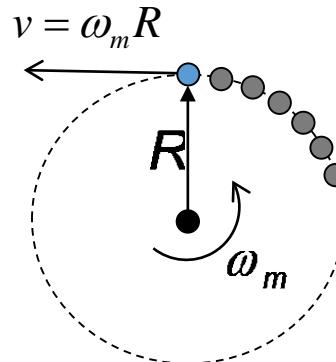
# Doppler VOR

Suppose we have an antenna that transmits at the carrier frequency,  $f$ , and rotates  $f_m$  rotations per second.



Signal received at this time instance has frequency:

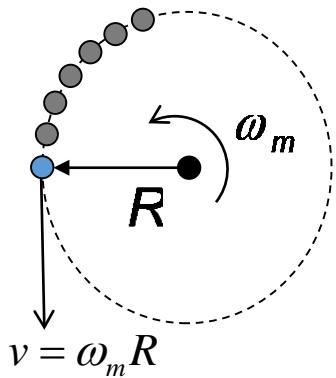
$$f + \Delta f$$
$$\Delta f = \frac{v}{c} f_{sc}$$



Signal received at this time instance has frequency:

$$f + \Delta f$$

$\Delta f = 0$  because  $v$  is perpendicular to line - of - sight



# Doppler VOR

BUT, at the same time the received frequency for Receiver B:

In other words, the signal at receiver B lags  $\theta = 90^\circ$  behind receiver A.

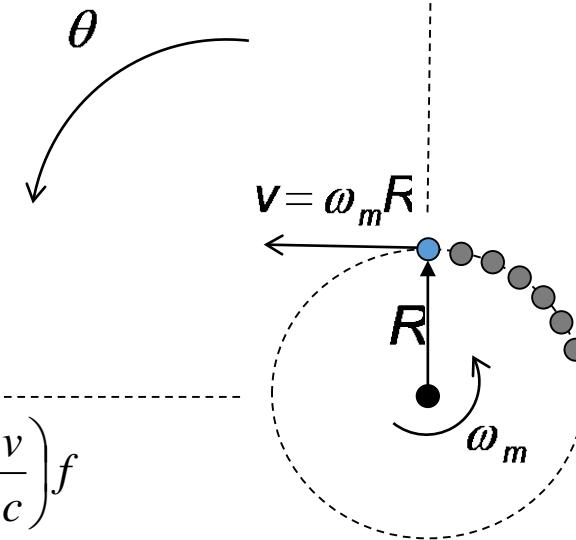
Receiver A

Signal received at this time instance has frequency:

$$\left(1 + \frac{v}{c}\right)f$$

Receiver B  $f$

$\Delta f = 0$  because  $v$  is perpendicular to line-of-sight



# Doppler VOR

- Central antenna transmits the reference signal:

$$[1 + 0.3 \cos(\omega_m t)] \cos(\omega_c t)$$

- Frequency of received signal (non-moving user):

$$f_r = f_c$$

- “Rotating” antenna transmits:

$$0.3 \cos([\omega_c + \omega_{sc}] t)$$

- On the receiving end due to Doppler (“rotating antenna”):

$$0.3 \cos\left([\omega_c + \omega_{sc}] t \pm \frac{v}{c} [\omega_c + \omega_{sc}] \sin(\omega_m t + \theta)\right)$$



$$\Delta f = \frac{v}{c} [f_c + f_{sc}] \Rightarrow 480 \text{ Hz} = \frac{v}{3 \cdot 10^8} [f_c + f_{sc}]$$

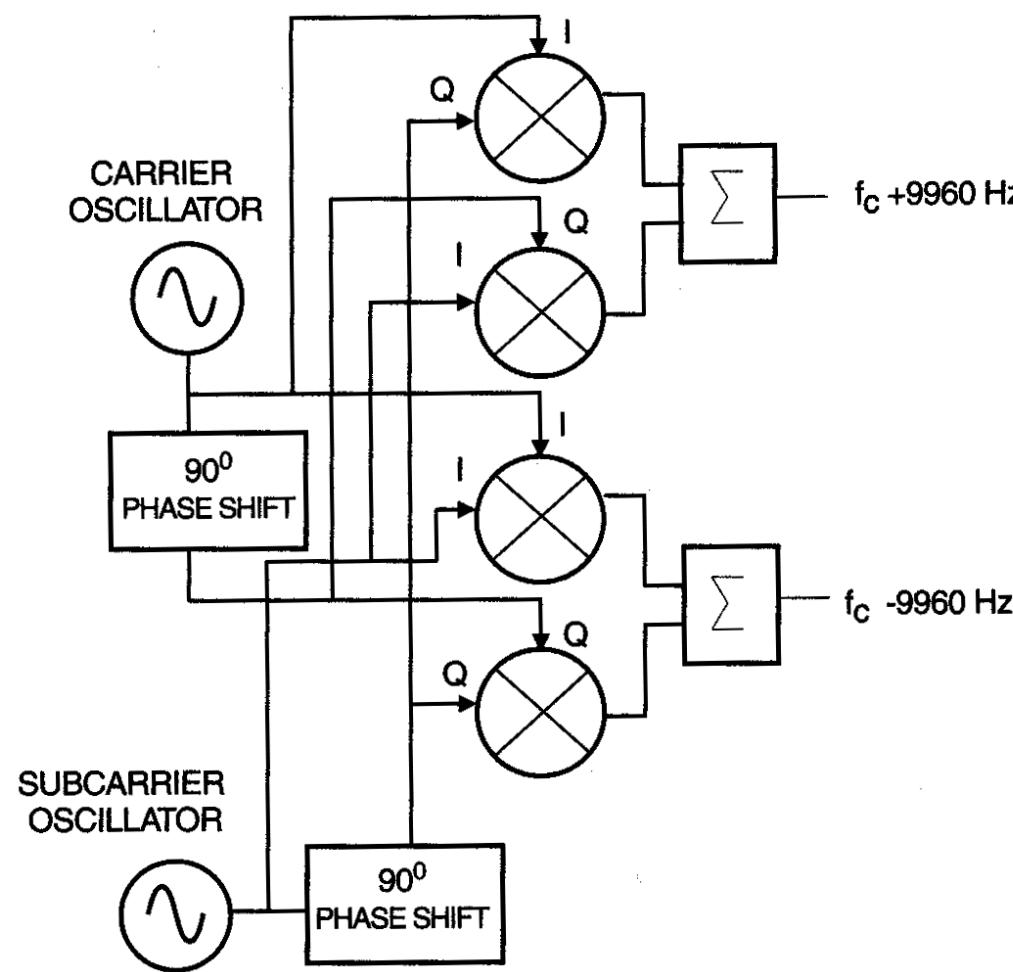
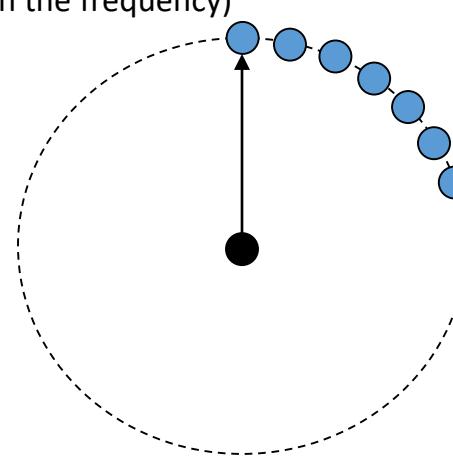


Figure 2.13 Method for generating signals for the Doppler VOR

# Doppler VOR

- The phase comparator in the VOR receiver doesn't know which signal is the reference phase signal and which signal is the variable phase signal
  - VOR can switch the reference and variable phases.
- To code the Doppler in space, need to “swing” the antenna around!
  - 30 rotations per second
  - Maximum velocity:  $v = \omega_m R = 2\pi(30)R = 188.5R$
  - Need a frequency shift of:
$$\Delta f = (v/c)f_c \Rightarrow v = \frac{c\Delta f}{f_c} = \frac{(3 \cdot 10^8)(480)}{108 \cdot 10^6} = 1333 \text{ m/s}$$
  - Radius =  $1333/188.5 = 7 \text{ m}$
$$R = 1333/188.5 = 7m$$
  - Use 52 fixed antennas with a 7-m radius (exact radius depends on the frequency)
  - Turn on one antenna at the time to make it look like a rotating antenna
  - Used when possible multipath is large
    - Reduced by a factor of 10
  - Use it when multipath errors are too large (multipath error reduced by a factor of 10)









# TACAN

Tactical Air Navigation



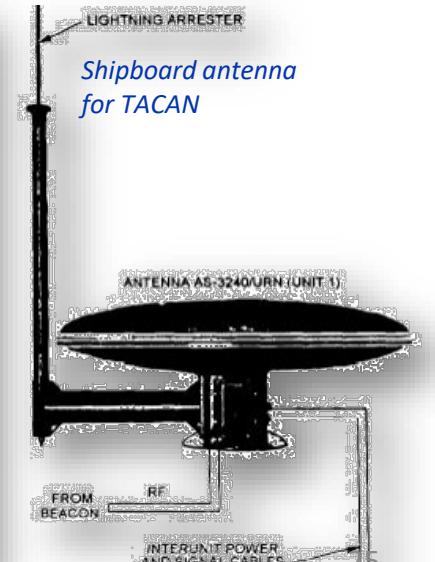
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# Tactical Air Navigation System (TACAN)

- More accurate version of VOR/DME system (provides bearing and range information for civil aviation).
- VORTAC facilities combine VOR and TACAN and use TACAN's DME portion for civil use.



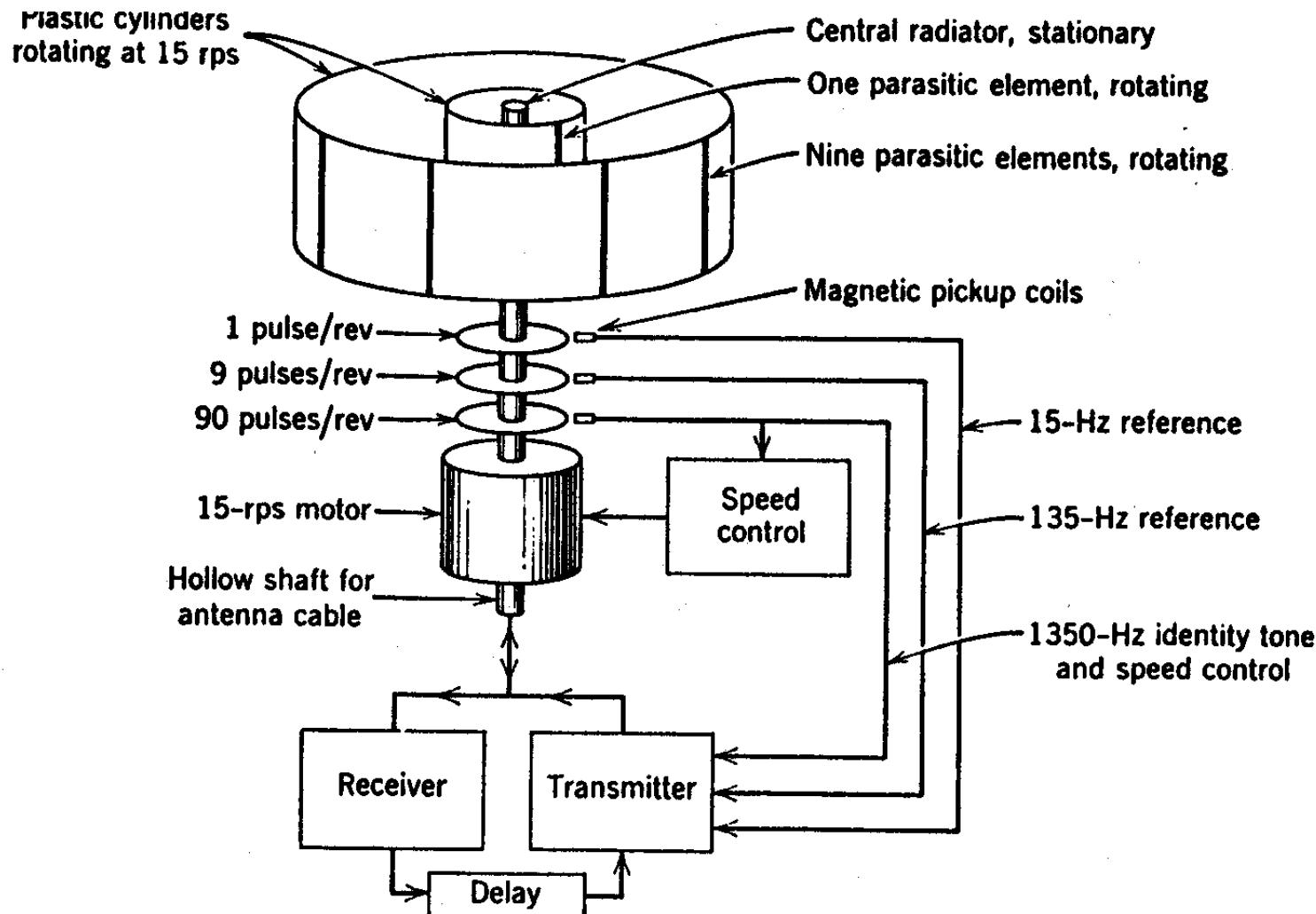
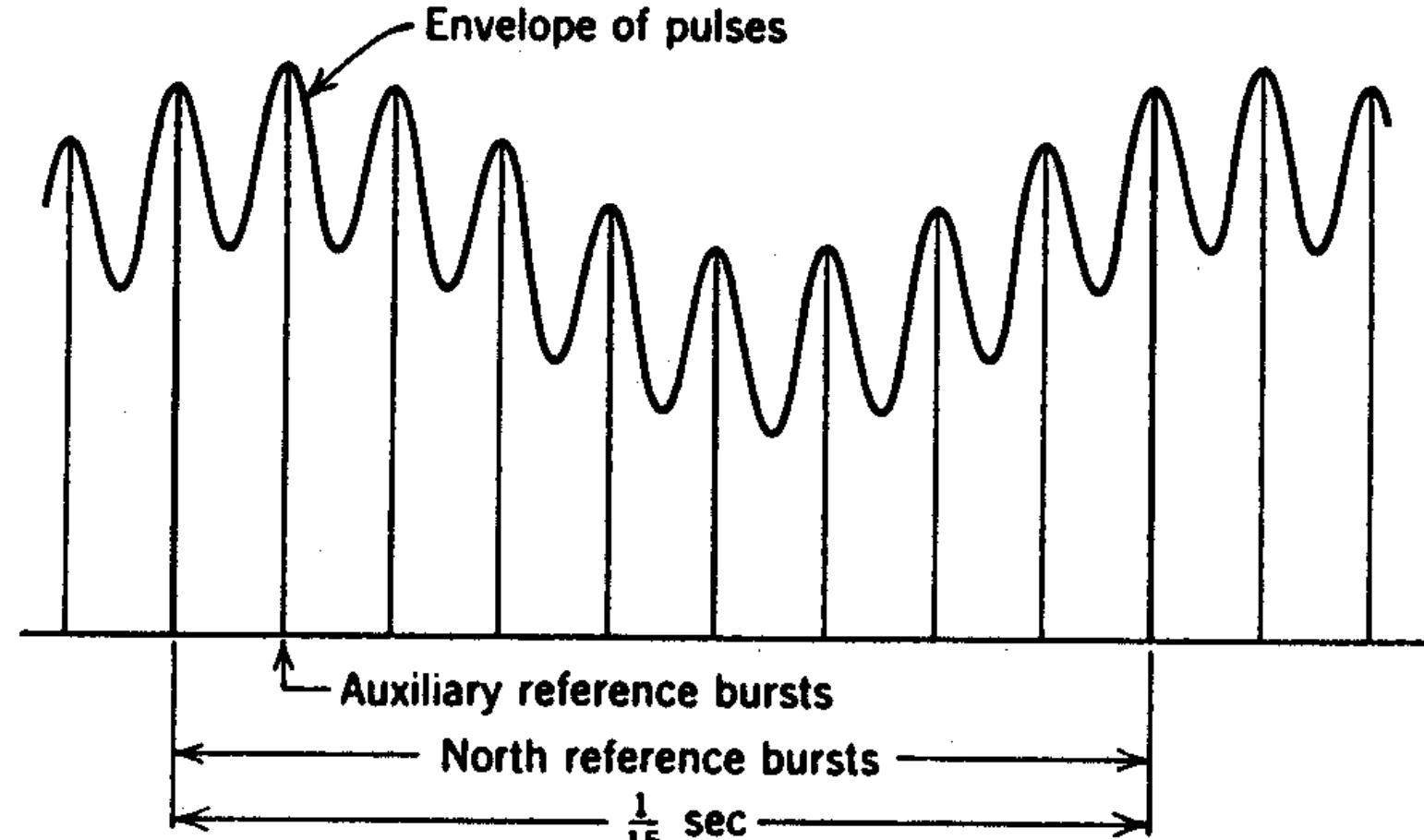


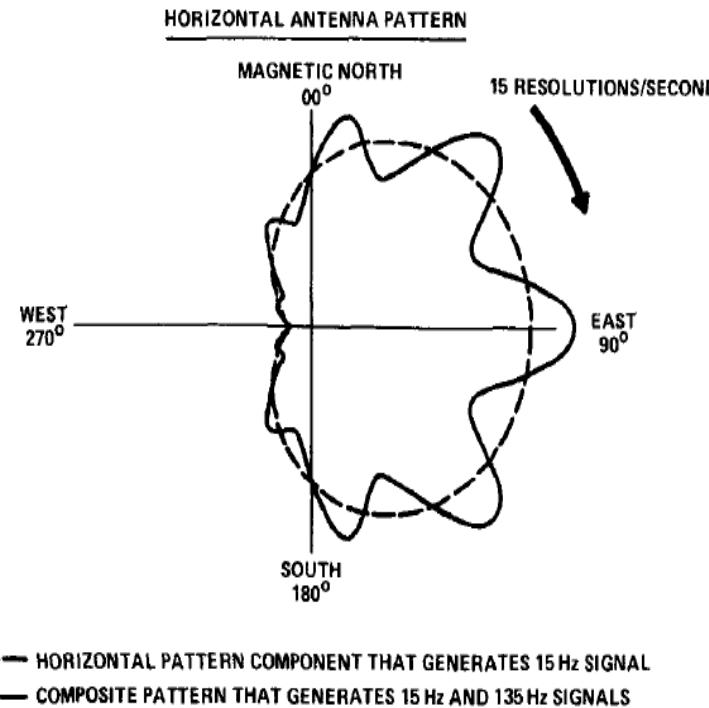
Figure 4.21 Tacan ground beacon.



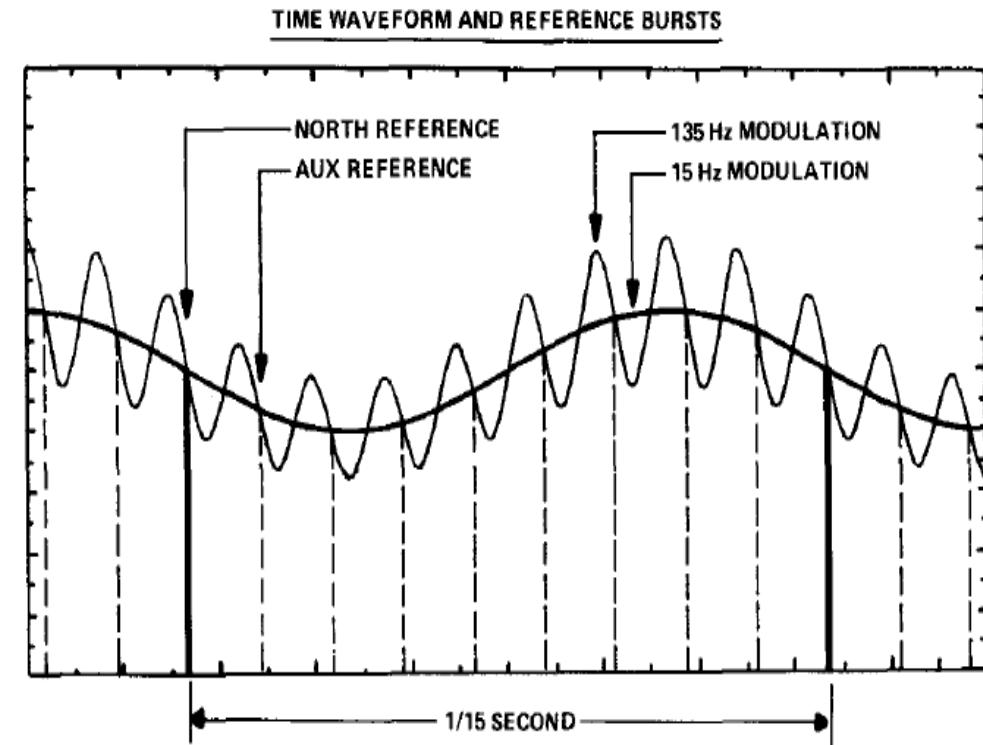
Spaces between reference bursts filled with  
2700 random DME replies per second

**Figure 4.22** Transmitted Tacan signal.

# Tactical Air Navigation System (TACAN)



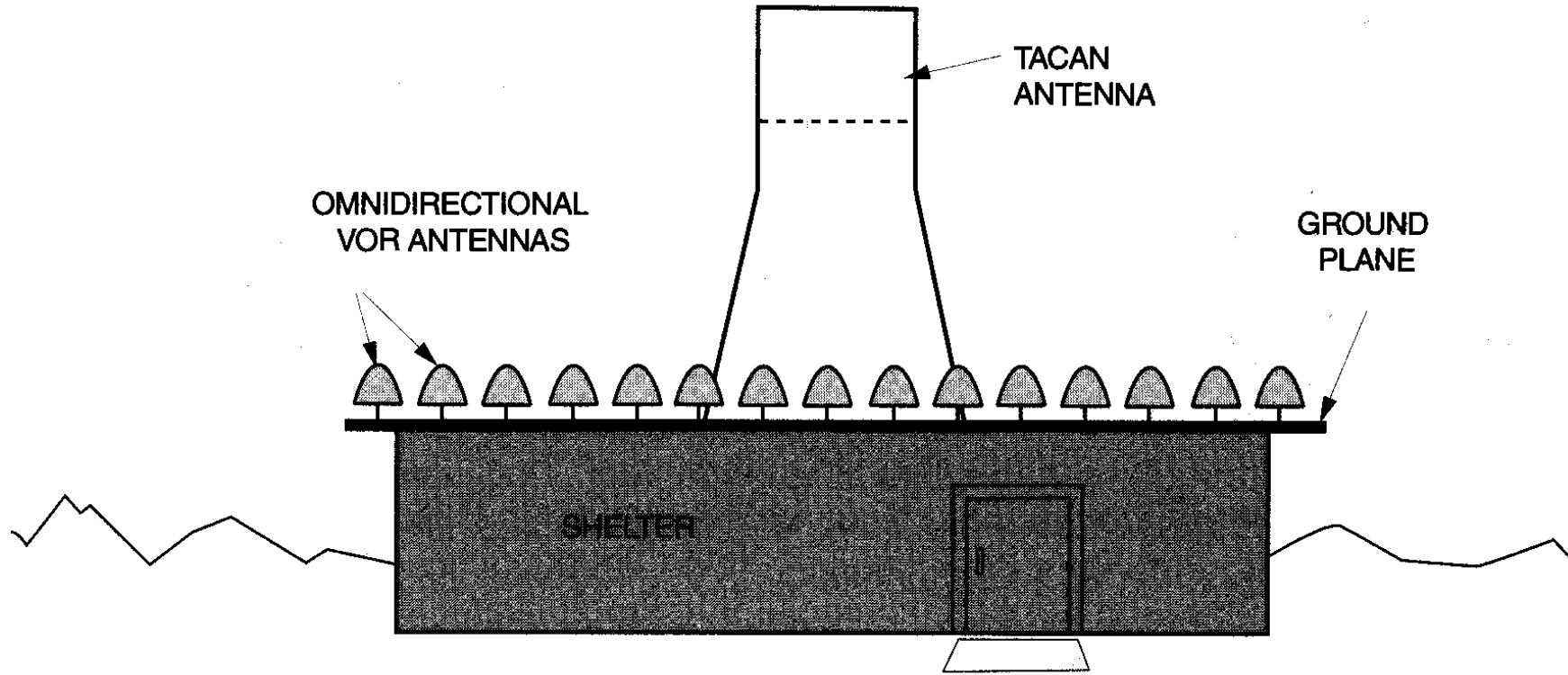
From [7] pp. 64



- ANTENNA PATTERN ORIENTATION SHOWN AT THE TIME OF NORTH REFERENCE BURST
- LET THE NORTH REFERENCE BURST DEFINE TIME 0.  
THE RECEIVED SIGNALS ARE THEN
 
$$15 \text{ Hz} : -\sin(30\pi t - \theta)$$

$$135 \text{ Hz} : -\sin(270\pi t - 9\theta)$$
 WHERE  $\theta$  IS THE BEARING FROM THE STATION.
- AUXILIARY REFERENCE BURSTS ARE TRANSMITTED EACH TIME A 135 Hz PATTERN PEAK POINTS EAST





*Figure 2.11. The Doppler VOR ground station*



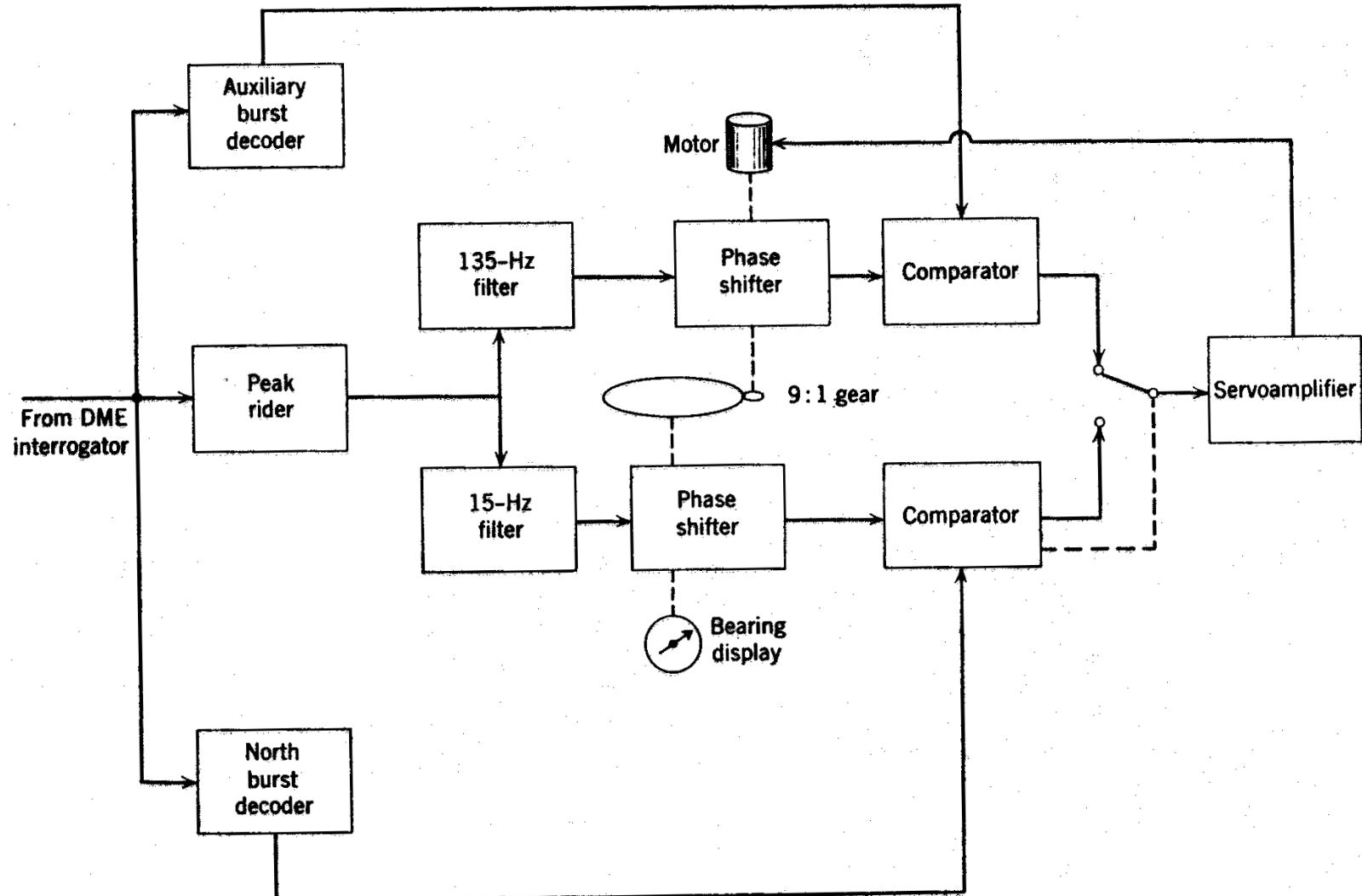


Figure 4.23 Airborne Tacan bearing circuit.

# Tema 5:

## ELS EQUIPS I ELS SISTEMES RADIOELÈCTRICS AEROPORTUARIS

Jordi Berenguer  
Novembre 2021



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# SISTEMES DE NAVEGACIÓ PER SATÈL·LIT

GNSS – Global Navigation Satellite Systems



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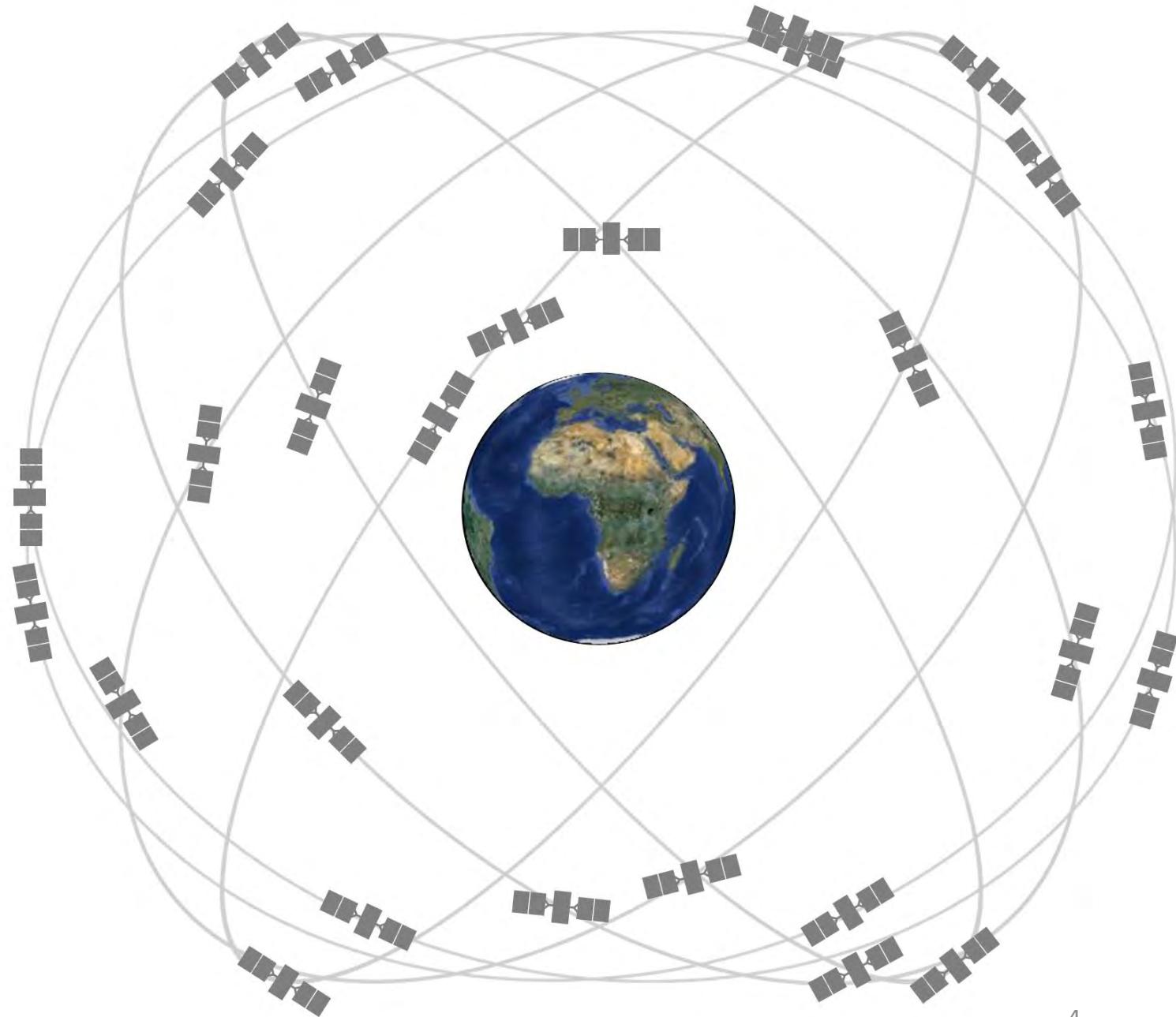
# GPS

GLOBAL POSITIONING SYSTEM



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# GPS CONSTELLATION

- GPS satellites fly in medium Earth orbit (MEO) at an altitude of approximately 20,200 km (12,550 miles). Each satellite circles the Earth twice a day.
- The satellites in the GPS constellation are arranged into six equally-spaced orbital planes surrounding the Earth. Each plane contains four "slots" occupied by baseline satellites. This 24-slot arrangement ensures users can view at least four satellites from virtually any point on the planet.
- The Air Force normally flies more than 24 GPS satellites to maintain coverage whenever the baseline satellites are serviced or decommissioned. The extra satellites may increase GPS performance but are not considered part of the core constellation.
- In June 2011, the Air Force successfully completed a GPS constellation expansion known as the "Expandable 24" configuration. Three of the 24 slots were expanded, and six satellites were repositioned, so that three of the extra satellites became part of the constellation baseline. As a result, GPS now effectively operates as a 27-slot constellation with improved coverage in most parts of the world

# Current and Future Satellite Generations.

The GPS constellation is a mix of old and new satellites. The following table summarizes features of the current and future generations of GPS satellites, including Block IIA (2nd generation, "Advanced"), Block IIR ("Replenishment"), Block IIR(M) ("Modernized"), Block IIF ("Follow-on"), and GPS III.

As of November 20, 2021, there were a total of **30 operational satellites** in the GPS constellation, not including the decommissioned, on-orbit spares.

LEGACY SATELLITES		MODERNIZED SATELLITES		
BLOCK IIA	BLOCK IIR	BLOCK IIR-M	BLOCK IIF	GPS III/IIIIF
0 operational	7 operational	7 operational	12 operational	4 operational
<ul style="list-style-type: none"> <li>▪ Coarse Acquisition (C/A) code on L1 frequency for civil users</li> <li>▪ Precise P(Y) code on L1 &amp; L2 frequencies for military users</li> <li>▪ 7.5-year design lifespan</li> <li>▪ Launched in 1990-1997</li> <li>▪ Last one decommissioned in 2019</li> </ul>	<ul style="list-style-type: none"> <li>▪ C/A code on L1</li> <li>▪ P(Y) code on L1 &amp; L2</li> <li>▪ On-board clock monitoring</li> <li>▪ 7.5-year design lifespan</li> <li>▪ Launched in 1997-2004</li> </ul>	<ul style="list-style-type: none"> <li>▪ All legacy signals</li> <li>▪ 2nd civil signal on L2 (L2C) <a href="#">LEARN MORE ➔</a></li> <li>▪ New military M code signals for enhanced jam resistance</li> <li>▪ Flexible power levels for military signals</li> <li>▪ 7.5-year design lifespan</li> <li>▪ Launched in 2005-2009</li> </ul>	<ul style="list-style-type: none"> <li>▪ All Block IIR-M signals</li> <li>▪ 3rd civil signal on L5 frequency (L5) <a href="#">LEARN MORE ➔</a></li> <li>▪ Advanced atomic clocks</li> <li>▪ Improved accuracy, signal strength, and quality</li> <li>▪ 12-year design lifespan</li> <li>▪ Launched in 2010-2016</li> </ul>	<ul style="list-style-type: none"> <li>▪ All Block IIF signals</li> <li>▪ 4th civil signal on L1 (L1C) <a href="#">LEARN MORE ➔</a></li> <li>▪ Enhanced signal reliability, accuracy, and integrity</li> <li>▪ No Selective Availability <a href="#">LEARN MORE ➔</a></li> <li>▪ 15-year design lifespan</li> <li>▪ IIIF: laser reflectors; search &amp; rescue payload</li> <li>▪ First launch in 2018</li> </ul>

SIS: Signal in Space



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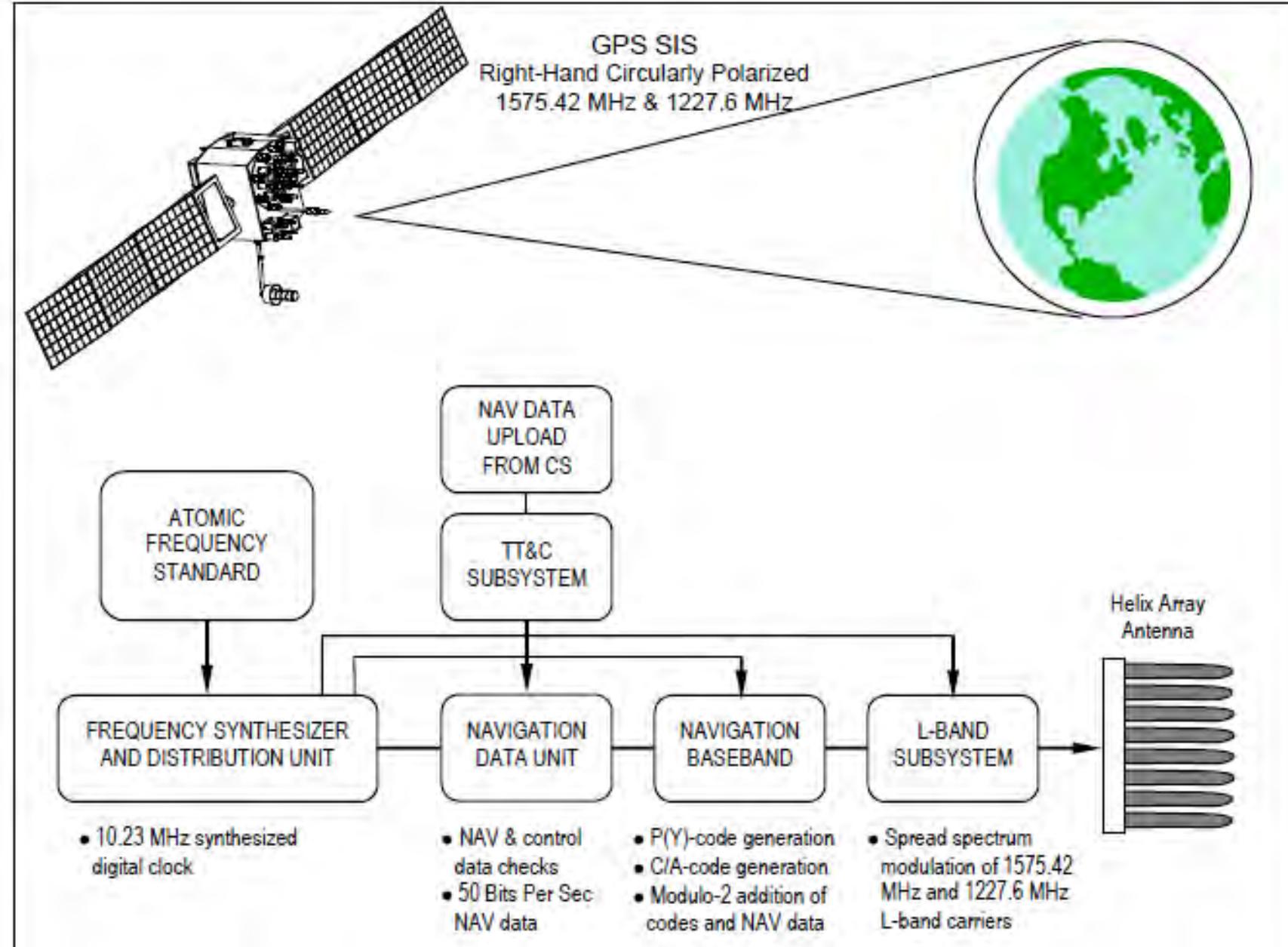


Figure 1.5-1. GPS SIS Generation and Transmission

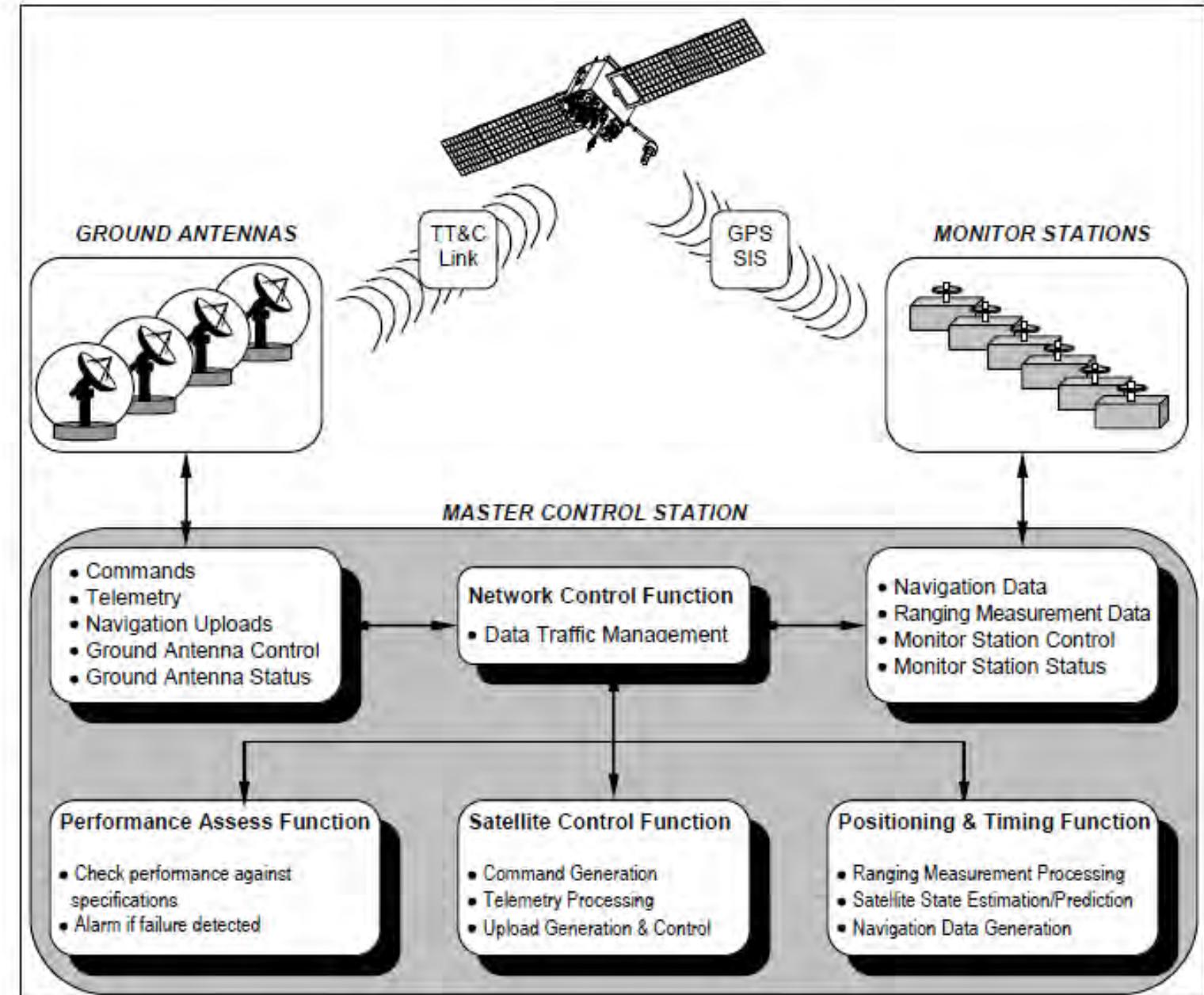


Figure 1.5-2. The GPS Operational Control System (OCS)

# Service Performances Standards for Standard Positioning Service (SPS)

GPS Performance Standard Metric		SPS User Performance	SPS Signal in Space Performance
Global Accuracy	All-in-View Horizontal 95%	<100 m	< 9 m
	All-in-View Vertical 95%	<156 m	< 15 m
Worst Site Accuracy	All-in-View Horizontal 95%	<100 m	< 17 m
	All-in-View Vertical 95%	<156 m	< 37 m
User Range Error (URE)		N/A	<7.8 m 95% of time
Time Transfer Accuracy		N/A	<40 ns 95% of time
Geometry (PDOP ≤ 6)	> 95.86% global		> 98% global
	> 83.9% worst site		> 88% worst site
Constellation Availability		N/A	>98% Probability of 21 Healthy Satellites

# Service Performances Standards for Precise Positioning Service (PPS)

GPS Performance Standard Metric	SPS User Performance	SPS Signal in Space Performance
Global Accuracy	All-in-View Horizontal 95%	< 36 m
	All-in-View Vertical 95%	< 77 m
User Range Error (URE)	N/A	<5.9 m 95% of time
Time Transfer Accuracy	N/A	<40 ns 95% of time
Integrity	N/A	< 1x10-5 Probability Over Any Hour
Geometry (PDOP ≤ 6)	>95.7% global	>98% global
Constellation Availability	N/A	>98% Probability of 21 Healthy Satellites

# PROGRAMES DE GNSS

UNIÓ EUROPEA



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# ORGANISMES DE GNSS DE LA UE

- **European GNSS Supervisory Authority (GSA)** <http://www.gsa.europa.eu/>
  - The European GNSS Supervisory Authority (GSA), is a Community Agency, officially took over responsibility from the former Galileo Joint Undertaking (GJU) on 1 January 2007. The Agency's first order of business: to establish a 20-year multi-billion Euro public-private partnership contract with a consortium whose task will be to implement the deployment and operations of the full Galileo system and commercialise its services.
  - Functions:
    - Manage the European satellite navigation programmes, control the use of the funds, and manage the related R&D activities.
    - Be the licensing authority vis-à-vis the private concession holder responsible for implementing and managing the Galileo deployment and operation phases and ensure that the concession holder complies with the contract;
    - Be responsible for matters related to the right to use the frequencies necessary for the operation of the systems, for the certification of their components, and for their safety and security;
    - Be the owner of all the tangible and intangible assets created or developed under the Galileo and EGNOS programmes.



# ORGANISMES DE GNSS DE LA UE

- **European Satellite Services Provider (ESSP)** <https://www.essp-sas.eu/>
  - ESSP SAS: founded in 2009 by the Air navigation services providers from France (DGAC/DSNA), Germany (DFS), Italy (ENAV), Portugal (NAV-P), Spain (Aena), Switzerland (skyguide) and UK (NATS) to act as service Provider for EGNOS.
  - On 12th of July of 2010, the French National Supervisory Authority (NSA) has delivered to the company ESSP SAS a certificate of Air Navigation Service Provider according to the Single European Sky Regulation 2096/2005. This certification is a prerequisite for ESSP to provide Navigation Services to airspace users.
  - The ESSP mission is the provision of the EGNOS Open Service (OS) and Safety of Life (SoL) Service compliant with ICAO SBAS standards and recommended practices throughout the European Civil Aviation Conference (ECAC) Region.
  - ESSP is also in charge of the provision of the [EDAS](#) Service (EGNOS Data Access Service).

# EGNOS

*European Geostationary Navigation Overlay Service*



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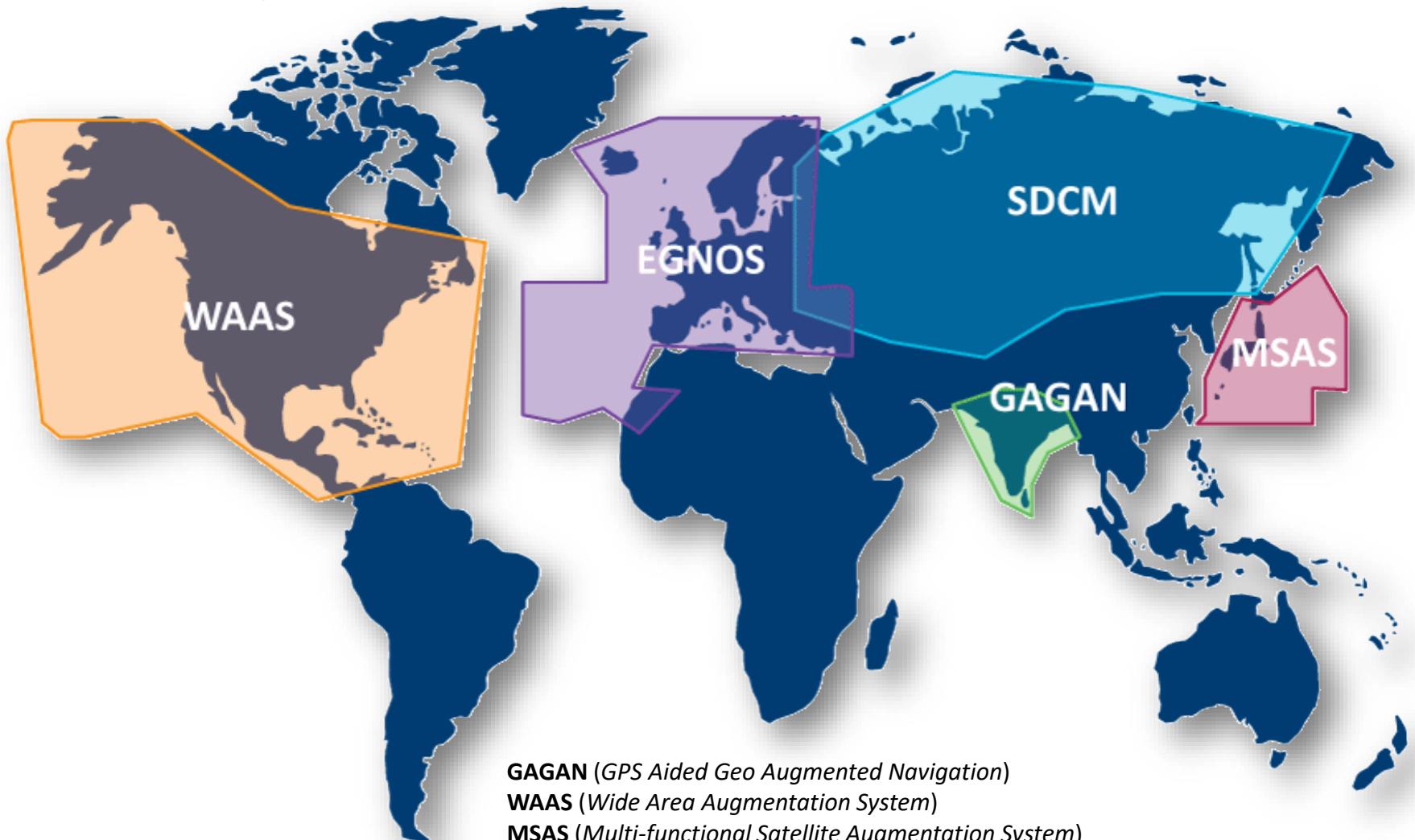
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# SBAS – Regional systems

EGNOS is part of a developing multimodal inter-regional **SBAS (Satellite Based Augmentation System)** service, able to support a wide spectrum of applications, such as aviation.

Similar SBAS systems, have already been commissioned by the US (**Wide Area Augmentation System – WAAS**), Japan (**MTSAT Satellite based Augmentation System – MSAS**) and India (**GPS Aided GEO Augmented Navigation – GAGAN**).

Analogous systems are under commissioning or deployment in other regions of the world (e.g. **System of Differential Correction and Monitoring – SDCM in Russia**) or under investigation (e.g. **Korea Augmentation Satellite System – KASS in South Korea**).

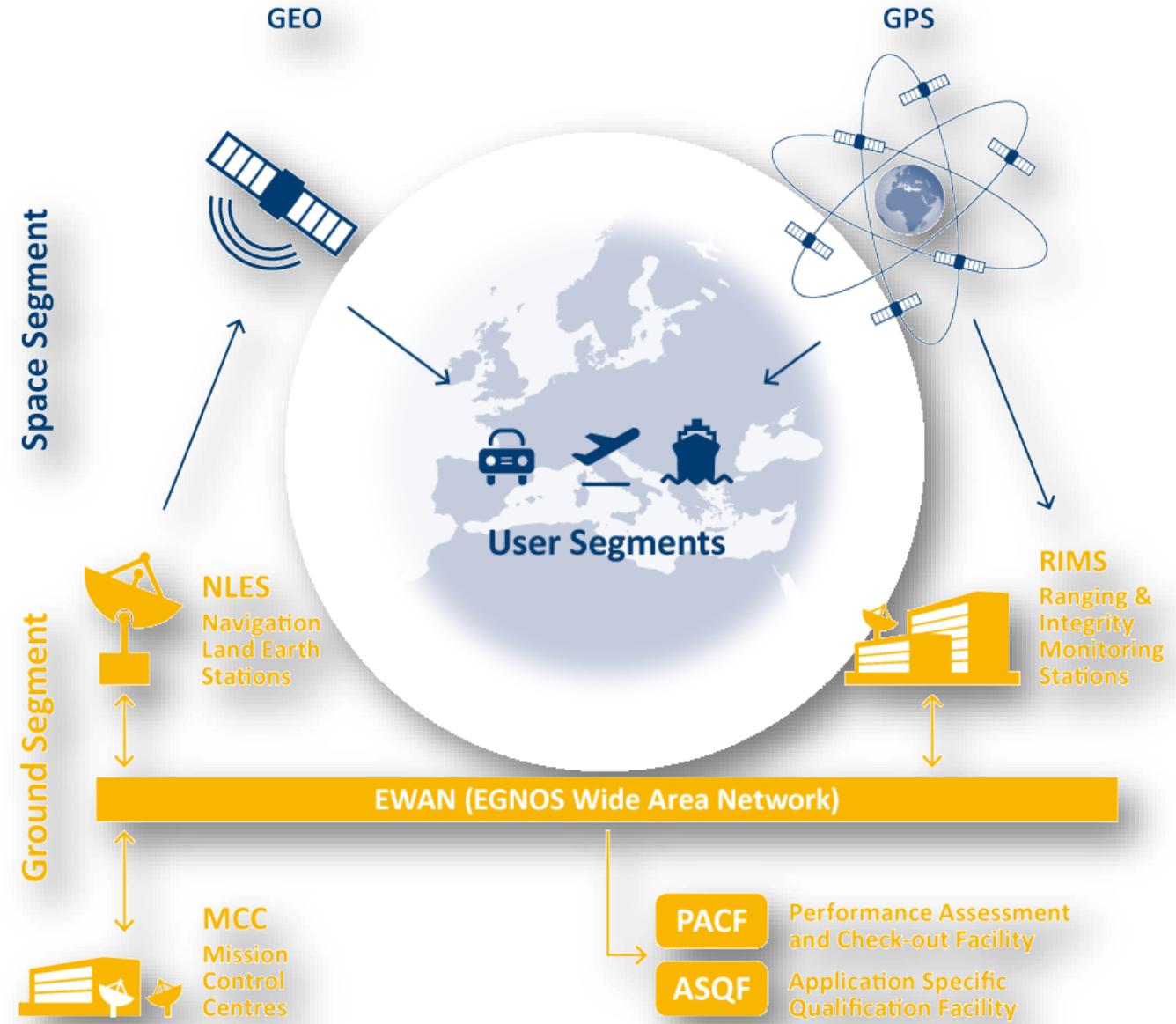


**GAGAN (GPS Aided Geo Augmented Navigation)**  
**WAAS (Wide Area Augmentation System)**  
**MSAS (Multi-functional Satellite Augmentation System)**  
**EGNOS (European Geostationary Navigation Overlay Service)**  
**SDCM (System for Differential Corrections and Monitoring)**

# SBAS - Interoperability

- Although all **Satellite-Based Augmentation Systems (SBAS)** are regional systems, it is important to ensure that they are compatible and that SBAS providers cooperate with each other and coordinate their actions.
- Compatibility will make each system more effective and ensure that all the systems can be integrated into a seamless worldwide navigation system. SBAS cooperation is currently coordinated through the Interoperability Working Groups EGNOS/MSAS and EGNOS/WAAS. Interoperability tests are regularly organised. At present, SBAS are being, or have been, developed to cover the following areas:
  - **Europe**
    - The European Tripartite Group, composed of ESA, the European Union and Eurocontrol, has developed EGNOS, the European Geostationary Navigation Overlay Service. EGNOS covers the European Civil Aviation Conference (ECAC) region.
  - **United States**
    - The United States Federal Aviation Administration leads the development of the Wide Area Augmentation System (WAAS). This covers the United States and Canada.
  - **Japan**
    - The Japanese Civil Aviation Bureau is implementing the MTSAT Satellite-Based Augmentation System (MSAS), which will cover the Flight Instrument Rules region of Japan.
  - **India**
    - The Indian Space Research Organization (ISRO) along with the Airport Authority of India (AAI) has worked on a joint programme to implement GAGAN, a Satellite Based Augmentation System using GPS/GLONASS over Indian airspace.

# EGNOS System



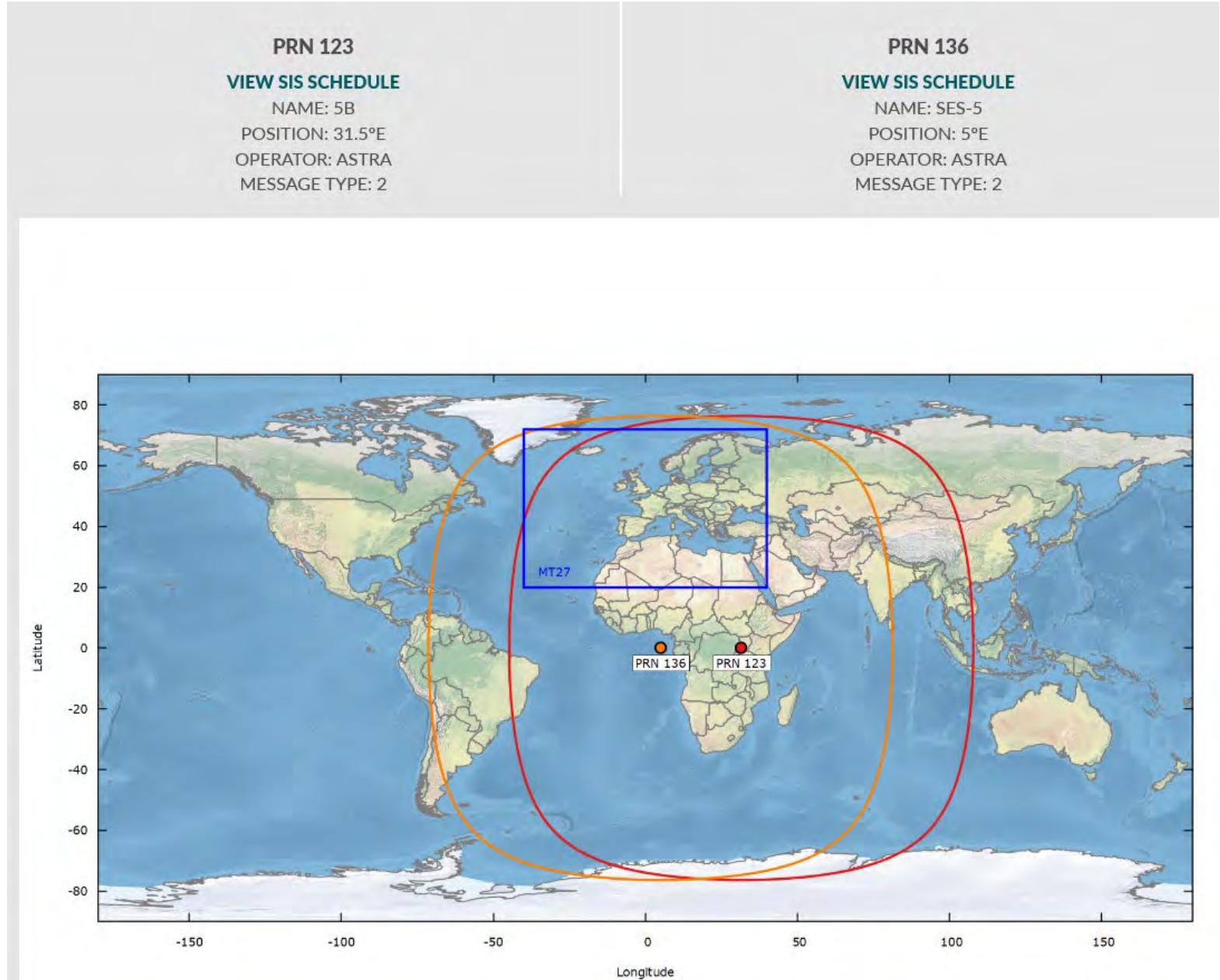
# EGNOS system

- EGNOS provides the information needed to use navigational signals from GPS satellites for such safety critical applications. It improves the accuracy of position measurements **from about five metres to less than two metres**, informs users of the errors in the position measurements and warns of disruption to a satellite signal within six seconds.
- **Three geostationary satellites** and a complex network of ground stations carry out this task. The three satellites send out a ranging signal similar to those transmitted by the GPS satellites. However, these signals are more than another opportunity for users to fix a position. **They also provide information about the accuracy of position measurements delivered by GPS** so that a pilot, for example, can assess whether the position is accurate enough to rely on.
- This information, or integrity data, is modulated onto the ranging signal. It includes accurate information on the position of each GPS satellite, the accuracy of the atomic clocks on board the satellites **and information on disturbances within the ionosphere that might affect the accuracy** of positioning measurements. The EGNOS receiver, decodes the signal to give a more accurate position than is possible with GPS alone, and an accurate estimate of errors.
- **The EGNOS signal is transmitted by three geostationary satellites:** two Inmarsat-3 satellites, one over the eastern part of the Atlantic, the other over the Indian Ocean, and the ESA Artemis satellite above Africa. Unlike the GPS satellites, these three do not have signal generators on board. A transponder transmits signals up-linked to the satellites from the ground, where all the signal processing takes place. The sophisticated ground segment consists of **34 Ranging and Integrity Monitoring Stations (RIMS), four master control centres and six up-link stations**.
- The RIMS measure the positions of each EGNOS satellite and compare accurate measurements of the positions of each GPS satellite with measurements obtained from the satellites' signals. The RIMS then send this data to the master control centres, via a purpose built communications network.
- The master control centres determine the accuracy of GPS and GLONASS signals received at each station and determine position inaccuracies due to disturbances in the ionosphere. All the deviation data is then incorporated into a signal and sent via the secure communications link to the up-link stations, which are widely spread across Europe. The up-link stations send the signal to the three EGNOS satellites, which then transmit it for reception by GPS users with an EGNOS enabled receiver.
- **Considerable redundancy is built into EGNOS** so that **the service can be guaranteed at practically all times**. At any one time, only one master control centre will be 'the master', with another on stand-by to take over instantaneously should the first one fail. There is redundancy in the up-link stations, too. Only three are needed to operate EGNOS, one for each satellite. The other three are in reserve in case of failure.

# EGNOS: Functional segments

- **Ground segment:** comprises a network of **39 Ranging Integrity Monitoring Stations (RIMS)**, **2 Mission Control Centres (MCC)**, **2 Navigation Land Earth Stations (NLES) per GEO**, and the **EGNOS Wide Area Network (EWAN)**, which provides the communication network for all the components of the ground segment.
  - **39 RIMS:** the main function of the RIMS is to collect measurements from GPS satellites and to transmit these raw data every second to the Central Processing Facilities (CPF) of each MCC. The configuration used for the initial EGNOS OS includes 40 RIMS sites located over a wide geographical area.
  - **2 MCC (control and processing centres):** these receive the information from the RIMS and generate correction messages to improve satellite signal accuracy and information messages on the status of the satellites (integrity). The MCC act as the EGNOS system's 'brain'.
  - **2 NLES per GEO:** the NLES transmit the EGNOS message received from the central processing facility to the GEO satellites for broadcasting to users and to ensure synchronisation with the GPS signal.
- **Support segment:** In addition to the above-mentioned stations/centres, the system has other ground support installations involved in system operations planning and performance assessment, namely the **Performance Assessment and Checkout Facility (PACF)** and the **Application Specific Qualification Facility (ASQF)** which are operated by the EGNOS Service Provider (ESSP).
  - **PACF (Performance Assessment and Check-out Facility):** provides support to EGNOS management in the form of performance analysis, troubleshooting, and operational procedures as well upgrading specifications and validations and providing maintenance support.
  - **ASQF (Application Specific Qualification Facility):** provides civil aviation and aeronautical certification authorities with the tools to qualify, validate and certify the different EGNOS applications.
- **Space Segment:** composed of at least **three geostationary satellites** broadcasting corrections and integrity information for GPS satellites in the L1 frequency band (1575.42 MHz). This space segment configuration provides a high level of redundancy over the whole service area in the event of a failure in the geostationary satellite link. EGNOS operations are handled in such a way that, at any point in time, at least two GEOS broadcast an operational signal.
- **User Segment:** the EGNOS user segment is comprised of EGNOS receivers that enable their users to accurately compute their positions with integrity. To receive EGNOS signals, the end user must use an EGNOS-compatible receiver. Currently, EGNOS compatible receivers are available for such market segments as agriculture, aviation, maritime, rail, mapping/surveying, road and location based services (LBS).

## Space Segment



# EGNOS performance explained

EGNOS provides enhanced performances over GPS according to four parameters: accuracy, availability, continuity and integrity. Although the concept of position accuracy is easy to understand, the other three notions are frequently misunderstood. They are defined as follows by the system requirements:

- **Integrity**

- Integrity relates to the trust which can be placed in the correctness of the information supplied by the Navigation System, it includes the ability of the system to provide timely warnings to the user when the system or data provided by the system should not be used for navigation.

- **Continuity**

- Continuity of Navigation service is defined as the probability that the accuracy and integrity requirements will be supported by the Navigation System throughout a flight operation or flight hour given that they are supported at the beginning of the flight phase and that the flight operation is initiated and predicated to be supported all along the flight phase. Satellite outages predicted at least 48 hours in advance of the outage do not contribute to a loss of continuity.

- **Availability**

- Availability of the Navigation Service is the probability that the Positioning service and the Integrity monitoring service are available and provide the required accuracy, integrity and continuity performances. Availability is computed, at any point within the service volume, as the percentage of the time during which the service is available over the lifetime of the system, taking into account all the outages whatever their origins. The service will be declared available when accuracy, integrity and continuity requirements are estimated to be met.

# EGNOS - Safety of Life (SoL)

- **The EGNOS Safety of Life (SoL) Service** provides the most stringent level of signal-in-space performance to all Safety of Life user communities.
- The main objective of the SoL service, which has been available since March, 2nd 2011, is to support civil aviation operations down to **LPV (Localiser Performance with Vertical guidance)** minima.
- To provide the SoL Service, the EGNOS system has been designed so that **the EGNOS Signal-In-Space (SIS) complies with the International Civil Aviation Organisation (ICAO) Standards and Recommended Practices for SBAS**.
- The SoL service is based on integrity data provided through the EGNOS satellite signals, it is provided openly and is **freely accessible without any direct charge**.
- The EGNOS SoL Service consists of an augmentation signal to the Global Positioning System (GPS) Standard Positioning Service (SPS) for positioning and an additional timing signal intended for a wide range of applications in different domains.

# EGNOS (SoL)

## Safety of Life service performance requirements (ICAO)

EGNOS Safety of Life (SoL)  
 Service Definition Document  
 Issue 3.4  
[https://egnos-user-support.esspsas.eu/new\\_egnos\\_ops/sites/default/files/documents/egnos\\_sol\\_sdd\\_in\\_force.pdf](https://egnos-user-support.esspsas.eu/new_egnos_ops/sites/default/files/documents/egnos_sol_sdd_in_force.pdf)

	Accuracy		Integrity				Continuity	Availability
Typical operation	Horizontal Accuracy 95%	Vertical Accuracy 95%	Integrity	Time-To-Alert (TTA)	Horizontal Alert Limit (HAL)	Vertical Alert Limit (VAL)		
En-route (oceanic/continental low density)	3.7 km (2.0 NM)	N/A	1 – 1x10 <sup>-7</sup> /h	5 min	7.4 km (4 NM)	N/A	1 – 1x10 <sup>-4</sup> /h to 1 – 1x10 <sup>-8</sup> /h	0.99 to 0.99999
En-route (continental)					3.7 km (2 NM)	N/A		
En-route, Terminal	0.74 km (0.4 NM)	N/A	1 – 1x10 <sup>-7</sup> /h	15 s	1.85 km (1 NM)	N/A	1 – 1x10 <sup>-4</sup> /h to 1 – 1x10 <sup>-8</sup> /h	0.99 to 0.99999
Initial approach, Intermediate approach, Non-precision approach (NPA), Departure	220 m (720 ft)	N/A	1 – 1x10 <sup>-7</sup> /h	10 s	556 m (0.3 NM)	N/A	1 – 1x10 <sup>-4</sup> /h to 1 – 1x10 <sup>-8</sup> /h	0.99 to 0.99999
Approach operations with vertical guidance (APV-I)	16.0 m (52 ft)	20 m (66 ft)	1 – 2x10 <sup>-7</sup> in any approach	10 s	40 m (130 ft)	50 m (164 ft)	1 – 8x10 <sup>-6</sup> per 15 s	0.99 to 0.99999
Category I precision approach	16.0 m (52 ft)	6.0 m to 4.0 m (20 ft to 13 ft)	1 – 2x10 <sup>-7</sup> in any approach	6 s	40 m (130 ft)	35.0 m to 10.0 m (115 ft to 33ft)	1 – 8x10 <sup>-6</sup> per 15 s	0.99 to 0.99999

# EGNOS (SoL) Safety of Life

**NPA** Non-Precision Approach

**LPV** Localizer Performance with Vertical guidance

**APV** APproach with Vertical guidance

EGNOS Safety of Life (SoL)  
Service Definition Document

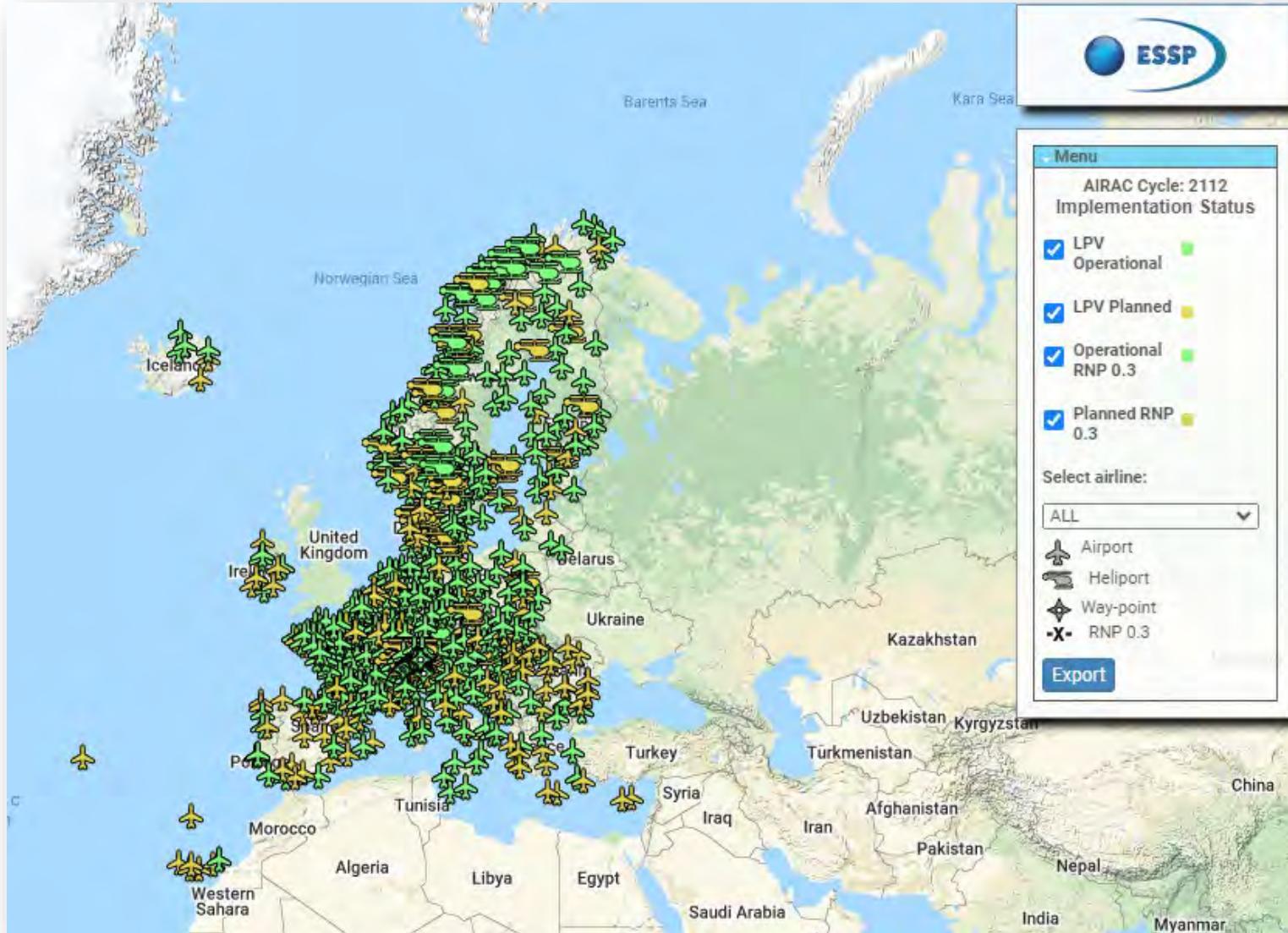
Issue 3.4

[https://egnos-user-support.essp-sas.eu/new\\_egnos\\_ops/sites/default/files/documents/egnos\\_sol\\_sdd\\_in\\_force.pdf](https://egnos-user-support.essp-sas.eu/new_egnos_ops/sites/default/files/documents/egnos_sol_sdd_in_force.pdf)

	Performance	NPA	Accuracy		Integrity		Continuity	Availability			
			Horizontal Accuracy 95%	Vertical Accuracy 95%	Integrity	Time-To-Alert (TTA)					
<b>Comment</b>	<b>APV-I &amp; LPV200<sup>18</sup></b>		220 m	N/A	1 – 1x10 <sup>-7</sup> /h	Less than 6 seconds	<1 – 1x10 <sup>-3</sup> per hour in most of ECAC <1 – 2.5x10 <sup>-3</sup> per hour in other areas of ECAC	0.999 in all ECAC			
			3 m <sup>19</sup>	4 m <sup>19</sup>	1 – 2x10 <sup>-7</sup> / approach						
		Accuracy values at given locations are available at: <a href="https://egnos-user-support.essp-sas.eu/new_egnos_ops/">https://egnos-user-support.essp-sas.eu/new_egnos_ops/</a>				See sections 6.3.1.3, 6.3.2.4 and 6.3.3.4 for detailed availability maps					
		For LPV-200 new accuracy requirements imposed by ICAO Annex 10 ([RD-1]) see section 6.3.3.2		N/A		See sections 6.3.1.4, 6.3.2.5 and 6.3.3.5 for detailed continuity maps					



Implantació de l'EGNOS en aeroports:  
[https://egnos-user-support.essp-sas.eu/new\\_egnos\\_ops/content/lpv-procedures-map](https://egnos-user-support.essp-sas.eu/new_egnos_ops/content/lpv-procedures-map)



# First EGNOS LPV-200 approach implemented at Charles de Gaulle Airport

12/05/2016

The European GNSS Agency (GSA) announces that the first LPV-200 approaches were implemented at Paris Charles de Gaulle Airport (LFPG) on 3 May – the first such approaches to be implemented in Europe.

The GSA announces that the first LPV-200 approaches were implemented at Paris Charles de Gaulle Airport (LFPG) on 3 May – the first such approaches to be implemented in Europe. LPV-200 enables aircraft approach procedures that are operationally equivalent to CAT I instrument landing system (ILS) procedures. This allows for lateral and angular vertical guidance during the final approach segment (FAS) without requiring visual contact with the ground until reaching a decision height (DH) of only 200 feet above the runway. (The minima for localiser performance with vertical guidance, or LPV, are as low as 200 feet.)

These EGNOS (European Geostationary Navigation Overlay Service)-based approaches are considered ILS look-alikes, as the LPV-200 service level is compliant with International Civil Aviation Organisation (ICAO) Annex 10 Category I precision approach performance requirements, but without the need for the expensive ground infrastructure required for ILS.

“EGNOS LPV-200 is now the most cost-effective and safest solution for airports requiring CAT I approach procedures,” says GSA Executive Director Carlo des Dorides. “The involvement of major aircraft manufacturers confirms that this service is a real added-value for civil aviation, setting the basis for a better rationalisation of nav-aids in European airports.”

The announcement of the approach implementation follows the publication of the EGNOS-based procedures on 28 April.

# EGNOS

- <http://www.gsa.europa.eu/egnos-aviation-lpv-200-lands-europe>
- <http://www.egnos-portal.eu/aviation-sector>

# GALILEO



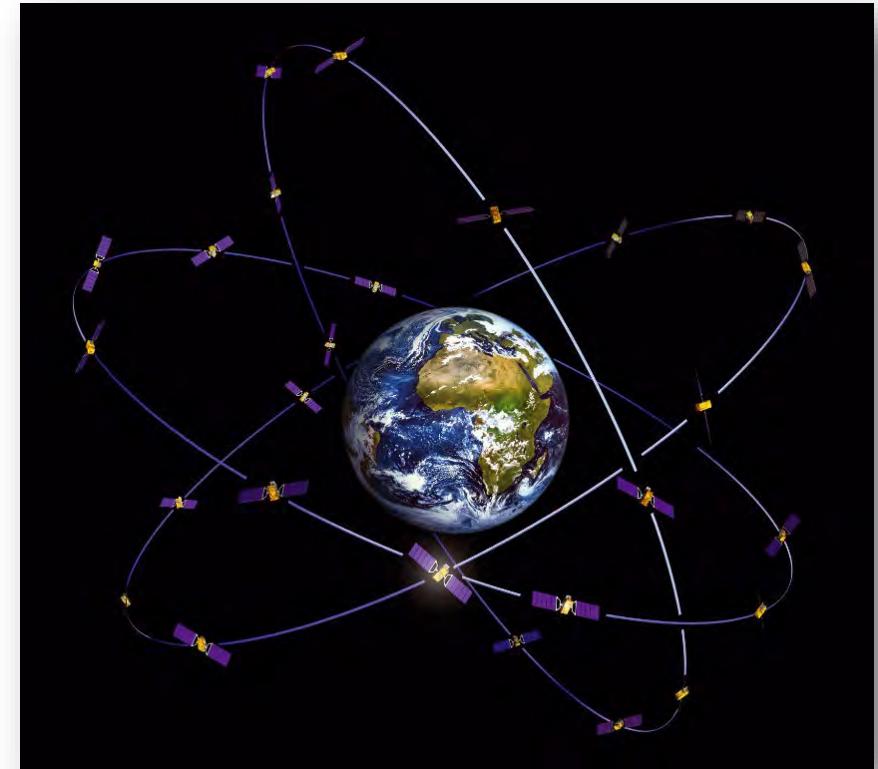
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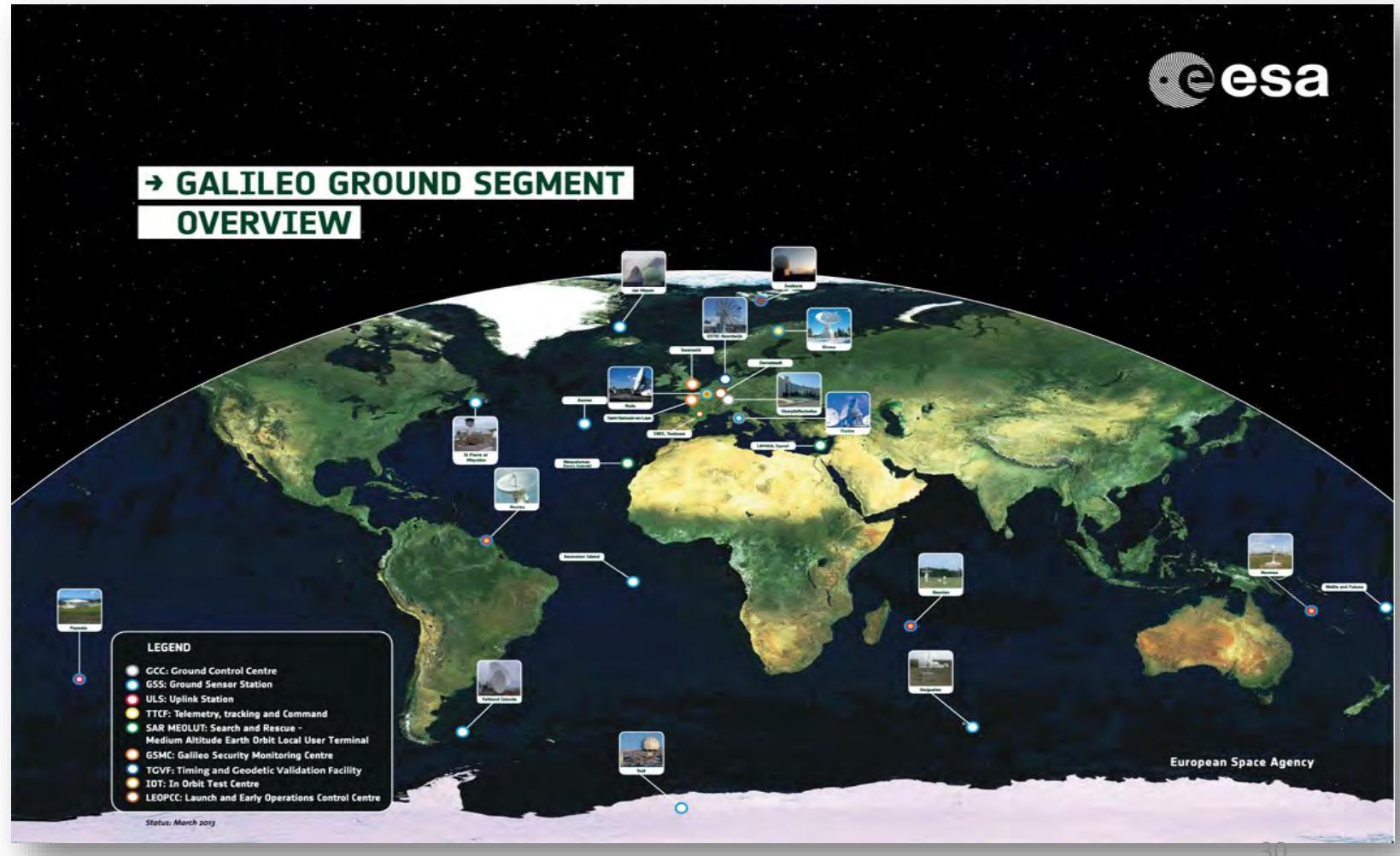
# GALILEO NAVIGATION SYSTEM

- Galileo is Europe's programme for a global navigation satellite system, providing a highly accurate, guaranteed global positioning service, **interoperable** with the US **GPS** and Russian **Glonass** systems.
- Galileo's modern and efficient design will increase Europe's technological independence, and help to set international standards for Global Navigation Satellite Systems (GNSS).
- Galileo is developed in collaboration between the European Union and the European Space Agency (ESA).
- The fully deployed Galileo system will consist of 24 operational satellites plus six in-orbit spares, positioned in three circular Medium Earth Orbit (MEO) planes at 23 222 km altitude above the Earth, and at an inclination of the orbital planes of 56 degrees to the equator.
- One satellite in each plane will be a spare; on stand-by should any operational satellite fail.
- With the satellites taking about **14 hours to orbit Earth**, there will always be at least **four satellites visible anywhere** in the world.



# GALILEO NAVIGATION SYSTEM

- Galileo also depends on an extensive ground infrastructure, which will have to make sure that time and positioning data are extremely accurate – a single billionth of a second clock error means a positioning error up to a range of 30 cm.
- This ground infrastructure includes sensor stations worldwide, two control centres, Mission Uplink stations, and Telemetry, Tracking and Command (TT&C) stations.



## Galileo Sites and Ground Stations

- HQ: Headquarters
- GCC: Galileo Control Centre
- GSMC: Galileo Security Monitoring Centre
- SGSC: SAR/Galileo Service Centre
- GSC: GNSS Service Centre
- GRC: Galileo Reference Centre
- GILSC: Galileo Integrated Logistic Support Centre
- TTCF: Telemetry, Tracking and Command
- ULS: Uplink Station
- GSS: Ground Sensor Station
- MEOLUT: Medium Altitude Earth Orbit Local User Terminal
- REFBE: Galileo/SAR Reference Beacons
- IOT: In-Orbit Testing station

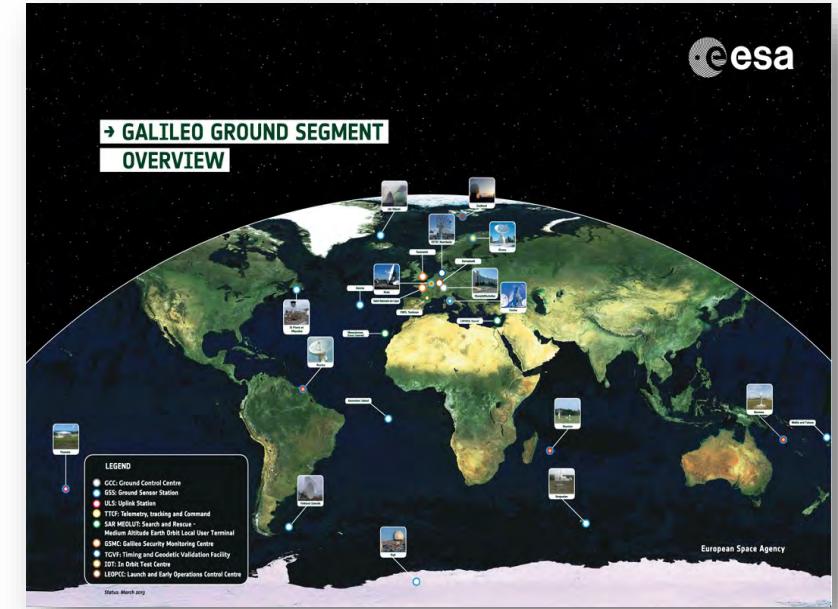


Galileo Sites and Ground Stations status as of September 2021



# GALILEO NAVIGATION SYSTEM

- Two Galileo Control Centres (GCCs) have been implemented on European ground to provide for the control of the satellites and to perform the navigation mission management.
- The data provided by a global network of Galileo Sensor Stations (GSSs) are sent to the Galileo Control Centres through a redundant communications network.
- The GCCs use the data from the Sensor Stations to compute the integrity information and to synchronise the time signal of all satellites with the ground station clocks.
- The exchange of the data between the Control Centres and the satellites is performed through up-link stations.
- As a further feature, Galileo is providing a global Search and Rescue (SAR) function, based on the operational Cospas-Sarsat system. Satellites are therefore equipped with a transponder, which is able to transfer the distress signals from the user transmitters to regional rescue co-ordination centres, which will then initiate the rescue operation.
- At the same time, the system will send a response signal to the user, informing him that his situation has been detected and that help is on the way. This latter feature is new and is considered a major upgrade compared to the existing system, which does not provide user feedback.



# GALILEO NAVIGATION SYSTEM

- By offering dual frequencies as standard, Galileo will deliver real-time positioning accuracy down to the metre range.
- It will **guarantee availability of the service** under all but the most extreme circumstances and will inform users within seconds of any satellite failure, making it suitable for safety-critical applications such as guiding cars, running trains and landing aircraft.
- On 21 October 2011 came the first two of four operational satellites designed to validate the Galileo concept in both space and on Earth.
- Two more followed on 12 October 2012. This In-Orbit Validation (IOV) phase is now being followed by additional satellite launches to reach Initial Operational Capability (IOC) by mid-decade.
- The Galileo navigation signals will provide good coverage even at latitudes up to 75 degrees north, which corresponds to Norway's North Cape - the most northerly tip of Europe - and beyond.
- The large number of satellites together with the carefully-optimised constellation design, plus the availability of the three active spare satellites per orbital plane, will ensure that the loss of one satellite should have no discernible effect on the user.

# GALILEO: Facts and figures

## (Satellites 1-4)

**Launch mass:** 700 kg  
**Size:** 2.74 x 14.5 x 1.59 m (solar wings deployed)  
**Available power:** 1420 W

## (Satellites 5-26)

**Launch mass** 732.8 kg  
**Size:** 2.5 x 14.67 x 1.1 m (solar wings deployed)  
**Available power:** 1900 W

## (Satellites 27-34)

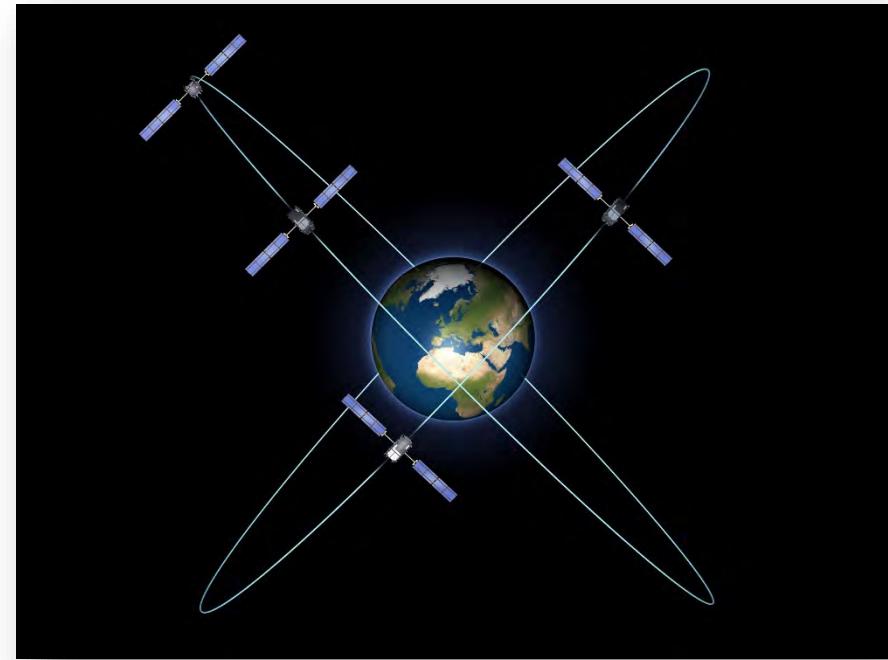
**Launch mass:** 700 kg approx.  
**Size:** 2.5 x 14.67 x 1.1 m (solar wings deployed)  
**Available power:** 1900 W  
**Launch vehicles:** Soyuz ST-B launcher (two-satellite configuration) or Ariane-5 (four-satellite configuration)

**Navigation payload:** Passive hydrogen maser atomic clocks (two); Rubidium atomic clocks (two); Clock monitoring and control unit; Navigation signal generator unit; L-band antenna for navigation signal transmission; C-band antenna for uplink signal detection; Two S-band antennas for telemetry and telecommands; Search and rescue antenna

**Orbit:** Circular Medium-Earth orbit, 23 222 km (satellites 5-6 in elongated orbit of 25 900 km apogee and 17 200 km perigee due to launch anomaly)

**Orbital inclination:** 56°

**Operational lifetime:** more than 12 years



# Satèl·lits en òrbita - Galileo

The first pair of Galileo's FOC phase, **GSAT0201** and **GSAT0202**, was launched in August 2014. Despite having been injected into an incorrect orbit, these were moved to an improved orbit at the end of 2014 and the beginning of 2015.

Subsequent FOC satellites were launched as follows:

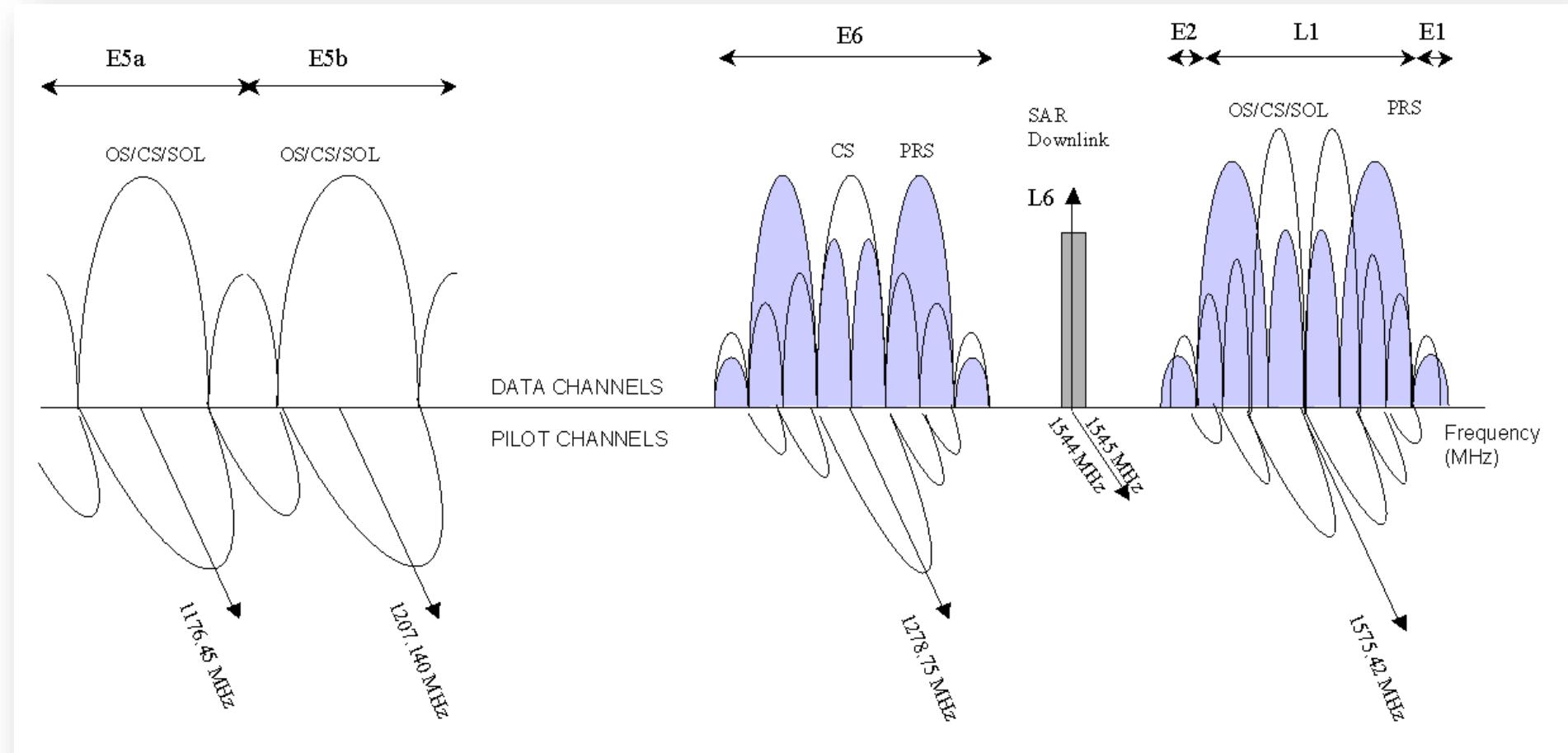
- **GSAT0203** and **GSAT0204**, in March 2015;
- **GSAT0205** and **GSAT0206**, in September 2015;
- **GSAT0208** and **GSAT0209**, in December 2015;
- **GSAT0210** and **GSAT0211**, in May 2016;
- **GSAT0207**, **GSAT0212**, **GSAT0213** and **GSAT0214**, in November 2016;
- **GSAT0215**, **GSAT0216**, **GSAT0217** and **GSAT0218** in December 2017.
- **GSAT0219**, **GSAT0220**, **GSAT0221**, **GSAT0222** in July 2018
- **GSAT0223** , **GSAT0224** in December 2021

The Galileo FOC satellites provide the same capabilities as the previous IOV satellites, but with improved performance, such as higher transmit power.

With 26 Galileo satellites in Orbit (4 IOV plus 22 FOC satellites), **the constellation is on track to reach completion in 2023.**

# GALILEO SIGNALS

Each Galileo satellite will broadcast 10 different navigation signals making it possible for Galileo to offer the open (OS), safety-of-life (SOL), commercial (CS) and public regulated services (PRS).



# GALILEO Services

- **Open Service (OS):** Galileo open and free of charge service set up for positioning and timing services. In the future, the Galileo Open Service will also provide Navigation Message Authentication, which will allow the computation of the user position using authenticated data extracted from the navigation message.
- **High Accuracy Service (HAS):** A service complementing the OS by providing an additional navigation signal and added-value services in a different frequency band. The HAS signal can be encrypted in order to control the access to the Galileo HAS services.
- **Public Regulated Service (PRS):** Service restricted to government-authorised users, for sensitive applications that require a high level of service continuity.
- **Search and Rescue Service (SAR):** Europe's contribution to COSPAS-SARSAT, an international satellite-based search and rescue distress alert detection system.

# High Accuracy Service (HAS)

HAS	SERVICE LEVEL 1	SERVICE LEVEL 2
COVERAGE	Global	European Coverage Area (ECA)
TYPE OF CORRECTIONS	PPP - orbit, clock, biases (code and phase)	PPP - orbit, clock, biases (code and phase) incl. atmospheric corrections
FORMAT OF CORRECTIONS	Open format similar to Compact-SSR (CSSR)	Open format similar to Compact-SSR (CSSR)
DISSEMINATION OF CORRECTIONS	Galileo E6B using 448 bits per satellite per second / terrestrial (internet)	Galileo E6B using 448 bits per satellite per second / terrestrial (internet)
SUPPORTED CONSTELLATIONS	Galileo, GPS	Galileo, GPS
SUPPORTED FREQUENCIES	E1/E5a/E5b/E6; E5 AltBOC L1/L5; L2C	E1/E5a/E5b/E6; E5 AltBOC L1/L5; L2C
HORIZONTAL ACCURACY 95 %	<20 cm	<20 cm
VERTICAL ACCURACY 95 %	<40 cm	<40 cm
CONVERGENCE TIME	<300 s	<100 s
AVAILABILITY	99%	99%
USER HELPDESK	24/7	24/7

# Service Performances for Galileo Open Service

GALILEO SIS RANGING ACCURACY MPL FOR ANY SATELLITE	CONDITIONS AND CONSTRAINTS
For each SF: • ≤ 7m (95%) global average, over all AODs	<ul style="list-style-type: none"> <li>Calculated over a period of 30 days</li> <li>For any healthy OS SIS above a minimum elevation angle of 5 degrees</li> <li>Including Broadcast Group Delay errors</li> <li>Propagation and user contributions excluded</li> <li>Neglecting single frequency ionospheric delay model errors<sup>10</sup></li> </ul>
For each DF combination: • ≤ 7m (95%) global average, over all AODs	<ul style="list-style-type: none"> <li>Calculated over a period of 30 days</li> <li>For any healthy OS SIS above a minimum elevation angle of 5 degrees</li> <li>Propagation and user contributions excluded</li> </ul>

GALILEO SIS RANGING ACCURACY MPL OVER ALL SATELLITES	CONDITIONS AND CONSTRAINTS
For each SF: • ≤ 2m (95%), over all AODs	<ul style="list-style-type: none"> <li>Calculated over a period of 30 days</li> <li>95<sup>th</sup> percentile of the time series of constellation average Galileo SIS Ranging Accuracy (computed as the rms of the instantaneous global average SISE)</li> </ul>
For each DF combination: • ≤ 2m (95%), over all AODs	<ul style="list-style-type: none"> <li>Calculated over a period of 30 days</li> <li>95<sup>th</sup> percentile of the time series of constellation average Galileo SIS Ranging Accuracy (computed as the rms of the instantaneous global average SISE)</li> </ul>

# Tema 5:

## ELS EQUIPS I ELS SISTEMES RADIOELÈCTRICS AEROPORTUARIS

Jordi Berenguer  
Novembre 2021



UNIVERSITAT POLITÈCNICA DE CATALUNYA

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# GBAS

Ground-Based Augmentation System



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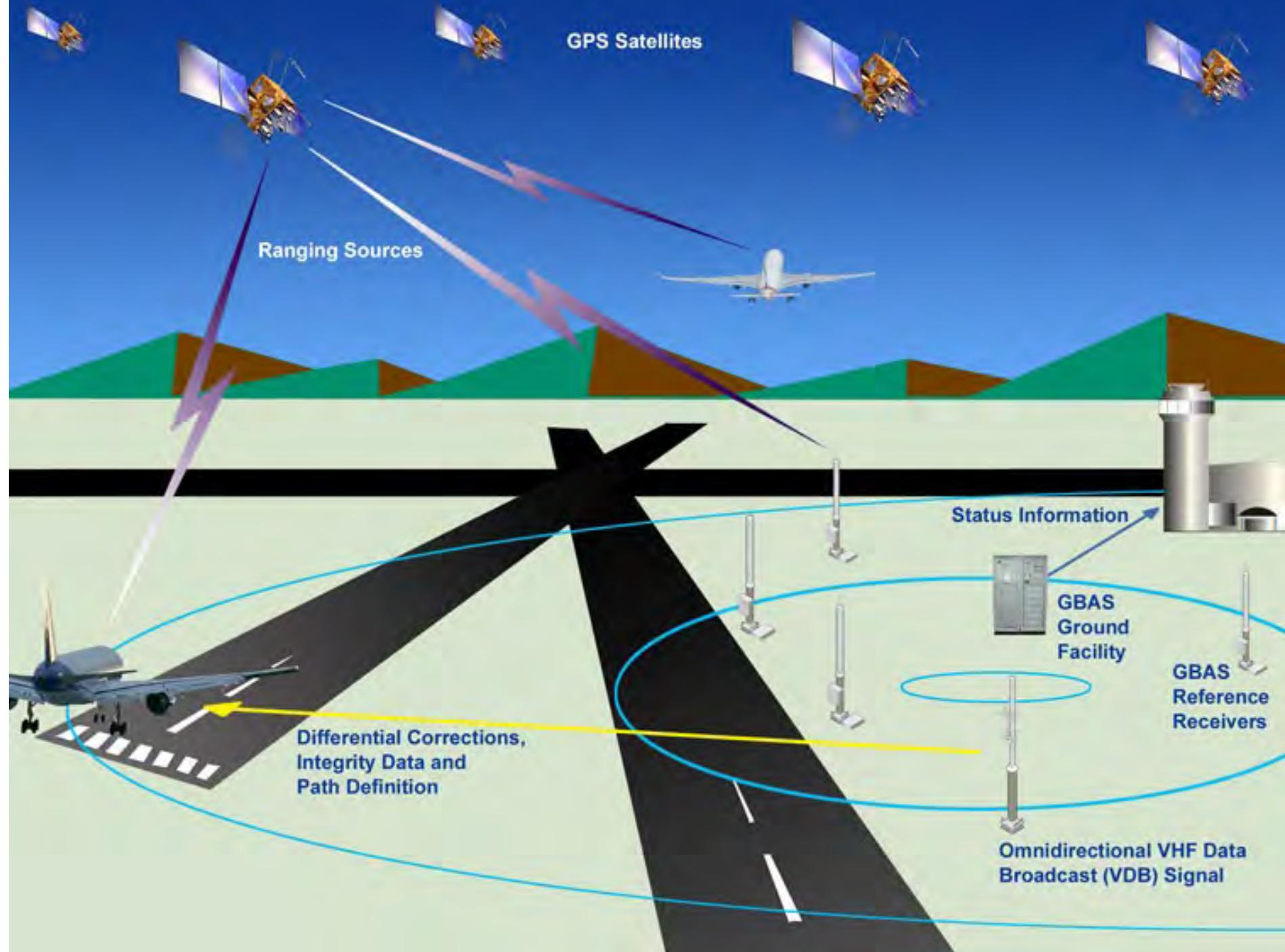
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# GBAS

- Augmentation of a global navigation satellite system (GNSS) is a method of improving –“augmenting”– the navigation system's performances, thanks to the use of external information to the GNSS into the user position solution. The performances are:
  - **integrity**,
  - **continuity**,
  - **accuracy**,
  - **availability**
- A Ground-Based Augmentation System (GBAS) is a civil-aviation safety-critical system that supports local augmentation –at airport level– of the primary GNSS constellation(s) by providing enhanced levels of service that support all phases of approach, landing, departure and surface operations. While the main goal of GBAS is to provide integrity assurance, it also increases the accuracy with position errors below 1 m (1 sigma).

# COMUNICACIÓNS AEROPORTUÀRIES



# GBAS – How it works

- The Ground Based Augmentation System (GBAS) is intended primarily to support precision approach operations. It consists of a **GBAS Ground Subsystem** and a **GBAS Aircraft Subsystem**.
- One GBAS Ground Subsystem **can support an unlimited number of aircraft units** within its GBAS coverage volume. The ground subsystem provides the aircraft with approach path data and, for each satellite in view, corrections and integrity information. The corrections enable the aircraft to determine its position relative to the approach path more accurately. The GBAS Signal in Space is defined to be only the data broadcast from the ground to the aircraft subsystem. The Satellite Signals in Space are part of the basic GNSS satellite constellations.
- **The ground infrastructure for GBAS includes two or more GNSS receivers** which collect pseudoranges for all the primary GNSS satellites in view **and computes and broadcasts differential corrections and integrity-related information** for them based on its own surveyed position.
- These differential corrections **are transmitted** from the ground system via a **Very High Frequency (VHF) Data Broadcast (VDB)**. The broadcast information includes pseudorange corrections, integrity parameters and various locally relevant data such as Final Approach Segment (FAS) data, referenced to the World Geodetic System (WGS-84).
- The aircraft within the area of coverage of the ground station may use the broadcast corrections to compute their own measurements in line with the differential principle. The differentially corrected position is used to generate navigation guidance signals.

# 1st. step



**GPS Reference Receivers Calculate Position**

Signals from GPS satellites are received by the 4 GBAS GPS Reference Receivers at the GBAS-equipped airport.

The reference receivers calculate their position using GPS.

# 2nd. step

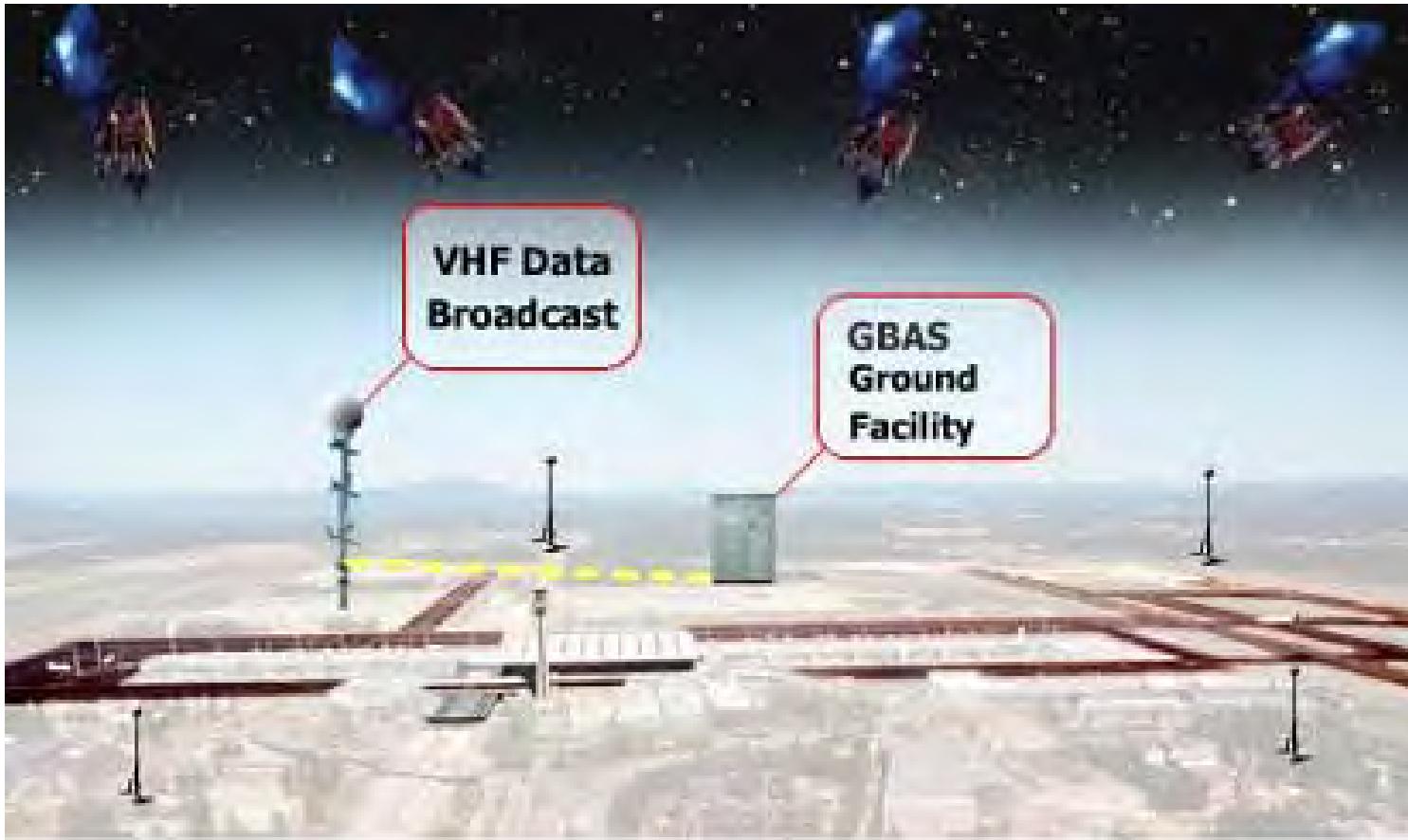


**GBAS Ground Facility (LGF) Calculates Errors in GPS Position and Formulates the GBAS Correction Message**

The GPS Reference Receivers and GBAS Ground Facility work together to measure errors in GPS-provided position.

The GBAS Ground Facility produces a GBAS correction message based on the difference between actual and GPS-calculated position which includes as well integrity parameters and approach path information.

# 3rd. step

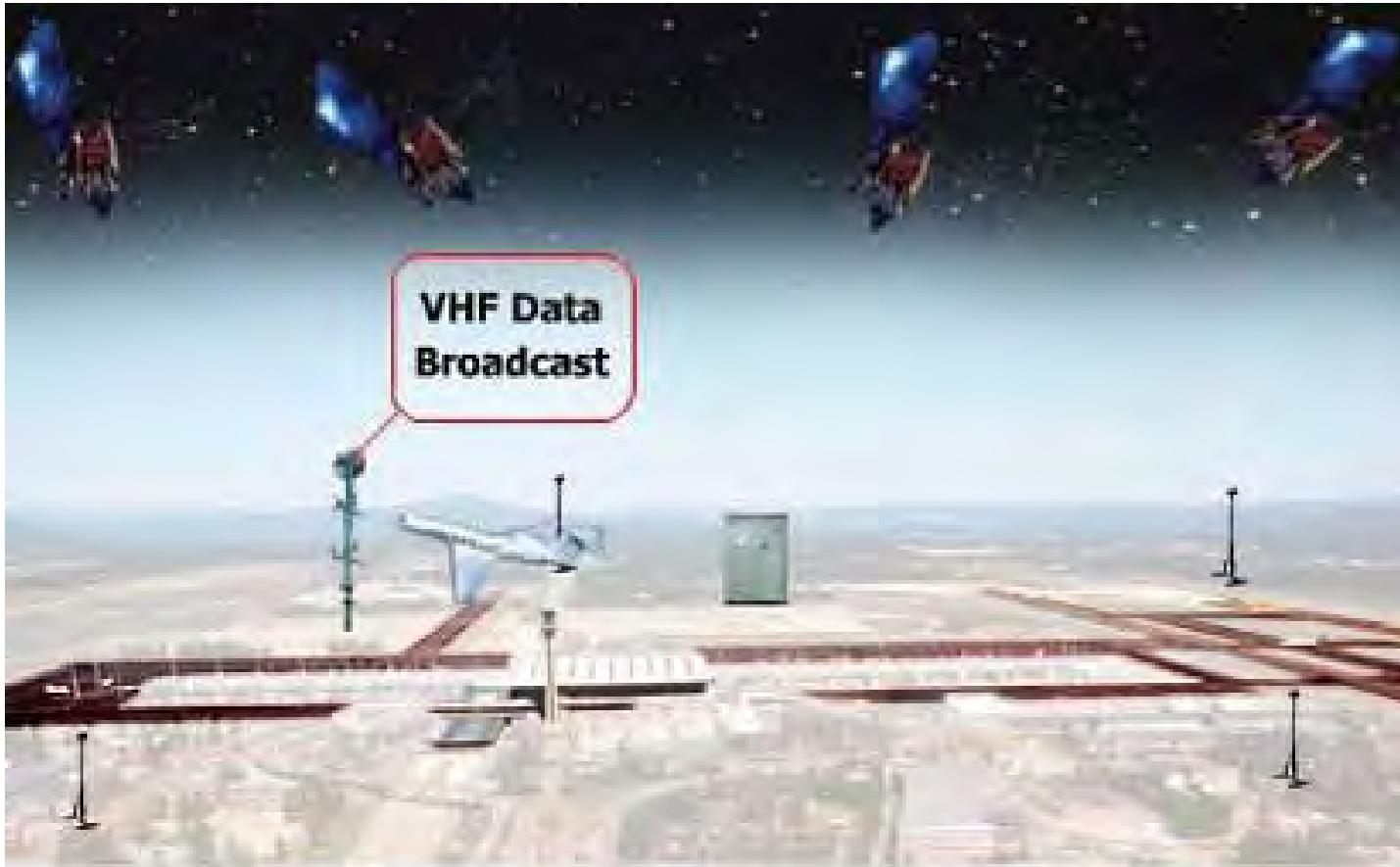


**The GBAS Ground Facility Sends the Correction Message to the VHF Data Broadcast (VDB) Transmitter**

This GBAS correction message is then sent to a VHF data broadcast (VDB) transmitter.

The VDB broadcasts the GBAS signal throughout the GBAS coverage area to avionics in GBAS-equipped aircraft. GBAS provides its service to a local area (approximately a 30 kilometer radius). The signal coverage is designed to support the aircraft's transition from en route airspace into and throughout the terminal area airspace.

# 4th. step



**The VDB Transmitter Broadcasts the GBAS Signal to Equipped Aircraft in the Service Area**

The GBAS equipment in the aircraft uses the corrections provided on position, velocity, and time to guide the aircraft safely to the runway.

This signal provides ILS-look-alike guidance as low as 200 feet (60 m) above touchdown. GBAS will eventually support landings all the way to the runway surface.

# GBAS Ground Subsystem

- The main purposes of the GBAS Ground Subsystem are:
  - reception and decoding of signals-in-space;
  - computation of the differential corrections to the carrier-smoothed codes;
  - integrity monitoring;
  - generation and broadcasting of GBAS messages.
- The GBAS Ground Subsystem consists of:
  - **2 to 4 GNSS Reference Receivers** and their respective geographically separated antennas;
  - A VHF data broadcast (**VDB transmitter**);
  - A **monitor system**;
  - Approach Database (**FAS data**);
  - **Ground processing** functions.



# GBAS Aircraft Subsystem

- The main element of GBAS Aircraft Subsystem is the aircraft GBAS Receivers.
- The primary functions of the GBAS aircraft subsystem are:
  - receive and decode the GNSS satellite and GBAS signals;
  - determine the aircraft position;
  - provide availability of the service;
  - compute deviations from the desired flight path calculated from the Final Approach Segment (FAS) data;
  - provide guidance signals and integrity information.
- The GBAS aircraft subsystem essential elements are:
  - An Aircraft GNSS Receiver Function that receives, tracks, and decodes the GNSS satellite signals.
  - A VHF Data Broadcast Receiver Function that receives and decodes the messages broadcast by the GBAS Ground Subsystem.
  - An Aircraft Navigation Processing Function that receives the measurement of the pseudo-ranges from the GNSS Receiver Function, applies the differential corrections received from the VHF Data Broadcast Receiver Function and calculates the differentially corrected aircraft position. The Aircraft Navigation Processing Function extracts from the different FAS path construction data received, the one having the Reference Path Selector selected by the crew through the GLS Channel Number Selector. The Aircraft Navigation Processing Function also calculates deviations from the selected FAS path based on its differentially corrected position.



# GNSS Satellites Subsystem

- The GBAS Satellites Subsystem is mainly the GNSS constellations declared operational for civil use. The minimum requirements of a GBAS system are limited for the use of GNSS satellites ranging sources, with additional ranging sources being supplied by SBAS as an option.

# GBAS Signal

- The GBAS Signal in Space is defined to be only the data broadcast from the ground to the aircraft subsystem. The Satellite Signals in Space are part of the basic GNSS satellite constellations.
- The GBAS ground subsystem differential computed corrections (contained in Type 1 message), GBAS ground subsystem related data (contained in Type 2 message) and Final Approach Segments (FAS) (contained in Type 4 message) are transmitted to the aircraft users via VHF Data Broadcast (VDB) Signal. The GBAS Messages are encoded in this signal. The specification of GBAS message data format is contained in the ICAO SARPS Appendix B for the aspects related with the signal in space, as well as in the RTCA MOPS DO-253C for the minimum operational performance requirements applicable to the airborne GBAS receiver equipment.
- The **VDB radio frequencies** used shall be selected from the radio frequencies in the band **108-117.975 MHz**.
- The lowest assignable frequency shall be 108.025 MHz and the highest frequency assignable shall be 117.950 MHz. The separation between assignable frequencies (channel spacing) shall be 25 kHz.

# The GBAS message types

Message type identifier	Message Name
0	Spare
1	GBAS Differential Corrections
2	GBAS Related Data
3	Reserved for ground-based ranging source
4	Final Approach Segment (FAS) data
5	Predicted ranging source availability
6	Reserved
7	Reserved for national applications
8	Reserved for test applications
9-255	Spare

# GBAS Performances

Typical Operation	Horizontal Accuracy (95%)	Vertical Accuracy (95%)	Integrity	Time-To-Alert (TTA)	Continuity	Availability
Initial approach, Intermediate approach, Non-precision approach (NPA), Departure	220m (720ft)	N/A	$1\text{--}1\times10^{-7}/\text{h}$	10s	$1\text{--}1\times10^{-4}/\text{h}$ to $1\text{--}1\times10^{-8}/\text{h}$	0.99 to 0.99999
Non Precision Approach with vertical guidance (NPV-I)	220m (720ft)	20m (66ft)	$1\text{--}2\times10^{-7}$ per approach	10s	$1\text{--}8\times10^{-6}$ in any 15s	0.99 to 0.99999
Non Precision Approach with vertical guidance (NPV-II)	16m (52ft)	8m (26ft)	$1\text{--}2\times10^{-7}$ per approach	6s	$1\text{--}8\times10^{-6}$ in any 15s	0.99 to 0.99999
Category I (CAT-I) Precision Approach	16m (52ft)	6.0m to 4.0m (20ft to 13ft)	$1\text{--}2\times10^{-7}$ per approach	6s	$1\text{--}8\times10^{-6}$ in any 15s	0.99 to 0.99999

# GBAS Performances

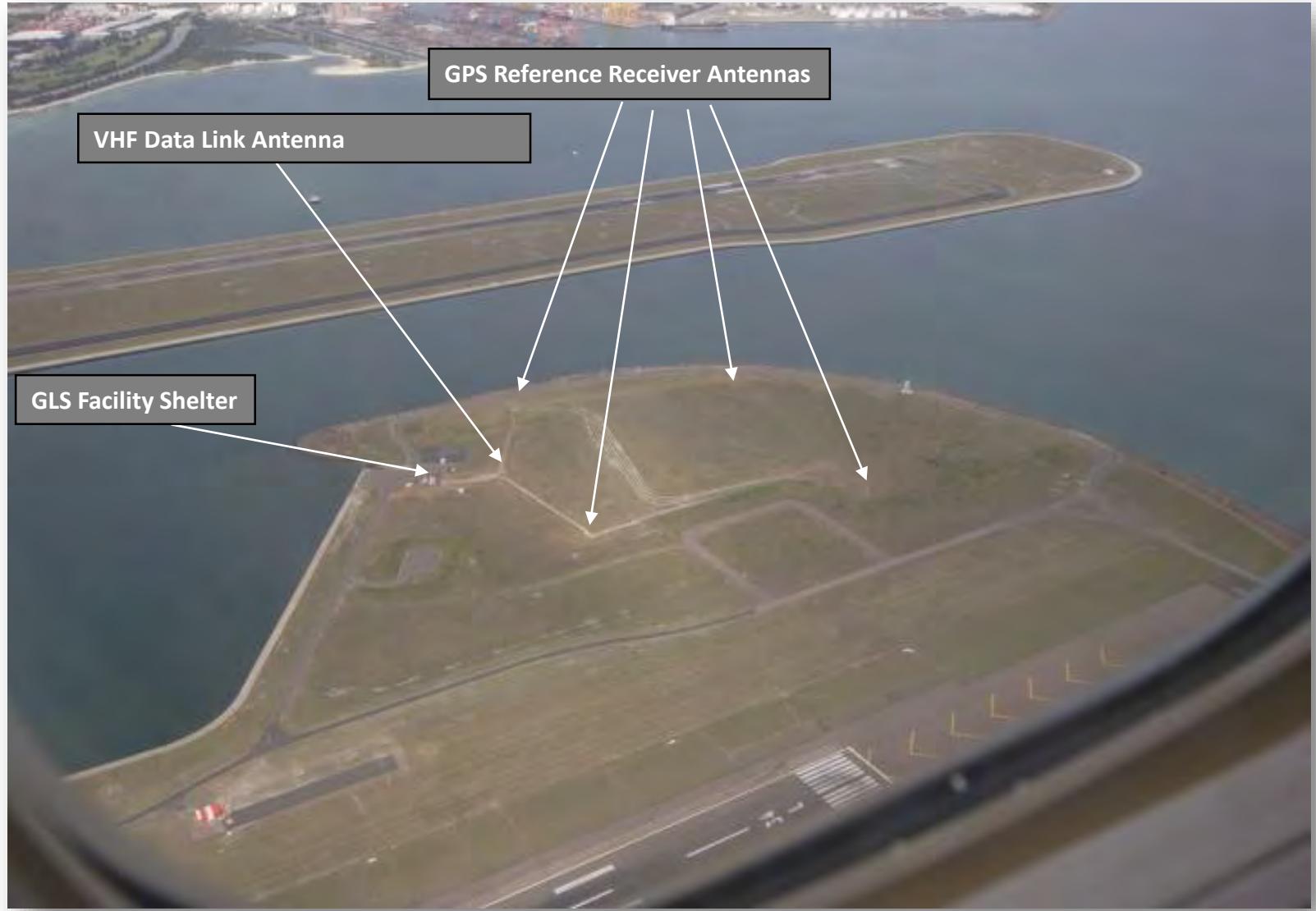
- Usually a GBAS system is designed to fulfil CAT-I Precision Approach.
- As indicated in the table above, the performance requirements are expressed in terms of four quantitative concepts, many of them to be interpreted as probabilistic figures:
  - **Accuracy:** is expressed in terms of Navigation System Error (NSE) as the difference between the real position of the aircraft and the position provided by the airborne equipment.
  - **Integrity:** is defined by ICAO as a measure of the trust that can be placed in the correctness of the information supplied by the system.
  - **Continuity:** is the probability that the specified system performance will be maintained for the duration of a phase of operation, presuming that the system was available at the beginning of that phase of operation and was predicted to operate throughout the operation. Lack of continuity means that the operation must be aborted (with the associated risk).
  - **Availability:** is the probability that the navigation service is available at the beginning of the planned operation. A GBAS system is considered available when the accuracy, integrity and continuity requirements are met throughout the coverage region.

# GBAS Implementation

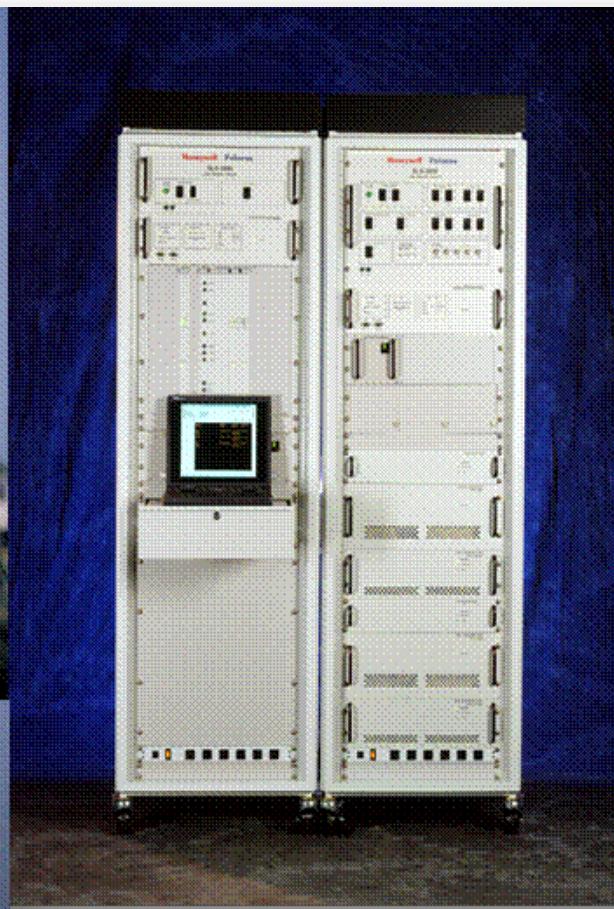
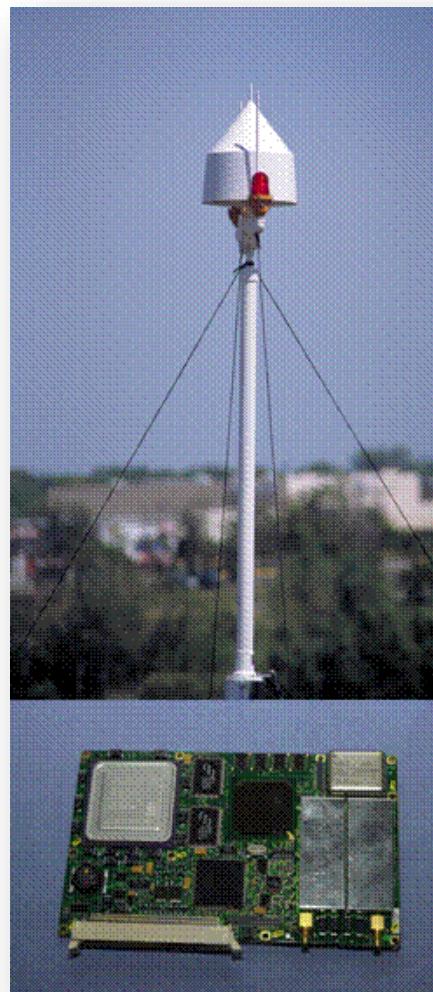
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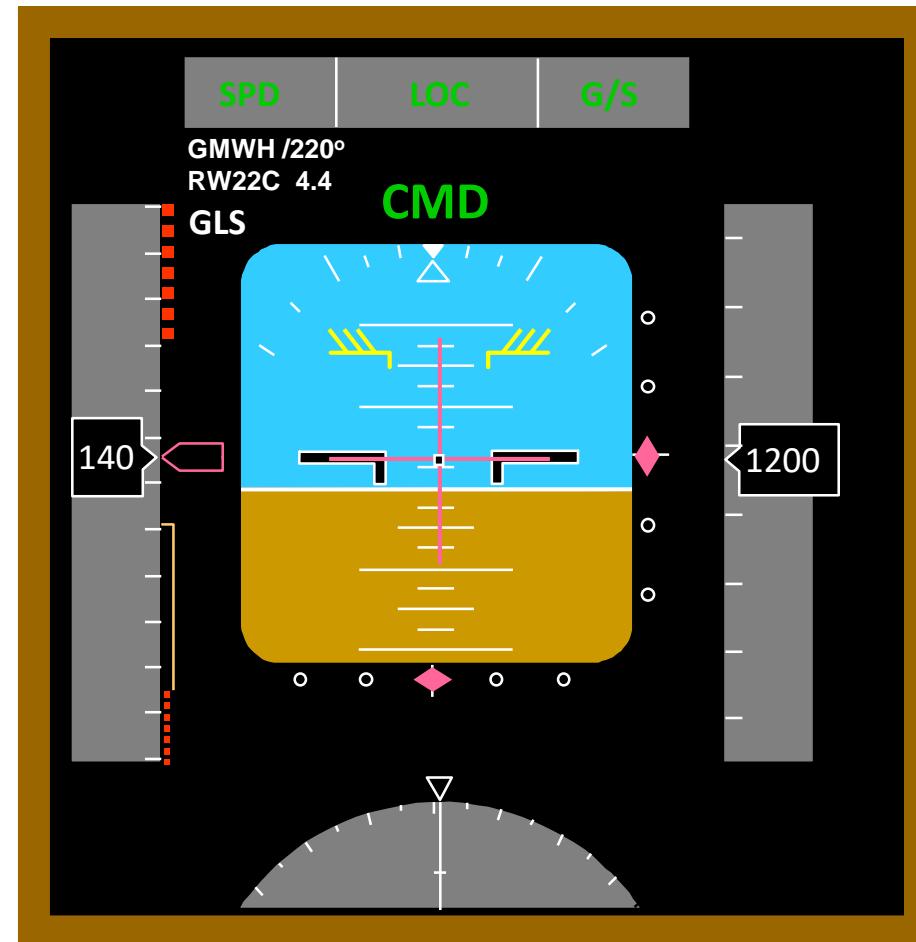
# The “Hook” at Sydney airport extending into Botany Bay



# GBAS Cat-1 Equipment



# GLS – Primary Flight Display



# GLS – Radio Tuning Panel



# GLS – FMS Selection



# Local Area Augmentation System (LAAS)

- The **U.S. version** of the Ground Based Augmentation System (GBAS) has traditionally been referred to as the **Local Area Augmentation System (LAAS)**.
- Honeywell has developed a Non-Federal CAT-1 LAAS which received System Design Approval (SDA) from the Federal Aviation Administration (FAA) in September 2009. Current proposed installations include: airports in Newark (New Jersey), Memphis (Tennessee), Atlantic City (New Jersey), and Olathe (Kansas).
- One of the primary benefits of LAAS is that a single installation at a major airport can be used for multiple precision approaches within the local area.
  - For example, if Chicago O'Hare has 12 runway ends each with a separate ILS, all 12 ILS facilities can be replaced with a single LAAS system. This represents a significant cost savings in maintenance and upkeep of the existing ILS equipment.
  - Another benefit is the potential for approaches that are not straight-in. Aircraft equipped with LAAS technology can utilize curved or complex approaches such that they could be flown on to avoid obstacles or to decrease noise levels in areas surrounding an airport.
- The FAA also contends that only a single set of navigational equipment will be needed on an aircraft for both LAAS and WAAS capability. This lowers initial cost and maintenance per aircraft