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FINAL REPORT PART I

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COMPATIBILITY ANALYSIS FOR THE 1535-1660 MHz BAND

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PREPARED BY
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FOR
ELECTRONICS RESEARCH CENTER
NATIONAL AERONAUTICS & SPACE ADMINISTRATION

IIT RESEARCH INSTITUTE
SYSTEM SCIENCES RESEARCH DIVISION
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(Final Report - Part I)

COMPATIBILITY ANALYSIS FOR THE 1535-1660 MHz BAND

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOREWORD

This Final Report, Part I, "Compatibility Analysis for the 1535-1660 MHz Band", was prepared for the Communication/Navigation Satellite Program Office of the NASA Electronic Research Center, Cambridge, Massachusetts by the Systems Sciences Research Division of IIT Research Institute (IITRI) under Contract Number NAS-12-639. The objective of the program suggested by Mr. Eugene Ehrlich, Space Applications Program Office, NASA, was to perform a study of the electromagnetic compatibility of certain equipments operating aboard the Supersonic Transport and other future high speed aircraft. The report was prepared under the technical direction of Mr. John M. Clarke of NASA/ERC, by Dr. Richard L. Martin and Mr. Robert A. Paul of IITRI. Other personnel of the IIT Research Institute who contributed to this report were Mr. Norbert M. Katz and Mr. Frank C. Pethel.

In addition to this Final Report, Part I, there is the Final Report, Part II, "Computerized Information Retrieval File for Radio Frequency Assignments", under separate cover. Also under this contract, two technical papers were presented jointly by Messrs. John M. Clarke of NASA/ERC and R. J. Otero and W. C. Wanbaugh of IITRI/SSRD. These papers were:

1. "Pulse Interference Effects in a Phase Lock Loop", presented at the 1969 IEEE Electromagnetic Compatibility Symposium, Asbury Park, N. J., June 17-19, 1969, and published in the symposium record, and
2. "Radio Spectrum Utilization in Aero-Space Communications Systems", presented at the International Communications Conference, Boulder, Colorado, June 9-11, 1969, and published in the conference proceedings.

Respectfully Submitted
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1.0 SUMMARY

The airborne systems that are proposed for allocation in the 1535-1660 MHz band* were determined and their external characteristics were identified as completely as possible. Potentially interfering situations were determined. The situations which lent themselves to reasonable analysis were analyzed for the distance separations required between antennas. Where particular characteristics were not specified, such as antenna directivity and patterns, assumptions were made in an effort to avoid either overly pessimistic or overly optimistic results. The general conclusion from this study is that for the proposed frequency allocations, the systems would operate compatibly aboard a relatively large aircraft where the required distance separations could be met.

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*The IRR allocations are:

1535-1540	SPACE (Telemetering)
1540-1660	AERONAUTICAL RADIONAVIGATION

The FCC allocations are:

1535-1540	SPACE (Telemetering)
1540-1660	GOVERNMENT AND NON-GOVERNMENT AERONAUTICAL RADIONAVIGATION

2.0 ANTENNA PLACEMENT RECOMMENDATIONS

Of the fourteen interference situations considered, only three resulted in required distance separations of one foot or greater. First, the distance between the ATC and the CAS antennas should be at least 30 feet. Second, the distance between the ATC and Radar Altimeter antennas should be at least 6.5 feet. This is no problem, however, since the antennas are on opposite surfaces of the fuselage. Third, the distance between the CAS and the Radar Altimeter antennas must be at least one foot.

Since the expected separation among the various antennas exceed the above figures for aircraft such as the SST and most other smaller commercial aircraft, the overall conclusion is that the various systems with the given frequency allocations would operate compatibly aboard the same aircraft. For smaller aircraft where the 30 foot separation between CAS and ATC antennas is difficult to achieve, additional discrimination against the CAS signal would probably be required.

3.0 INTRODUCTION

Although this study has general applicability to the electromagnetic compatibility problems of aerospace systems, it is specifically presented as an analysis of the interference problem faced by proposed systems in the 1535-1660 MHz band on-board the supersonic transport (SST) and other future high-speed aircraft. The sub-allocation plan proposed by the Federal Aviation Administration is shown in Figure 1 with two additional proposed frequencies for the Satellite Air Traffic Control System (ATC). The systems that necessitate interference analysis are the ATC, the Collision Avoidance System (CAS), the Glide Slope and the Radar Altimeters. Due to the limitations of this study the interference situations analyzed will be limited to those portrayed on Figures 2 and 3.

The basis for the potential interference situations is the susceptibility of the airborne ATC, CAS and Glide Slope receivers to emissions from their counterpart transmitters. Transmitters are located; 1) on the satellite for the ATC system, 2) both on the test aircraft (cosite) and on other aircraft for the CAS, 3) on the ground for the Glide Slope system, and 4) both on the test aircraft (cosite) and on other aircraft for the radar Altimeters.

Figure 3 is a matrix depicting the various interference situations; the victim receivers versus the possibly

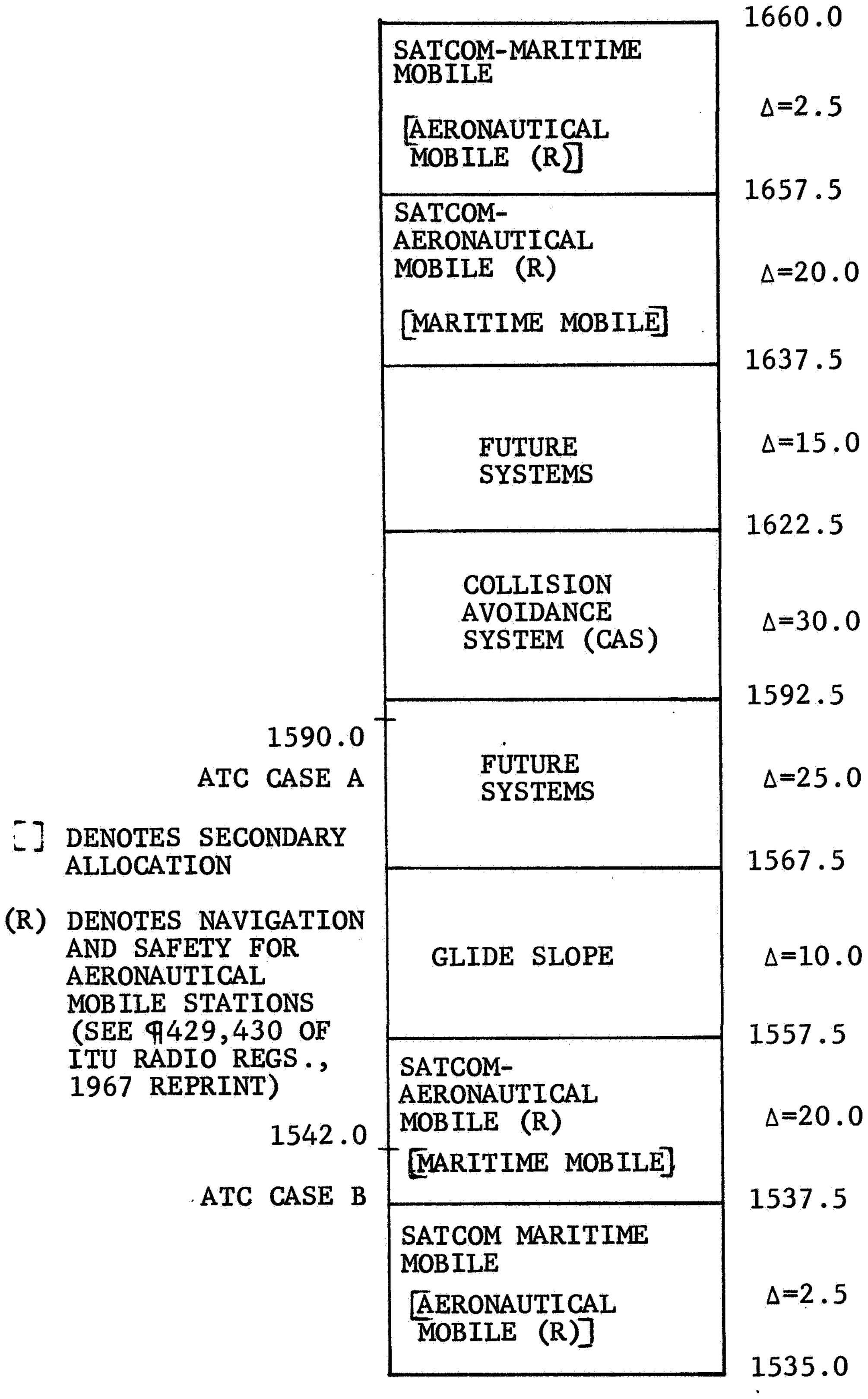


FIGURE 1

PROPOSED SUB ALLOCATION 1535-1660 MHz BAND

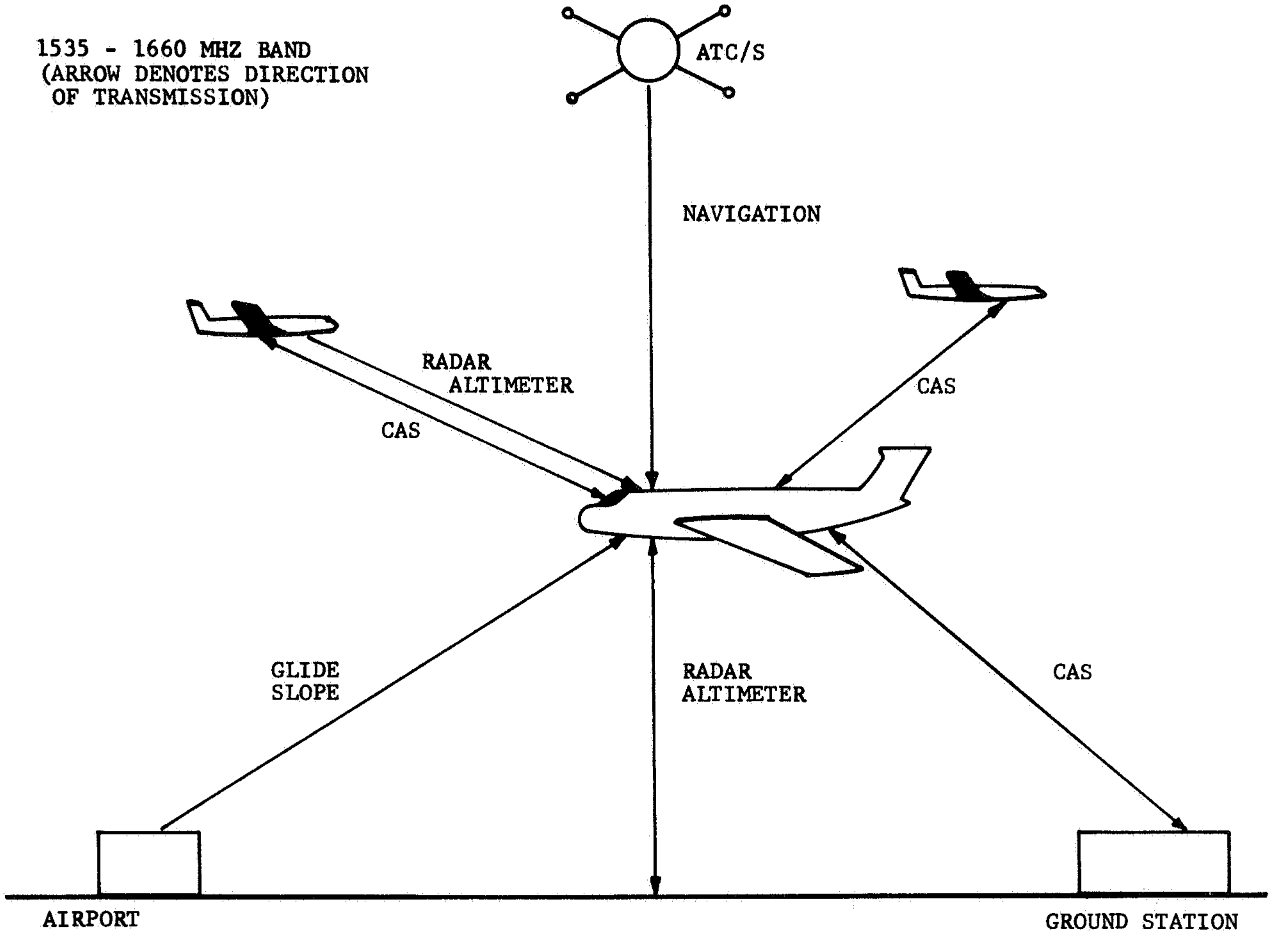


FIGURE 2

EQUIPMENTS POSSIBLY INTERFERING WITH SATELLITE ATC SYSTEM

RECEIVERS	ATC	CAS	GLIDE SLOPE	RADAR ALTIMETER
TRANSMITTERS				
ATC	---	6	10	---
CAS				
1) Test Aircraft	1	---	11	---
2) Other Aircraft	2	---	12	---
Glide Slope	3	7	---	---
Radar Altimeter				
1) Test Aircraft	4	8	13	---
2) Other Aircraft	5	9	14	---

FIGURE 3

INTERFERENCE SITUATIONS ANALYZED

interfering transmitters. The numbers within the matrix refer to the interference situations studied under "Analysis of Interference Situations". Interference effects were not analyzed for the Radar Altimeter receivers due to a lack of information describing their characteristics.

4.0 SYSTEM DESCRIPTIONS

The antennas for the various systems are assumed to be as shown in Figure 4. Two antennas are required for the CAS to provide satisfactory spherical coverage. One is located atop the fuselage of the aircraft and one on the underside. The ATC antenna must be placed on the upper portion of the aircraft for best reception from the satellite. The Glide Slope receiver and the Radar Altimeters are normally on the underside of the aircraft in the forward area. The relative separation of the antennas on the aircraft is a basic parameter which must be determined in the interference analysis.

The Satellite Air Traffic Control will transmit on two separate frequencies: Case A is 1590.0 MHz and Case B is 1542.0 MHz. This signal is received on the aircraft after a 188.55 dB space loss derived from the equation:

$$L = 37.8 + 20 \log f + 20 \log d$$

Where L is in decibels,
and f is in megahertz,
and d is in miles

For Case A, the receiver utilizes a phase-locked loop with three tracking bandwidths: 1.0 kHz, 100 Hz and 20 Hz (only the first two are analyzed). In addition, Case A assumes a coding sequence that increases the signal

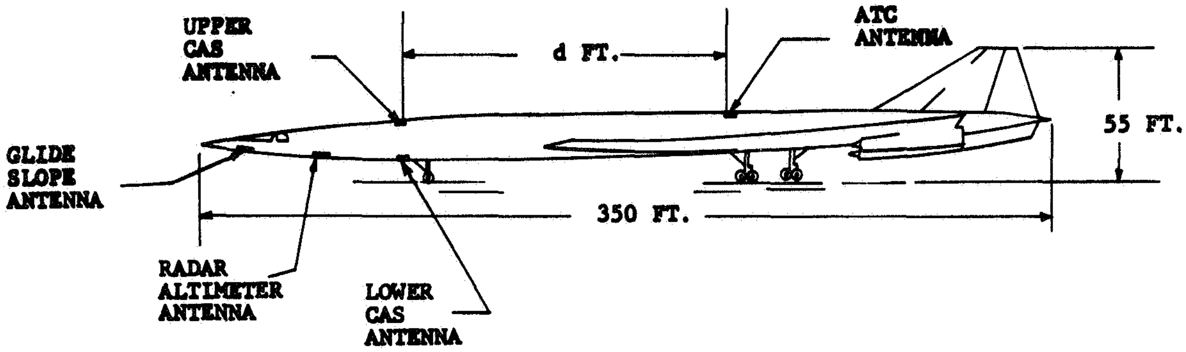


FIGURE 4

ASSUMED SST ANTENNA LOCATIONS

to interference ratio by 33 and 43 dB. The single Case B bandwidth is 2.5 kHz and does not utilize the coding sequence.

The Collision Avoidance System recommended by the Air Transport Association has four frequencies as shown in Figure 5. The CAS message will be transmitted and received by all aircraft. Transmission will be in each of the four frequencies in succession to avoid garbling due to simultaneous reception of messages transmitted by two different aircraft in adjacent time slots. The basic message format is presented in Figure 6, with the various pulses which must be analyzed to determine the worst interfering situations.

The Glide Slope signal transmitted from the airport is essentially a CW signal and may be anywhere between 1557.5 MHz and 1567.5 MHz. Although the Radar Altimeters may not be in the 1535 to 1660 MHz band at all, if they are in the band they will most probably be in the 1622.5 to 1637.5 portion.

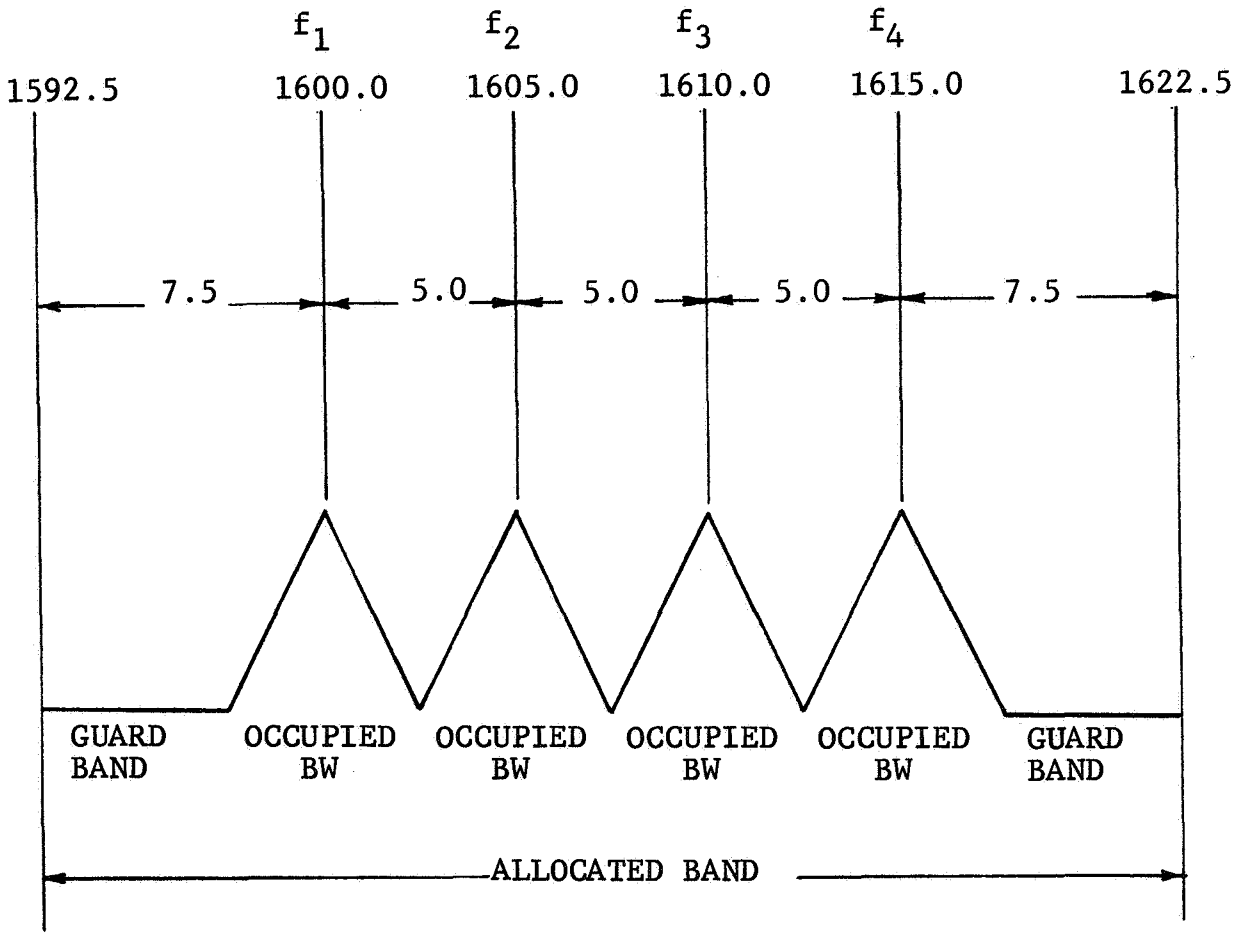


FIGURE 5

POSSIBLE CAS FREQUENCIES

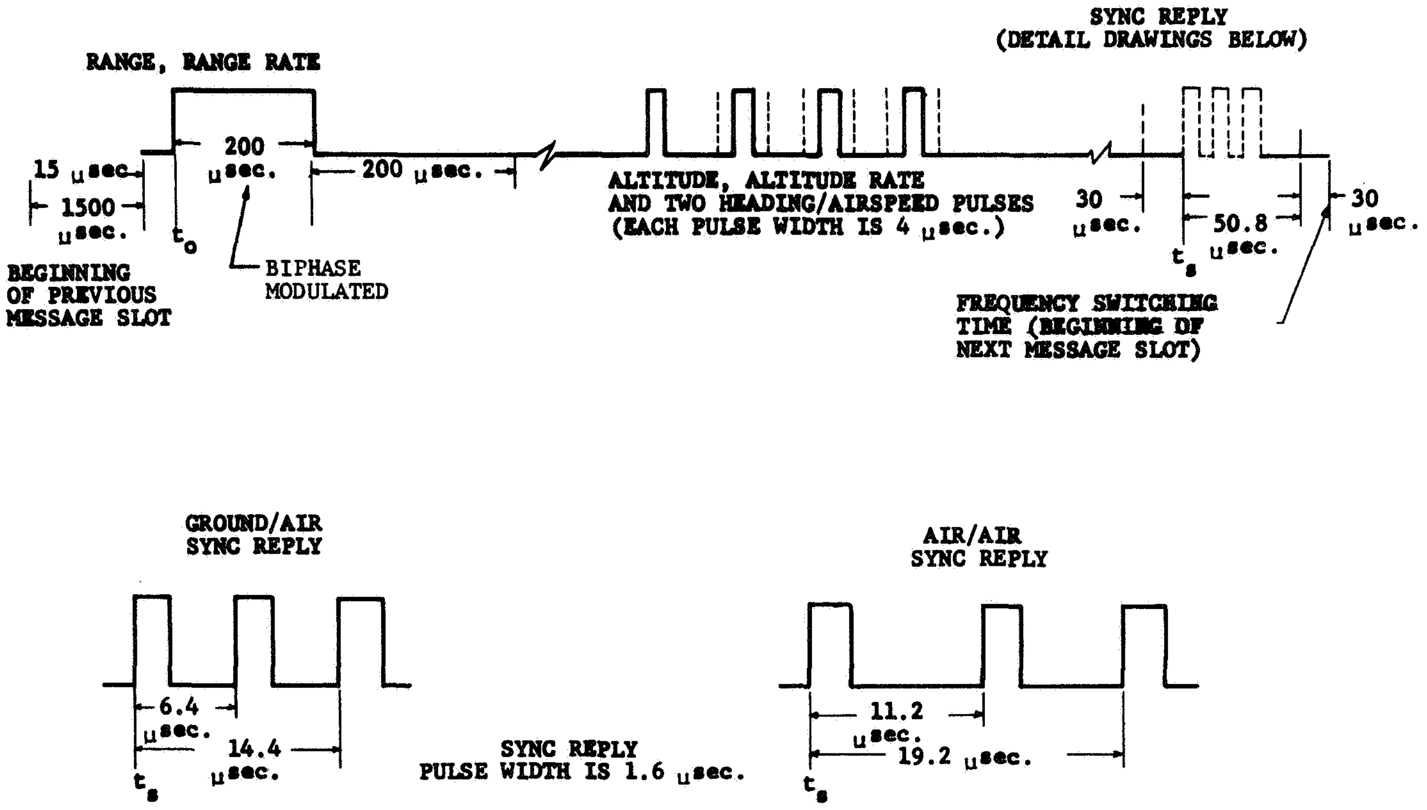


FIGURE 6

COLLISION AVOIDANCE SYSTEM MESSAGE FORMAT, BASIC SIGNAL

4.1 Analysis of Interference Situations

1. Interference with the ATC Receiver by the CAS Transmitter on the Same Aircraft.

This situation is considered to be the primary interference situation. Both the transmitting and receiving antennas are low gain types affording little separation due to directivity. Also, there are two CAS antennas (top and bottom), thus limiting the added effective separation that can be gained by using the fuselage of the aircraft as a shield.

Figure 7 gives a brief description of the ATC system characteristics. Case A refers to the transmission at 1590 MHz while Case B refers to the 1542 MHz transmission. In addition to the two different frequencies, under Case A two different bandwidths are considered, namely 1000 Hz and 100 Hz. Thus considering nominal and worst case conditions for both the ATC and CAS, six situations are analyzed.

In determining the interference potential of the CAS, the CAS message format plays a major role. Since the entire message is relatively short (1500 μsec) while the repetition rate for the message is extremely low (3 sec) the interfering power must be adjusted from the level expected from a continuous interference source. This adjustment is derived in Appendix I. The complete tabulation of the CAS interference analysis with the level adjustment is shown in Figure 8.

ASPECT	UNITS	NOMINAL		WORST	
		CASE A	CASE B	CASE A	CASE B
ATC					
Transmitter Power	dBm	51.8	51.8	50.8	50.8
Satellite Losses	dB	-1.55	-1.55	-2.0	-2.0
Satellite Antenna Gain	dB	16.0	16.0	15.5	15.5
Space Loss	dB	-188.55	-188.55	-188.55	-188.55
Available Isotropic Power at ATC Receiver	dBm	-122.30	-122.30	-124.25	-124.25
Required SNR	dB	7	6	7	6
Allowable Maximum Interfering Power at ATC Receiver For No Interference	dBm	-129.30	-128.30	-131.25	-130.25

FIGURE 7

PROPOSED ATC SYSTEM CHARACTERISTICS

ASPECT	UNITS	NOMINAL			WORST		
		Case A		Case B	Case A		Case B
CAS Transmitter Power	dBm	62	62	62	65	65	65
Cable Loss	dB	-5	-5	-5	-5	-5	-5
Antenna Gain	dB	2	2	2	2	2	2
CAS Power Spectral Density at ATC Center Frequency	dBm/MHz	5	5	-25	15	15	-15
Tracking Bandwidth of ATC	kHz	1.0	0.1	2.5	1.0	0.1	2.5
Peak CAS Power into ATC Receiver w/o Coding or Separation Loss	dBm	-39	-69	-57	-29	-59	-47
Interference Margin Due to Coding	dB	-33	-43	0	-33	-43	0
Peak Power into ATC Receiver (w/o Separation Loss)	dBm	-72	-112	-57	-62	-102	-47
Allowable Maximum Interfering Power	dBm	-129.3	-129.3	-128.3	-131.25	-131.25	-130.25
Required Separation Loss	dB	57.3	17.3	71.3	69.25	29.25	83.25
Required Antenna Separation (Free Space, Isotropic Antennas)	Ft	33	<1	165	130	1.3	650
Required Antenna Separation (Free Space with 20 dB Directivity Loss)	Ft	3.3	<1	16.5	13	<1	65
Required Antenna Separation (From Figure 9 with $\Psi = 0°$ and 20 dB Directivity Loss)	Ft	7	<1	30	20	<1	100

FIGURE 8

CAS INTERFERENCE ANALYSIS

Consider the analysis for the 1000 Hz bandwidth under Case A in the worst case situation. The power of each pulse (CAS transmitter power) is specified as 65 dBm. Using the Mason and Zimmerman approximation, the strongest power spectral density expected from the CAS at a frequency 10 MHz removed from its center frequency is 15 dBm/MHz. Using a 1 kHz bandwidth, the received power would be -15 dBm. With a -14 dB correction from Appendix I, the peak CAS power available to the ATC receiver is -29 dBm. By including an interference margin of -33 dB due to the coding of the ATC message, the level of interference would be -62 dBm (if the CAS transmitter were connected directly into the ATC receiver). Now using a maximum allowable interfering power of -131.25 dBm, the required loss due to the separation of the antennas is 69.25 dB. At frequencies near 1600 MHz this indicates a required free space separation of 130 feet between two isotropic antennas.

However, neither the CAS transmitting antennas nor the ATC receiving antenna is expected to be isotropic. In fact the CAS specification is for uniform horizontal coverage from both the lower antenna and the upper antenna which would imply a vertical monopole or dipole type antenna. Meanwhile the ATC receiving antenna is expected to be a vertically directed slot, horn or phased array. Although the ATC antenna is a low gain type, its pattern in the horizontal direction is considerably reduced. Therefore, by noting the decrease in field strength at 90° for even a single dipole reduction of 20 dB in the received power from the CAS. Therefore the required separation to see no interference in the ATC from the CAS may be stated as 13 feet.

Certain studies have been made concerning the coupling between antennas on the surface of a cylinder. However, these studies are rather limited in their application to this problem due to the directivity of the antennas involved. As a more or less gross check of the above results, by applying the same 20 dB correction and entering Figure 9 at 49 dB on the Ψ=0° curve, a required separation of 25 feet is obtained. For the case when the CAS is transmitting from the antenna mounted on the lower side of the aircraft, Figure 9 indicates that with either Ψ=135° or Ψ=180°, a coupling loss greater than 69.25 dB is obtained regardless of the longitudinal spacing between antennas. This therefore implies that there would be no interference.

Surveying the bottom two rows of Figure 8, the conclusion then is: By placing the ATC antenna and the upper CAS antenna at a separation of approximately thirty feet only one interference situation would result. This would be the worst case consideration for the ATC reception at 1542 MHz. For the nominal values of CAS transmitter power, pulse widths, and rise and fall times, interference is not expected. Furthermore, where the

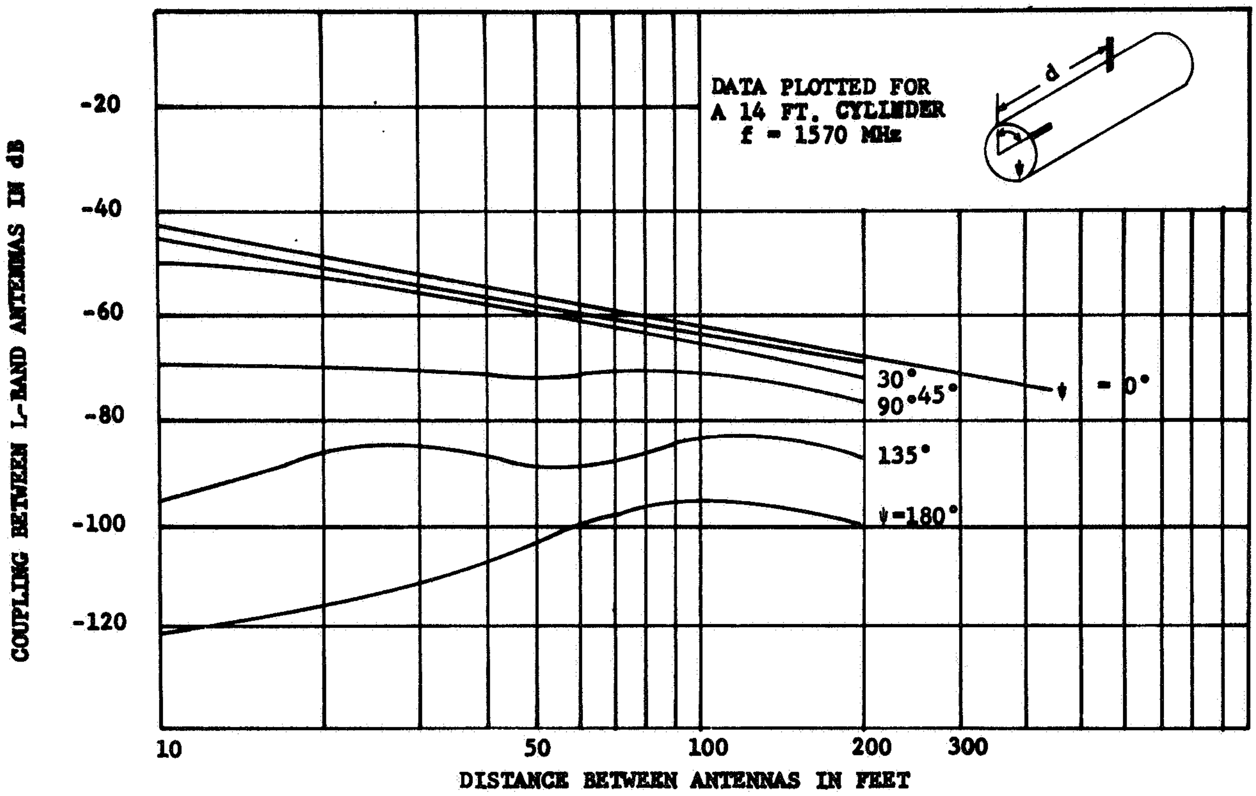


FIGURE 9

COUPLING BETWEEN ANTENNAS ON A CYLINDER

interference is expected, its effect would be minimal due to the short duration of the CAS message. To determine an estimate of the amount of information which would be lost, an in-depth investigation of the ATC receiver and data format would be required.

For the interference to be catastrophic, the tracking of the phase lock loop would have to be affected. Measurements have shown that pulse signals at a duty cycle of 0.01 (much greater than the CAS duty cycle) would have to be on the order of 40 dB above a locked-on carrier to steal the loop lock. In none of the situations shown would the interference be at that level.

2. Interference with the ATC Receiver by the CAS Transmitter on Another Aircraft.

This situation is essentially covered in the previous situation. Referring to Figure 8 once again, the second and third rows from the bottom apply. Two aircraft each flying a level course would produce interference if their antennas (mounted on their respective fuselages) were within 65 feet of one another. If the aircraft were oriented such that the ATC antenna was looking straight at the opposing CAS antenna, a separation of 650 feet would be required. Since this would require opposite roll maneuvers, this orientation would certainly not last very long. Therefore no interference is expected from the CAS on another aircraft.

3. Interference with the ATC Receiver by the Glide Slope Transmitter.

Since the Glide Slope signal is essentially a CW signal, the Glide Slope transmitter has a very sharp output spectrum (see Figure 10). There should be no interference with any system operating more than 0.5 MHz away from the transmitting center frequency unless the receiver had an exceptionally wide bandwidth. As shown in Figure 1, there is an adequate frequency separation.

4. Interference with the ATC Receiver by the Radar Altimeter on the Same Aircraft.

Here the same six interference situations are analyzed as were done previously under (1). That is, the nominal and worst case conditions for the ATC reception are assumed. Case A refers to reception at 1590 MHz where two different tracking bandwidths and coding margins are considered while Case B refers to reception of 1542 MHz. The Radar Altimeter is assumed to be operating at 1622.5 MHz. Average power spectral density plots for four representative radar altimeters are shown in Figure 11. The average power spectral density is used here rather than peak since the Radar Altimeter pulse widths are all much less than the reciprocal of the ATC receiver bandwidths.

The interference analysis is presented in Figure 12. The overall worst situation results in a required separation

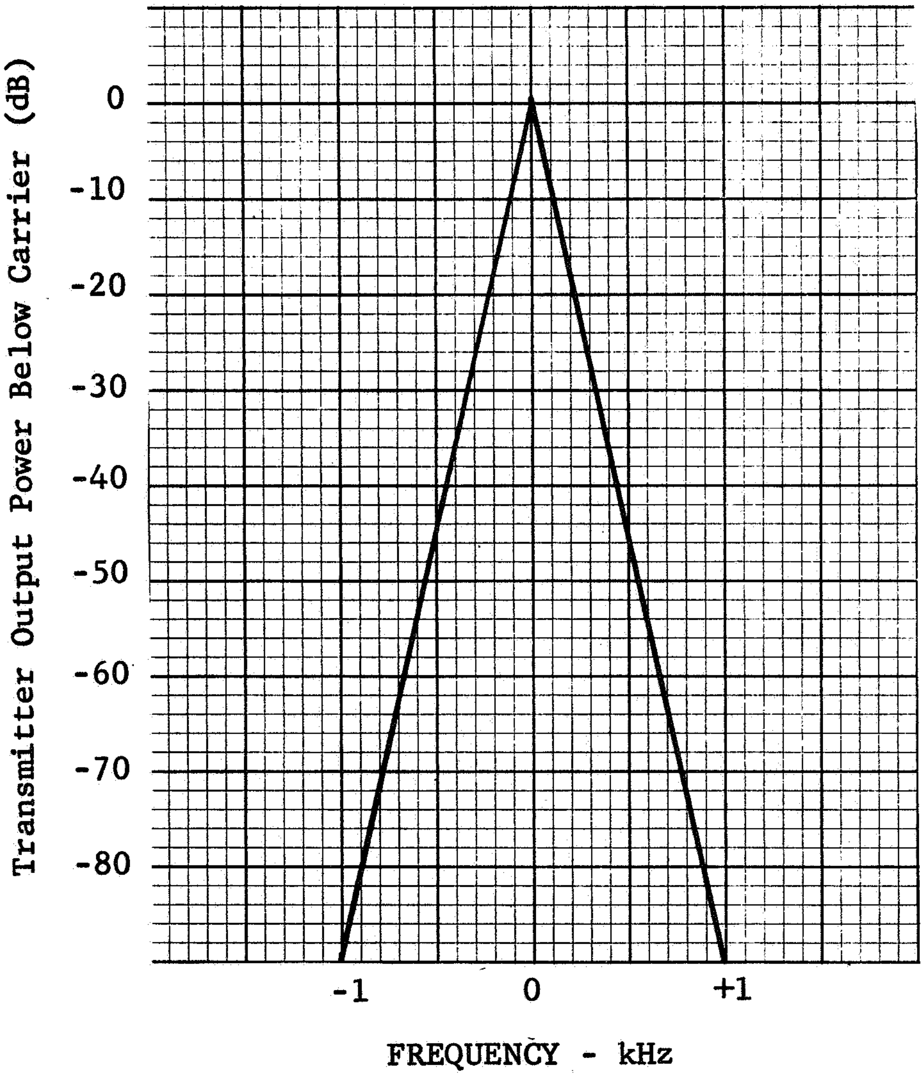


FIGURE 10

GLIDE SLOPE TRANSMITTER OUTPUT SPECTRUM

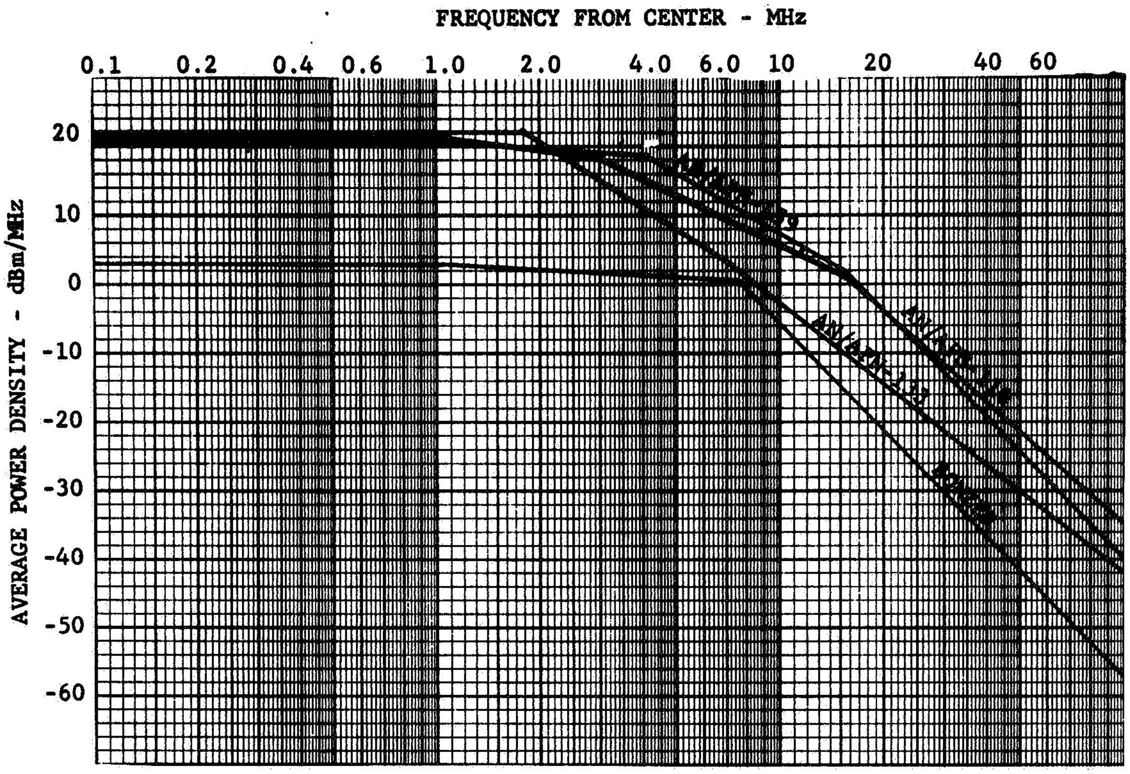


FIGURE 11

RADAR ALTIMETER AVERAGE POWER DENSITY SPECTRA

ASPECT	UNITS	NOMINAL			WORST		
		Case A		Case B	Case A		Case B
Transmitter Average Power Density at Altimeter Center Frequency	dBm/MHz	22	22	22	22	22	22
Transmitter Average Power Density at ATC Center Frequency	dBm/MHz	-13	-13	-31	-13	-13	-31
Tracking Bandwidth of ATC	kHz	1.0	0.1	2.5	1.0	0.1	2.5
Average Power into ATC Receiver w/o Coding or Separation Loss	dBm	-43	-53	-57	-43	-53	-57
Interference Margin Due to Coding	dB	-33	-43	0	-33	-43	0
Average Power into ATC Receiver w/o Separation Loss	dBm	-76	-96	-57	-76	-96	-57
Allowable Interfering Power	dBm	-129.3	-129.3	-128.3	-131.25	-131.25	-130.25
Required Separation Loss	dB	53.3	33.3	71.3	55.25	35.25	73.25
Required Antenna Separation (Free Space, Isotropic Antennas)	Ft	21	2.1	165	26	2.6	205
Required Antenna Separation (Free Space with 30 dB Shielding and Directivity Loss)	Ft	<1	<1	5.2	<1	<1	6.5

FIGURE 12

RADAR ALTIMETER INTERFERENCE ANALYSIS

loss of 73.25 dB. For free space with isotropic antennas, a separation of 205 feet is required for no interference. However, the directivity and orientation of the antennas indicates an additional loss of 30 dB is a reasonable assumption, based on the combined antenna isolation effects. The Radar Altimeter antenna is relatively high gain, positioned on the underside of the aircraft, while the ATC antenna is on the top side. In the worst case then, a separation of 6.5 feet would be adequate. With an aircraft diameter of 14 feet, no real restriction of the positioning of the antennas is indicated.

5. Interference with the ATC receiver by a Radar Altimeter on Another Aircraft.

If another aircraft were above the test aircraft such that the ATC antenna were in the main lobe of the radar altimeter in question, interference could occur. Assuming approximately a 30 dB gain for the radar altimeter antenna, the required antenna separation for free space isotropic antennas (see Figure 12) would increase by a factor of approximately 30. In the worst case this would require a separation greater than one mile. However, such an orientation between two aircraft is not likely to last for any substantial period of time even when flying in the same general direction. Therefore no interference is expected in this situation.

6. Interference with the CAS Receiver by the ATC Satellite Transmitter.

The specification for the CAS hazard range for an approaching aircraft is 40 nautical miles with a 10 dB fade margin and a synchronization range of 97 nautical miles with "some" fade margin. Using the 97 NM figure, the free space loss is 143 dB. With a nominal transmitted power of 59 dBm and assuming a 6 dB fade, the received CAS signal would be at a level of -90 dBm. Since the interfering ATC signal is expected to be at a level of -122 dBm, no interference is expected.

7. Interference with the CAS Receiver by the Glide Slope Transmitter.

This is the same as (3) where the conclusion is that there should be no interference with any system operating more than 0.5 MHz away from the transmitting center frequency.

8. Interference with the CAS Receiver by the Radar Altimeter on the Same Aircraft.

Assuming that the Radar Altimeter is operating at a frequency of 1622.5 MHz, the nearest CAS frequency is at 1615.0 MHz. The average output power density for the radar altimeter is then 11 dBm/MHz. The spurious response specification for the CAS, as indicated in the ATA report (see bibliography), indicates that the CAS shall be able to operate in the presence of an interfering signal at 1622.5 MHz at a level of -25 dBm. If the CAS bandwidth were as wide as 1 MHz, the signal at the Radar Altimeter antenna would be 11 dBm. Thus a propagation loss of 36 dB would be required between the two antennas. This is equivalent to a free space separation of 3 feet between two isotropic antennas. Considering that the directivity of the Radar Altimeter antenna would mean less power at the CAS antenna, no interference is expected for separation greater than 1 foot.

9. Interference with the CAS Receiver by a Radar Altimeter on Another Aircraft.

In light of the analysis in (8) above and an additive directivity of 30 dB, an antenna separation of 100 feet would be adequate to avoid interference from the radar altimeter on another aircraft.

10. Interference with the Glide Slope Receiver by the ATC Satellite Transmitter.

At a distance of 10 miles from the Glide Slope transmitting antenna, the receiver power is approximately -52 dBm. Since the ATC signal is at a level of -122 dBm, no interference is expected.

11 and 12. Interference with the Glide Slope Receiver by the CAS.

As stated above, the specified Glide Slope signal power at the receiver is -52 dBm. Also, the Glide Slope frequency is in the 1557.5 to 1567.5 MHz band. With the nearest CAS frequency at 1600 MHz, the peak CAS power density is -5 dBm/MHz. Assuming a 50 kHz Glide Slope receiver bandwidth, the peak CAS power becomes -18 dBm. The separation loss between the Glide Slope and CAS antennas must then be 34 dB for no interference. For isotropic antennas this implies a separation of 2 feet. Considering that the Glide Slope antenna will have moderate directivity looking forward at a slight downward tilt (looking away from the CAS antennas) no interference is expected from the cosite mounted antennas.

For the CAS on another aircraft to interfere with the Glide Slope receiver, the other aircraft would have to be in front of the test aircraft at a distance less than 20 feet; another unlikely situation.

13 and 14. Interference with the Glide Slope Receiver by Radar Altimeters.

Here again the Glide Slope signal power at the receiver is taken as -52 dBm at a frequency of 1567.5 MHz. The center frequency for the Radar Altimeters is taken as 1622.5 MHz giving a frequency separation of 55 MHz.

In the worst case, AN/APN-110, the average power density is -24 dBm/MHz. With a receiver bandwidth of 50 kHz, the interfering power is -40 dBm. A coupling loss of 12 dB is thus required between the Glide Slope antenna and the Radar Altimeter antenna. Even considering additional antenna directivity gains, neither the cosite mounted Radar Altimeter nor one on another aircraft would interfere with the Glide Slope receiver. A one foot separation easily fulfills this criteria.

APPENDIX I

Collision Avoidance System Analysis Techniques

A widely used technique for interference analysis when the output spectrum from a transmitter is unknown is to approximate the expected spectrum by one of a variety of techniques. Generally the worst (or widest) spectrum is found from the shortest pulse in the output message. The level of the resulting power spectral density is then found using the power level of the pulse.

In the CAS message format shown in Figure I-1, a variety of pulses exist. First there is the Range/Doppler pulse, a 200 μsec burst of biphase modulation which may contain the Epoch Start triplet, three pulses of nominally 1.6 μsec duration. Then there are the four 4.0 μsec pulses containing the altitude and heading information. Finally there is the synch reply triplet, again three pulses of 1.6 μsecs duration.

Synch Reply Pulse

At first glance, the 1.6 μsec synch reply pulse appears to produce the widest output spectrum. The actual pulse is shown in Figure I-2 with the nominal and worst case straight line approximations. The approximations were used so that the Mason and Zimmerman envelope bounds could be drawn.

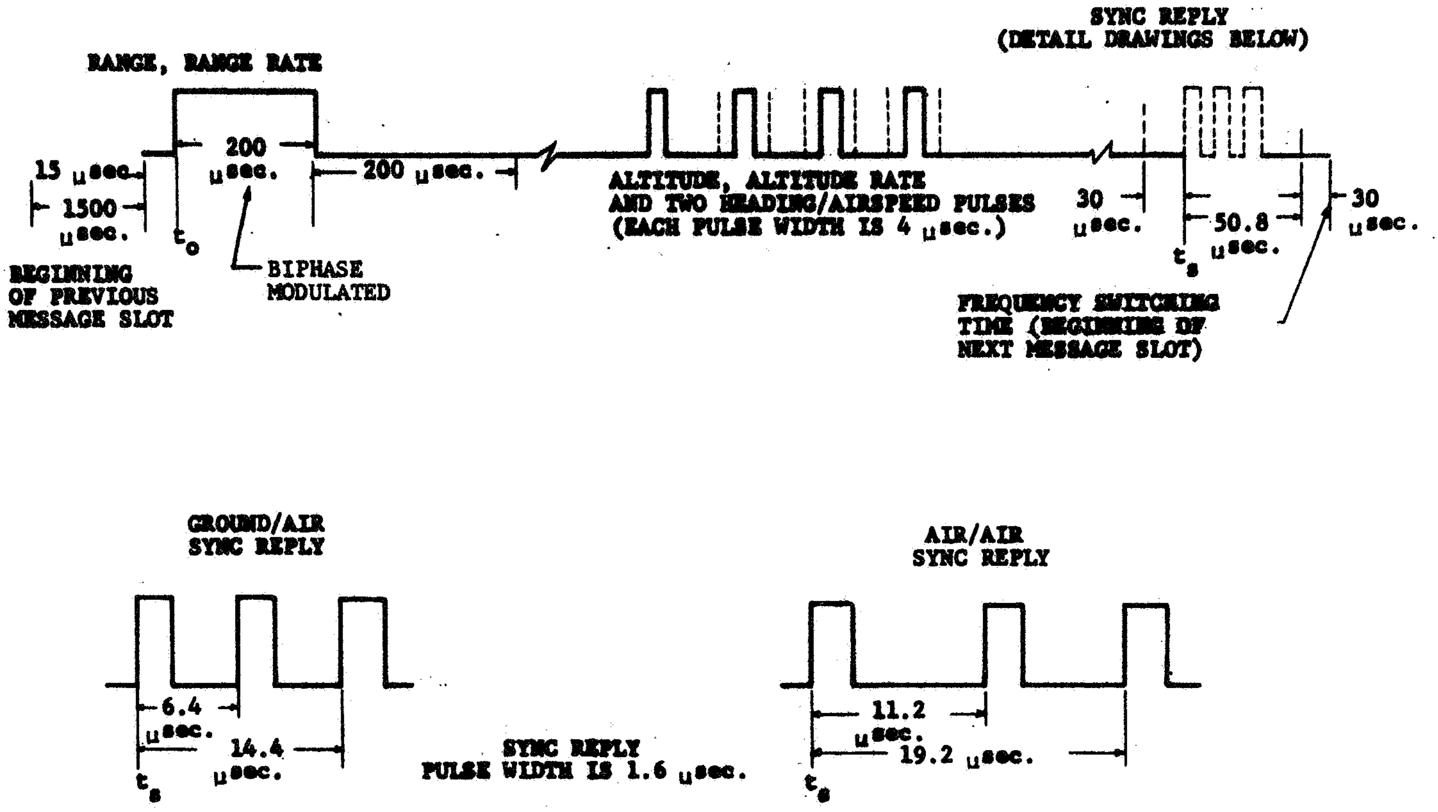
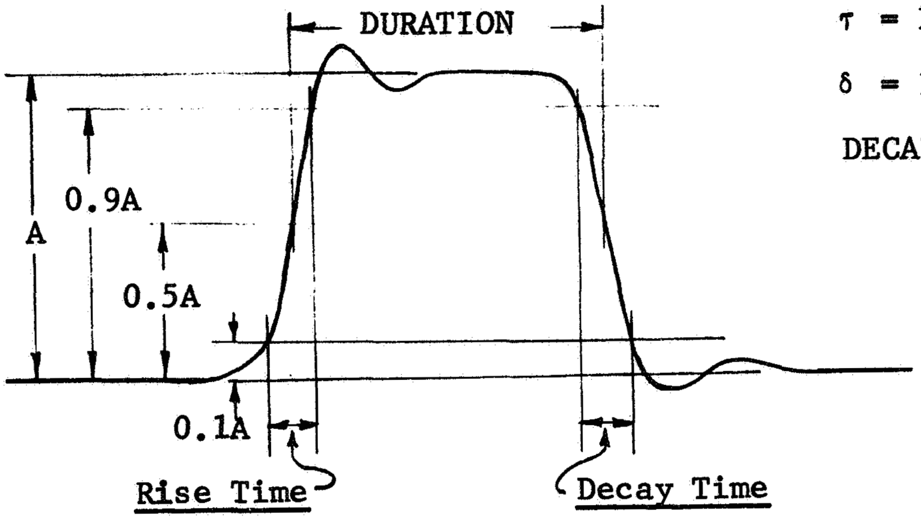


FIGURE I-1

COLLISION AVOIDANCE SYSTEM MESSAGE FORMAT, BASIC SIGNAL

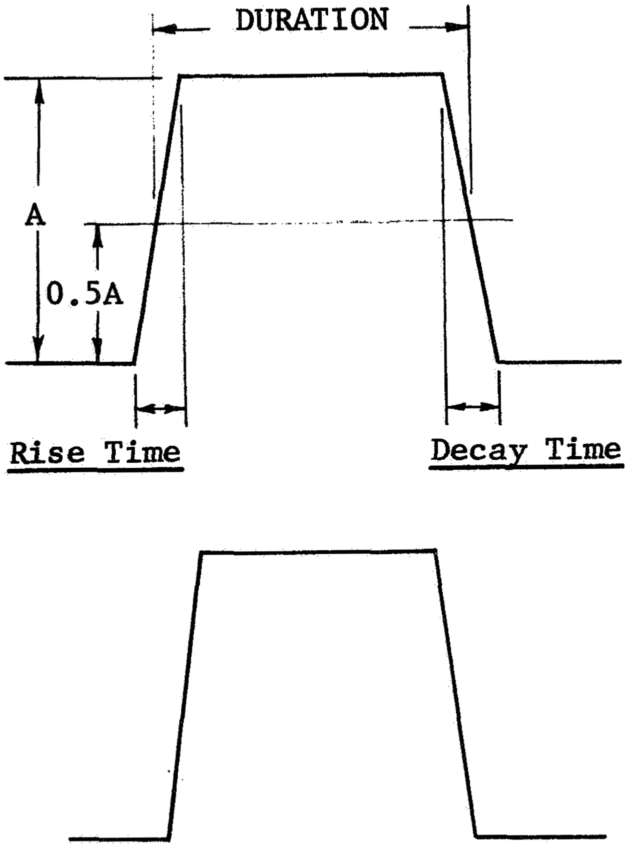


τ = DURATION = 1.6 ± .2 usec

δ = RISE TIME = 0.3 ± 0.1 us

DECAY TIME = $0.3^{+0.2}_{-0.1}$ usec

ACTUAL PULSE



NOMINAL:

DURATION = 1.6 usec

RISE TIME = 0.3 usec

DECAY TIME = 0.3 usec

WORST:

DURATION = 1.4 usec

RISE TIME = 0.2 usec

DECAY TIME = 0.2 usec

APPROXIMATION PULSES

FIGURE I-2

CAS SYNCH REPLY PULSE

Straight Line Approximation of the Power Density Spectrum for a Trapezoidal Pulse

Mason-Zimmerman state that the boundary of the frequency spectrum of a trapezoidal pulse is enclosed within the following envelope, Figure I-3.

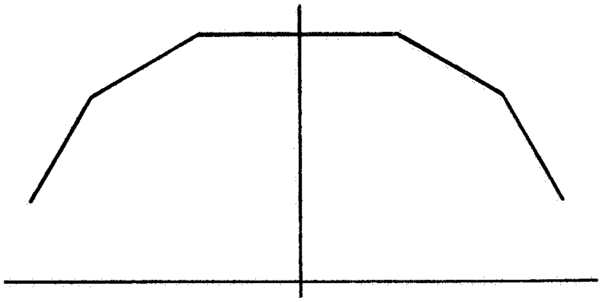


FIGURE I-3

MASON-ZIMMERMAN BOUNDS

It is indicated that $\Delta f_1 = \Delta f_2$, $\Delta f_3 = \Delta f_4$ and that the various Δf can be found by the following formula:

$$\Delta f_1 = \frac{1}{\pi\left(t+\frac{\delta_1+\delta_2}{2}\right)} \qquad \text{and} \qquad \Delta f_3 = \frac{1}{2\pi}\left(\frac{1}{\delta_1}+\frac{1}{\delta_2}\right)$$

where:

t is the pulse width measured along the top of the pulse

δ_1 is the rise time of the pulse

δ_2 is the fall time of the pulse

If the rise time equals the fall time and τ is the half amplitude pulse width then:

$$\Delta f_1 = \frac{1}{\pi\tau} \qquad \text{and} \qquad \Delta f_2 = \frac{1}{\pi\delta_1}$$

In order to determine if any significant difference existed between the Mason-Zimmerman bound and the exact spectrum for a trapezoidal pulse, the exact spectrum was calculated using the computer program shown in Figure I-4. Although the resulting plot (Figure I-5) shows large nulls occuring every 5 MHz, since the frequencies correspond to $^1/\delta$, their placement cannot be depended upon. The result is that the Mason-Zimmerman bound (Figure I-6) is indeed a worthwhile approximation to use.

Range/Doppler Pulse

Although the Range/Doppler pulse has a 200 μsec width, the biphase modulation is such that the phase could change every microsecond. Thus the Range/Doppler pulse could look like a burst of 1 μsec pulses with nominally 0.4 μsec rise and fall times. Therefore the Mason-Zimmerman approximation for a 1 μsec pulse with the fastest specified rise time (0.3 μsec) is presented in Figure I-7 for comparison with Figure I-6. At a delta-frequency of 10 MHz the worst power spectral density of one synch reply pulse is 15 dBm/MHz while that of one pulse of biphase modulation is 13 dBm/MHz; no significant difference.

```
90    P9 = 3.14159265
100   'FOURIER FOR 3 TRAPEZOIDAL PULSES'
110   'ENTER A1, A2, T1, T2, S1, AND S2.'
120   '  (T1, T2, S1, AND S2 ARE IN MICROSECONDS.)'
130   INPUT A1, A2, T1, T2, S1, S2
140   PRINT
150   'FMIN CANNOT BE ZERO.'
160   'ENTER FMIN, FMAX, AND DELTA-F,'
165   'WARNING -- CHOOSE CAREFULLY -- OUTPUT OF 50 PAGES IS COMMON!'
170   INPUT F7, F3, D1
180   PRINT
190   PRINT
200   F5 = F7 / D1
210   F4 = F3 / D1 + 4
220   FOR I = F5 TO F4
230   F = I * D1
240   B1 = P9 * F * T1
250   B2 = P9 * F * T2
260   P1 = SIN(B1) / B1
270   P2 = SIN(B2) / B2
280   T8 = A1 * P1 * P1 - A2 * P2 * P2
290   T9 = T8 * T8
300   T7 = 10 * LGT(T9)
310   W1 = 2 * P9 * F * S1
320   W2 = 2 * P9 * F * S2
330   W3 = 2 * P9 * F * (S1-S2)
340   S4 = 3 + 2 * (COS(W1) + COS(W2) + COS(W3))
350   P5 = T9 * S4
360   P6 = 10 * LGT(P5)
400   PRINT F, T7, P6
430   IF F > F3 THEN 450
440   NEXT I
450   PRINT
460   'DO YOU WANT TO TRY ANOTHER DATA SET';
470   INPUT AS
480   IF AS = 'YES' THEN 600
490   IF AS = 'NO' THEN 999
500   'YES OR NO';
510   GO TO 470
600   PRINT
610   PRINT
620   GO TO 110
999   END
```

DATA

	CASE	A1	A2	T1	T2	S1	S2
WORST	I	3.2	1.8	.8	.6	11.2	8.0
NOMINAL	II	3.02	1.41	.95	.65	11.2	8.0
	III	3.2	1.8	.8	.6	8.0	9.0
	IV	3.02	1.41	.95	.65	8.0	9.0
	V	3.0625	1.5625	.875	.625	11.2	8.0

FIGURE I-4

COMPUTER PROGRAM AND DATA

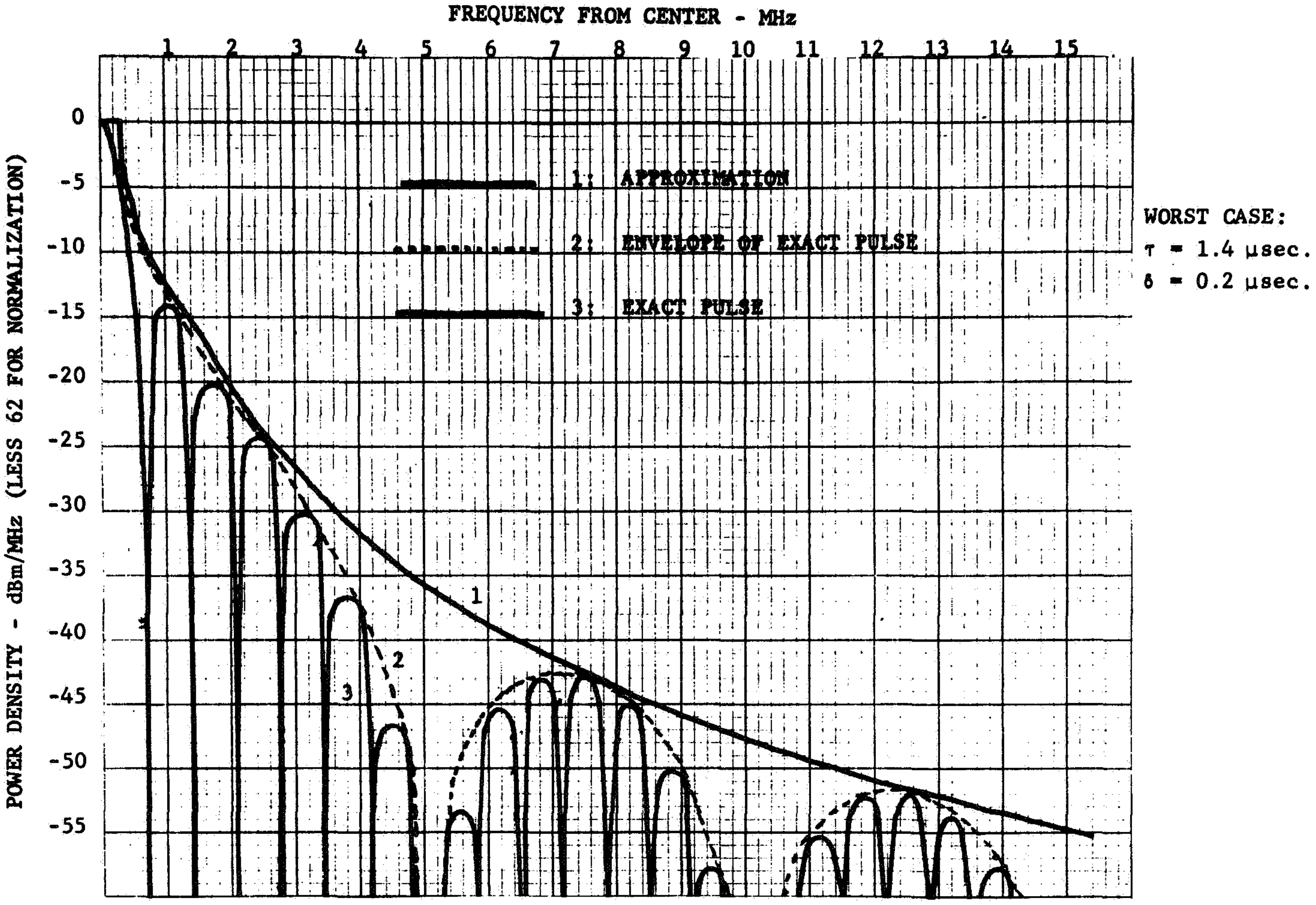


FIGURE I-5

EXACT POWER DENSITY SPECTRUM OF ONE TRAPEZOIDAL PULSE - NORMALIZED

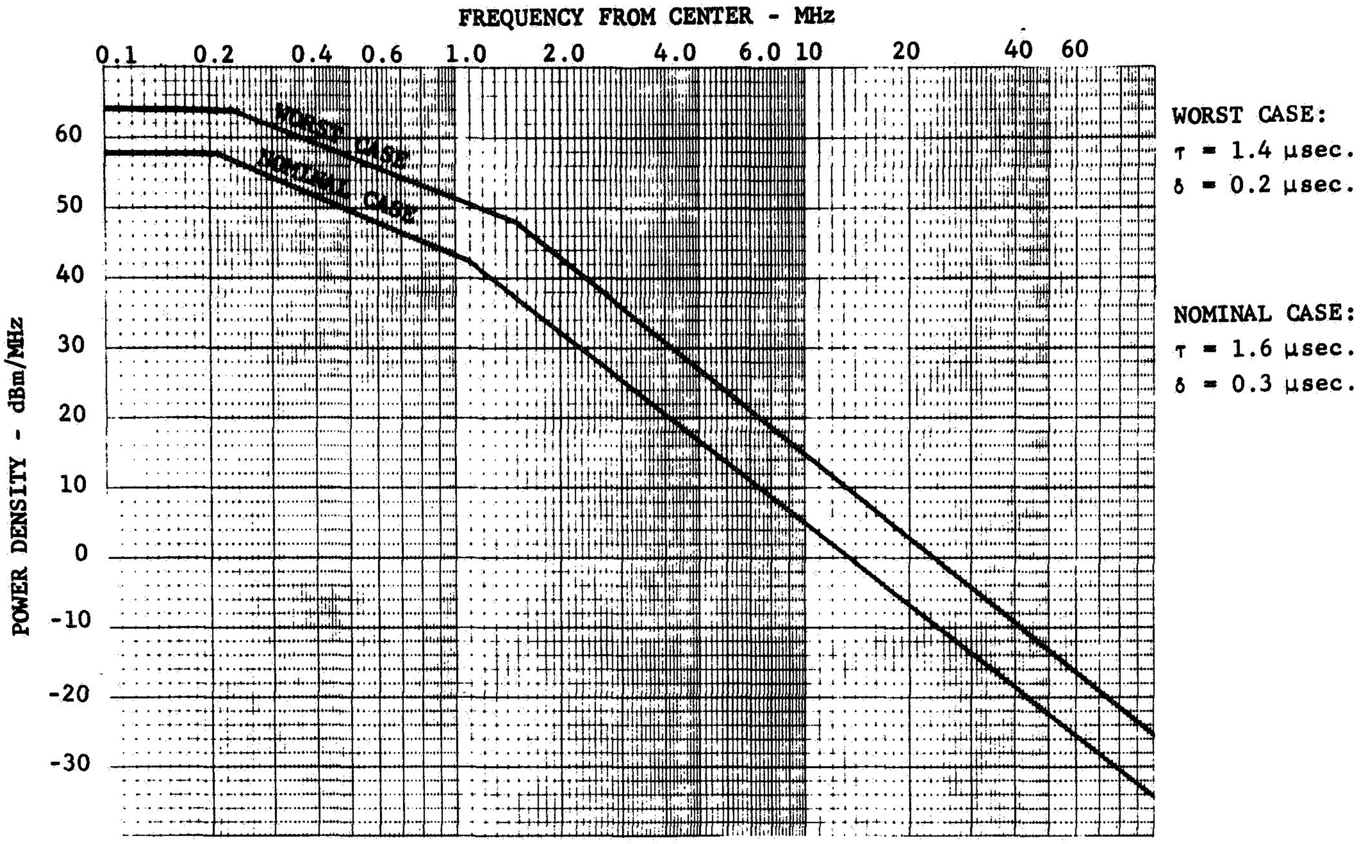


FIGURE I-6

APPROXIMATE POWER SPECTRAL DENSITY OF ONE SYNC REPLY PULSE

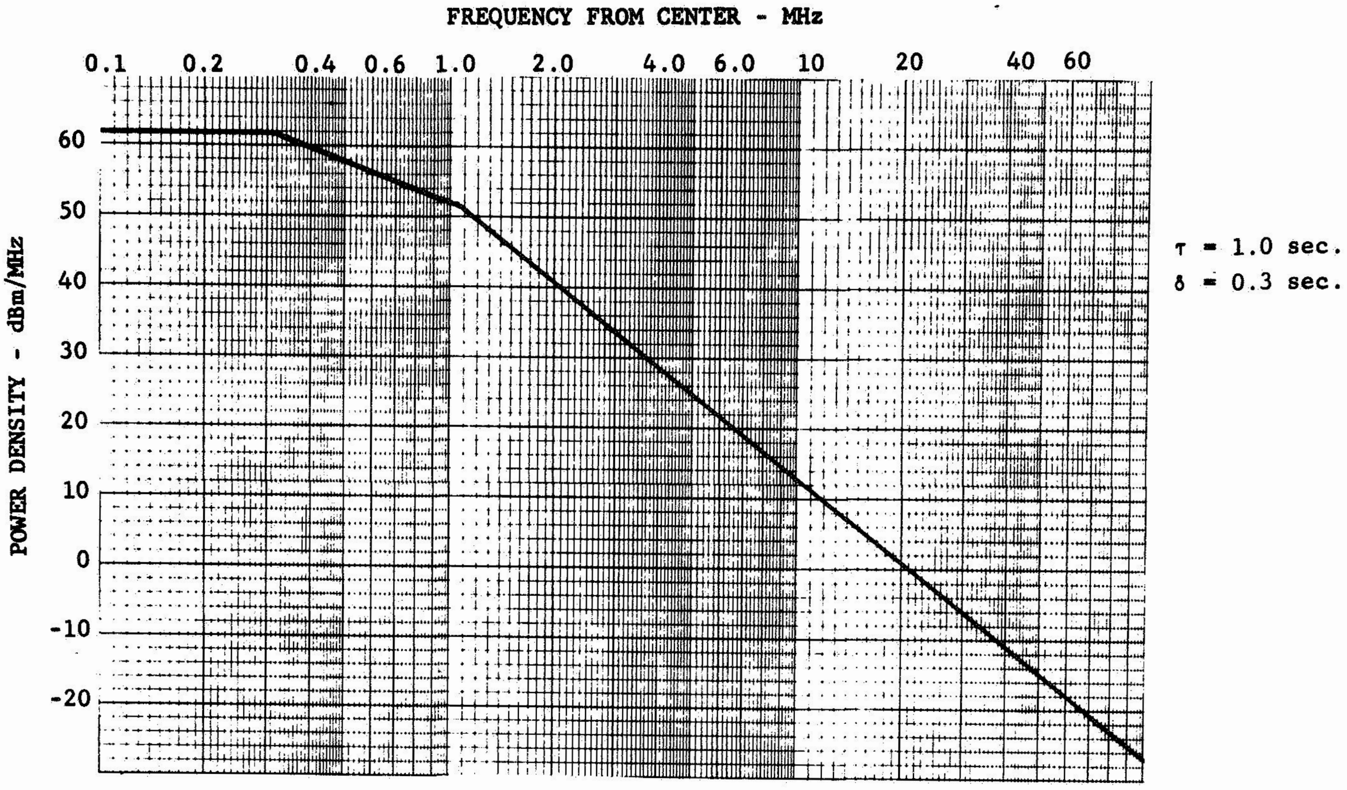


FIGURE I-7

APPROXIMATE POWER SPECTRAL DENSITY OF ONE PULSE OF BI-PHASE MODULATION

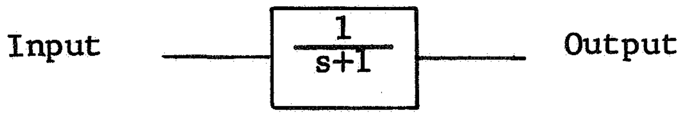
Effect of Receiver Bandwidth

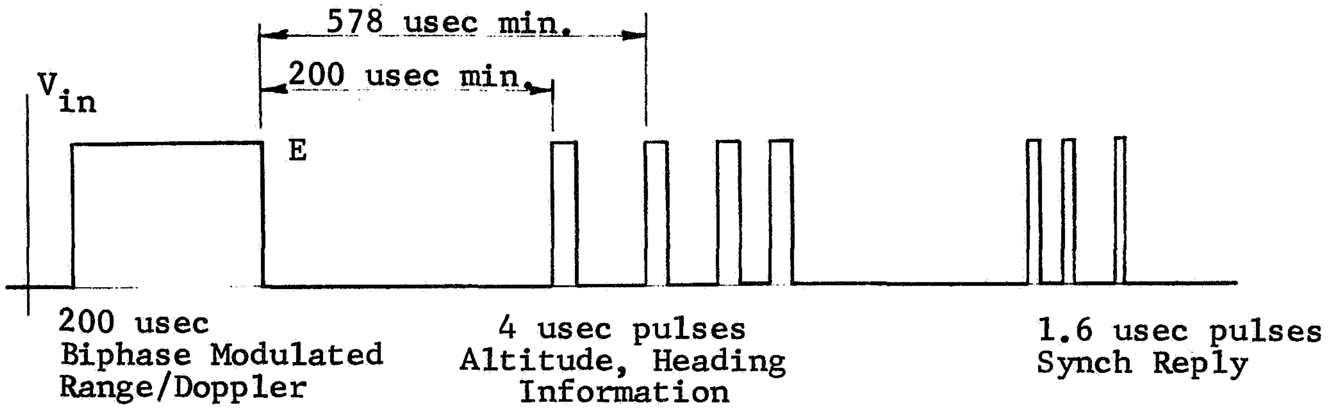
When a pulse of short duration is passed through a low pass filter, the output of the filter is a relatively long smear whose peak is determined by the pulse width and amplitude and the filter time constant. If a pulse train is considered instead of a single pulse, the output voltage smear varies around a d-c level which is equal to the d-c level of the input. Generally for narrow bandwidth receivers with pulse type interference, this d-c level is used for the interfering power level. The Collision Avoidance System, however, has such a long time between bursts that the d-c level would be meaningless.

Consider the CAS message format again in Figure I-8. If the filter time constant τ is much less than the repetition period of no less than 3 seconds, then the output wave will begin from zero when the Range/Doppler pulse begins. The equation for V_o is then

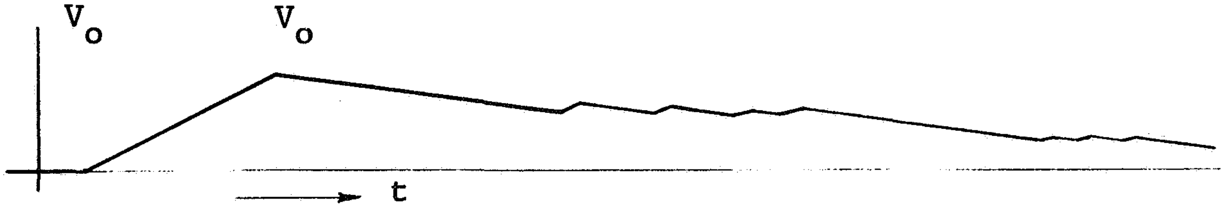
$$V_o = E(1-e^{-\frac{t}{\tau}}) \doteq E\,\frac{t}{\tau} \text{ for } t<<\tau$$

Figure I-9 summarizes the peak values for V_o for the three ATC bandwidths considered in the body of this report. The last column of Figure I-9 is the correction applied to the peak power density.





Input Wave (Not to scale)



Output Wave (Not to scale)

FIGURE I-8

CAS SIGNAL THROUGH A LOW-PASS FILTER

Bandwidth (Hz)	τ (μsec)	t (μsec)	$\frac{t}{\tau} = \frac{V_o \text{ peak}}{E}$	$20 \log \frac{V_o \text{ peak}}{E}$
2500	400	200	1/2	-6
1000	1000	200	1/5	-14
100	10000	200	1/50	-34

FIGURE I-9

PEAK VALUES OF FILTERED CAS MESSAGE

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