Criteria for Positioning Active Multilateration Stations Located Close to Distance Measuring Equipment

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The need for the use of another surveillance system when radar cannot be used is the reason for the development of the Multilateration (MLT) Systems. However, there are many systems that operate in the L-Band (960-1215MHz) that could produce interference between systems. At airports, some interference has been detected between transmissions of MLT systems (1030MHz and 1090MHz) and Distance Measuring Equipment (DME) (960-1215MHz).

1. INTRODUCTION

It is therefore necessary to study MLT and DME Systems and investigate the possibility of interferences existing between them. This research involves two main phases:

- **Static Analysis:** This calculates the interference signal level available at the receiver in terms of distance. It aims to establish the received power as a function of the distance between multilateration and DME antennas, determining at the received nominal frequency when the interference signal level available is below the sensitivity of the receiver.
- **Dynamic Analysis:** This is to show the behavior of the receiver when interferences are introduced and how under this situation it acquires the received signal. By using this simulated signals and receiver (specifically modeled), the system is analyze an evaluated by taking characteristics of the detections as functions of the channel frequency of the DME and the distance between antennas.

1.1 MLT

MLT is a surveillance system that calculates the aircraft position by means of measurement of time difference of arrival (TDOA) of the transponder squitter, for which there is a need for a minimum of 3 station receiver.

The operating principle of this system is based on the principle of secondary radar (SSR): ground interrogator excite the aircraft transponder (1030MHz), which in turn emits the squitter (1090MHz) that is received at the ground station receiver. The TDOA is processed by a central unit to determinate the aircraft position. [3]

1.2 DME

The DME provides the aircraft with an indication of the slant distance between the onboard equipment and ground system, in line of sight. This slant distance measurement is the first error to consider; this error increases as the aircraft get closed to the ground station.

The operating principle of the DME is that the onboard equipment emits an interrogation signal formed by a pair of pulses with nominal value of 3.5µs. Initially these interrogations are made in search mode between 20 and 150pps. This interrogation is captured by ground system which replies with the same sequence but delays the signal for some time (systematic delay) depending on the mode used (Mode X or Y), with a constant rate of 2700pps useful cycle.[1][2]

2. STATIC ANALYSIS

2.1. Propagation models

These models attempt to predict the propagation losses based on optical geometry. Two types of models are considered:

- Free space: It considers isotropic antennas located in a perfect, homogeneous and isotropic dielectric and an ideal medium without obstacles, maintaining the distance between antennas.

$$L_{tf}(dB) = L_{bf}(dB) - G_t(dB) - G_r(dB)$$

Equation 1: Transmission losses in the free space

  Where:

  - $L_{bf}(dB) = 20 \cdot \log\left(\frac{4\pi d}{\lambda}\right)$: Basic losses in the free space. [4]
    - d: Antennas distance (m).
    - λ: Wavelength (m) is equal to c/f, where c is the speed of light ($3 \cdot 10^8$ m/s) and f is the frequency.
  - G_t: Transmitter gain.
  - G_r: Receiver gain.

- Free space modified by ground effect: This is used in the case of Very High Frequency (VHF) band and higher. The hypothesis of this model is based on the ground plane, homogeneous environment, small incidence angle ($\psi << 1$). And also the modulus of the reflection coefficient is approximately equal to one ($|R| \cong 1$) and has a phase approximately equal to pi ($\beta \cong \pi$).

$$l_b = \left(\frac{4\pi \cdot d}{\lambda}\right)^2 \left(\frac{\lambda \cdot d}{4\pi \cdot h_{tx} \cdot h_{rx}}\right)^2 = \frac{d^4}{(h_{tx} \cdot h_{rx})^2}$$

Equation 2: Basic loses

  Where:

  - h_{tx}: height of transmitter antenna.
  - h_{rx}: height of receiver antenna.
  - d: Distance between antennas (m).

  It is important to note that this model is valid at distances higher than $(12 \cdot h_{tx} \cdot h_{rx} / \lambda)$, because is the region in which all the hypothesis are applicable.

2.2. Calculation of received power at multilateration ground beacon receiver

The objective of this subsection is to determine the power of the signal from the DME/N ground transmitter received at the multilateration ground beacon receiver. This is expressed by the signal level as a function of the range using the following expression:

$$p_{dR} = A_{eR} \cdot \varphi_i = \frac{\lambda^2}{4\pi} g_R \frac{p_{eT} \cdot g_T}{4\pi \cdot d^2}$$

Equation 3: Friis Equation

Where:

- A_{eR} is the effective area.
- φ_i is the power density produced by the transmitter antenna in the place of the receiver antenna.
- P_{eT} is the power level signal transmitted.

$$p_{dR} = p_{eT} \cdot g_{tx} \cdot g_{rx} \frac{(h_{tx} \cdot h_{rx})^2}{d^4}$$

Equation 4: Power available at the receiver with corrected field

Where:

- $G_{tx(DME)}$=12dB. Transmitter gain (DME ground transmitter).
- $G_{rx(MLT)}$=0dB. Receiver gain (MLT ground receiver).
- p_{eT} has to be equal to 100W in a DME/N in Terminal areas and 1000W for DME/N en Route.
- $c=3\cdot10^8$m/s. Speed of light.
- $h_{tx(DME)}$=3.5m. Height of transmitter antenna (DME ground transmitter).
- $h_{rx(MLT)}$=3m. Height of receiver antenna (MLT ground receiver).
- f=frequency. There are two cases that is important to analyze:
  - Nominal transmitter frequency: This is the DME transmitter channel frequency (962-1024MHz and 1151-1213MHz), which gives the signal with more power. The most interesting studies, for this case, are realized when using the frequency close to the nominal receiver frequency (1090MHz) which is the signal that might result in interferences.
  - Nominal receiver frequency: This is the MLT reception frequency (1090MHz), which might create more interference. In this case, it is necessary make use of spectrum of the DME/N, which permits the application of correspondent attenuation of the power signal (see Figure 1).

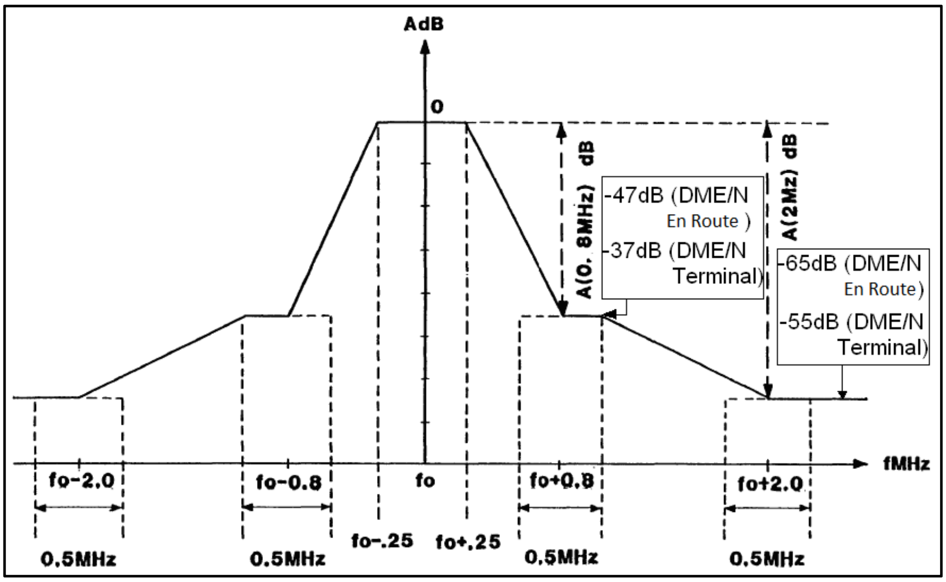

Figure 1: DME spectrum envelope shape

Figure 2 and Figure 3 shows an example of a nominal DME frequency (interference signal) of 1024MHz. In these diagrams there are five curves to consider:

- The solid red line depict the computed DME signal power level entering MLT ground beacon receiver at antenna output port making use of free-space propagation mode.
- The dotted red line represent the same as the solid red line but using free-space propagation modified by ground effect at the transmitter DME frequency.
- The black solid line represents the same as the solid red line but at the nominal receiver frequency.
- The black dotted line denotes the same as the previous curve but with free-space modified by ground effects.
- The violet line correspond to sensitivity value, -85dBm to MLT.

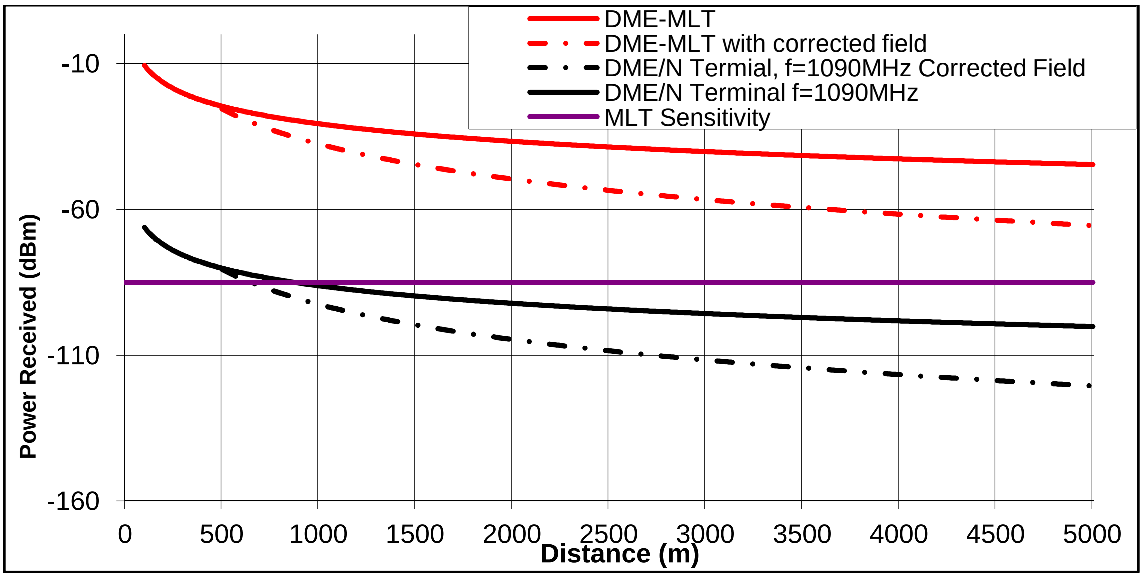

Figure 2: Received power at multilateration ground station by DME/N ground transmitter, with P_t=100W and f=1024MHz

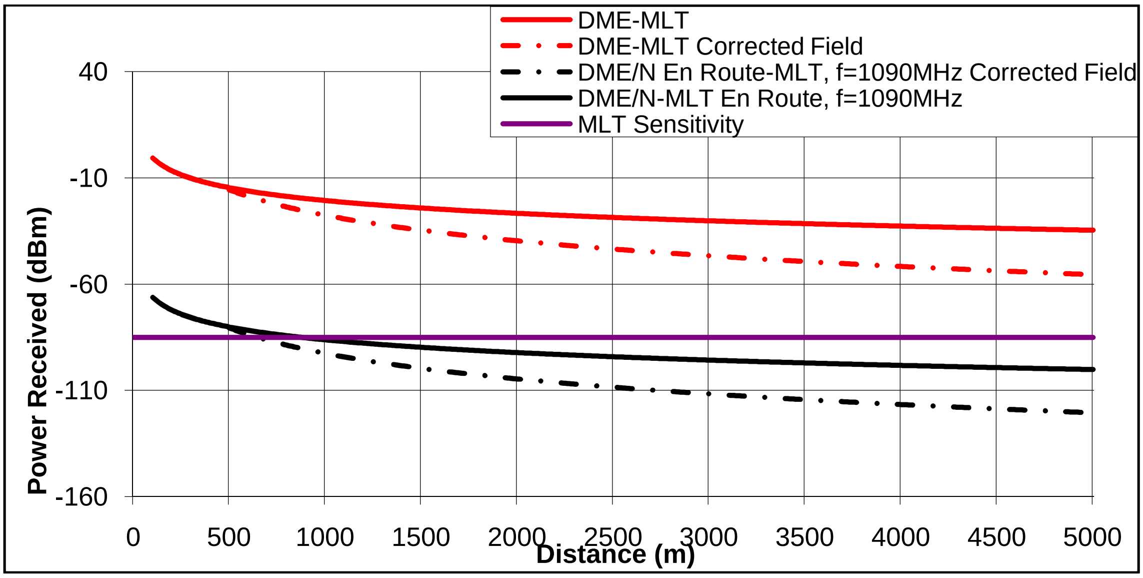

Figure 3: Received power at multilateration ground station by DME/N ground transmitter, with P_t=1000W and f=1024MHz

The goal of this study is to calculate the distance which the receiver sensitivity is above interference signal power level. The most interesting case in this analysis is when the frequency of the interference is equal to the nominal receiver frequency because the receiver filter might delete the other interferences. For example: using a Butterworth filter of 6^{th} order and 22MHz of bandwidth, at 60MHz (minimum difference between nominal frequency received and transmitted), the signal is attenuated around -110dB.

The results of this analysis is made from conservative point of view because of the spurious attenuation is at 65dB (DME/N En route) and at 55dB (DME/N Terminal areas). The result indicates the need to separate the interfering antenna and the receiver antenna by 650m for both types of DME (en routes and Terminal areas). It is important to observe that the DME/N transmit the 90% of the signal power level at 2MHz, thus is reasonable that at 60MHz to the nominal transmitted frequency the level of the signal will be below -91dBm (MLT sensitivity).

2.3. *Calculation of received power at DME/N ground beacon receiver*

This makes use of Equation 3 and Equation 4 like in the section 2.2, but in this case with the following values:

- $G_{tx(MLT)}$=7.5dB. Transmitter gain (MLT ground transmitter).
- $G_{rx(DME)}$=8dB. Receiver gain (DME ground receiver).
- $h_{tx(MLT)}$=3m. Height of transmitter antenna (MLT ground transmitter).
- $h_{rx(DME)}$=3.5m. Height of receiver antenna (DME ground receiver).
- p_{eT} has to be equal to 1200W.
- f=frequency. There are two cases that is important to analyze:
  - o Nominal transmitter frequency: This is the MLT transmitted frequency (1030MHz) that has a signal with more power.
  - o Nominal receiver frequency: This is the DME/N ground reception frequency (1025-1087MHz and 1088-1150MHz {1025-1040MHz Reserved}) that has the signal that might create more interference. In this section, it is necessary to make use of spectrum of the MLT ground transmitter (see Figure 4), which permits the application of correspondent attenuation of the signal power level.
- In the analysis with free-space modified by ground effect propagation model, 2dB of cable losses and 2dB of signal losses have been added.

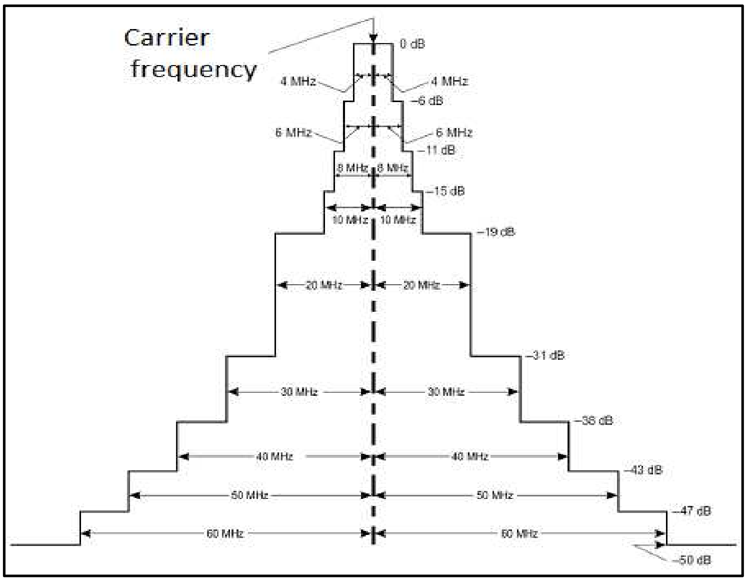

Figure 4: MLT transmitter spectrum envelope shape [3]

In the graph shown in the Figure 5, an example for a nominal MLT transmitted frequency (interference signal) of 1030MHz can be seen. In this diagram, there are six curves:

- The solid red line depict the computed MLT signal power level entering DME ground beacon receiver at antenna output port making use of free-space propagation mode.
- The dotted red line represent the same as the solid red line but using free-space propagation modified by ground effect at the transmitter DME frequency.
- The black solid line represents the same as the solid red line but at the nominal receiver frequency.
- The black dotted line denotes the same as the previous curve but with free-space modified by ground effects.
- The light violet line correspond to sensitivity value, -81dBm to DME/N terminal areas.

- The dark violet line correspond to sensitivity value, -91dBm to DME/N en route.

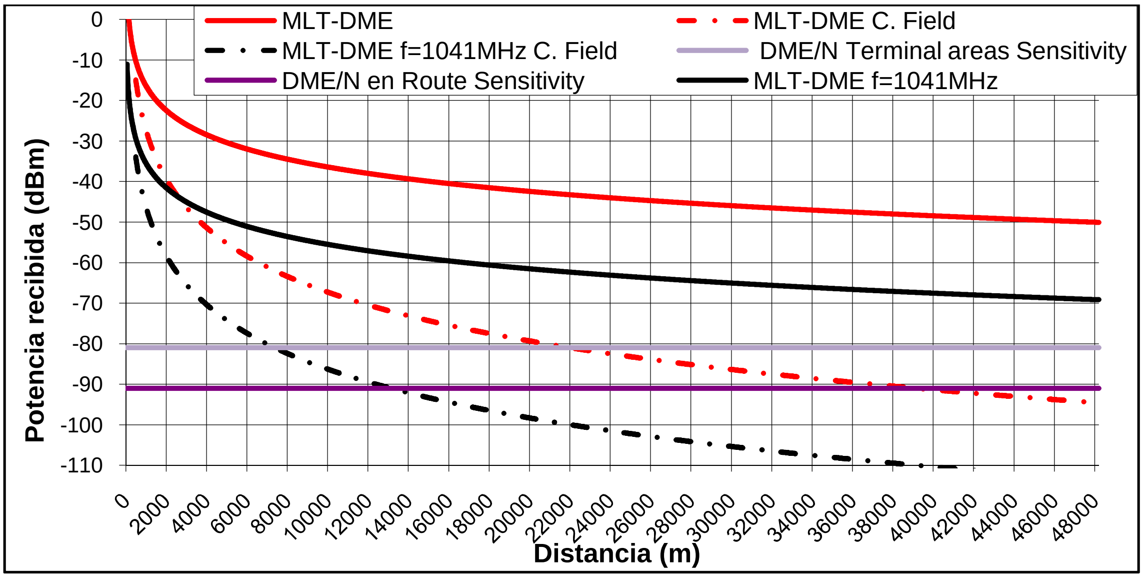

Figure 5: Received power at DME/N ground station by MLT ground transmitter, with Pt=1200W and f=1030MHz

This analysis was performed with every possible value of nominal receiver frequency in conjunction with the Equation 4 because this expression is more realistic. Results can observe in the Table 1.

Table 1: Distance between DME/N-MLT ground antennas to prevent interferences

f_{DME} (MHz)	$\lvert f_{DME}-f_{MLT} \rvert$ (MHz)	MLT Attenuation envelope (dB)	Antennas Distances with Corrected Field (m)	
			Receiver Terminal DME/N	Receiver en Route DME/N
1041-1050	11	-19	7380	13120
1051-1060	21	-31	3700	6580
1061-1070	31	-38	2480	4400
1071-1080	41	-43	1860	3300
1081-1087	51	-47	1480	2620
1088-1090	58	-47	1480	2620
Above 1091	63	-50	1240	2210

3. DINAMIC ANALYSIS

3.1. DME/N ground receptor design

Figure 6 shows the schematic of the DME/N receiver. It begins with the signal passing through the receiving antenna, a bandpass filter and amplifier as first step. This process has not been simulated due to the inability to model the bandpass filter, since the cutoff frequencies are in the GHz band. The purpose of this filter is to avoid the inclusion of interference signals from other parts of the spectrum, for example, it limits the bandwidth of the noise that enters the receiver.

Then there is a local oscillator fixed at the on-board DME channel frequency, to carry out the multiplication of the signal coming out of the local oscillator with the sum of the input signals received (DME interrogation, MLT interference, CW interference, Gaussian white noise). The purpose of this step is to acquire the baseband signal, in other words, the envelope of the interrogation signal, which is the DME pulse signal to be reviewed. The logarithmic amplifier is necessary to regulate the DME signal power level. Finally the video signal is evaluated in order to check if the pair pulse is within tolerances (12±0.1µs distance between pulses and 3.5±0,5µs width of the pulse).

$$S_{MLT}(t) = \sqrt{P_T} \cdot \sum_{k=-\infty}^{+\infty} S_{P1P2P6}(t-t_k) \cdot \cos(2\pi \cdot f_{MLT}(t-t_k)+\varphi)$$

$$S_{P1P2P6}(t) = w\left(\frac{t}{T_1}\right) + w\left(\frac{t-\Delta T_{12}}{T_2}\right) + w\left(\frac{t-\Delta T_{16}}{T_6}\right) \cdot M(t-\Delta T_{16})$$

Equation 5: MLT signal model

$$S_{DME}(t) = \sqrt{P_T} \cdot \sum_{k=-\infty}^{+\infty} S_{PP}(t-t_k) \cdot \cos(2\pi \cdot f_{DME} \cdot t+\varphi)$$

$$S_{PP}(t) = e^{-\alpha \cdot t^2} + e^{-\alpha(t-\Delta t_{PP})^2}$$

Equation 6: DME signal model

$$Y = \log_{10}\left(\frac{X}{X_{máx}} \cdot K\right)$$

Equation 7: Logarithmic Amplifier model

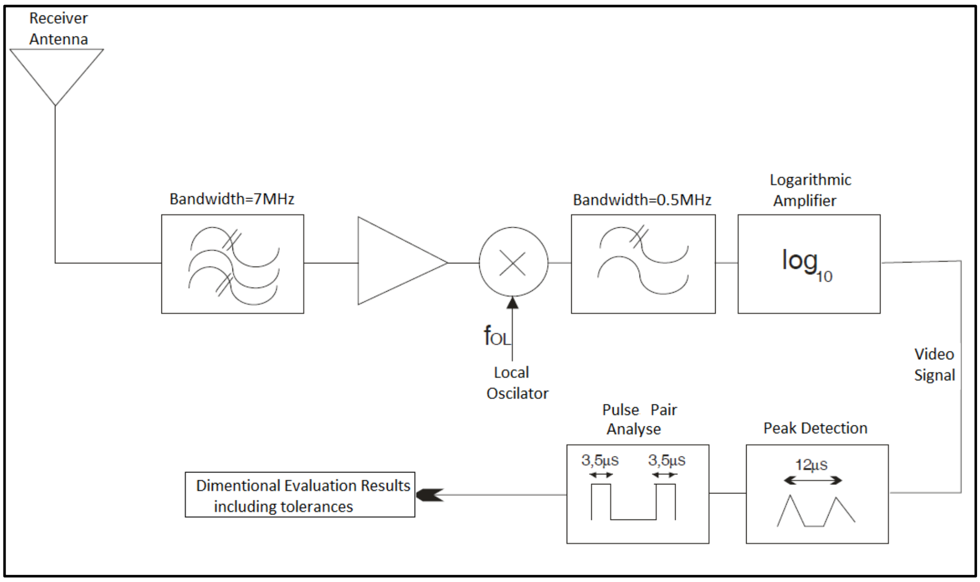

Figure 6: DME/N Receiver Design

3.2. Results

In the case of analysing Noise and Continuous Wave (CW) interference, there were right detections except when the received DME frequency overlapped with CW frequency and the CW signal power level was higher than -75dBm.

In the case of Noise and MLT interference without consider spurious, there were right detections in all conditions. In the case of Noise and MLT interference considering spurious, there were 6 cases:

- f_{DME}-f_{MLT} between 10 and 20MHz, Is necessary a distance between antennas of 8500m.
- f_{DME}-f_{MLT} between 20 and 30MHz, d≥4500m.

- f_{DME}-f_{MLT} between 30 and 40MHz, d≥3000m.
- f_{DME}-f_{MLT} between 40 and 50MHz, d≥2500m.
- f_{DME}-f_{MLT} between 50 and 60MHz, d≥2000m.
- f_{DME}-f_{MLT} >60MHz, d≥1500m.

Finally, if it includes every kind of interferences (CW, MLT considering spurious and Noise) we obtained:

- For P_{drCW}≥-75dBm (case of CW).
- For P_{drCW}≤-120dBm (case of MLT considering spurious).
- For the rest, a mixture of the two cases.

3.3. CONCLUSION

It is necessary to separate the antennas of the MLT ground station transmitter and the antennas of the DME/N ground receiver according to:

- The values obtain in accordance to de frequency of DME channel.
- Te power level of the DME signal from the DME receiver.

The transmissions of the DME ground station do not interfere with the process of the MLT ground station receiver.

REFERENCES

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