

# Modeling C-Band Co-Channel Interference From AeroMACS Omni-Directional Antennas to Mobile Satellite Service Feeder Uplinks

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## **Summary**

A new C-band (5091 to 5150 MHz) airport communications system designated as Aeronautical Mobile Airport Communications System (AeroMACS) is being planned under the Federal Aviation Administration's NextGen program. An interference analysis software program, Visualyse Professional (Transfinite Systems Ltd), is being utilized to provide guidelines on limitations for AeroMACS transmitters to avoid interference with other systems. A scenario consisting of a single omni-directional transmitting antenna at each of the major contiguous United States airports is modeled and the steps required to build the model are reported. The results are shown to agree very well with a previous study.

## 1.0 Introduction

Aeronautical Mobile Airport Communications System (AeroMACS) is a new C-band (5091 to 5150 MHz) airport communications system being planned under the Federal Aviation Administration's NextGen program (Ref. 1). Radio Technical Commission for Aeronautics (RTCA) Special Committee 223 is now engaged in defining standards for the AeroMACS service in the United States. European Organization for Civil Aviation Equipment (EUROCAE) Working Group 82 is conducting a parallel activity in Europe. It is essential that significant interference with other C-band systems already occupying the band does not occur. Services for which approved allocations now exist in the 5091 to 5150 MHz band include Aeronautical Radionavigation Service (ARNS), Aeronautical Mobile Service (AMS) (specifically Aeronautical Security (AS)), Aeronautical Mobile Telemetry (AMT), Aeronautical Mobile (Route) Service (AM(R)S), and Fixed Satellite Service (FSS) (specifically Mobile Satellite Service (MSS) feeder uplink). The Globalstar low Earth orbit (LEO) constellation is currently using the FSS service allocation in this band. The other services allocated in this band are not yet being used. At the same time, the AeroMACS system will operate as AM(R)S, with a higher priority than the other services allocated except the incumbent FSS system. Hence, the issue of primary and immediate interest is interference from AeroMACS into the FSS, specifically the MSS feeder uplink. The ultimate goal of this effort is to enable the establishment of practical limits on AeroMACS transmissions from airports so that the threshold of interference into MSS is not exceeded. The limits thus established will be used in the RTCA standards development process.

#### 2.0 Analysis

In this interference modeling of a simplified AeroMACS architecture, Visualyse Professional Version 7 software from Transfinite Systems Limited (United Kingdom) (Ref. 2) is utilized. In order to benchmark the software, the architecture configuration of a case from Hoh, Gheorghisor and Box (Ref. 3) is used in the model and the results compared. In Reference 3, the co-channel interference from an Airport Network and Location Equipment (ANLE/now referred to as AeroMACS) system to non-geostationary mobile-satellite-service (MSS) feeder uplinks was analyzed. It was assumed that there was

one transmitter with an omni-directional antenna at each of 497 major airports in the contiguous United States. A worst case scenario was modeled with all transmitters on 100 percent of the time.

In the model, each airport transmitting antenna contributes the interference power  $P_r$  at the LEO, 1414 km above the surface:

$$P_r(dBW) = P_t + G_t - L_c + G_r - L_{free}(d) - L_{feed} - L_p + B_f$$
(1)

where

 $P_t$  transmitter power = 8.6 dBW (7.2 W)

- $G_t$  AeroMACS antenna gain (8 dBi peak)
- $L_c$  cable/line loss in AeroMACS transmission system = 1 dB
- $G_r$  satellite antenna gain (6 dBi peak)
- $L_{\text{free}}$  free-space path loss (dB)
- $L_{\text{feed}}$  feed loss = 2.9 dB
- $L_p$  polarization discrimination = 1 dB
- $B_{\text{LEO}}$  receiver bandwidth at LEO satellite = 1.23 MHz

 $B_{AER}$  transmitter bandwidth at AeroMACS ground station = 20 MHz

- $B_f$  bandwidth factor =  $10*\log(B_{\text{LEO}}/B_{\text{AER}}) = -12.1 \text{ dB}$
- *d* distance between AeroMACS transmitter and LEO satellite receiver (1414+ km)

The components of the model consist of antennas, stations, carriers, links, and interference paths. The details of building these components into the model are indicated below.

#### 2.1 Antennas

#### 2.1.1 Globalstar Antenna

From Reference 3, the Globalstar (LEO-D) satellite has a 100.9° field of view (FOV) which enables it to cover approximately 9% of the Earth's surface. Its receiving antenna has a maximum gain of 6 dBi at a nadir angle of 45°.

To model this antenna, the antenna submenu is selected and an antenna named 'Globalstar antenna' is entered (Fig. 1). The 'Edit' button is clicked, a circular beam is selected, and the 'Change' button is clicked. The following gain table (Fig. 2) is entered and the gain distribution is shown graphically in Figure 3.

Antenna List 🛛 🗙
(%) Antennas Filter:
AntennaType
Globalstar antenna Omnidirectional
🗘 Add 🖉 Edit 🖓 Duplicate 🗙 Delete

Figure 1.—Naming Globalstar antenna in Antenna submenu.

Roll-	Off				анан алар алар алар алар алар алар алар	X
0	Standard Equa	ation				
	Equation					
	All		~			
۲	Gain Table —					
				Table si:	ze: 3.0	
	Apple (Dec)	0.0	45.0	55.0		
	Angle (Deg)	0.0	45.0	55.0		
	Gain (dB)	2.2	6.0	4.2		

Figure 2.—Entering Globalstar receiving antenna gain distribution.



Figure 3.—Globalstar (LEO-D) satellite receiving antenna gain.

#### 2.1.2 Omni-Directional Antenna (for AeroMACS Base Stations)

For this antenna, the gain pattern as a function of elevation angle is given in ITU-RF.1336-1 (Ref. 4) with maximum gain  $G_0 = 8$  and

$$G(\theta) = \max[G_1(\theta), G_2(\theta)]$$
(2a)

$$G_1(\theta) = G_0 - 12 \left(\frac{\theta}{\theta_3}\right)^2 \tag{2b}$$

$$G_2(\theta) = G_0 - 12 + 10 \log\left[\left(\max\left\{\frac{|\theta|}{\theta_3}, 1\right\}\right)^{-1.5} + k\right]$$
(2c)

where

- $G(\theta)$  gain relative to an isotropic antenna (dBi),
- $G_0$  the maximum gain in or near the horizontal plane (dBi),

 $\Theta$  absolute value of the elevation angle relative to the angle of maximum gain (degrees),

- $\theta_3$  the 3 dB beamwidth in the vertical plane (degrees), and
- *k* parameter which accounts for increased side-lobe levels above what would be expected for an antenna with improved side-lobe performance.

The relationship between the gain (dBi) and the 3 dB beamwidth in the elevation plane (degrees) is:

$$\theta_3 = 107.6 \times 10^{-0.1 \, G_0} \tag{2d}$$

In cases involving typical antennas operating in the 1 to 3 GHz range, the parameter k should be 0.7 (Ref. 4). The corresponding antenna gain as a function of elevation angle is shown in Figure 4. A shaped beam is selected in the Antenna Properties for the Omni-Directional Antenna. Equation (2a) is input into a Microsoft Excel (Microsoft Corporation) spreadsheet and the output is entered into the Elevation/Azimuth table shown in Figure 5.





Antenna Prope	rties			×
Omnidirectiona	al de la constante de la const			
0 () a	rcular 🔿 🕖	Elliptical	⊙ 💭 :	Shaped 🔵 🎯 Contour
Edit			B Z	Slice angle: ① <u>0.0</u> deg
El/Az	-180.0	-175.0	. 🔨	
80.0	-4.978	-4.978		
79.0	-4.968	-4.968		
78.0	-4.957	-4.957		
77.0	-4.946	-4.946		
76.0	-4.935	-4.935		
75.0	-4.924	-4.924		Peak = 8.0
74.0	-4.912	-4.912		Polar Cartesian
			>	
Electronically	steerable			
	Advanced			
				OK Cancel

Figure 5.—Entering elevation gain pattern for base station omnidirectional antenna.

#### 2.2 Stations and Station Groups

Stations identify the locations of the transmitters and receivers. In the Station submenu (Fig. 6), a Globalstar (G\*) satellite is added and through the Select Station Type submenu is defined to be a Terrestrial Fixed station. The position of a Globalstar satellite was then defined. The latitude and longitude were arbitrarily chosen and the altitude was defined to be that of the Globalstar orbits, 1414 km (Fig. 7). The Globalstar satellite was then linked to the previously defined Globalstar antenna (Fig. 8). A feeder loss of 2.9 dB was entered corresponding to the value in Table 3-2 of Reference 3. Because a Terrestrial Fixed Station was used to represent a satellite, the elevation needed to be set to  $-90^{\circ}$ . One of the 497 airport base stations was also defined to be a Terrestrial Fixed Station and identified as Custom-2-2-1 (Fig. 9). Its latitude and longitude were entered and a height above terrain of 20 ft (6.096 m) was defined. Its antenna was linked to the omni-directional antenna previously defined (Fig. 10). This station is used as a template for the other 496 airport base station transmitters through the wizard in the Stations Groups submenu (Fig. 11). The latitudes and longitudes of the other base stations are entered through reading a comma-separated values (csv) file (Fig. 12). This results in a Station List of 1+497 = 498 stations (Fig. 13). In the Station Groups submenu, the airport base stations are linked together as 'Locations Service Area' (Fig. 14).



Figure 6.—Station types.

Terrestria	al Fixed	Station					Z
∳ <sub>⊜</sub> ∝	* satelli	te		Add antennas	Delete	e Duplicate	
Position	Antenn	ia   Advanced	н				
Lat	titude:	-11.022727	deq	Height above <u>Terrain</u>	= 1414.	.0 km	
Lor	ngitude:	-143.0	deq	Terrain height (above s	ea): 0.0	m	

Figure 7.—Setting the position of a Globalstar satellite.

Terrestrial Fixed Station	X
🖌 🕁 G* satellite	Add antennas () Delete Duplicate
Position Antenna Advanced	
Antenna type:	
Globalstar antenna	Select Feeder Loss: 2.9 dB
Pointing options:	
<ul> <li>Fixed pointing direction</li> </ul>	O Point at another station
🔘 Scan between two azimuths	○ Allow the link to set the pointing
ORotating in the azimuth plane	O Point at another station OR the common volume
Azimuth: 0.0 deg	
Elevation: -90.0 deg	

Figure 8.—Linking Globalstar satellite to Globalstar antenna.

Terrestrial Fixed	Station				
° Custom-2 ⊡	2-2-1		Add antennas 🕨	Delete Du	iplicate
Position Antenn	ia   Advanced	1			
Latitude:	31.30875	deq	Height above <u>Terrain</u> =	6.096	m
Longitude:	-86.393778	<u>deq</u>	Terrain height (above sea):	0.0	m

Figure 9.—Defining the position of the first airport base station.

Terrestrial Fixed Station	×
° Custom-2-2-1 ☑ Position Antenna Advanced	Add antennas (• Delete Duplicate
Antenna type: Omnidirectional	Select Feeder Loss: 0.0 dB
Pointing options:	O Point at another station
O Scan between two azimuths	O Allow the link to set the pointing
O Rotating in the azimuth plane	<ul> <li>Point at another station</li> <li>OR the common volume</li> </ul>
Azimuth: 0.0 deg	
Elevation:   <sup>0,0</sup> deg	More Options
	OK Cancel Apply

Figure 10.—Linking the first airport base station to the omni-directional antenna.

Template Station		
New Service Area	Station icon:	0
Template station		
O Generate new (empty) terrestrial fixed stations		
<ul> <li>Use an existing station as a template</li> </ul>		
Custom-2-2-1 v		
O Define your own template station Edit		

Figure 11.—Defining the first airport base station as a template.

Template Station
Define service area by: Region Beam footprint Country OLocations Hexagonal Cells Import Locations From CSV File: Et/Edd Airports conv.csv
Figure 12.—The latitudes and longitudes of the other 496 airport

base stations are entered.

Station List	
© Stations Filter:	
G* satellite Custom-2-2-1 Custom-2-2-2 Custom-2-2-3 Custom-2-2-4 Custom-2-2-5 Custom-2-2-6 Custom-2-2-7 Custom-2-2-7 Custom-2-2-9 Custom-2-2-9 Custom-2-2-10 Custom-2-2-11 Custom-2-2-12 Custom-2-2-13 Custom-2-2-14	
Custom-2-2-15 Custom-2-2-16 Custom-2-2-17 Add Control Control Con	× Delete
	Close Help

Figure 13.—List of stations include a Globalstar satellite and 497 airport base stations.

Station Group			×
Locations Service Area			Wizard
In the Simulation:		In the Group:	
G* satellite Custom-2-2-1 Custom-2-2-2 Custom-2-2-3 Custom-2-2-4 Custom-2-2-5 Custom-2-2-6 Custom-2-2-7 Custom-2-2-7 Custom-2-2-9 Custom-2-2-9 Custom-2-2-9 Custom-2-2-10 Custom-2-2-11 Custom-2-2-12 Custom-2-2-12 Custom-2-2-14 Custom-2-2-16 Custom-2-2-17 Custom-2-2-17 Custom-2-2-18	<ul> <li></li> &lt;</ul>	Custom-2-2-1 Custom-2-2-2 Custom-2-2-3 Custom-2-2-10 Custom-2-2-11 Custom-2-2-13 Custom-2-2-15 Custom-2-2-16 Custom-2-2-17 Custom-2-2-18 Custom-2-2-19 Custom-2-2-22 Custom-2-2-24 Custom-2-2-25 Custom-2-2-25 Custom-2-2-26 Custom-2-2-28 Custom-2-2-28 Custom-2-2-29	
OK Apply Now	Cancel	)	Help

Figure 14.—The airport base stations are linked together as 'Locations Service Area'.

## 2.3 Carriers

The carrier submenu is used to designate bandwidths, polarization, and other characteristics of the signal spectrum. The AeroMACS carrier with 20 MHz bandwidth and Globalstar carrier with 1.23 MHz bandwidth are defined in Figures 15 and 16.

Bandwidth	
	Occupied Bandwidth
4	≱0.0 MHz
	Allocated Bandwidth
	✓ same as occupied
Polarisation ———	
<ul> <li>Linear horizor</li> </ul>	ntal OLeft-hand circular
O Linear vertica	l ORight-hand circular
Masks ——	
🗌 Use T× Mask	Edit
Use Rx Mask	Edit
Modulation	Radar
Digital	Is radar carrier
	<ul> <li>Continuous Wave</li> </ul>
0	Chirped Pulsed Signal
	Chirp pulse width: Not avail s

Figure 15.—Defining AeroMACS carrier.

🎷 Carrier	×					
Globalstar carrier						
Bandwidth	Bandwidth					
Occupied Bandwidth						
-	1.23 MHz					
	Allocated Bandwidth					
	✓ same as occupied					
Polarisation ———						
💽 Linear horizont	al 🔘 Left-hand circular					
O Linear vertical	O Right-hand circular					
Masks ———						
🗌 Use Tx Mask	Edit					
🗌 Use Rx Mask	Edit					
Modulation ———	Radar					
💿 Digital	Is radar carrier					
🔿 Analogue	Continuous Wave					
	Chirped Pulsed Signal					
	Chirp pulse width: Not avai s					
	Chirped bandwidth; Not avai MHz					
Traffic	OK Cancel					

Figure 16.—Defining Globalstar carrier.

#### 2.4 Links

Links are used to connect stations, define propagation parameters, and criteria for interference levels. A link defines a communications path. In this model, transmit links are defined from the airport transmitters and a receive link is defined at the Globalstar satellite. Transmitter links are defined for each of the 497 airport base stations in the 'Locations Service Area' (Fig. 17), each utilizing the previously defined AeroMACS carrier at 5.1 GHz with a transmitter power of 8.6 dBW (7.24 W). In Reference 3, it is assumed that there is 1 dB of line losses at the transmitters, so the transmit link power is set to 7.6 dBW (Fig. 18). The receiver link is defined at the Globalstar satellite (Fig. 19) and utilizes the Globalstar carrier at 5.1 GHz (Fig. 20).

Transmit Link	
Airports TX	Type: Space<>Earth
Start Transmit ->   Traffic   Advanced	
<ul> <li>Use all the stations in the group selected below:</li> </ul>	
Locations Service Area	~
O Use a named station:	
<click a="" select="" station="" to=""></click>	Ŧ
Transmit antenna:	
×	

Figure 17.—Setting up transmit links at each of the airport base stations.

Corrier	Exercise
AeroMACS carrier	Fixed value: 5.1     GHz
= 5.0 MHZ	
Fixed power level	Polarisation: From carrier
Power: 7.6 dBW	O From antenna

Figure 18.—The transmit links utilize the AeroMACS carrier at 5.1 GHz with a transmitter power of 8.6 dBW. (In Ref. 3, it is assumed that there is 1 dB of line losses at the transmitters, so the transmit link power is set to 7.6 dBW.)

Receive Link				
RX at G* altitude		Type: Space<>Earth		
End	Receive <-   Traffic   Advanced			
	Station:			
	G* satellite	-		
Receive antenna:				
	Antenna 💙			

Figure 19.—Receive link defined at Globalstar satellite.

Receive Link	
RX at G* altitude	Type: Space<>Earth
End Receive <-   Traffic   Advanced	
Carrier:	Frequency:
Globalstar carrier 🛛 🗸	5.1 GHz
= 1.23 MHz	
Receiver	
Receive level: -100.0 dBW	300 K 300 K, 3 dB
	System Noise: 590.0 K
	Calculate system noise
	Noise figure: 3.0103 dB
	Add rain noise
	OK Cancel Apply

Figure 20.—Receive link utilizes Globalstar carrier.

All the links are defined as type 'Earth <-> Space'. Other types in Visualyse are Terrestrial Fixed, Terrestrial Mobile, Space <-> Space, and Broadcasting. With this type we can choose from a number of propagation models. The model ITU-R Rec. P.525, Basic Transmission Loss in Free Space (Ref. 5), is selected from the window below (Fig. 21).

## **Propagation Model Selection**

Propagation Models					
ITU-R Rec. P.525	basic transmission loss in free space				
ITU-R Rec. P.452	propagation model for terrestrial interference analysis				
ITU-R Rec. P.526	propagation loss due to diffraction over terrain				
ITU-R Rec. P.530	multipath model used in design of terrestrial links				
ITU-R Rec. P.1546	propagation model for terrestrial services				
ITU-R Rec. P.1791	propagation model for ultra-wideband applications				
ITU-R Rec. P.1812	propagation model for point-to-area services in VHF/UHF ban				
ITU App. S7 Mode 1	(WRC 95) great circle path loss				
ITU App. S7 Mode 2	(WRC 95) rain scatter loss				
ITU App. 57 182	(WRC 95) great circle and rainscatter loss				
🔄 Egli	for terrestrial mobile at 900Mhz				
Hata/COST 231	for terrestrial mobile up to 2GHz				
Lee	for point to area model applicable at 900Mhz				
TIA Bulletin 10F	used in fixed service coordination				
Extra Losses	fixed or path dependent losses				
Rain Model <del>s</del>					
🗌 ITU-R Rec. P.530	rain model used in design of terrestrial links				
ITU-R Rec. P.618	rain model used in the design of satellite links				
🗌 Crane Rain Model	rain attenuation model				
Atmospheric Losses					
TTU-R Rec. SF.1395	loss due to atmospheric gas for FSS into FS				
ITU-R Rec. P.676	loss due to atmospheric gas for terrestrial and slant paths				
ITU-R Rec. P.840	attenuation due to clouds and fog				
Dry Air	attenuation through a dry atmosphere				
Water	attenuation due to water vapour				
	OK Cancel				

×

Figure 21.—Basic Transmission Loss in Free Space propagation model selected.

#### 2.5 Interference Paths

An interference path consists of a wanted or 'victim' link and an unwanted or 'interfering' link or links (Fig. 22). In this case the interference path is designated as 'Airports into G\*' to represent the Globalstar receive link as the victim link and the transmit links at each of the AeroMACS airport base stations as the interfering links (Fig. 23).

J	nterference s	settings	×			
	Airports into G	G*				
	Wanted Links	Interfering Links Advanced				
	Choose the wanted link that wil be the victim of the interference					
	You can set more than one wanted link by choosing a link group					
	Link Gro	pup: Link List 🗸 🗸				
	Link:	RX at G* altitude				
		Start -> End -> Start				

Figure 22.—Designating the Globalstar receive link as the 'wanted' link.

Interference settings		×
Airports into G*		
Wanted Links Interfering Links	Advanced	
In Simulation:	Interferers:	
⊶ Airports TX	→ Airports TX	
	«	

Figure 23.—Designating the transmit links at each of the AeroMACS airport base stations as the interfering links.

## 2.6 Output Menu

In order to plot the interference power over a map of the Western Hemisphere, the Create Area Analysis submenu is selected from the Output Menu and the following coordinates, station, link, and plot parameter are entered. The plot resolution is set to 175.74 km which provides 2° of longitude resolution (Fig. 24).

Area Analysis Properties				
Name: Area Analysis				
Top: Left: 90.0 Right: -200.0 0.0 Bottom: -15.0				
Moving Station Station: G* satellite				
Link: RX at G* altitude				
I/N C/I ⊂/urrent ○ Minimum ○ Maximum ○ Mean				
Plotting Options Contour plot Colour block plot Plot resolution: At least: 175.7* km (between test points) Display Settings Suspend drawing for faster updates OK				

Figure 24.—Setting up the output map of interference power.

## 3.0 Results

The simulated interference power is shown in global view in Figure 25. The corresponding twodimensional view is shown in Figure 26.



Figure 25.—Simulated interference power in global view.



Figure 26.—Simulated interference power in two-dimensional view.

The agreement is excellent between the Visualyse simulated interference power distribution shown in Figure 26 and that calculated by Hoh, et al. in Reference 3. In the Visualyse model, the maximum interference power is -149.3 dBW at the location 64° N 105° W, which compares well with the value of -150.0 dBW in Reference 3 at the location 67° N 104° W. This maximum interference power over northern Canada is due to the maximum transmitting gain of the AeroMACS antennas in the horizontal direction.

## 4.0 Conclusions

The software program Visualyse Professional has been used to model a simplified architecture for the proposed Aeronautical Mobile Airport Communications System (AeroMACS). The model scenario consisted of a single omni-directional transmitting antenna at each of the 497 major contiguous United States airports. The AeroMACS transmitter power was chosen to be the same as a previous study in order to verify the model. Details of the model building were described and the results agreed closely to that of the previous study in which the interference power over almost all of North America exceeds the desired threshold. This agreement provides confidence that the model is accurate and serves as a starting point for developing and investigating more sophisticated and realistic AeroMACS scenarios.

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<b>14. ABSTRACT</b> A new C-band (5091 to 5150 MHz) airport communications system designated as Aeronautical Mobile Airport Communications System (AeroMACS) is being planned under the Federal Aviation Administration's NextGen program. An interference analysis software program, Visualyse Professional (Transfinite Systems Ltd), is being utilized to provide guidelines on limitations for AeroMACS transmitters to avoid interference with other systems. A scenario consisting of a single omni-directional transmitting antenna at each of the major contiguous United States airports is modeled and the steps required to build the model are reported. The results are shown to agree very well with a previous study.					
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