EHF COMMAND TECHNOLOGY

Louis H. Sacks
MTS
Communications Department
Electronics and Optics Division
The Aerospace Corporation
El Segundo, California

ABSTRACT

The Air Force Satellite Control Facility is considering performing the command and telemetry functions at the EHF/SHF frequency bands (44 GHz uplink/21 GHz downlink). Among the factors affecting performance at the higher frequencies are the satellite and ground station antenna characteristics, receiver and power amplifier availability and weather effects. Of these factors weather effects, particularly rain, is the most severe and can result in temporary outages in the command and telemetry operation. It is recommended therefore that S-band operation be retained if greater than 99% link availability is required. TT&C operation at the EHF/SHF frequency bands could be achieved only if periodic weather outage and variable data rate transmission becomes acceptable.

INTRODUCTION

Because of certain advantages such as higher data rates, lower probability of intercept and antijam features, spacecraft systems are moving to higher frequencies to perform the communications functions. It would also be advantageous to perform the command and telemetry functions at the same higher frequencies. For this reason the AFSCF is considering utilizing the EHF/SHF frequency bands for the command and telemetry functions for certain spacecraft programs.

Among the factors affecting the command and telemetry functions at the higher frequencies are the satellite and ground station antenna characteristics, weather effects and receiver and power amplifier availability. These factors and their effect on the command and telemetry link performance will be discussed in the following sections.

SATELLITE ANTENNA PERFORMANCE

Omni antennas are used on satellites to provide the telemetry and command control functions. The omnidirectional coverage is necessary because the telemetry and command functions are often required while the satellite is in periods of rapid directional change, i.e., during launch ascent, injection, maneuvering or unstablized (uncontrolled) rotation. Some of the command functions are needed to despin or align the spacecraft and to point the main antennas. The omni antennas must therefore provide a link between the satellite and ground stations which is fairly constant regardless of the satellite orientation. Because of the omnidirectional coverage requirement, it is unlikely that future technology or higher frequencies will result in a replacement of the basic omni antenna.

The free-space transmission equation between a fixed size ground station and an omni antenna is $W_R = W_T A_T / 4\pi R^2$ where W_T is the input power to the ground station antenna, W_R is the power received by the omni antenna, A_T is the effective area of the ground station antenna and R is the distance between the two antennas. Since the transmission equation is frequency independent, there is no advantage - - or disadvantage - - from a strictly ground station antenna size criteria, in going to a higher operating frequency.

It is anticipated that omni antennas can be built at the higher 44 and 21 GHz frequency bands and that their performance and cost will be comparable to the S-band omni antennas presently used on spacecraft. Because of spacecraft blockage, two omni’s are usually employed on opposite sides of the spacecraft to provide the required omnidirectional coverage. Since the blockage is basically a line-of-sight phenomenon, the higher frequency operation should provide the same net coverage as for the S-band case. The primary difference would be a higher frequency ripple in the antenna pattern intereference region at the 44 and 21 GHz frequencies due to diffraction and phase cancellation effects.

GROUND STATION ANTENNA PERFORMANCE

In the previous discussion of satellite antenna performance it was shown that for a fixed size ground station antenna the net free space transmission link is frequency independent. For typical ground station antennas, mechanical considerations such as surface accuracy, tracking accuracy and radome losses will determine the achievable performance at the higher frequencies.

The major factor determining the achievable antenna gain at the EHF frequencies is the reflector surface accuracy. For up to 40 ft diameter ground station antennas, present commercial technology can achieve 0.024 in. (24 mils) surface accuracy which would result in a 5.5 dB gain loss at 44 GHz (1). Improved technology exists which can achieve 12 mil surface accuracy (1.8 dB loss at 44 GHz) although at an additional cost of about

$200K per antenna. California Institute of Technology has built a 34 foot diameter radio telescope (2) with 1 mil surface accuracy but it has not been determined whether its tracking capability or maintainability of surface accuracy (during all tracking maneuvers and over long periods of time) is suitable for SCF type missions.

Tracking loss at 44 GHz can be kept to within 1.5 dB (1) with advanced tracking systems (3) for reflector antennas up to 40 feet in diameter. Radomes can improve the tracking accuracy by reducing wind loading but result in additional losses; the radome transmission loss for a 68 foot diameter metal space frame radome is about 1.0 dB at 21 GHz and 1.8 dB at 44 GHz (4). Rain produces additional losses due to creation of a water film on the radome surface. Newly developed hydrophobic coatings are claimed to provide radomes with a non-filming surface which lasts for the life of the radome. The use of these non-filming radomes should significally reduce the wet radome attenuation, i.e., at 44 GHz for an elevation angle of 5° and a rain rate of 50 MM/hr the predicted wet radome attenuation is 3.5 dB for the hydrophobic coating vs 9.0 dB for the non-hydrophobic case (5).

WEATHER EFFECTS

“Clear Sky” atmospheric attenuation due to oxygen and water vapor is negligible for frequencies below 7 GHz but becomes appreciable for the EHF frequencies particularly at the low elevation angles; i.e., at 45 GHz and a 10° elevation angle the oxygen plus water vapor attenuation is 3.5 dB. Table I shows the atmospheric plus rain attenuation as a function of frequency, availability and elevation angle for several climate regions (6) in the United States. The table illustrates the large attenuation values at the EHF frequencies, particularly at the lower elevation angles. Rain attenuation can be mitigated through “diversity gain” by using two separate ground stations (6), (7). Diversity gain is based on the hypothesis that intense rain cells that cause the most severe fading are limited in spatial extent; therefore, as two ground stations are placed further apart the likelihood of a single rain cell interfering with both stations simultaneously becomes more remote.

RECEIVER AND POWER AMPLIFIER AVAILABILITY

The low noise receiver and transmit power availability at 21 GHz should be fairly close to what is presently available a S-band (1). At 44 GHz however, the respective receiver and power availabilities are likely to be about 2 dB and 10 dB below existing S-band values resulting in a net loss of at least 12 dB to the command link performance.

LINK CALCULATIONS

Table II illustrates a S-and SHF-band downlink calculation for TT&C omni antenna operation assuming a 33 ft diameter ground station antenna. A specific ground station location (Colorado Springs), weather availability (99%) and orbit (synchronous, 10° elevation angle) were assumed in order to obtain some representative link margin values. As shown in the table the SHF-band downlink margins are about 6 dB below those at S-band. For both frequency bands (for the specific site, weather and orbit parameters chosen) the margin is sufficient to close the link for all the specified data rates.

Table III illustrates a S-band and EHF uplink calculation for the same parameters as used for the downlink. As shown in the table the S-band link margin is sufficient for all the specified data rates. At 44 GHz however the link can be closed only at the lowest(75 bps) data rate. For clear weather conditions however, i. e., no rain, the link could be closed at 44 GHz for all the specified data rates. Therefore, any shift to the EHF frequency bands would make the TT&C operation weather dependent and would preclude greater than 99% link availability.

SUMMARY AND CONCLUSIONS

Moving to the EHF/SHF frequency bands (44 GHz uplink/21 GHz downlink) from its present S-band frequency will result in lower link margins for the command and telemetry functions. Among the factors causing the degradation to link performance are antenna characteristics, receiver and power amplifier availability and weather effects. The last factor, particularly rain, is the most severe and can result in temporary outages in the command and telemetry operation. It is recommended therefore that S-band operation be retained if greater than 99% link availability is required. TT&C operation at the EHF/SHF frequency bands could be achieved only if periodic weather outage and variable data rate transmission becomes acceptable.

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TABLE I ESTIMATES OF ATMOSPHERIC PLUS RAIN ATTENUATION

CLIMATE REGION	AVAILABILITY	ELEV. ANGLE = 10 DEG.				ELEV. ANGLE = 20 DEG				ELEV. ANGLE = 90 DEG.			
		FREQUENCY (GHz)				FREQUENCY (GHz)				FREQUENCY (GHz)			
		7	20	30	45	7	20	30	45	7	20	30	45
		ATTENUATION (db)				ATTENUATION (db)				ATTENUATION (db)			
B COLORADO SPRINGS	97.0%	0	3	5	11	0	1	2	5	0	0	0	1
	98.0%	0	3	6	14	0	2	3	6	0	0	1	1
	99.0%	0	4	8	19	0	2	4	8	0	0	1	2
	99.5%	1	6	12	25	0	3	5	12	0	1	1	3
	99.7%	1	7	14	30	0	3	7	15	0	1	2	4
	99.9%	1	9	20	42	0	5	10	21	0	1	3	6
D WASHINGTON, D. C.	97.0%	1	5	10	24	0	2	5	11	0	1	1	2
	98.0%	1	6	13	30	0	3	6	14	0	1	1	3
	99.0%	1	8	18	39	0	4	9	19	0	1	2	4
	99.5%	1	11	25	53	0	6	13	28	0	2	3	7
	99.7%	1	14	32	64	1	8	18	35	0	2	5	10
	99.9%	1	22	50	96	1	13	30	58	0	4	10	19
F WHITE SANDS	97.0%	1	6	12	27	0	2	5	11	0	0	1	2
	98.0%	1	7	15	34	0	3	6	15	0	1	1	2
	99.0%	1	8	19	42	0	4	9	19	0	1	2	4
	99.5%	1	10	23	49	0	5	11	24	0	1	2	5
	99.7%	1	12	27	57	0	6	13	29	0	1	3	6
	99.9%	1	16	36	74	1	9	20	40	0	2	5	10

TABLE II DOWNLINK CALCULATIONS FOR OMNI ANTENNA OPERATIONS

ITEM		S-BAND (2.2 GHz)	SHF (21 GHz)	COMMENTS
SATELLITE	TRANSMIT POWER	+ 10.1 dBw	+ 9.0 dBw	8 WATTS AT 21 GHz
	ANTENNA GAIN	+ 0.0 dB	+ 0.0 dB	
	RF LOSSES	- 1.0 dB	- 1.7 dBw	
PROPA-GATION	FREE SPACE	-191.5 dB	-211.1 dB	SYNCHRONOUS ORBIT, 10^o ELEV. ANGLE, 99% AVAILABILITY, COLORADO SPRINGS
	ATMOSPHERIC PLUS RAIN	- 0.5 dB	- 4.0 dB	
GROUND TERMINAL	ANTENNA GAIN (33' DIA.)	+ 42.9 dB	+ 62.7 dB	1.2 dB SURFACE ACCURACY LOSS AT 21 GHz
	RF LOSSES	- 1.0 dB	- 1.6 dB	
	POINTING LOSS	- 0.2 dB	- 0.8 dB	
	MODULATION LOSS	- 4.1 dB	- 4.1 dB	
	NOISE TEMP	- 26.1 dB/ K	- 26.1 dB/ K	180 K PARAMP +220 K ANTENNA
	BOLTZMANN'S CONSTANT	+228.6 dBw/ K-HZ	+228.6 dBw/ K-HZ	
	AVAILABLE C/N_O	+ 57.2 dB-HZ	+ 50.9 dB-HZ	
	REQUIRED E_B/N_O	- 14.0 dB	- 14.0 dB	
DATA RATE		MARGIN	MARGIN	
	75 BPS (-18.8 dB-Hz)	+24.4 dB	+18.1 dB	
	300 BP (-24.8 dB-Hz)	+18.4 dB	+12.1 dB	
	2.4 KBPS (-33.8 dB-Hz)	+ 9.4 dB	+ 3.1 dB	

TABLE III UPLINK CALCULATIONS FOR OMNI ANTENNA OPERATION

ITEM		S-BAND (1.8 GHz)	EHF (44 GHz)	COMMENTS
GROUND TERMINAL	TRANSMIT POWER	+ 33.0 dBw	+ 23.0 dBw	2KW S-BAND, 200W EHF
	ANTENNA GAIN (33' DIA.)	+ 41.0 dB	+66.8 dB	1,8 dB SURFACE ACCURACY LOSS AT EHF
	RF LOSSES	- 1.0 dB	- 2.0 dB	FILTERS, COUPLERS, WAVEGUIDE, ETC.
	POINTING LOSS	- 0.2 dB	- 1.5 dB	
	MODULATION LOSS	- 4.1 dB	- 4.1 dB	
PROPA-GATION	FREE SPACE	-189.7 dB	-217.5 dB	SYNCHRONOUS ORBIT, 10^{o} ELEV. ANGLE, 99% AVAILABILITY, COLORADO SPRINGS
	ATMOSPHERIC PLUS RAIN	- 0.5 dB	- 19.0 dB	
SATELLITE	ANTENNA GAIN	+ 0.0 dB	+ 0.0 dB	
	RF LOSSES	- 1.0 dB	- 3.5 dB	
	POLARIZATION LOSS	- 0.5 dB	- 0.5 dB	
	NOISE TEMP	- 29.1 dB/ K	- 31.6 dB/ K	1150 K RCVR, 290 K ANT. AT EHF
	BOLTMANN'S CONSTANT	+228.6 dBw/ K-HZ	+228.6 dBw/ K-HZ	
	AVAILABLE C/N_O	+ 76.5 dB - HZ	+ 38.7 dB - HZ	
	REQUIRED E_B/N_O	- 14.0 dB	- 14.0 dB	
DATA RATE		MARGIN	MARGIN	
	75 BPS (-18.8 dB-HZ)	+43.7 dB	+5.9 dB	
	300 BPS (-24.8 dB-HZ)	+37.7 dB	-0.1 dB	
	2.4 KBPS (-33.8 dB-HZ)	+28.7 dB	-9.1 dB	