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Advanced Communications Payload for Mobile Applications

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ABSTRACT

An advanced satellite payload is proposed for single hop linking of mobile terminals of all classes as well as VSAT's. It relies on intensive use of communications on-board processing and beam hopping for efficient link design to maximize capacity and large satellite antenna aperture and high satellite transmitter power to minimize the cost of the ground terminals. Intersatellite links are used to improve the link quality and for high capacity relay. Power budgets are presented for links between the satellite and mobile, VSAT, and hub terminals. Defeating the effects of shadowing and fading requires the use of differentially coherent demodulation, concatenated forward error correction coding, and interleaving, all on a single link basis.

INTRODUCTION

Each class of mobile terminal, land, maritime, and aeronautical, has its own set of system constraints. These stem from differences in traffic demand including data rates, number of users, and the use of scheduled or demand access. Of great importance are the differences in channel characteristics including the carrier frequency, fading, and interference conditions. Thus the design of an optimal link for each of the three mobile classes will be different thereby requiring flexibility and programmability in the satellite. It has been demonstrated that on-board communications signal processing (OBP) can achieve lower cost in mobile terminals and higher efficiency in spectrum utilization. However, the use of OBP has meant that the payload will have to be committed to a specific waveform prior to launch. Because of economic and traffic uncertainties, a commercial satellite owner/operator would most likely be reluctant to build a satellite with a committed OBP payload. To alleviate this limitation, a versatile OBP payload is needed which flexibly meets the communications requirements of all classes of users in the mobile community. The payload flexibility will enable not only connectivity between mobile and fixed ground terminals, but also between mobiles of the same class as well as between mobiles of different classes.

SATELLITE PAYLOAD DESIGN PHILOSOPHY

The satellite payload described here uses OBP, intersatellite links (ISL), and scanning spot beam techniques to achieve unprecedented flexibility in waveform processing and connectivity for mobile communications. The on-board modems, codecs, interleavers and deinterleavers are programmable by ground command which allows the processing described above to be achieved in "uncommitted" hardware which can be adapted to traffic demand. The OBP also allows for the implementation of hopping spot beams by virtue of digital buffering of data between hops. For a mobile satellite (MSAT) the hopping spots can be ultra-narrow beams to achieve super high antenna gain to service low capability terminals including very small personal terminals. The ISL permits intercontinental circuit connections on a single hop basis. It also enables a higher elevation angle line of sight from a terminal to the satellite thereby allowing the terminal to employ a narrower beam antenna for mitigation of multipath fading, shadowing and interference.

SYSTEM OPERATION AND REQUIREMENTS

A number of design features will facilitate reducing the cost and complexity of the earth terminals for which typical design parameters are given in Figure 1. These advantages can be illustrated by describing the procedures and links required to setup and implement voice calls between users. Calls can be made either between mobiles and telephone network users or directly between mobiles. It is assumed that all mobiles carry LORAN or GPS receivers so that they know their location and, therefore, can have their calls forwarded to them through the proper beam. The MSAT will broadcast a beacon signal modulated by the network symbol clock through an earth coverage beam. When transmitting to the satellite, it will be required that the mobile terminal synchronize its reference frequency to the beacon carrier, its symbol rate to the beacon clock, and adjust its baud phase, through the use of GPS timing or a closed loop protocol, so that its baud arrival time at the satellite is synchronous with all other uplink baud arrival times. Having all users synchronize to align their baud transition times at the satellite is not too stringent a requirement at the low baud rates of coded voice and it greatly simplifies and enhances the reliability of the satellite multichannel demodulator (MCD). Requiring all users to synchronize their frequency synthesizer reference oscillators to the beacon carrier will ensure that the uplink FDMA signals can have a minimum of guard band between channels without mandating expensive ultrastable carrier oscillators in the mobiles. The differentially coherent 8PSK demodulation requires a very small ratio of Doppler shift to symbol rate, less than .05 assuming an L-band carrier. Estimates of the maximum value of this ratio for an automobile is about 0.1 and about 1.0 for a subsonic aircraft which shows that the modems on the mobile platforms will need to use active Doppler phase compensation to avoid excessive BER degradation.

The call setup procedure for random and demand access will by its very nature be outside of the reservation type of multiple access system; for example, an ALOHA type system operating at very low data rate through an earth coverage beam. The setup establishes a set of reserved uplink and downlink frequency channels, time slot reservations, and a pair of beams between the terminals and the satellite. In the case of the nonhopping beams which cover the metropolitan areas, only frequency and beam reservations are required, while the users in a hopping beam will also need a time slot assignment.

Since the satellite is a fully regenerating repeater, the uplink and downlink are effectively decoupled and the link calculations can be performed independently. Then the overall link BER is at worst twice the BER of either for balanced links and, for highly unbalanced links, approaches the BER of the weakest link. Public switched network users are connected through a central ground station called a hub. All satellite traffic to and from hubs will be transmitted on a single carrier in TDM through a Ku-band CONUS coverage beam.

Traffic between mobiles and the satellite will be transmitted through two types of L-band spot beams, fixed and hopping. Spot beams will be about one degree wide with fixed ones over urban areas having a large average volume of use. Mobile users communicating through fixed spot beams will use the minimum transmission data rate 4.8 Kbps and a very bandwidth efficient modulation, differentially coherent 8PSK (8DPSK). When coding of rate 1/2 is used and if it is filtered with a 40 % excess bandwidth raised cosine filter, this signal occupies 4.5 KHz and can be confined to channels on 5 KHz centers including ± 250 Hz guard bands which is a standard for mobile channels [1]. The block diagram for a mobile terminal is shown in Figure 2.

PAYLOAD DESCRIPTION

The advanced payload concept for an MSAT baseband processor shown in Figure 3 is representative of the functions in the payload and not the quantities of each type of block. The interfaces to and from the baseband processor are shown to be at 4 GHz, a convenient and typical satellite IF frequency, and the transponder bandwidth shown as a standard 72 MHz which could accommodate a maximum of 14,400 5 KHz channels. On reception, the FDMA and FDMA/TDMA 8PSK signals will first encounter a multichannel demultiplexer and demodulator (MCD). The MCD will likely be a SAW demultiplexer followed by a time-shared digital demodulator [2]. The demultiplexer uses the chirp Fourier transform principle to transmultiplex the FDMA signals to a TDMA signal which is then sampled, digitized and operated on by the digital demodulator which could employ standard digital signal processors or ASIC's. More recently even more compact MCD's have been described using integrated optics [3]. The 8DPSK demodulator is a Doppler compensating type and requires neither a carrier nor clock recovery phase-locked loop (PLL) [4]. However, for use with nonfading VSAT links, to achieve more power and/or bandwidth efficiency, the modem could be flexibly programmable by command to accommodate both coherent and differentially coherent demodulation as well as be adaptable to different modulation formats and symbol rates. Contracts for flexible satellite modems and complementary flexible codecs have been issued by NASA in the past several years and are currently under development [5], [6].

Following the demodulator is the FEC decoder and deinterleaver. To mitigate the channel fades, a concatenated pair of coders and deep interleavers at both the transmission ends of the links and at the receiving ends are used. The outer codec typically uses a Reed-Solomon (RS) code while the inner code is convolutional using Viterbi Algorithm decoding. Interleaving may be used between the inner and outer encoders and decoders as well as between the inner codec and modem. The purpose of the interleaver is to randomize the channel errors to enable the codes to perform their error correction by distributing error bursts over the shuffled code words such that the number of errors in a single code word does not exceed its maximum correction capability. Because of the very deep and long fades, occasionally the error correction capability of the code will be exceeded and an error will be committed. At these times, and for data transmission only, the capability of the RS decoder to detect the presence of errors (beyond its capability to correct) will be exploited to request a repeated transmission from the transmitter (ARQ). Because of the presence of the decoder in the payload, ARQ's can be generated in the payload thereby avoiding the up and downlink delay which would result from placing the decoder only on the ground. Throughput is degraded because of the ARQ but for low data rate high reliability transmissions, such as paging, this is probably acceptable. Because of its greater error tolerance and more severe timeliness requirement, no ARQ can be used for digitized voice.

Using concatenated convolutional and RS codes on a Rayleigh fading channel with interleaving and MSK modulation, recent simulation results showed more than 40 dB coding and interleaving improvement [7]. Interleaving used in these results ranged from about 500 to more than 4000 bits resulting in interleaving delays of from about 100 ms to more than 800 ms for each interleaving and deinterleaving pair of operations For mobile to mobile the interleaving delay for an uplink and downlink would be twice these values. Clearly the upper limit is excessive for voice conversations thereby restricting the maximum interleaving depth to about 500 bits for voice but possibly much higher for services such as one-way paging and data.

The decoded data will undergo descrambling and will be entered into an input buffer memory followed by a routing switch and output buffer memory. It is in these blocks that the data is routed to its intended destination port, formatted, and repacked with other data for its downlink transmission. Data destined for FDMA downlinks to mobiles will be rescrambled, FEC encoded, modulated, and multiplexed for transmission through a common L-band power amplifier on a specific beam. The payload concept allows other modes of transmission to be accommodated such as wideband TDMA and wideband continuous data streams. The latter may be those arriving and leaving the payload via the ISL or to and from Ku-band VSATs and hubs.

The baseband switch, buffer memory, beam hopping, as well as all traffic timing is under the control of the timing and control processor which is programmed through the order wire transmission from a master control station. The program controls access authorization, priorities, and logs traffic for billing. The master control station commands also will upload programs to control the payload configuration and schedules for the high capacity, non-demand access links such as hub links, video relay, and ISL.

TYPICAL LINK PERFORMANCE

The power budgets between a mobile and satellite for both voice and voiceband compatible data is given for no coding in Table 1. A modest 39 dBm e.i.r.p. is assumed for the ground transmitter while a large multibeam satellite antenna with a 47 foot diameter is assumed. Unfurlable parabolic antennas for L-band with this diameter are feasible. A circularly polarized ground antenna has been recently reported with autotrack capability and very reasonable mounting requirements atop a ground vehicle [8]. The FDMA downlink is for a metropolitan area spot beam with 1000 FDMA carriers. This requires a 200 watt transmitter radiating through the large 47 foot diameter satellite aperture.

The power budgets for the links to VSATs and hub terminals are given in Tables 2 and 3 respectively. These links operate in Ku-band using CONUS coverage beams. The links to the hubs use TDM transmission at 4.8 Mbps to be received by hub stations with 14.5 foot diameter antennas. The 1000 uplink signals at 4.8 Kbps on a single beam are not the same signals that are aggregated for downlink transmission to a single hub. The TDM transmissions to the hubs are aggregated according to the hub destination of the uplink signals arriving at the OBP payload on many different beams.

If possible, it would be desirable to tile the entire field of view of the satellite with contiguous one degree spot beams, but those beams not falling on metropolitan areas would only have a fraction of their receive and transmit capacity utilized. More efficient use of the satellite resource can be achieved by having, in addition to the fixed metropolitan area beams, a number of agile beams which are time shared between low density user locations. The algorithm of the time sharing might be strictly periodic, according to preprogrammed estimate of traffic demand, or it might even be adaptable to traffic demand. Assuming the case where a single beam is equally time shared among 100 spots, the uplink and downlink data rates would need to be increased by a factor of 100. The ground terminal peak e.i.r.p. would then need to be increased by 100 fold (although the average would still be 1 W) and the satellite downlink e.i.r.p. per carrier also increased by 100 over that of a stationary beam to maintain the same revisit time. The latter is only possible since the number of carriers per hopping spot is much fewer than the 1000 assumed for each metro beam. Thus, if the hopping spot only needs to service ten users, then the 200 W satellite transmitter would be sufficient to close the link even for 100 times speedup in the data rate. The main impact on the ground user of this speedup is that the synchronization precision to align the uplink bauds at the satellite must be 100 times better.

There are at least three classes of mobile platforms, land, sea, and air. Seagoing platforms which have been operating for a number of years in the INMARSAT system do not experience severe fades and some test results have recently been reported to indicate that the propagation environment for the aeronautical link suffers only minor fading [9]. The most difficult environment for satellite communications is land mobile which, unlike ships at sea or airborne terminals, are subjected to a hostile propagation environment caused by obstructions and reflecting objects in the terrain which produce partial or complete blocking of the line of sight path (flat fades and shadowing), mutipath fading (frequency selective fades), and combinations of these which will dictate the following important characteristics of the land mobile signal:

• Because of periodic deep fades, differentially coherent detection is preferred to coherent detection to avoid the frequent cycle slips in the coherent demodulator carrier PLL. (The ground terminal PLL for the pilot tone will have a very narrow tracking bandwidth and will not break lock unless the fade persists for an inordinately long time; besides its only function is to track out the long term frequency drifts between the satellite and reference oscillators.) The cost of 8DPSK versus coherent 8PSK detection is about 3 dB in power efficiency although it is possible to use multiple symbol differential detection to achieve less degradation [10].

• In the fading channel, a great deal of additional link margin will be required. This margin will be achieved through a combination of forward error correction (FEC) coding and interleaving of symbols to mitigate the effects of error bursts.

The links given in the tables are for additive white Gaussian noise channels which are applicable to the ocean and airborne environments of mobile platforms and the satellite to VSAT and hub links. They are not applicable to the land mobile links except under unusually good conditions. Measurements on the L-band channel have shown the probability density function (PDF) of the received power to exhibit Rician fading in the non-shadowed environment and, when shadowing is present, to have a conditional Rayleigh amplitude PDF, (i.e., a conditional exponential PDF of power), conditioned on the short term mean received power which fits the lognormal PDF [11]. To properly evaluate the overall link fading requires the summing of the PDF's from the shadowing and nonshadowing cases where each is weighted by the frequency of its occurrence. Evaluation of coding and interleaving with this complex fading model will need to be achieved through simulation for candidate modulation formats such as 8DPSK.

CONCLUSIONS

• Air, sea, land mobile, and VSAT communications will use the same satellites with flexible OBP functions to reduce the cost of the overall communications system and the ground terminals in particular by trading off for more complex satellite payloads

• Hopping beams between areas of low demand will optimize cost of service

• To close the land mobile links in a fading and shadowing environment, differentially coherent demodulation and concatenated coding and interleaving will be employed

• MSAT systems will use a multi-satellite constellation connected by ISL's to maintain the highest feasible elevation angles to the satellites in order to minimize fading and interference

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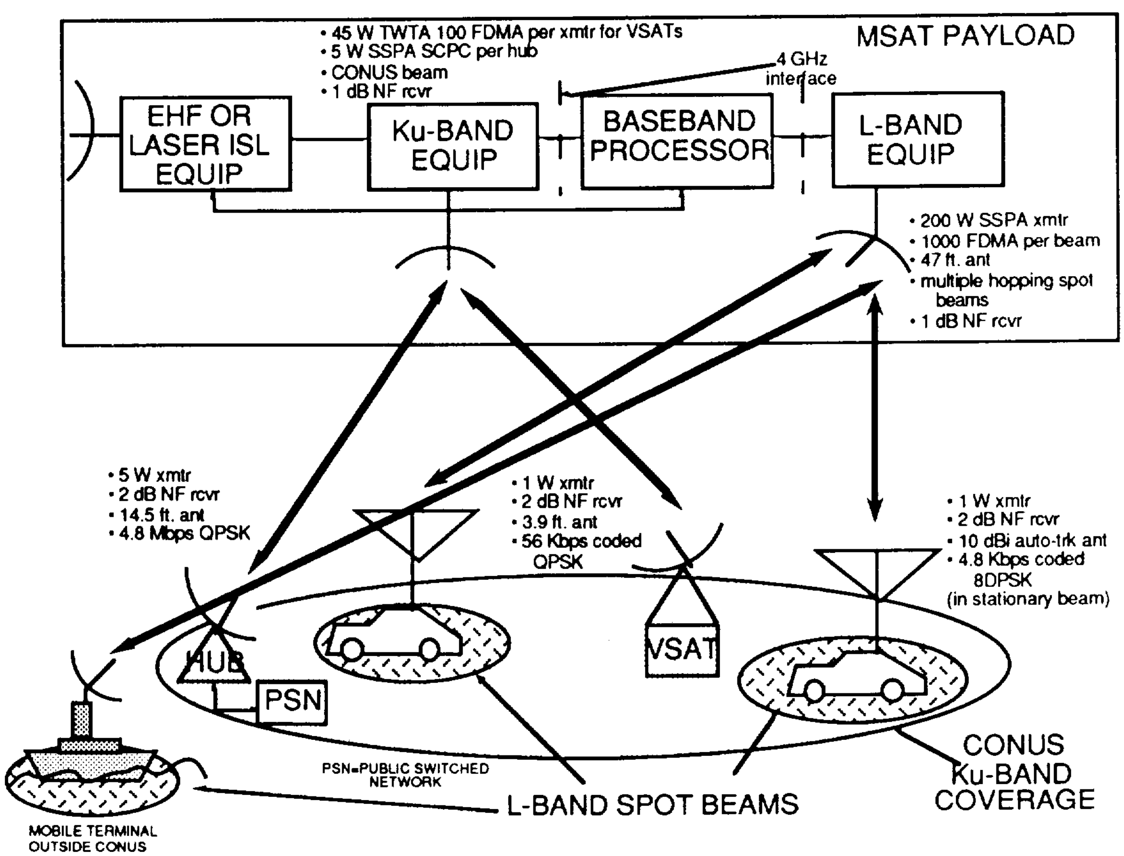

Figure 1 MSAT system showing salient terminal characteristics

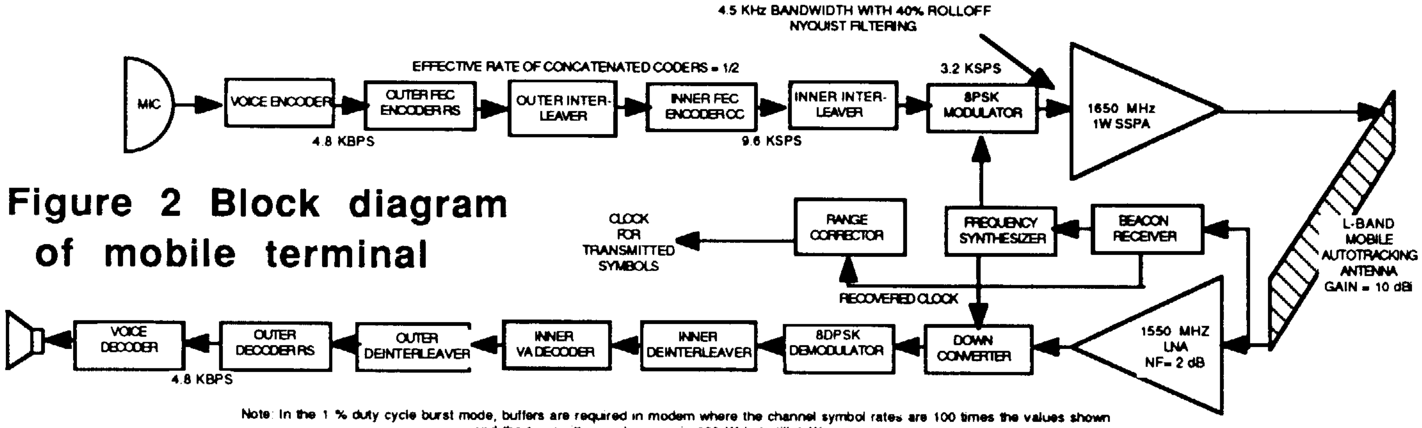

Figure 2 Block diagram of mobile terminal

Note: In the 1 % duty cycle burst mode, buffers are required in modem where the channel symbol rates are 100 times the values shown and the transmitter peak power is 100 W but still 1 W average.

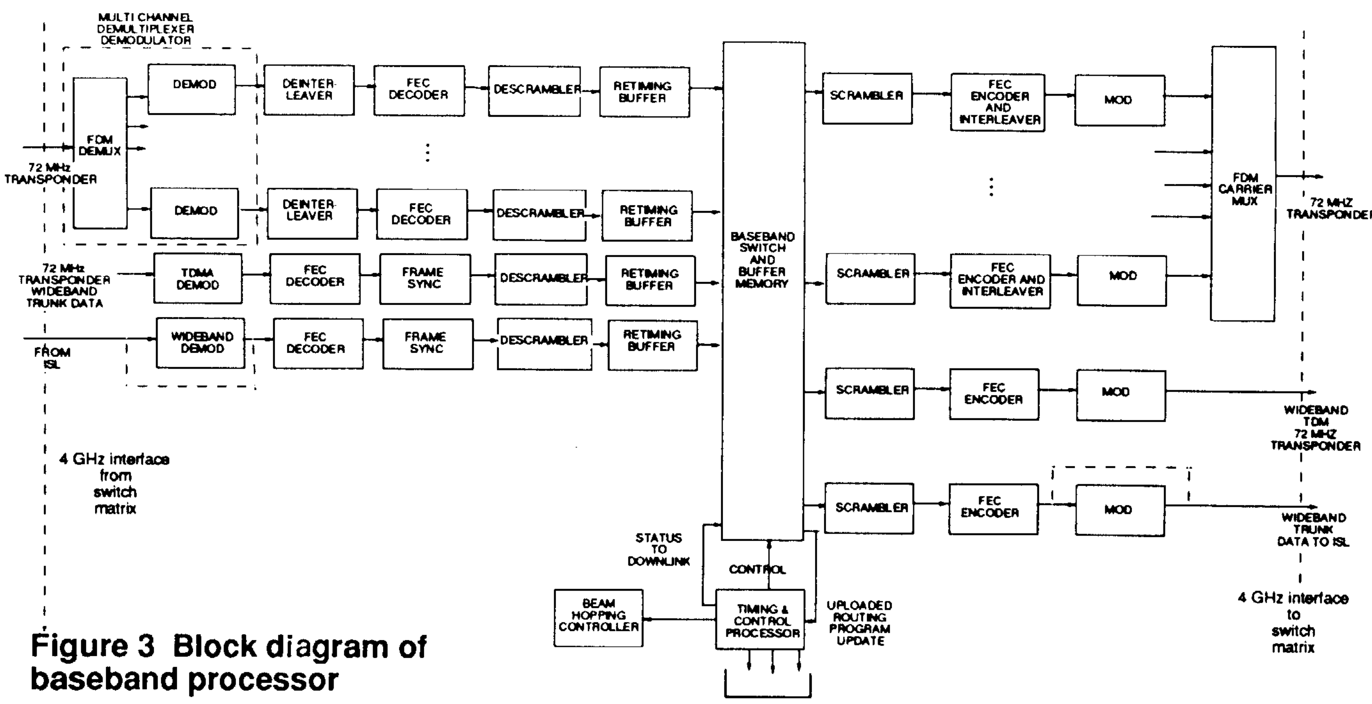

Figure 3 Block diagram of baseband processor

MSAT Mobile Links									
				COMMENTS	DOWNLINK 1550 MHz			COMMENTS	
Ground Transmitter Power	30.0	dBm	1	W SSPA	Satellite Transmitter Power	53.0	dBm	200	W SSPA
Ground Transmitter Losses	1.0	dB			Satellite Transmitter Backoff	6.0	dB	FDM	
Ground Transmitter Antenna Gain	10.0	dBi		JPL auto-tracking	Satellite Power per Carrier	17.0	dBm	1000	carriers
Ground e.i.r.p.	39.0	dBm			Satellite Transmitter Ant. Gain	44.5	dBi	47' diam, 55% effic., 1degree b.w.	
Free Space Loss	189.0	dB			Satellite Transmitter Losses	1.0	dB		
Satellite Antenna Gain	45.0	dB		47' diam., 55% illumination efficiency	Satellite e.i.r.p	60.5	dBm	per carrier	
Sat. Rec. System Noise Temp.	25.6	db-deg K		290 deg earth, 1dB noise figure	Free Space Loss	188.5	dB		
Satellite G/T	19.4	db/deg K			Ground Terminal Ant. Gain	10.0	dBi	JPL auto-tracking	
Eb/No	29.7	dB		4.8 Kbps data, modem impl. loss 1.5 dB	Ground Receiver Noise Temp.	22.3	dB-deg K	2 dB noise figure	
Required Eb/No	14.0	dB		BER=10e-3 for 8DPSK	Ground Receiver G/T	-12.3	dB/deg K		
Margin for BER=10e-3	15.7	dB		AWGN without coding	Eb/No	20.0	dB	4.8 Kbps, 1.5 dB modem impl. loss	
Required Eb/No	17.0	dB		BER=10e-6 for 8DPSK	Required Eb/No	14.0	dB	D8PSK, BER=10e-3	
Margin for BER=10e-6	12.7	dB		AWGN without coding	Margin	6.0	dB	AWGN without coding	

Table 1 MSAT Mobile Links

MSAT VSAT Links									
UPLINK 14.2 GHz				COMMENTS	DOWNLINK 11.9 GHz			COMMENTS	
Ground Transmitter Power	30.0	dBm	1	W SSPA	Satellite Transmitter Power	46.5	dBm	45	W TWTA
Ground Transmitter Losses	1.0	dB			Satellite Transmitter Backoff	6.0	dB	FDM	
Ground Transmitter Antenna Gain	42.5	dBi		3.9' ant.	Satellite Power per Carrier	20.5	dBm	100	carriers
Ground e.i.r.p.	71.5	dBm			Satellite Transmitter Ant. Gain	29.0	dBi	1' diam., CONUS coverage	
Free Space Loss	207.5	dB			Satellite Transmitter Losses	1.0	dB		
Satellite Antenna Gain	30.5	dB		1' diam., CONUS coverage	Satellite e.i.r.p	48.5	dBm	per carrier	
Sat. Rec. System Noise Temp.	25.6	db-deg K		290 deg earth, 1dB noise figure	Free Space Loss	206.0	dB		
Satellite G/T	4.9	db/deg K			Ground Terminal Ant. Gain	40.5	dBi	3.9' ant.	
Eb/No	18.5	dB		56 Kbps data, modem impl. loss 1.5 dB	Ground Receiver Noise Temp.	22.3	dB-deg K	2 dB noise figure	
Required Eb/No	10.6	dB		BER=10e-6 for QPSK, uncoded	Ground Receiver G/T	18.2	dB/deg K		
Margin for BER=10e-6	7.9	dB		AWGN	Eb/No	10.3	dB	56 Kbps data, modem impl. loss 1.5 dB	
Required Eb/No	11.3	dB		BER=10e-7 for QPSK, uncoded	Required Eb/No	5.5	dB	BER=10e-6 for QPSK, R=1/2 K=7, VA decoder	
Margin for BER=10e-7	7.2	dB		AWGN	Margin	4.8	dB		

Table 2 MSAT VSAT Links

MSAT Hub Links									
UPLINK 14.2 GHz				COMMENTS	DOWNLINK 11.9 GHz			COMMENT	
Ground Transmitter Power	37.0	dBm	5	W SSPA	Satellite Transmitter Power	37.0	dBm	5	W SSPA
Ground Transmitter Losses	1.0	dB			Satellite Transmitter Backoff	0.0	dB	TDM	
Ground Transmitter Antenna Gain	52.4	dBi		14.5' ant.	Satellite Power per Carrier	37.0	dBm	1	carrier
Ground e.i.r.p.	88.4	dBm			Satellite Transmitter Ant. Gain	29.0	dBi	1' diam., CONUS coverage	
Free Space Loss	207.5	dB			Satellite Transmitter Losses	1.0	dB		
Satellite Antenna Gain	30.5	dB		1' diam., CONUS coverage	Satellite e.i.r.p	65.0	dBm		
Sat. Rec. System Noise Temp.	25.6	db-deg K		290 deg earth, 1dB noise figure	Free Space Loss	206.0	dB		
Satellite G/T	4.9	db/deg K			Ground Terminal Ant. Gain	52.0	dBi	14.5 ' diam. hub terminal	
Eb/No	16.1	dB		4.8 Mbps data, modem impl. loss 1.5 dB	Ground Receiver Noise Temp.	22.3	dB-deg K	2 dB noise fig.	
Required Eb/No	10.6	dB		BER=10e-6 for QPSK, uncoded	Ground Receiver G/T	29.7	dB/deg K		
Margin for BER=10e-6	5.5	dB		AWGN	Eb/No	19.0	dB	4.8 Mbps, 1.5 dB implem. loss	
Required Eb/No	11.3	dB		BER=10e-7 for QPSK, uncoded	Required Eb/No	10.6	dB	QPSK, BER=10e-6	
Margin for BER=10e-7	4.8	dB		AWGN	Margin	8.4	dB	AWGN, uncoded	

Table 3 MSAT Hub Links