Before the

FEDERAL COMMUNICATIONS COMMISSION

Washington, D.C.

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In the Matter of	)	
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Establishing Rules and Policies for the Use of Spectrum for Mobile Satellite Service in the Upper and Lower L-band	))))	IB Docket No. 96-132

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Reply Comments of Radio Satellite Corporation

Introduction

Radio Satellite Corporation ("RSC") hereby submits its Reply Comments to the Notice of Proposed Rule Making ("NPRM") released June 18, 1996 proposing to assign additional L-band Mobile Satellite Service ("MSS") spectrum to the American Mobile Satellite Corporation ("AMSC").

Commenters overwhelmingly urged the Commission to use the additional spectrum to foster competition, rather than to give it away to AMSC as the Commission proposes. The Commission already gave AMSC an extremely valuable monopoly which it has grossly misused. As RSC described in its Opposition, AMSC has used its monopoly position to prevent RSC's innovative RadioSat services from reaching the public. AMSC blocked RSC in spite of the fact that the Commission wanted AMSC to foster entrepreneurial efforts to open new markets.

Lockheed Martin Company (hereinafter "LMC") points out in its Comments that AMSC's spectrum requirements are inflated.

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RSC concurs and provides further evidence in these Reply Comments. LMC urges the Commission to "undertake a critical reassessment of commercial and technical objectives for MSS in the United States" and to authorize competing systems. RSC heartily agrees. It has been nearly a decade since the Commission first decided to establish a geostationary L-band MSS monopoly. AMSC has completely failed to accomplish the objectives the Commission laid out for it and that AMSC agreed to. The best way of resolving this problem is for the Commission to undertake a full reevaluation with the goal of establishing competing systems, as proposed by LMC.

LMC offers to participate in L-band coordination efforts. RSC urges the Commission to accept LMC's offer.

AMSC has failed to provide RSC with access to the only spectrum appropriate for its system. RSC implores the Commission to use the additional spectrum contemplated in this NPRM to establish a competing geostationary MSS provider in the 1525-1559 MHz and 1626.5-1660.5 MHz bands and to license competing operators to use AMSC's unused orbital slots. Only in this way can the public ever benefit from revolutionary RadioSat services.

Reply to Comments of Lockheed Martin Corporation

RSC strongly endorses the comments of Lockheed Martin Corporation (hereinafter "LMC Comments"). LMC points out that current technology uses the spectrum much more efficiently

than proposed by AMSC and that AMSC has no incentive to attempt to use the spectrum efficiently.

A report (attached) written by the author of the present Reply Comments and filed in the original MSS proceedings in 1986 explains some of the reasons for AMSC's inflated spectrum requirements in greater detail.[1] "A second generation LMSS system supporting communications only with mobiles using omnidirectional antennas needs as little as 2 MHz of spectrum; communications with directive mobile antennas can require as much as 36 MHz of spectrum." The new MSS systems under development by LMC in Asia (ACeS) and the Middle East (SatPhone) would communicate exclusively with terminals using omnidirectional antennas.

The market has already demonstrated that the steered antennas used by AMSC, and on which its inflated spectrum demands have been based, are not viable.

"Indeed, Reston, Va.-based American Mobile Satellite Corp., which has only a single satellite offering commercial phone service in North America, has had a tough time attracting customers ... acknowledged spokeswomen Renate Brown Neely. ... Since it began operating in January, the service has attracted only 15,500 subscribers, a small fraction of the 100,000 the company says it needs to break even."[2] This dismal

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[1] Noreen, Gary K., "Second Generation Land Mobile Satellite Service Spectrum Requirements," ATSC-SSD-R-037905, October 31, 1986. This report is attached to the end of this filing.

[2] Los Angeles Times, September 9, 1996.

performance has arisen, in large part, from AMSC's use of expensive and bulky steered antennas. The omnidirectional antennas that the RadioSat system and LMC's new MSS systems will use have much greater appeal to the public - and result in the use of far less spectrum.

LMC asks the Commission to reexamine AMSC's spectrum needs in the light of new technology and to provide an opportunity for competitors to use the spectrum under consideration in this NPRM. RSC agrees.

LMC points out that AMSC is not motivated to fight for spectrum that might be used by a competing system. RSC adds that AMSC has taken every opportunity it could to aggrandize free spectrum and to block others that might compete with it[3] LMC's participation in the L-band coordination process is critically important to enable competition in the future and should be welcomed by the Commission.

RadioSat Requirements

The RadioSat system described in RSC's Opposition requires spectrum suitably positioned near the GPS L1 frequency in order to provide its integrated services. The chart below shows the current L-band geostationary MSS bands and the GPS L1 frequency.

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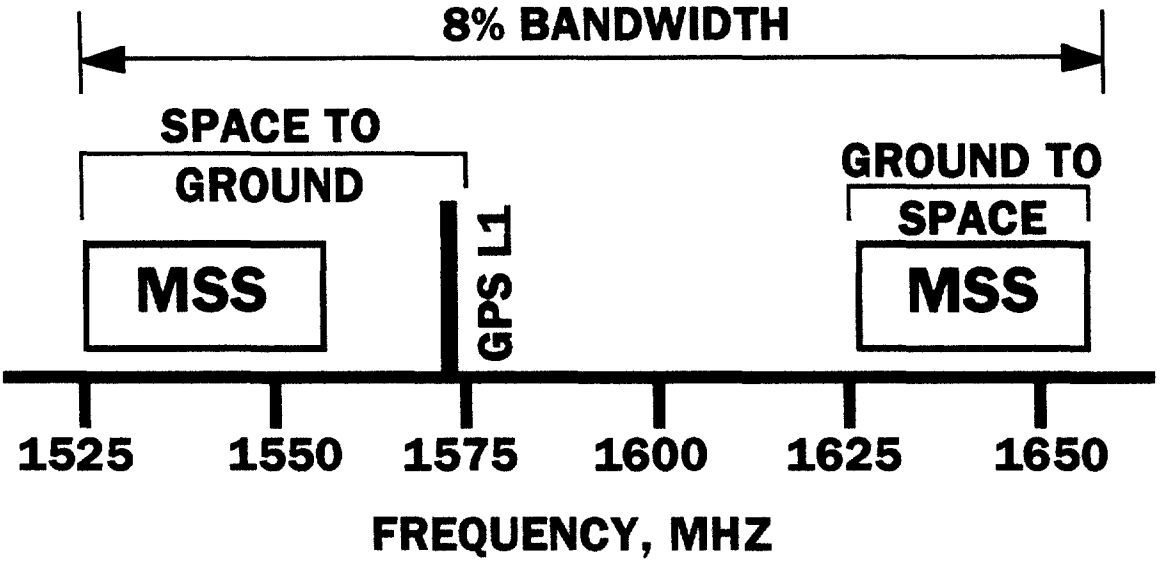
[3] Note AMSC's AMRC application for DARS, its application and behavior in the Big LEO proceeding, and the vocal and transparently self-serving opposition of Lon Levin (AMSC's regulatory counsel) to satellite spectrum auctions.



RadioSat mobile satellite terminals would provide integrated private network broadcast, precision navigation and communications services. The GPS L1 transmission centered at 1572.45 MHz lies conveniently between the geostationary L-band MSS bands. The close proximity of the GPS L1 transmission to the MSS space-to-ground allocation makes it possible for RadioSat mobile terminals to use a common receiver front end to receive both MSS and GPS transmissions. The low antenna bandwidth (8%) makes it possible to use a single inexpensive omnidirectional antenna to transmit and receive MSS communications and to receive GPS transmissions.

Reply to Comments of Celsat

Celsat America, Inc. suggests that AMSC be granted the additional spectrum in return for agreeing not to use spectrum Celsat covets. Celsat suggests that in this way, the Commission can foster competition. Unfortunately, Celsat's

proposed MSS system is unsuitable for providing RadioSat services, so RSC does not consider Celsat a viable alternative to AMSC. RSC thus opposes Celsat's suggestion.

While the Celsat system would be a geostationary MSS system, it would operate at 2 GHz and it would thus be difficult for RSC to integrate a GPS receiver into a RadioSat terminal designed to operate through the Celsat system. Furthermore, while suitable for two-way voice communications, 2 GHz frequencies are inferior to L-band for RadioSat private network broadcast services. The power required for a broadcast satellite system increases with the square of frequency,[4] so RadioSat private network broadcast transmissions at Celsat's proposed frequencies would require 70% more satellite power than in the 1525 to 1559 MHz L-band allocation.

Reply to Comments of AMSC Subsidiary Corporation

In its Comments, AMSC states that it secured financing "based on the Commission's stated goal of access to between 20 MHz and 28 MHz of spectrum," implying that the Commission is somehow obligated to AMSC's investors to provide this much spectrum to AMSC.[5] AMSC's problems with investors, however, are not related to the alleged spectrum shortage and are decidedly of its own making. AMSC attracted investors with

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[4] Noreen, Gary K., "An Integrated Mobile Satellite Broadcast, Paging, Communications and Navigation System," 40th IEEE Broadcast Symposium, September 7, 1990.

[5] P. 2.

promises unrelated to spectrum that it has completely failed to live up to. A news report in 1995 details some of these promises:

"American Mobile Satellite Corp. expects cash flow to break even in the third quarter of 1996, Chief Executive Officer Brian Pemberton said. He told the Bear Sterns 1995 Technology Conference the first wireless telecommunications company licensed to provide national cellular coverage expects to have sufficient revenues to end its negative cash flow during that quarter. He said the nationwide voice and data service is set to begin during the third quarter of this year. This service will be targeted at remote, mobile, and air- and sea-based users.

"Pemberton also said American Mobile expects cash flow to break even in terms of both cash expenses and capital expenditures in the first quarter of 1997, when it expects to have 132,000 subscribers."[6]

As noted earlier in these Reply Comments, AMSC now has only 15,500 subscribers. It is interesting that break even has been reduced from 132,000 to 100,000.[7]

RSC begged AMSC from 1989 through 1991 to fulfill its common carrier obligations and provide RSC with capacity on its system.[8] AMSC declined, in spite of the fact that the Commission made it clear throughout the MSS proceedings that

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[6] Reuters, June 20, 1995.

[7] See Footnote 2 of these Reply Comments.

[8] See Opposition of RSC.

it was structuring a monopoly MSS system specifically to foster entrepreneurial efforts to develop new markets.[9] Had AMSC simply carried out its obligation as a common carrier, RSC would be in service today, providing AMSC with much needed customers and revenue. RSC would have been able to provide MSS to tens of millions of consumers, AMSC would have earned a substantial return for its investors - and since RSC would have provided its innovative services only to mobiles with omnidirectional antennas, AMSC would have required **less** spectrum. As it is, with only 15,500 subscribers out of the 300,000 its system was supposedly designed to support, AMSC's request for additional spectrum is completely unwarranted.

RSC once again urges the FCC to use the additional spectrum proposed in this NPRM and AMSC's unused orbital slots to establish a competing geostationary L-band MSS system.

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[9] At the May 31, 1989 FCC Open Meeting at which the FCC granted AMSC its initial MSS license (4 F.C.C Rcd. 6041), Gerald Brock (at that time Chief of the Common Carrier Bureau) said "it is important that a wide variety of services be offered in order to make this system viable. ... We expect a wide variety of services to be provided. ... Many of these services are not yet fully developed, and we cannot be certain what markets will exist, but by this action today, we are providing the opportunity for any number of entrepreneurs to try their hand at developing new markets for mobile satellite services. Although there will be a single system, there will be a large number of people that will have access to that system and will be able to, on a retail basis, develop services."

Respectfully submitted,

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Second Generation Land Mobile Satellite Service Spectrum Requirements

by

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ASTC-SSD-R-037905 October 31, 1986

Executive Summary

The decision of the Federal Communications Commission to allocate L-band frequencies to Mobile Satellite Service (MSS) has resulted in an increase of effectively an order of magnitude in the amount of spectrum available for Land Mobile Satellite Service (LMSS). This spectrum could be used to support competing LMSS systems.

The amount of spectrum required for each L-band LMSS system, and thus the number of systems that could be accommodated within a given allocation, depends primarily on the type of mobile antenna used and on the quality of service provided. A second generation LMSS system supporting communications only with mobiles using omnidirectional antennas needs as little as 2 MHz of spectrum; communications with directive mobile antennas can require as much as 36 MHz of spectrum. In practice, there should be a mix of omnidirectional and directive antennas on each system, resulting in a spectrum requirement of between 4 MHz and 12 MHz per system in the second generation. Orbit reuse techniques could be used in the second generation to permit two satellites in the orbital arc to use the same frequencies. Combining frequency reuse through multiple spot beams and orbit reuse will permit 4 to 14 systems in a 27 MHz allocation.

Communications with L-band transportable antennas could use hundreds of MHz of spectrum. An MSS operator could always use L-band transportables to use as much spectrum as available. However, Ku-band transportable terminals (VSATs) make more effective use of spectrum and orbital reuse, and the cost of Ku-band VSATs is rapidly declining, so Ku-band terminals are preferred for transportable applications.

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LMSS orbit reuse schemes appear to be somewhat risky for first generation systems, though they should be practical for second generation systems.

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The rapidly declining cost of Ku-band VSATs, their low satellite power requirements, the high degree of orbit reuse possible at Ku-band, and the availability of spectrum at Ku-band all combine to make Ku-band VSATs preferable to MSS for transportable applications.

6. Multiple System Scenarios *10*

Each second generation LMSS system should have a mix of directive and omnidirectional mobile antennas and use between 4 and 12 MHz of L-band spectrum. Orbit reuse techniques make multiple LMSS systems possible at L-band even if each system uses all the available spectrum.

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The decision of the Federal Communications Commission to allocate L-band rather than UHF frequencies to MSS has resulted in an effective increase of an order of magnitude in the spectrum available for LMSS. This spectrum can be used to support multiple LMSS systems, enabling competition.

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Second Generation Land Mobile Satellite Service Spectrum Requirements

1. Introduction

This report shows the amount of spectrum required for several domestic UHF and L-band Land Mobile Satellite Service (LMSS) system configurations. Each system provides complete coverage of Canada, Alaska, and CONUS.

The Federal Communications recently allocated 27 MHz of L-band spectrum to Mobile Satellite Service (MSS).[1] The Commission originally planned to allocate 8 MHz of UHF spectrum to MSS.[2] L-band spectrum can be reused nearly four times more than UHF spectrum on second generation MSS systems,[3] so the Commission's decision to move MSS from UHF to L-band has effectively increased the amount of spectrum available for MSS by an order of magnitude. This increase in spectrum makes multiple MSS systems feasible, enabling competition in this important new service.

This report estimates the spectrum requirements only of second generation LMSS systems. W&B/TCI proposed in its MSS application that the first generation MSS system use only a small secondary MSS payload launched on a satellite with another primary payload.[4] Such a payload requires under 1 MHz of spectrum.

While multiple LMSS systems are now clearly feasible, the question remains of just how many LMSS systems can be accommodated within the available spectrum. The purpose of this report is to estimate how much spectrum is required by each system so that this question can be answered. It is shown that the answer depends on how LMSS is to be used. For example, if the primary LMSS service is to be communications with mobiles using small, inexpensive omnidirectional antennas, under 4 MHz of spectrum is shown to be sufficient for each second generation system. If the primary service is to be high reliability communications with mobiles using expensive, complex directive antennas, as much as 12 MHz per system may be necessary.

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[1] *Report and Order*, FCC 86-333, released September 26, 1986.

[2] *Notice of Proposed Rule Making*, Gen. Docket No. 84-1234, 50 Fed. Reg. 8149 (February 28, 1985).

[3] *See* Noreen, Gary K., *Land Mobile Satellite Service at 1600 MHz and 800 MHz: A Comparative Review*, W&B/TCI Report #WBR-037801, December 6, 1985, pp. 7-8.

[4] *See* Application of W&B/TCI for Authorization to Construct and Operate a Domestic Mobile Satellite Service System, submitted to the FCC on April 30, 1985, at Appendix I.

LMSS spectrum requirements depend more on mobile antenna characteristics than on satellite antenna size. This is because increasing satellite antenna diameter also reduces the size of the satellite antenna beamwidth, enabling an increase in the number of beams over the coverage area and thus an increase in the amount of frequency reuse.

Spectrum can be also be reused by placing different satellites at different locations in the orbital arc and using sophisticated intersatellite isolation techniques to prevent intersatellite interference. These techniques are briefly reviewed herein. Since these techniques have not been demonstrated in the Mobile Satellite Service, W&B/TCI does not recommend their use in first generation systems. However, these techniques could be demonstrated with a first generation space segment and implemented in second generation systems.

By combining orbit reuse with multiple beam LMSS satellites, 14 second generation LMSS systems using 4 MHz of spectrum each could be accommodated within the 27 MHz of spectrum the Commission recently allocated to LMSS. Alternatively, 4 MSS systems using 12 MHz of spectrum could be accommodated.

Much more spectrum would be required to support communications with transportable terminals. However, given the much greater degree of frequency reuse possible with VSATs that operate at higher frequencies than MSS and the rapid decrease in VSAT prices, VSATs appear better suited to transportable applications than MSS. L-band spectrum should be reserved for the mobile services it supports particularly well.

2. Power Constraints

The number of channels that can be supported by an LMSS system is limited by the emitted spacecraft power, by mobile antenna gain, and by propagation characteristics.

LMSS channels can be thought of as consumers of two limited resources: satellite power and spectrum. Satellite power is normally of concern only for satellite-to-mobile links, which require far more satellite power per channel than other LMSS links. Thus two factors limit the number of channels that can be supported by an LMSS system: transmitter power available for satellite-to-mobile links, and spectrum available to the system.

If a satellite system is power-limited, it has access to enough bandwidth to support all the channels it can supply with power. If, on the other hand, a satellite system is bandwidth-limited, it has power (or capacity) left over after filling all the channels it has been authorized bandwidth to support.

The number of channels a satellite system can support given a fixed power level is calculated by dividing total available power by average required power/channel. The number of channels given a fixed bandwidth is calculated by dividing the available bandwidth by the

frequency reuse factor and by channel spacing, then multiplying by the number of satellite spot beams.[5] The number of channels supported by an LMSS space segment can never exceed the power limit or the bandwidth limit of the system, so the lesser of the two determines the total number of channels that can be supported.

In this section, we calculate the number of power-limited channels N_{PB} that can be supported per beam on each of six RCA Astro-Electronics satellite designs[6] assuming assorted mobile antennas and excess path losses. In the next section, we calculate how much bandwidth must be made available to support these channels.

The number of power-limited channels per beam N_{PB} is equal to

$$N_{PB} = EIRP_B/(EIRP_C \cdot AF), \qquad (1)$$

where $EIRP_B$ is Effective Isotropic Radiated Power per beam, $EIRP_C$ is required Effective Isotropic Radiated Power per channel, and AF is activity factor. $EIRP_B$ is the product of beam transmitter power, transmit antenna gain, and transmitter circuit loss.

The RCA study used as the basis for this report[7] was commissioned by the Jet Propulsion Laboratory (JPL) of the California Institute of Technology. JPL specified the number of beams for each satellite antenna. All satellites provide coverage of the Contiguous United States (CONUS), all of Canada, and Alaska. All downlink channels were assumed to operate with an activity factor of 100%, which RCA noted is "unrealistic" but which simplified the analysis.[8] Each of the RCA designs was limited to a Geostationary Transfer Orbit (GTO) weight of 5800 pounds, the limit of the RCA Series 4000 Geosynchronous Communications Spacecraft bus assumed in the study. The RCA configurations reviewed herein all provide 50% eclipse capability. Table 1 shows $EIRP_B$ for each of 6 LMSS satellite designs prepared by RCA Astro-Electronics. A transmitter circuit loss of 2.4 dB is assumed herein on each satellite.

$EIRP_C$ must be high enough to ensure a carrier-to-noise power density C/N_0 of at least 45 dB-Hz, assuming 2400 bps 5 kHz Gaussian Filtered Minimum Keying (GMSK) modulation at a bit error rate of 10^{-3}.[9] Other types of modulation are under consideration for LMSS, but most require a C/N_0 of at least 45 dB-Hz for every 5 kHz of bandwidth.

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[5] Sue, Miles K. and Young H. Park, *Second-Generation Mobile Satellite System: A Conceptual Design and Trade-Off Study*, JPL Publication 85-58, June 1, 1985, p. 2-9.

[6] *Spacecraft (Mobile Satellite) Configuration Design Study*, prepared by RCA Astro-Electronics Division, Princeton, New Jersey; MSAT-X Report No. 114, JPL No. 9950-1154, June 14, 1985.

[7] Id.

[8] Id. at 1-3.

[9] Bell, D. J. and S. A. Townes, *MSAT-X System Definition and Functional Requirements*, Revision 1, JPL, November 12, 1984.

RCA assumed an $EIRP_C$ of 28.6 dBw per channel at UHF frequencies and 34.7 dBw at L-band in its study.[10] RCA based its $EIRP_C$ requirements on JPL link budgets.[11] These budgets assume an excess path loss of 4 dB, a mobile antenna gain of 10 dBi, and a margin of 3 dB. We have generally followed JPL link budgets herein, except for noted variations in excess path loss and mobile antenna gain.

C/N_o on LMSS links is computed from the link equation[12]

$$C/N_0 = EIRP_C \cdot L_S L_{EOB} L_P L_E G_R / N_0, \qquad (2)$$

where L_S is free space loss, L_{EOB} is Edge-Of-Beam loss, L_P is loss between transmit and receive antennas due to polarization mismatch, L_E is excess path loss due to shadowing and multipath, G_R is receive antenna gain, and N_0 is one-sided noise spectral density.

Free space loss L_S is the ratio of received power to transmitted power between two antennas in free space. Free space loss can be characterized by

$$L_S = \lambda^2/(4\pi r)^2 \qquad (3)$$

where λ is the wavelength of the radio signal and r is the distance between the transmit and receive antennas.

Edge-Of-Beam loss L_{EOB} arises from offset of the location of the mobile receiver from the boresight of the satellite antenna. It is assumed equal to the reduction in gain of the satellite antenna from boresight to the edge of the beam, a worst-case condition.

Excess path loss L_E is path loss between the transmitter and receiver that is in excess of the space loss L_S. Shadowing is the primary contributor to excess path loss on LMSS links. Shadowing is due largely to trees and other obstructions to the line-of-sight.

Because MSS satellites are 22,000 miles from mobiles, signals received by mobiles are quite weak. As a result, LMSS links are critically sensitive to obstructions to the line-of-sight that reduce received signal levels. In some areas, such as dense urban areas, buildings will obscure the line-of-sight a high proportion of the time. In these regions, LMSS will probably not be a practical means of communications. In other areas, such as suburban areas or forest regions, signals may be disrupted over an unacceptable range of loca-

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[10] *Spacecraft (Mobile Satellite) Configuration Design Study*, prepared by RCA Astro-Electronics Division, Princeton, New Jersey; MSAT-X Report No. 114, JPL No. 9950-1154, June 14, 1985 at Table 3-1.

[11] *See* Sue, M.K. and Y.H. Park, *Second-Generation Mobile Satellite System: A Conceptual Design and Trade-Off Study*, JPL Publication 85-58, June 1, 1985, at Table 3-3, p. 3-17.

[12] Yuen, Joeseph H., *Telecommunications Systems Design*, Chapter 1 of DEEP SPACE TELECOMMUNICATIONS ENGINEERING, ed. by Joseph H. Yuen, Plenum Press, 1983.

tions. In open areas with clear views of satellites, there is minimal excess path loss and reception is optimal.

Because of the dependence of excess path loss on the areas and ways in which LMSS systems are used, this report performs all calculations based on two excess path loss levels: 6 dB and 10 dB. An excess path loss of 6 dB corresponds roughly to an "availability" of 90% at L-band; 10 dB corresponds to 95% "availability."[13]

Mobile antenna receive gain G_R depends on the type of mobile antennas used. Mobile satellite antennas are best divided into two classes: gain-constrained and aperture-constrained. These classes correspond to antennas that are azimuth omnidirectional (those that need not be actively pointed towards the satellite) and azimuth directive (those that must be actively pointed).

Mobile satellite antennas that do not actively point towards a satellite can still have moderate directivity in elevation. This is because MSS satellites will lie within an elevation angle of 25 to 60 degrees when viewed from CONUS. A gain of 4 dBi can be achieved without difficulty with a circularly polarized antenna that is omnidirectional in azimuth. This gain is independent of frequency; it is derived from the directivity requirement.

When mobile antennas are actively pointed towards satellites, the situation is much different. Gain is then limited by mobile antenna aperture, i.e. by the maximum size of mobile antennas that can be placed on vehicles. Antennas as large as 3 feet in diameter could be placed on vehicles, but as a practical matter, mobile antennas will probably have to be significantly smaller than this. Estimates of the gain of directive mobile antennas generally range from 10 to 13 dBi.

Pointing land mobile antennas requires complex, expensive mechanisms that may be prone to failure. The manufacturing cost of these antennas is predicted to be many hundreds of dollars each, even in large quantities.[14]

Because of the present uncertainty about the relative number of omnidirectional and directive mobile antennas that will be used for LMSS and the uncertainty about the gain of directive antennas, this report calculates spectrum requirements assuming 4 dBi, 10 dBi, or 13 dBi mobile antenna gain.

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[13] Noreen, Gary K., *Land Mobile Satellite Service at 1600 MHz and 800 MHz: A Comparative Review*, Wismer & Becker/Transit Communications, Inc. Report #WBR-037801, December 6, 1985.

[14] *Concepts and Cost Trade-Offs for Land-Vehicle Antennas in Satellite Mobile Communications*, MSAT-X Report No. 102, Jet Propulsion Laboratory, July 1984 and *Trade-Off Between Land Vehicle Antenna Cost and Gain for Satellite Mobile Communications*, MSAT-X Report No. 103, Jet Propulsion Laboratory, August 1984.

Transportable antennas have been proposed that would be manually pointed towards LMSS satellites. Set-up locations can be selected to avoid obstructions to the line-of-sight to the satellite, so there will be no excess path loss when transportable antennas are used.

Transportable antennas have substantially greater gain than mobile antennas. 1-meter L-band dish antennas, for example, have 21 dBi gain.

One-sided noise spectral density N_0 is equal to kT, where k is Boltzmann's constant and T is receiver noise temperature. T is given by[15]

$$T = T_A + (L_R NF - 1) T_0 \qquad (4)$$

where T_A is antenna noise temperature, L_R is receiver circuit loss, NF is noise figure, and T_0 is ambient temperature of the receiver.

The $EIRP_C$ required to ensure a C/N_0 of 45 dB-Hz with a margin of 3 dB is calculated from the link equation through link power budgets as shown in Tables 4, 5, and 6. Tables 4 and 5 assume 10 dBi mobile antenna gain and 6 dB excess path loss. Table 6 is a link power budget for an L-band transportable antenna. Table 2 shows required $EIRP_C$ for other combinations of mobile antenna gain and excess path loss.

The activity factor on each channel depends on the type of service using the channel. For voice communications, activity factors of 0.25 to 0.3 are typical. For data communications, activity factors can approach 1.0. This report assumes an activity factor of 0.4. The number of channels that can be supported by each beam is increased by 2.5 when the activity factor is accounted for.

Table 3 shows the number of channels that can be supported by each configuration for various combinations of mobile antenna and excess path loss based on available satellite power. The number of channels that can be supported by each configuration depends also on available spectrum, as described in the next section.

3. Spectrum Requirements

Each L-band system supporting communications with predominantly omnidirectional mobile antennas requires less than 2 MHz of downlink spectrum. Even L-band systems communicating with predominantly directive mobile antennas generally require less than 6 MHz of downlink spectrum.

The number of channels that can be supported by an MSS system depends not only on available power, but on available spectrum. In this section we compute the spectrum required to support each system configuration examined in the previous section.

The total bandwidth B_T required for a mobile satellite to operate at capacity is equal to

[15] Bell, Dave, *Noise Figure, What Is It?* Jet Propulsion Laboratory Interoffice Memo 3392-83-134, October 3, 1983.

$$B_T = N_{PB} \cdot B_C \cdot F_R, \quad (5)$$

where N_{PB} is the number of power-limited channels per beam (calculated in the previous section), B_C is the channel bandwidth, and F_R is the frequency reuse factor.

The channel bandwidth for LMSS is generally 5 kHz. Some have proposed the use of 30 kHz "narrow band" FM (NBFM), which requires a C/N_0 of 53 dB-Hz for toll quality communications (a factor of more than six times greater than the 45 dB-Hz required for voice communications). Due to the high C/N_0 requirement of NBFM, a power-limited satellite system using NBFM will require less total spectrum than one using GMSK. Thus, our assumption of 5 kHz channels and a C/N_0 of 45 dB-Hz results in an estimate of maximum spectrum requirements.

The term "frequency reuse factor" refers not to the number of times frequency is reused but to the number of sub-bands used by a system.[16] Adjacent beams in multiple-beam LMSS systems must use different frequency sub-bands to avoid interference. In general, a frequency reuse factor of at least 7 (meaning the spectrum used by a system is broken into 7 sub-bands, each with 1/7th of the total spectrum) is necessary to permit the use of non-overlapping feeds.[17] This report assumes a frequency reuse factor of 7.

The total downlink bandwidth required for each satellite is shown in Figures 1 through 4 for each of the 6 RCA satellite designs for 4 dBi, 10 dBi, and 13 dBi mobile antenna gains and for excess path loss levels of 6 and 10 dB. Figure 5 shows total downlink bandwidth for L-band transportable antennas.

It is important to note that Figures 1 through 5 show only *downlink* (satellite-to-mobile) spectrum requirements. An equal amount of additional spectrum will normally be required for *uplink* (mobile-to-satellite) communications.

Figures 1 through 5 assume that each satellite is used for communications with a single type of ground antenna and with a single excess path loss level. In practice, there will be combinations of mobile antenna types and excess path levels for any LMSS system. Several trends are clear from Figures 1 through 5, however. For example, L-band systems supporting communications primarily with mobiles with omni antennas will not be able to use much more than 2 MHz of downlink spectrum (4 MHz including uplink spectrum).

4. Orbit Reuse with Mobile Antennas

LMSS orbit reuse schemes appear to be somewhat risky for first generation systems, though they should be practical for second generation systems.

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[16] Id., pp. 2-9.

[17] Id., Section 2.4.4.

As in other satellite services, the limited spectrum available for LMSS compels spectrum managers to consider ways of reusing spectrum between multiple satellites. Unfortunately, several characteristics of mobile communications severely limit the degree to which multiple LMSS satellites can share spectrum.

Reuse of frequencies in fixed satellite services is normally accomplished by pointing fixed ground antennas toward individual satellites. The high directivity of fixed satellite antennas provides sufficient isolation to communicate with satellites placed as little as 2° apart. Because of the low frequency of operation of mobile satellite services, constraints on mobile antenna aperture size, and the difficulty of pointing antennas on moving vehicles, mobile antenna directivity is very limited in the land mobile satellite service. Thus, little orbit reuse is possible -- two satellites at most can cover any one area with common frequencies.

For satellites to reuse frequencies, there must be sufficient isolation to ensure an adequately large carrier-to-interference power ratio *C/I*. Preliminary channel simulator results have indicated that a *C/I* of about 17 dB is required. If *C/I* drops significantly below 17 dB on the satellite-to-mobile link, serious degradations of digital signals occur[18] that require costly increases in satellite transmitter power.

Four ways of providing isolation between LMSS satellites have been proposed: (1) mobile antenna off-axis discrimination through the use of directive steerable antennas; (2) polarization; (3) satellite antenna off-axis discrimination; and (4) channel staggering.[19]

By definition, omnidirectional antennas point in all directions, so they cannot isolate any particular satellite by pointing at it. Omnidirectional antennas have axial ratios of 2.8 to 5.7 dB, resulting in 10 to 16 dB of polarization isolation. Polarization isolation of omnidirectional antennas, while significant, is not sufficient by itself to allow orbit reuse.

Medium gain mobile antennas provide, in the worst case, 13 dB (electronically steered) to 18 dB (mechanically steered) of discrimination between satellites spaced 30° apart. Tapering the excitation adds 2 dB (mechanically steered) to 7 dB (electronically steered) to the discrimination, at a cost of about 0.7 dB loss in gain. A total of about 20 dB of discrimination is achievable with tapering.[20] Errors in pointing will increase this value; however, the 17 dB C/I needed for two satellites in the orbital arc to reuse frequencies can certainly be achieved.

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[18] Id., Section 2.9.2; also, see Figure 2-47.

[19] Berner, Jeff, *Techniques for Orbit Reuse Applicable to Mobile Satellite Systems*, Session 4, Presentation 6 of MOBILE SATELLITE INDUSTRY BRIEFING sponsored by NASA/JPL, November 13-14, 1985. Also, *Orbit/Spectrum Resource Capacity for Land-Mobile-Satellite Service (LMSS) Systems*, Technical Report #2341, ORI, Rockville, Maryland, 20850, prepared for the Jet Propulsion Laboratory under JPL Contract No. 956753.

[20] Id.

Satellite antenna off-axis discrimination is possible if satellites use spot beams. With this technique, spot beams are interleaved between systems. The degree of isolation possible with this technique depends strongly on specific satellite configurations.[21]

Land mobile satellite channels can be staggered between satellites so that peak power levels on channels through one satellite occur in the guard bands of channels on the other satellite. Channel staggering has improved C/I by 5 dB in tests.

There is already substantial risk of MSS interference caused by passive intermodulation products.[22] Indeed, "[a]ll but the latest of the five high power mobile communications satellites that have become operational since 1975 have been impacted in a significant way by [passive intermodulation]. ... Spacecraft that are likely to be susceptible to this phenomenon are high powered multichannel satellites that are typically designed to operate in mobile or tactical satellite systems. The spacecraft that have encountered this problem have all operated at UHF or L-band."[23] To increase the risk of interference still further by introducing unproven orbit reuse techniques does not seem prudent, at least not in the first generation. Orbit reuse techniques could certainly be tested and evaluated in experiments using the first generation space segment, then introduced without risk in the second generation. Alternatively, L-band orbit reuse techniques can be tested through the existing Inmarsat space segment.

5. Transportable Antennas for MSS

The rapidly declining cost of Ku-band VSATs, their low satellite power requirements, the high degree of orbit reuse possible at Ku-band, and the availability of spectrum at Ku-band all combine to make Ku-band VSATs preferable to MSS for transportable applications.

Note from Figure 3 that hundreds of MHz would be required to support an LMSS system supporting communications only with transportable antennas. This is because very little power per channel must be transmitted by satellites to transportables, so an enormous number of channels can be supported.

There is, of course, far less spectrum available than what could be used to support communications with transportables. An LMSS operator that has an incentive to use all the allocated spectrum can easily do so by providing transportable services. This use of the spectrum seems questionable, however, given the many advantages of Ku-band VSATs and the high value of L-band spectrum for mobile applications.

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[21] *Orbit/Spectrum Resource Capacity for Land-Mobile-Satellite Service (LMSS) Systems*, Technical Report #2341, ORI, Rockville, Maryland, 20850, prepared for the Jet Propulsion Laboratory under JPL Contract No. 956753.

[22] *See* Hoeber, Christopher F., et. al., *Passive Intermodulation Product Generation in High Power Communications Satellites*, presented at the 11th AIAA COMMUNICATIONS SATELLITE SYSTEMS CONFERENCE, March 17-20, 1986, Paper #86-0657.

[23] Id.

Much greater degrees of orbit reuse are possible with transportable antennas than with mobile antennas, since transportable antennas can be set up to point at satellites and thus can be much more directive than mobile antennas (directivity is proportional to gain[24]). Satellite spacing depends on directivity: the greater the directivity of ground antennas, the closer together satellites can be spaced. For a given antenna size, directivity and gain increase with the square of frequency, so the higher the frequency of operation, the easier it is to discriminate between satellites that are close together. Thus, it is preferable to operate transportable terminals at higher frequencies than L-band so that more satellites can be placed in the orbital arc and so that satellite power requirements are minimized. Furthermore, since transportable terminals can always be set up where there are direct views of satellites, excess path loss is not as much of a concern with transportable antennas (though rain becomes a problem at high frequencies). The rapidly declining cost of Ku-band VSATs, their low satellite power requirements, the high degree of orbit reuse possible at Ku-band, and the greater amount of spectrum available at Ku-band all combine to make VSATs preferable to MSS for transportable applications.

Finally, L-band spectrum's favorable mobile propagation characteristics (and Ku-band's unfavorable mobile characteristics) ought not to be wasted on transportable applications. L-band mobile services should not be crowded out by inappropriate transportable services which can be better provided in another band.

6. Multiple System Scenarios

Each second generation LMSS system should have a mix of directive and omnidirectional mobile antennas and use between 4 and 12 MHz of L-band spectrum. Orbit reuse techniques make multiple LMSS systems possible at L-band even if each system uses all the available spectrum.

By combining frequency reuse with orbit reuse, many L-band MSS systems can be accommodated within the spectrum the Commission has set aside for LMSS. We briefly examine several multiple system scenarios in this section.

From Figures 1 and 2, it can be seen that 4 MHz (bi-directional) of L-band spectrum is the most that is needed for each system that supports communications only with omnidirectional mobile antennas. By combining polarization diversity, channel staggering, and satellite antenna off-axis discrimination, it may be possible to achieve the necessary 17 dB of intersatellite discrimination, permitting two satellites to use each 4 MHz slot. Thus, if 27 MHz of MSS spectrum is available, a total of at least 14 of these systems could be accommodated in the second generation.

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[24] Rahmat-Samii, Yahya and Gary K. Noreen, *Spacecraft Antennas*, Chapter 8 of DEEP SPACE TELECOMMUNICATIONS ENGINEERING, ed. by Joseph H. Yuen, Plenum Press, 1983.

If communications are exclusively with directive mobile antennas, it is evident from Figures 1 and 2 that substantially more spectrum will be necessary - as much as 36 MHz (bi-directional) per system. However, this is an extreme case - 13 dBi mobile antennas operating with an excess path loss of 6 dB, corresponding to an availability of 90%. Most L-band systems supporting communications with directive mobile antennas require less than half of the 27 MHz allocation (see figures 1 and 2). Also, orbit reuse is much easier to achieve with directive mobile antennas than with omnidirectional antennas due to the 18 to 20 dB of discrimination achieved by pointing mechanically steered antennas towards one of two satellites. Thus, even if all the available spectrum is used by each system, two separate systems could use the same spectrum, enabling competition between at least two systems.

As a practical matter, each MSS system will probably support a mix of directive and omnidirectional mobile antennas. Figure 6 shows a frequency plan that provides for dedicated bands on each of two satellites for communications with omni antennas and a shared band for communications with directive antennas.[25] Channel staggering would also be used in the shared band [f_3, f_4] to maximize isolation between the two satellites. The amount of spectrum required for each satellite in this case will be somewhere between what is required for omni-only operation and what is required for directive-only operation - probably between 4 MHz and 12 MHz.

Nearly all UHF second generation systems considered herein require more than 4 MHz of UHF spectrum (bidirectional - see Figures 4 and 5). As much as 100 MHz would be required to support a single UHF system communicating with directive antennas (Figure 4). No more than 4 MHz of UHF spectrum is available for LMSS.[26]

7. Conclusion

The decision of the Federal Communications Commission to allocate L-band rather than UHF frequencies to MSS has resulted in an effective increase of an order of magnitude in the spectrum available for LMSS. This spectrum can be used to support multiple LMSS systems, enabling competition.

The amount of spectrum required for each L-band LMSS system, and thus the number of systems that can be accommodated at L-band, depends primarily on the type of mobile antenna used and on the quality of service provided. A second generation system supporting communications only with mobiles using omnidirectional antennas needs as little as 2 MHz spectrum; communications with directive mobile antennas can require as much as 36

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[25] Berner, Jeff, *Techniques for Orbit Reuse Applicable to Mobile Satellite Systems*, Session 4, Presentation 6 of MOBILE SATELLITE INDUSTRY BRIEFING sponsored by NASA/JPL, November 13-14, 1985.

[26] *Report and Order*, FCC 86-333, released September 26, 1986.

MHz of spectrum. In practice, there will be a mix of omnidirectional and directive antennas on each system, resulting in a spectrum requirement of between 4 MHz and 12 MHz for the second generation. This would permit 4 to 14 systems in a 27 MHz allocation. Orbit reuse techniques can be used in the second generation to permit two satellites in the orbital arc to use the same frequencies if mobile antennas are directive.

Transportable antennas do not use L-band frequencies effectively. Ku-band transportable terminals (VSATs) make more effective use of spectrum and the orbital slots, and the cost of Ku-band VSATs is rapidly declining, so Ku-band VSATs are preferred for transportable applications. Furthermore, the use of transportable antennas at L-band would crowd out the mobile services that L-band supports particularly well.