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CHAPTER 1

INTRODUCTION

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1.0 BACKGROUND

A recent study by the National Telecommunications and Information Administration (NTIA) has concluded that the 21st century will be the age of information in which the telecommunication infrastructure will be vital to the social and economic well being of our society [1]. To meet the challenge of the coming age, JPL has been performing studies on a personal access satellite system (PASS) for the 21st century. Such a system will advance satellite communications to a truly personal level. It will also augment terrestrial cellular systems by extending services to remote areas. Many innovative services can be supported: direct personal voice and data, personal computer file transfer, database inquiry and distribution, low-rate broadcast (voice, data, and video), telemonitoring and control, and disaster and emergency communications (see Figure 1.1). The long-term objectives of the PASS study are to develop and demonstrate system concepts and high-risk technologies leading to commercialization of a personal satellite communications system at the turn of the century.

The PASS study can be traced back to a 1987 study performed by Signatron under contract to JPL, in which the technical feasibility and potential applications of a high-frequency (20/30 GHz), low-data rate satellite system were identified using small fixed terminals [2]. Subsequent studies further expanded the applications to provide personal communications using compact personal terminals. By early 1989, a strawman system had been designed, and operational constraints and critical technologies had been identified [3,4,5]. Study efforts since then have been directed to refining the strawman design, alleviating operational constraints and providing solutions to some of the challenging problems.

In this chapter, we will first describe the PASS concept and strawman design and then identify the key challenges and possible solutions. Finally, we will summarize our plan for the future. (It should be noted that only key results are presented in this chapter. Detailed discussions are given in subsequent chapters.)

1.1 A BRIEF DESCRIPTION OF THE SYSTEM CONCEPT

PASS is a satellite-based personal communications system that will offer users freedom of access and mobility. Equipped with a user terminal, a subscriber will have, through the satellite, access to a host of voice and data services anywhere in the service area. The system will be capable of handling a range of data rates, starting from less than 100 bps for emergency and other low-rate services, to 4.8 kbps for voice service, to T1 (1.544 Mbps) for high-rate services and computer file transfer.

The concept of PASS is illustrated in Figure 1.2. The system operator, service providers, and system users or subscribers are the players of the system. The major elements of PASS include one or more satellites; a network management center (NMC); tracking, telemetry and command (TT&C) stations; supplier stations; and user terminals. The satellites serve as a relay between the user and the supplier. The NMC and TT&C stations enable the system operator to control the operation of the system. User equipment includes three major types of user terminals: the basic personal terminal (BPT), the enhanced personal terminal (EPT), and telemonitors. The EPT is similar to today's VSAT terminals. The BPT is a compact personal terminal that will provide users greater freedom and mobility. The telemonitors are used for remote data collection and monitoring.

1.2 A BRIEF SUMMARY OF THE STRAWMAN DESIGN

1.2.1 System Description

The system contains a space segment, a network management center, supplier stations, and a number of user terminals. Services are facilitated by properly linking users and suppliers. The strawman architecture utilizes 142 fixed spotbeams to provide simultaneous, continuous coverage to users in the service area, i.e., CONUS. In addition to these spotbeams, a single CONUS beam is employed to complete the user-to-supplier and/or supplier-to-user links. The uplink frequency is 30 GHz and the downlink frequency is 20 GHz.

Access to the system by suppliers and users will be provided by means of a hybrid Time Division Multiple Access (TDMA)/Frequency Division Multiple Access (FDMA) scheme. A combination of uplink power control and an adjustable data rate is employed to combat rain attenuation. Uplink power control is for the forward link only, whereas a variable data rate is applicable for both directions.

A detailed description of the strawman design is given in [5].

1.2.2 High-Risk Enabling Technologies

Several high-risk enabling technologies have been identified. Some of these technologies are system architecture specific while others are not. The key enabling technologies are

- Low-Cost, Compact, High-Gain Tracking User Antennas
- Low-Cost, Accurate, User Terminal Frequency References
- MMIC Transmitters
- High-Gain, Low-Noise MMIC Receivers
- VLSI-Based Integrated Vocoder/Modem
- Efficient Multiple Access Schemes
- Multi-beam Antenna and Beam-Forming Network

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- Robust and Power-Efficient Modulation and Coding
- Variable Rate Modem

Timely development and validation of these technologies are essential to the implementation of PASS.

1.2.3 Additional Technological Challenges

In addition to the above high-risk technologies, the strawman design reveals a number of challenges that are vital to the success of PASS. They are as follows [5]:

- User Terminal Radiation Level
- System Reliability and Service Quality During Rain
- Stationary Operations Constraints
- Nonuniform User Distribution
- Choice of Frequency

1.3 POSSIBLE SOLUTIONS

The objectives of the FY'89 study are

- To refine and/or optimize the strawman design by performing tradeoff studies and evaluating alternative design options, and

- To overcome some of the obstacles identified in previous studies.

A number of studies have been performed to address the above challenges, with the objective of improving system performance, increasing system capacity, alleviating operational constraints, and/or reducing the burden on the spacecraft and user terminals. While many challenges still lie ahead, these studies have brought us one step closer to realizing the benefits of PASS.

1.4 SPREAD SPECTRUM MULTIPLE ACCESS (SSMA)

SSMA has been studied as an alternative multiple access technique because it promises the following benefits:

- Provide users instant access to the system,
- Enable ambulatory and even mobile operation by taking advantage of the inherent multipath rejection capability of SSMA, and
- Increase system capacity by increasing coding gain.

1.4.1 Initial SSMA System Design

Our study effort has focused on direct-sequence SSMA. A system architecture based on code division multiple access (CDMA) has been investigated and documented in Chapter 2 and elsewhere [6]. CDMA is a subset of spread spectrum multiple access (SSMA). For convenience, these two terms are used interchangeably in this report. This system employs spread spectrum (SS) TDMA in the forward direction and random-access code division multiple access (RA-CDMA) in the return direction. Our initial study indicates that the SSMA system will:

- Have system capacity and hardware complexity similar to the strawman design,
- Enable the user instant access to the system, and
- Result in minimum network control.

1.4.2 An SSMA System Using Powerful Codes

One major disadvantage of CDMA, based on the initial design, is that it will result in a significant increase in bandwidth requirements. One way to alleviate this problem is to employ on-board processing as discussed in Chapter 2, resulting in a much more complex satellite. Due to the large number of channels required, the feasibility of on-board processing is not certain and was not pursued. Another way to alleviate this problem is to take advantage of a property of SSMA that allows more coding gain without increasing the bandwidth. Studies performed after the initial design have indeed indicated that an SSMA system can have system capacity and bandwidth requirements comparable to the strawman system, by taking advantage of more powerful codes (such as rate 1/3, k=9, convolutional code or k=11 super-orthogonal code). Table 1.1, derived from [7], compares the bandwidth requirements and system capacity for CDMA and FDMA systems. The system capacity and bandwidth requirements shown in Table 1.1 were derived under a set of simplifying assumptions and are solely for the purpose of comparing CDMA and FDMA designs. They do not represent the actual system capacity nor the bandwidth requirements for PASS.

1.5 THE USE OF NON-GEOSTATIONARY ORBITS

The potential of non-geostationary orbits for PASS has been examined with the objective of reducing the burden on user terminals. Both elliptical and circular orbits have been examined. Low earth orbits in general have several important advantages over geostationary orbits:

- higher elevation angle and hence less multipath and rain attenuation,
- less space loss, and
- lower launch costs.

The major disadvantages of non-geostationary satellites are

- the large number of satellites required to provide continuous CONUS coverage,
- complicated spacecraft antenna pointing, and
- complex satellite handover.

The non-geostationary orbit study is discussed in Chapter 4. The major advantages and disadvantages are given in the following sections.

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1.5.1 Impacts on Rain Attenuation

For a given location, rain attenuation in general is severer at low elevation angles than at high elevation angles. The exact amount depends on the link availability (LA) requirement. Figure 1.3 shows the % of time (P) that a given amount of rain attenuation is exceeded as a function of attenuation at 30 GHz for Portland, Maine with elevation angles as a parameter. P can be interpreted as the cumulative probability and is related to the link availability (LA), i.e., LA (%)= 100-P(%). As indicated in the figure, the attenuation at low elevation angles (near 20 degrees) for 99% availability is about 3 dB higher than that at high elevation angles (above 30 degrees). The difference however is reduced significantly as the link availability decreases. For PASS, which has an availability requirement of 95%-98% (see Section 1.8), non-geostationary satellites will not result in more than 2 dB improvement in rain attenuation.

1.5.2 Impacts on the Number of Required Satellites

Non-geostationary orbits have one major drawback for systems that are required to provide continuous and simultaneous coverage to a large geographical area. Figure 1.4 gives the number of satellites required to provide continuous CONUS coverage as a function of satellite orbits. In calculating the number of satellites, the size of the satellite multibeam antenna is adjusted such that the number of spotbeams required to cover CONUS is fixed at 142 beams. As shown, the number of satellites increases from 1 for the geostationary orbit to 3 for the Molniya orbit, to 8 for a 20,000 km circular orbit, and to almost 50 for a 50,000 km circular orbit.

1.5.3 Recommended Satellite Orbits for PASS

Based on this study, the use of non-geostationary satellites in place of geostationary ones is not recommended for PASS. However, non-geostationary satellites can be used to augment geostationary satellites in order to extend coverage to high-latitude regions, and can be extremely useful for an international personal communications satellite system providing personal communications and position determination services on a global scale.

1.6 INTERBEAM POWER MANAGEMENT

Nonuniform user distribution can significantly reduce the utilization of the satellite resource if not properly accounted for in the design of the satellite; a reduction of 50% or more is possible [5]. While this problem is common to all systems employing multiple spotbeams, the large number of spotbeams and hence small footprints in PASS exacerbates this problem. The mitigation of this problem is essential to the economic viability of PASS. One way to do this is to employ switched/scanning beams to dynamically adapt to traffic variations. The other way is to employ interbeam power management.

1.6.1 Alternative Antenna Coverage Concepts

Different antenna coverage concepts have been studied as a means to effectively mitigate the traffic variation problem. By dynamically varying the dwell times, a system employing scanning/switched beams can effectively adapt to traffic variations. Both scanning/switched beams and hybrid switched/fixed multiple beams have been studied. Results indicate that while these beam concepts can better utilize the satellite resource by adapting to traffic demand, there is an increase in satellite complexity and user terminal eirp. Specifically, the disadvantages are

- o Increased complexity for the antenna beam-forming network,
- o Increased message delays, and
- o Increased user transmitted data rate and radiated power.

The disadvantages have been judged to outweigh the benefits. Therefore, these beam coverage concepts are not recommended.

1.6.2 A Practical Adaptive Power Management Scheme

Another way to mitigate the problem of traffic variations is to incorporate an adaptive power management scheme in the beam-forming network. The basic idea is to design a beam-forming network such that a common set of power amplifiers is shared by all beams. Two techniques have been examined and are summarized in the following subsections (see Chapter 6 for more information).

1.6.2.1 A Hybrid Transponder Concept

The first technique employs a set of hybrids and input filters to enable power sharing and signal routing, and hence interbeam power management. A 4-port hybrid power management scheme is shown in Figure 1.5 as an example. (It is noted that the input filters are not shown in the figure.) This device is composed of 90-degree hybrids and is capable of providing power management for four beams. All signals that are present at the input filter for a given beam (Beam A for example) will be amplified by all amplifiers and transmitted via that beam (Beam A, see Figure 1.5). Because the same set of amplifiers is shared by all beams, the number of carriers (or channels) transmitted from each beam can be changed from 0 to a maximum value by selecting the appropriate carrier frequencies (channels), limited only by the total transmitter power and the input filter bandwidth. (One observation that can be made is that interbeam power management will result in a lower spectrum utility because a larger bandwidth will have to be allocated for each beam in order to accommodate traffic variations.)

1.6.2.2 A Phased-Array Near Field Concept

The second interbeam power management technique examined is principally the same as the first, but utilizes a set of phase

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shifters instead of hybrids. This technique is illustrated in Figure 1.6.

1.6.2.3 The Recommended Interbeam Power Management for PASS

While there are advantages and disadvantages, both interbeam power management techniques are technically feasible and are applicable for systems having a limited number of spotbeams. Applying these techniques to PASS, which has 142 spotbeams, however will result in an unmanageably complex beam-forming network. In addition, the frequency reuse capability will be significantly reduced.

As a compromise, a partial interbeam power management scheme is proposed. Instead of interconnecting the 142 beams to achieve full interbeam power management, a nine-beam power management scheme is recommended. This scheme will interconnect 9 spotbeams, each with a distinct frequency assignment, to a set of shared amplifiers. This in effect reduces the traffic variation of 142 beams to a much more manageable 16 (142/9) groups of beams. By properly connecting beams with different user density, traffic variations among the 19 groups of beams can be reduced and hence the effective system capacity can be increased (see Appendix A for more details).

Figures 1.7-1.9 illustrate the nine-beam power management architecture. Figure 1.7 shows the transponder block diagram. Figure 1.8 shows the footprints of the 142 spotbeams and the corresponding frequency assignments. Due to the small footprints, the number of users in a beam can vary drastically from one beam to another. Figure 1.9 illustrates the nine-beam power management architecture. As shown, nine spotbeams each with a distinct frequency assignment are connected together to facilitate interbeam power management.

1.7 USER TERMINAL RADIATION

The current baseline design requires the user terminal to have a transmit antenna gain of about 23 dBi and a 0.17-W transmitter (see Section 1.10.5). Radiation safety is an important issue. Studies have been conducted to ensure that the radiation level complies with established safety standards. The findings are summarized as follows [8].

- o The current ANSI standard for frequency above 1.5 GHz is 5 mW per square centimeter averaged over a 6-minute period. This standard includes a safety factor of 10 or more.
- o At 30 GHz, the eye, particularly the cornea, is most susceptible to radiation damage due to the lack of blood circulation which drains the deposited heat.
- o Independent experiments recently conducted by the USAF School of Aerospace Medicine using cat's eyes have indicated that incident densities up to 100 mW/cm^2 did not cause any harm [9].

Based on these findings, we believe that the radiation safety issue is manageable. By exploiting a combination of transmitter duty cycles (voice activity factor), call duration, antenna gain, and transmitted power, we feel that the safety standard can be complied with. For example, using current user terminal design values (23-dBi transmit antenna, 0.17-W transmitter power, and 14.5-dBW eirp), a 90-second call at 35% duty cycle would produce a peak radiation density of 3.6 mW averaged over a 6-minute period. The peak radiation density occurs at a point on the antenna boresight at a distance about 6 cm from the antenna aperture. The radiation density drops off rapidly as the distance from the aperture increases. The peak radiation density can be further reduced by employing a larger user antenna. If we increase the antenna gain for example from 23 to 25 dBi and maintain the same eirp, the resulting peak radiation level would be reduced to about 1 mW/cm^2, averaged over a 6-minute interval. Appendix B and Chapter 5 address this issue in more detail.

1.8 SYSTEM RELIABILITY AND SERVICE QUALITY

The strawman system as well as the current baseline design employs a combination of uplink power control and an adjustable data rate to combat rain attenuation. Uplink power control is applicable for the uplinks from the suppliers and EPTs. When increased uplink power from the suppliers/EPTs fails to fully compensate for rain degradation, the data rate will be reduced to close the link. No uplink power control will be employed by BPTs due to the limited power capability of the small terminals. Instead, only a variable data rate scheme will be used. During rain, the data rate will be reduced by a factor equal to multiples of 2. These schemes will result in a reduction of service quality or even the termination of certain services during heavy rain. A quantitative assessment of the impacts on service availability has been performed and results are summarized below. (It is noted that there are techniques, such as the use of a processing satellite, that alleviate this problem; however, they have not been actively pursued. On-board processing may not be suitable for PASS due to the large number of single-channel-per-carrier [SCPC] channels.)

1.8.1 Desired Service Availability

Link or service availability is a measure of system performance. Rain attenuation affects the link availability and sufficient rain margin must be provided to maintain a desired link availability. Higher link availability requires a correspondingly large rain margin. Business-oriented and safety-related systems usually require an extremely high availability, i.e., 99.9% or better. A huge rain margin would normally be required for these systems. PASS is mainly to provide personal communications, and consequently can accept a lower service availability. The design goal is to maintain 95% to 98% availability for the basic personal communications services, i.e., 4.8 kbps voice. Accepting a slightly lower availability would significantly reduce the required rain margin, which could result in cost savings and complexity reduction.

1.8.2 Estimated Rain Attenuation

Rain attenuation varies from one location to another. To assess the extent of rain attenuation, five locations in CONUS have been selected for analysis: Seattle, Los Angeles, Mobile, Miami, and Portland (Maine). These locations approximately represent the four corners of CONUS and one southern location. The percentage of time that a given attenuation is exceeded as a function of the attenuation has been computed using a rain model developed by Manning [10]. The resulting data are shown in Figures 1.10 and 1.11 for the uplink frequency (20 GHz) and the downlink frequency (30 GHz), respectively. These figures show that for 98% of the time, the rain attenuation will not exceed approximately 1.0 dB at 20 GHz and 2.5 dB at 30 GHz. For 99.9% of the time, the attenuation will not exceed 20-40 dB.

1.8.3 Estimated Link (Service) Availability

The service availability for the forward and return link has been analyzed in Appendix C in detail. Results show that the current link design provides an estimated 98% availability at 4.8 kbps and about 99% at 2.4 kbps. While these results are based on the limited locations examined, they indicate that the proposed rain compensation technique is adequate for PASS.

Table 1.2 summarizes the estimated rain attenuation, the corresponding degradation on the overall signal-to-noise ratio (SNR), and the proposed compensation techniques.

1.9 CHOICE OF FREQUENCY

The system is designed to operate in the 20/30 GHz bands. While there are advantages, there are a number of issues associated with these bands:

- The wide separation of transmit and receive frequencies may present a technical problem to the design of the user antenna.
- These bands are sensitive to rain attenuation.

A number of studies have been performed to address these issues.

1.9.1 The 20/30 GHz Separation Problem

The wide separation between transmit and receive frequencies raises a question whether separate antennas for transmit and receive will have to be used. The technical feasibility of using the 20/30 GHz bands for PASS has been examined (Chapter 6). Based on studies conducted, we believe that it is technically feasible to use the 20/30 GHz bands, although a band-pair with a smaller separation (such as 20/21 GHz or 20/22 GHz) is preferable.

The 20/21 GHz or 20/22 GHz band-pair has two advantages: (1) easier for the design of user antennas, and (2) lower rain attenuation on the uplink. Rain attenuation can be significantly different at 20 and 30 GHz, depending on the desired link availability. For the assumed 98% PASS link availability, the difference is small (about 1 dB), as illustrated in Figures 1.12 and 1.13.

Although it is more desirable in terms of antenna designs to have a narrower separation between transmit and receive frequencies, the technical challenges posed by the 20/30 GHz separation are manageable. By using dual resonant radiating elements or interleaved transmit and receive arrays, a single antenna can be designed to operate at these frequencies (Chapter 5). In addition, the wide separation can improve the isolation between the transmit and receive signals. The isolation requirement often is a design driver for the diplexer.

1.9.2 20/30 GHz vs. Lower-Frequency Bands (UHF, L-band, etc.)

The 20/30 GHz bands are more suitable for PASS than lower-frequency bands (UHF, L-band, etc.) for three reasons, as explained in [5]:

- There are ample, unused spectra in the 20/30 GHz bands that will alleviate the spectrum congestion existing in lower-frequency bands, and accommodate future growth.
- These bands have the potential for developing compact user terminals, which are the key to the realization of PASS.
- The use of these bands will enable PASS to benefit from 20/30 GHz technology programs, including the opportunity for an early demonstration of PASS using NASA's ACTS.

One disadvantage of the 20/30 GHz bands is that these frequencies are much more susceptible to rain effects than L- and C-bands, and hence may require a much higher link margin. For PASS-type systems that do not require an extremely high link availability, rain attenuation is manageable based on studies performed.

1.10 SUMMARY OF CURRENT BASELINE SYSTEM DESIGN

The various trade studies performed this year have resulted in some modifications and refinement of the strawman design. These studies also reaffirm some of the decisions on the selection of many of the key features of the strawman system. Only the key features and features that are different from the strawman design are summarized in the following sub-sections. A complete description of the PASS system concept is given in [5].

1.10.1 The Space Segment

The satellite employs fixed multibeams to provide simultaneous, continuous coverage to users in the service area, i.e., CONUS. In addition, the satellite has a single CONUS beam to link suppliers to the satellite. A nine-beam interbeam power management is employed to mitigate the problem of traffic variations. The transponder block diagram is shown in Figure 1.7.

1.10.2 Multiple Access Scheme

Access to the system by suppliers and users will be provided by means of a hybrid TDMA/FDMA scheme. In the forward direction, suppliers gain access to the system using TDMA. There will be 142 uplink channels at 100 kbps for the BPTs, one for each spotbeam. Each supplier will be assigned to a time slot for each of these channels for transmission of its uplink signals. Signals destined to different users in the same beam will be time multiplexed (TDM) onto a single channel before transmission. The TDMA architecture maximizes the utilization of satellite power in the forward direction, which is severely constrained by the available satellite power. (It should be noted that there is a 300-kbps channel in each beam for the EPTs. The multiple access technique for these high-rate [300-kbps] channels is the same as for the low-rate [100-kbps] channels. The discussion here focuses on the BPT. A more complete description of the entire system is given in [5].)

In the return direction, access to the system by users is provided using narrowband SCPC architecture, and a frequency division, demand assigned multiple access (FD-DAMA) scheme. Each user will be assigned a dedicated channel on a demand assigned basis.

1.10.3 Rain Attenuation Compensation Techniques

As stated earlier, a combination of uplink power control and an adjustable data rate is employed for PASS and the resulting service availability is estimated to be 98% at 4.8 kbps and about 99% at 2.4 kbps.

1.10.4 Operating Frequency

The uplink frequency is in the 30-GHz band and the downlink frequency is in the 20-GHz band. These frequency bands have ample bandwidth and good potential for compact terminals, and allow the early demonstration of system concepts and technology on NASA's ACTS.

1.10.5 Link Budgets

A detailed link budget is shown in Table 1.3 for the return link. This budget is for voice communications using a 4.8-kbps digital voice. This link is designed to provide a 1.0E-3 bit-error rate (BER) with a 3-dB link margin in clear weather. The 1.0E-3 BER is sufficient for providing good quality voice. Data messages generally require a lower BER in order to minimize packet errors. Additional FEC coding therefore will be needed for data messages and will increase the overhead accordingly.

Table 1.4 is a similar link budget for the forward link. Although the signals in the forward direction are time-division multiplexed and normally operate at 100 kbps, the link budget was performed for a hypothetical voice channel operating at 4.8 kbps. Similar to the return link, the forward link is sized to provide a 3-dB margin during clear weather. Due to the TDM/TDMA architecture, the forward link is designed to provide 1.0E-5 BER, which is adequate for voice and data communications.

1.10.6 System Capacity

Economic viability is a very important factor that will determine whether PASS will be implemented commercially. While there are many factors affecting PASS's economic viability, the significance of system capacity cannot be overstated. Studies have shown that large-capacity systems benefit from economy of scales. Towards that end, the system has been optimized for a higher capacity. Using a high-power commercial satellite bus having a GTO mass of 6500 lbs, the estimated system capacity is equivalent to 7500 duplex voice channels. The capacity is based on the assumption that all user terminals are BPTs (a worst case scenario), and that all traffic is voice, with a voice activity factor of 0.35. The actual capacity depends on the voice and data traffic mix and user equipment mix (i.e., BPT, EPT and telemonitors).

The number of users who can be supported is a function of the traffic model, which is characterized by parameters such as traffic mix, grade of service, and offered traffic. Assuming a typical traffic scenario and including users of EPTs and telemonitors, the number of users who can be served by PASS can easily exceed one million.

1.10.7 Salient Features and Summary of Design Requirements

The salient features of the system are presented in Table 1.5. Design requirements for the satellite and the BPT are given in Tables 1.6 and 1.7.

1.10.8 Alternative System Architecture

The study of multiple access techniques has identified the potential of a spread-spectrum-based architecture. This system would employ TDMA and SSMA in combination with satellite switching.

In the forward direction, the architecture is very similar to the baseline design. Suppliers will access the satellite using a wideband TDMA channel. The satellite received signals will be demodulated, buffered, remodulated, frequency converted, spread by a PN sequence generated on-board the satellite, and transmitted via the spotbeams. The complexity of on-board spreading of 142 signals is within current technology capability and is not expected to result in significant mass and power penalties.

The multiple access technique for the return direction is SSMA. The signal transmitted by each user is spread by a PN sequence as described in Chapter 2.

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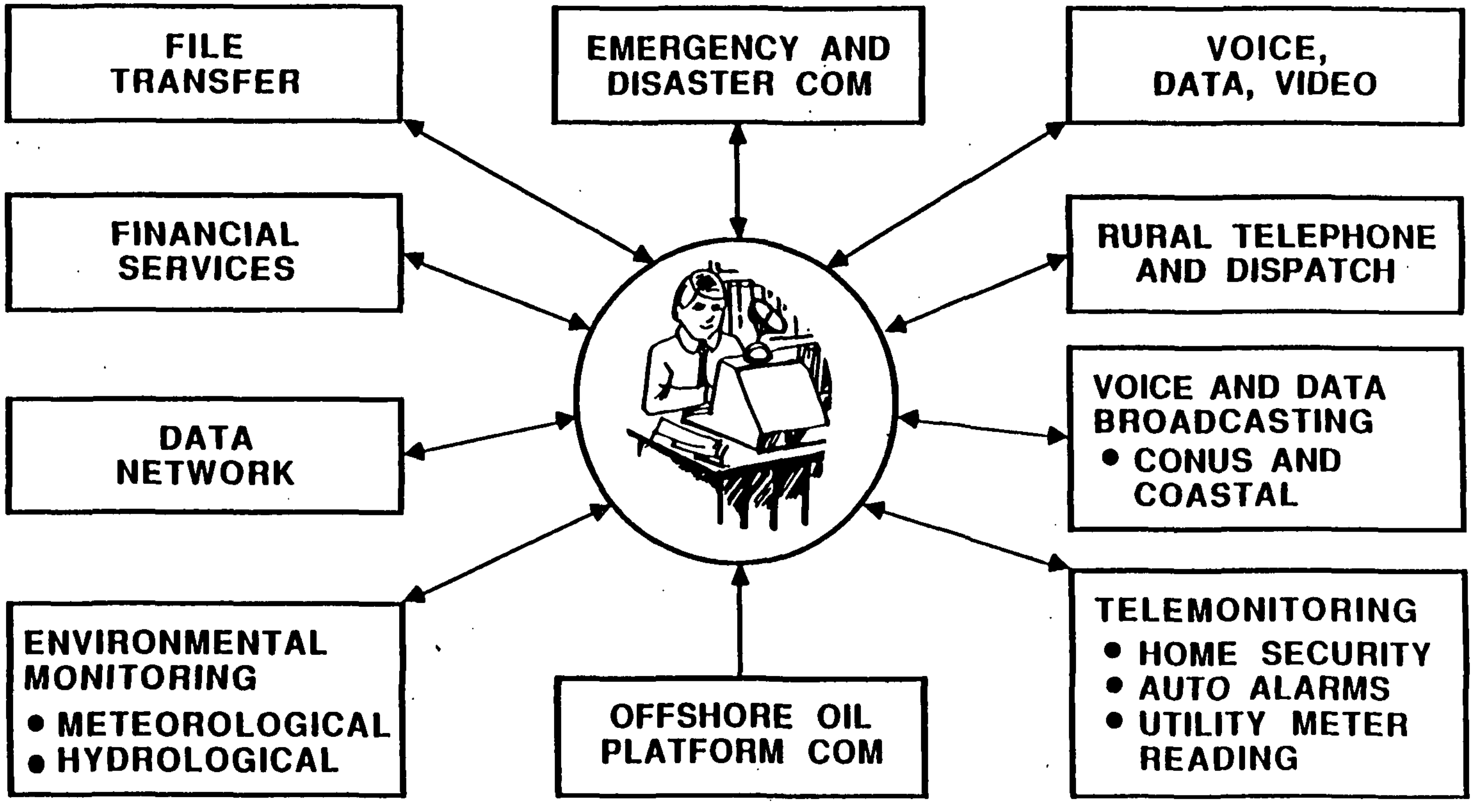
The spread spectrum signal structure in both the forward and return directions enables full realization of some of the benefits of a spread spectrum system.

1.11 FUTURE PLAN

As currently conceived, PASS is a satellite-based communications system designed to provide a variety of services, ranging from low-rate personal communications to high-rate computer file transfer. The 21st century will be the age of information with the existence of various space and terrestrial telecommunications media. Expansion and advancement of these systems will create fierce competition. This will dictate the integration of space and terrestrial networks and force each to play an optimized role in the telecommunications infrastructure, ultimately benefiting the user. Telecommunications in the 21st century will be characterized by diversity of services, choice of media, and user-transparent, optimized information routing. In recognition of these trends, a two-prong approach has been adopted with the following objectives.

The first objective is to continue the 20/30 GHz PASS system study and technology development with the goal of advancing Ka-band technology in general and Ka-band mobile/personal technology in particular. Technologies targeted for development are user antennas, user terminal components (vocoder/modem, transceiver, MMIC front-end, and frequency reference), modulation and coding, rain compensation techniques, and multiple access schemes. It is our plan to incorporate these technologies into the ACTS mobile terminal (AMT) to the extent possible and conduct a field demonstration using ACTS. The AMT is currently being developed by JPL to demonstrate Ka-band mobile applications.

The expansion of cellular phones suggests they will play a significant role in personal communications in the 21st century. Considering this and other telecommunications trends, the second objective is to specifically address the roles of communications satellites in personal communications and to devise a system concept for an integrated satellite/ground personal communications network. Such a network will provide choice of media and route selection. The key to integrating the characteristically and architecturally different space and terrestrial telecommunications networks lies in compatible networking protocols. The ultimate objective is to devise a system concept capable of providing personal communications to the user using a truly universal personal terminal.



PASS WILL PROVIDE LOW-COST INTEGRATED SERVICES TO PUBLIC

Figure 1.1. Potential Applications for PASS

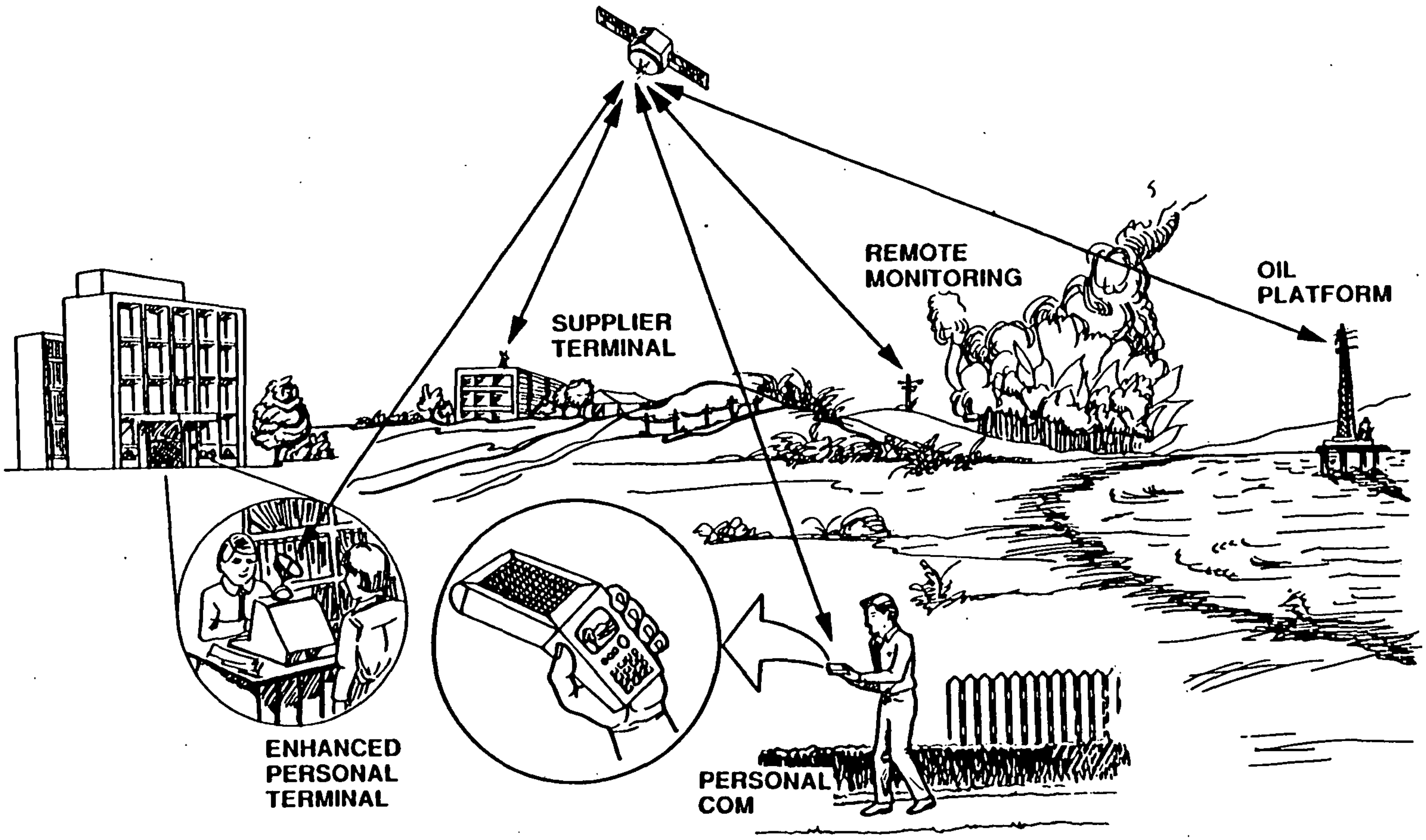


Figure 1.2. PASS Concept

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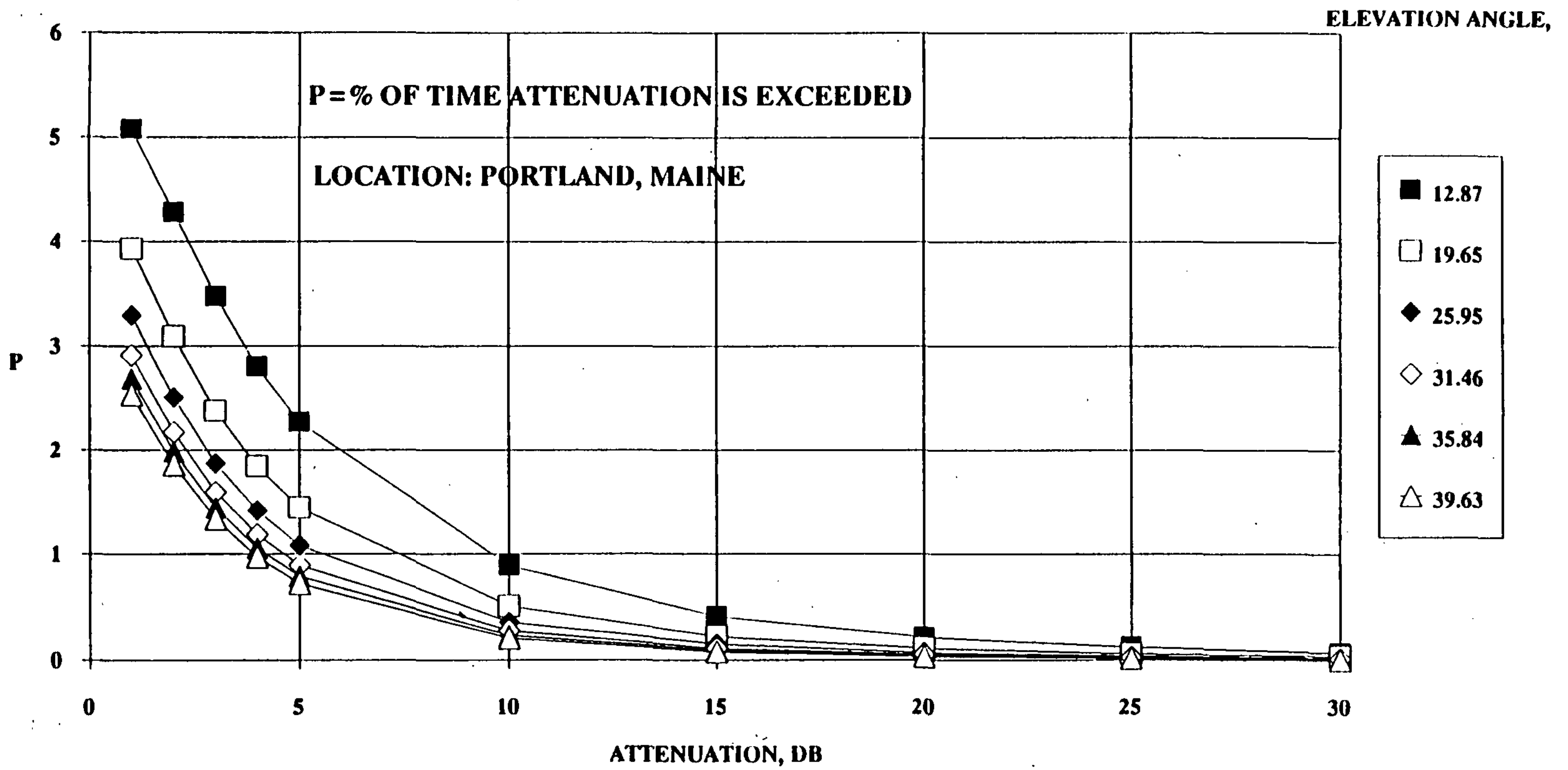

Figure 1.3. Rain Attenuation for Selected Elevation Angles

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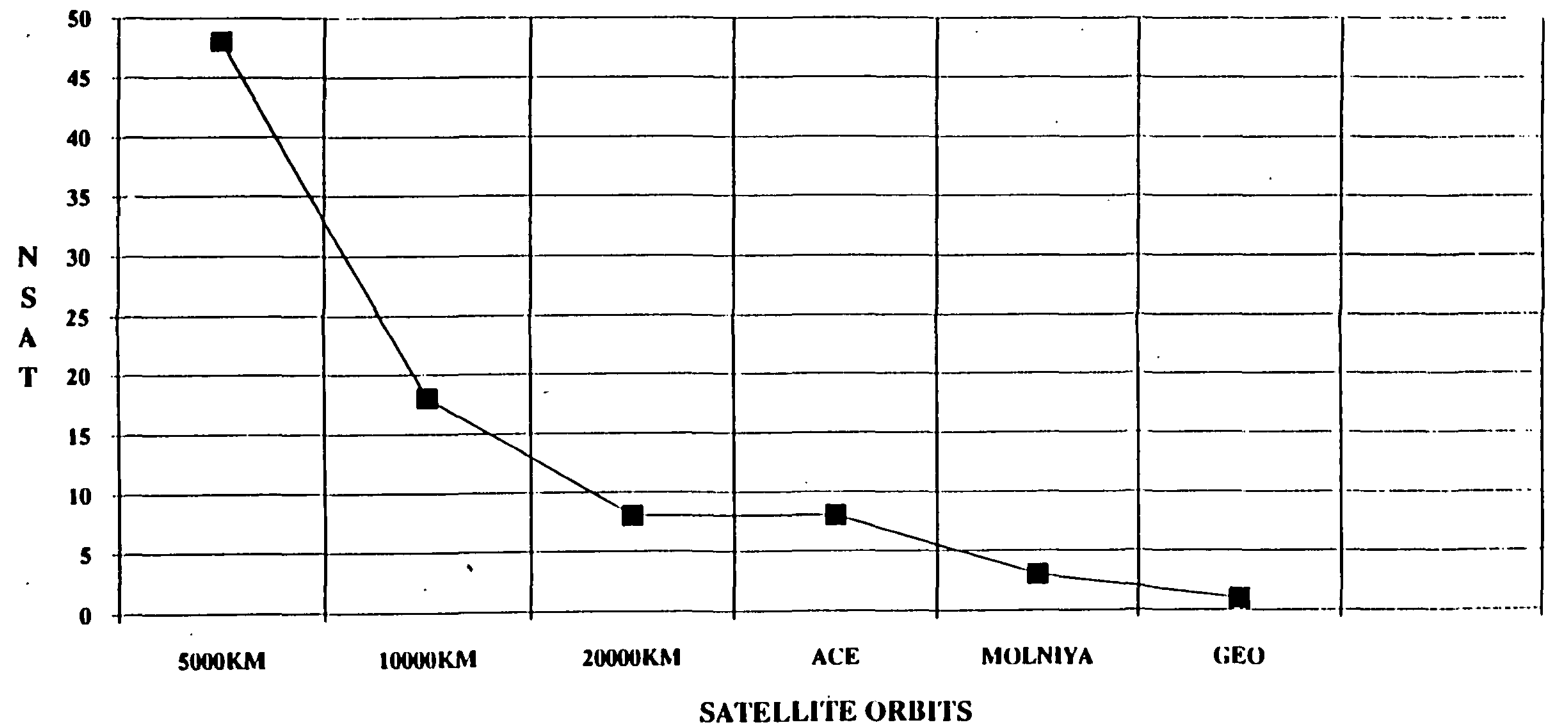
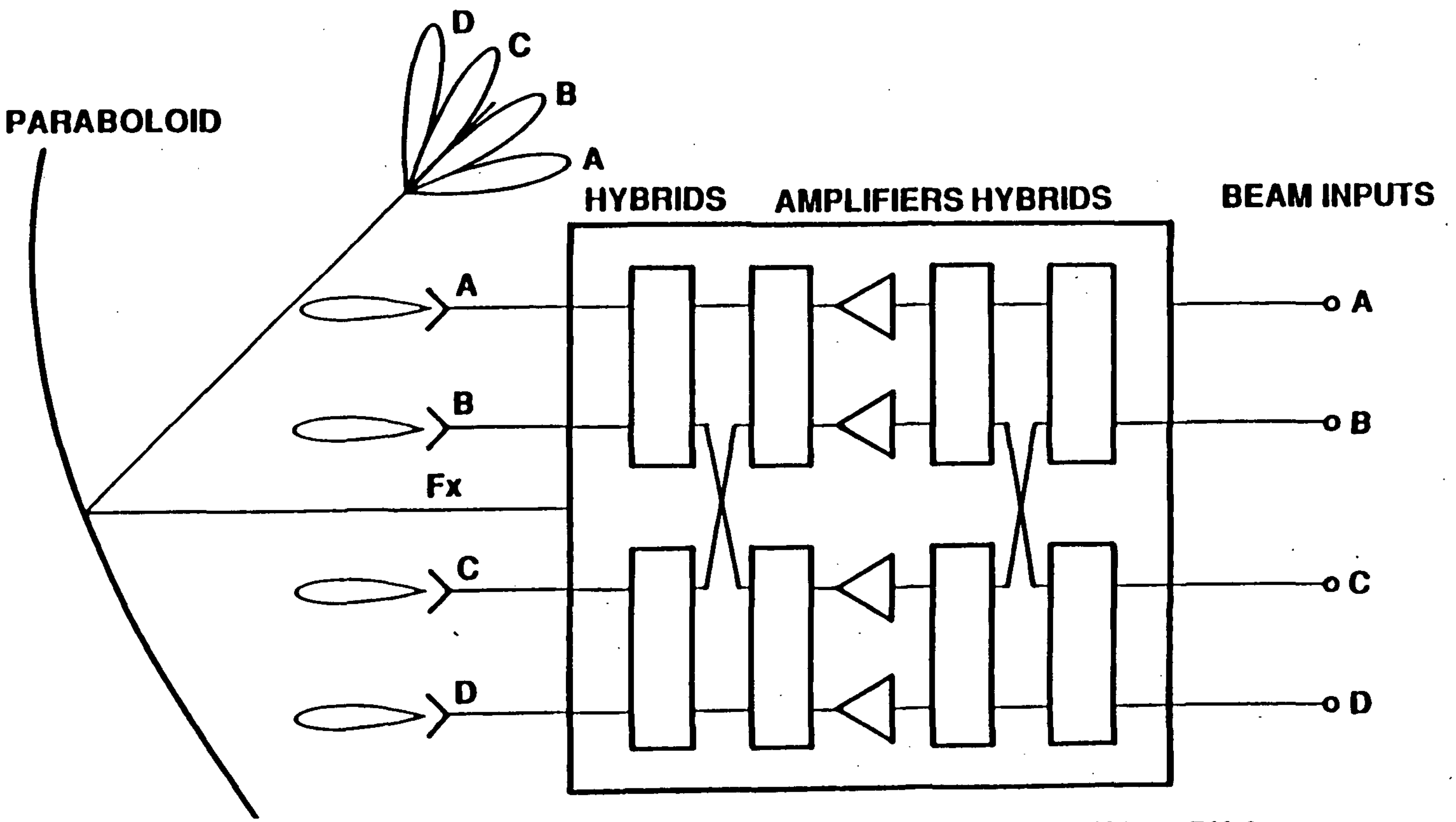
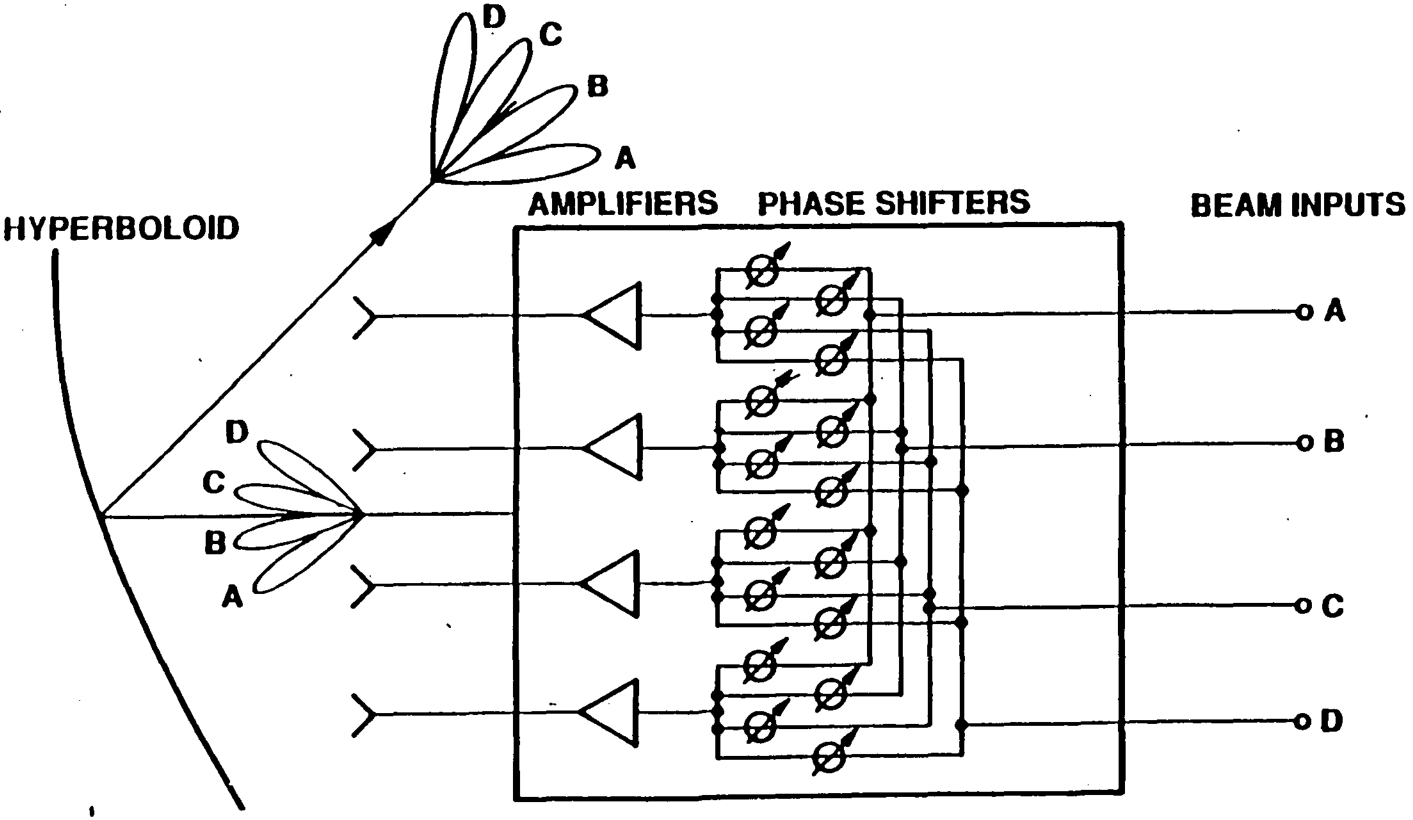


Figure 1.4. Number of Satellites vs. Satellite Orbits for CONUS Coverage (Derived from Chapter 4)



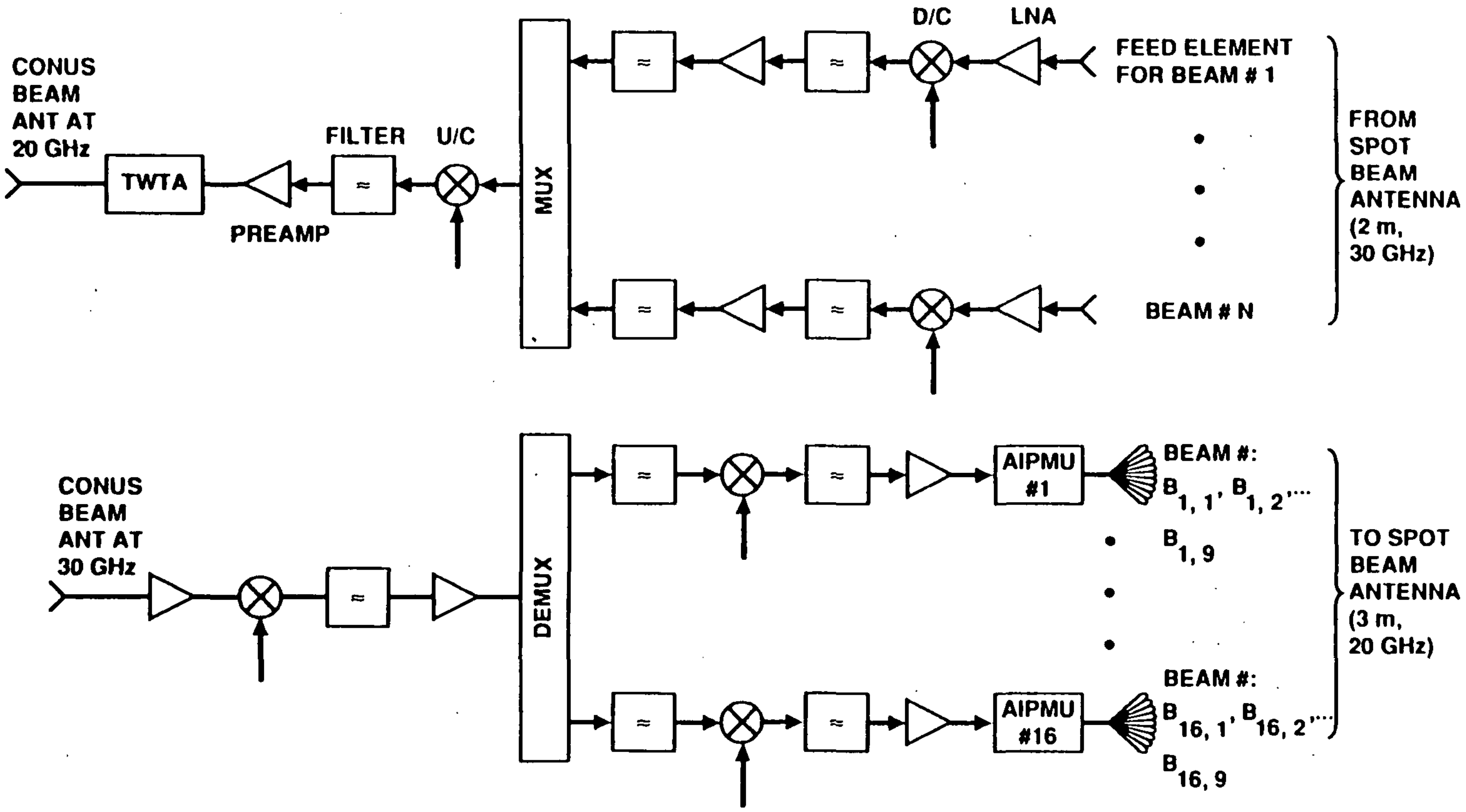
(A) HYBRID TRANSPONDER CONCEPT EACH BEAM IS PRODUCED BY A SEPARATE FEED BUT SHARES IN ALL THE AMPLIFIERS

Figure 1.5. A Hybrid Transponder Concept for Interbeam Power Management (Derived from Chapter 6)



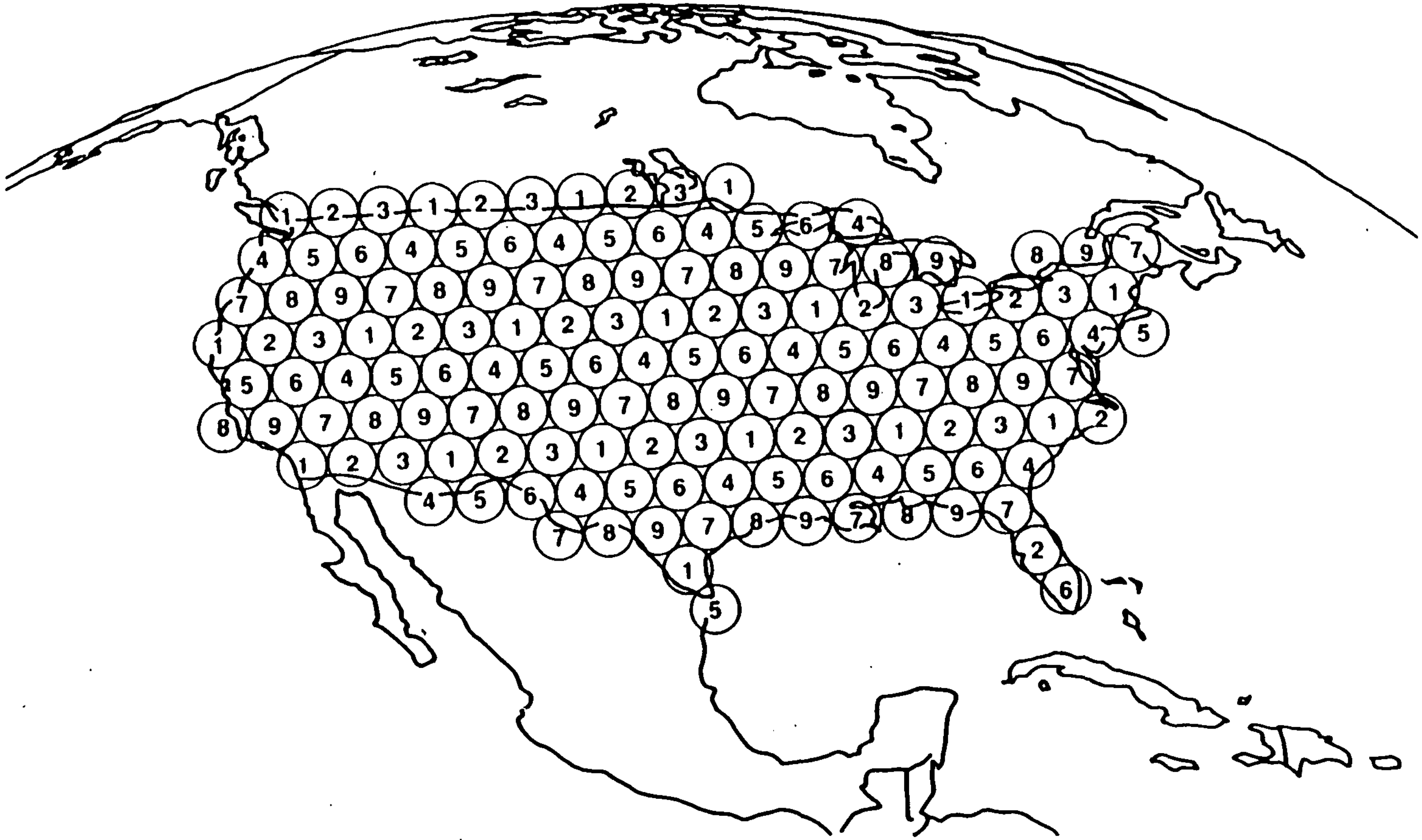
(B) PHASED ARRAY NEAR FIELD CONCEPT EACH BEAM IS PRODUCED BY ALL FEED ELEMENTS AND SHARES IN ALL THE AMPLIFIERS

Figure 1.6. A Phased Array Near-Field Concept for Interbeam Power Management (Derived from Chapter 6)



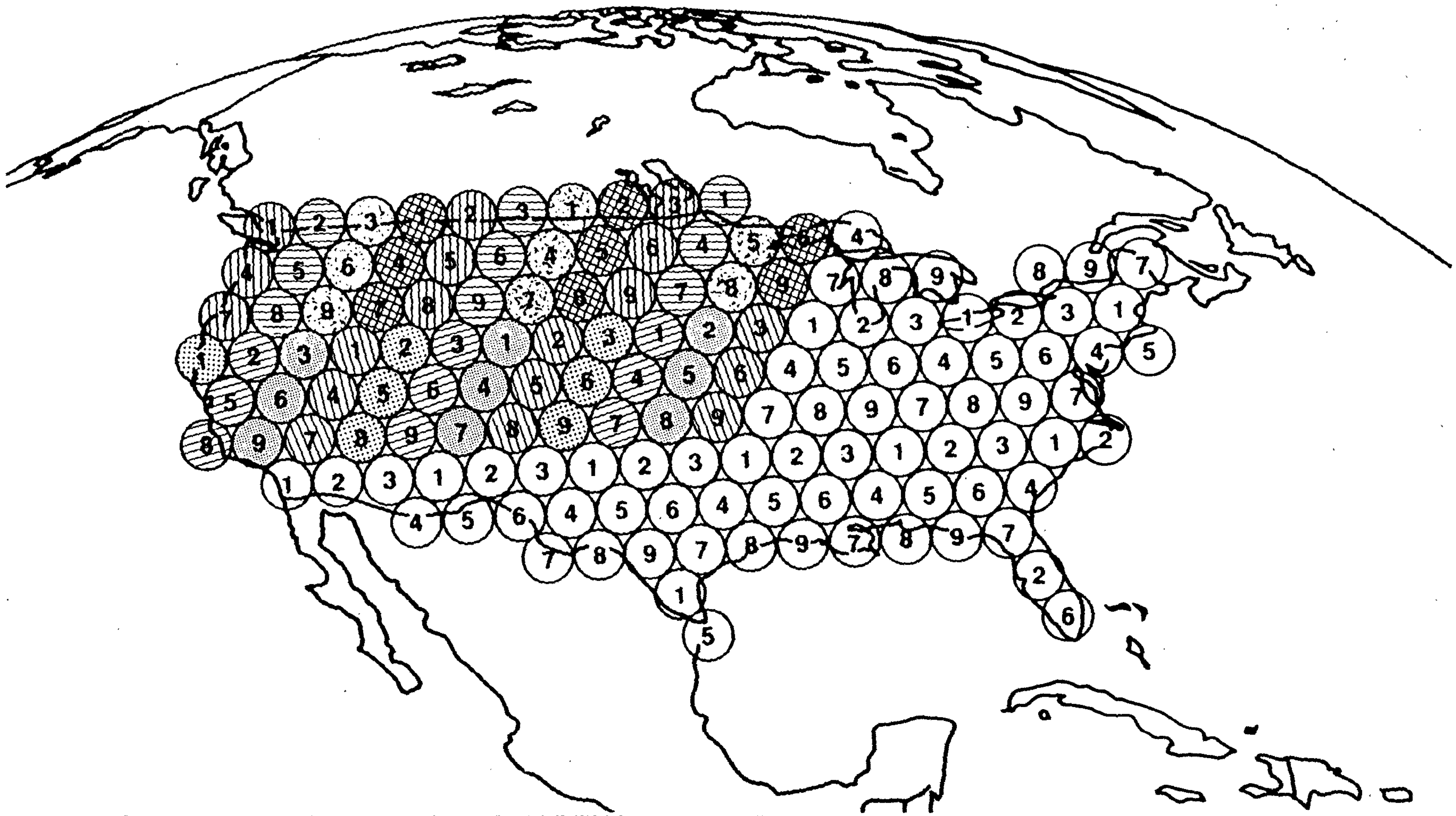
AIPMU = ADAPTIVE INTERBEAM POWER MANAGEMENT UNIT

Figure 1.7. Transponder Block Diagram with 9-Beam Interbeam Power Management



NOTE: NUMBER IN EACH BEAM DENOTES THE FREQUENCY SUBBAND ASSIGNMENT FOR THAT BEAM.

Figure 1.8. Frequency Assignments for the 142 Multiple Spotbeams with 9-Frequency Reuse [Chapter 6]



NOTE: 1. NUMBER IN EACH BEAM DENOTES THE SUBBAND ASSIGNMENT FOR THAT BEAM.
2. BEAMS HAVING THE SAME SHADED PATTERN BELONG TO THE SAME GROUP AND ARE CONTROLLED BY THE SAME INTERBEAM POWER MANAGEMENT UNIT. THIS FIGURE GIVES THE ARCHITECTURE FOR ONLY 8 GROUPS OF BEAMS, OUT OF A TOTAL OF 16 GROUPS.

Figure 1.9. An Illustration of Beam/Frequency Architecture for the 9-Beam Interbeam Power Management

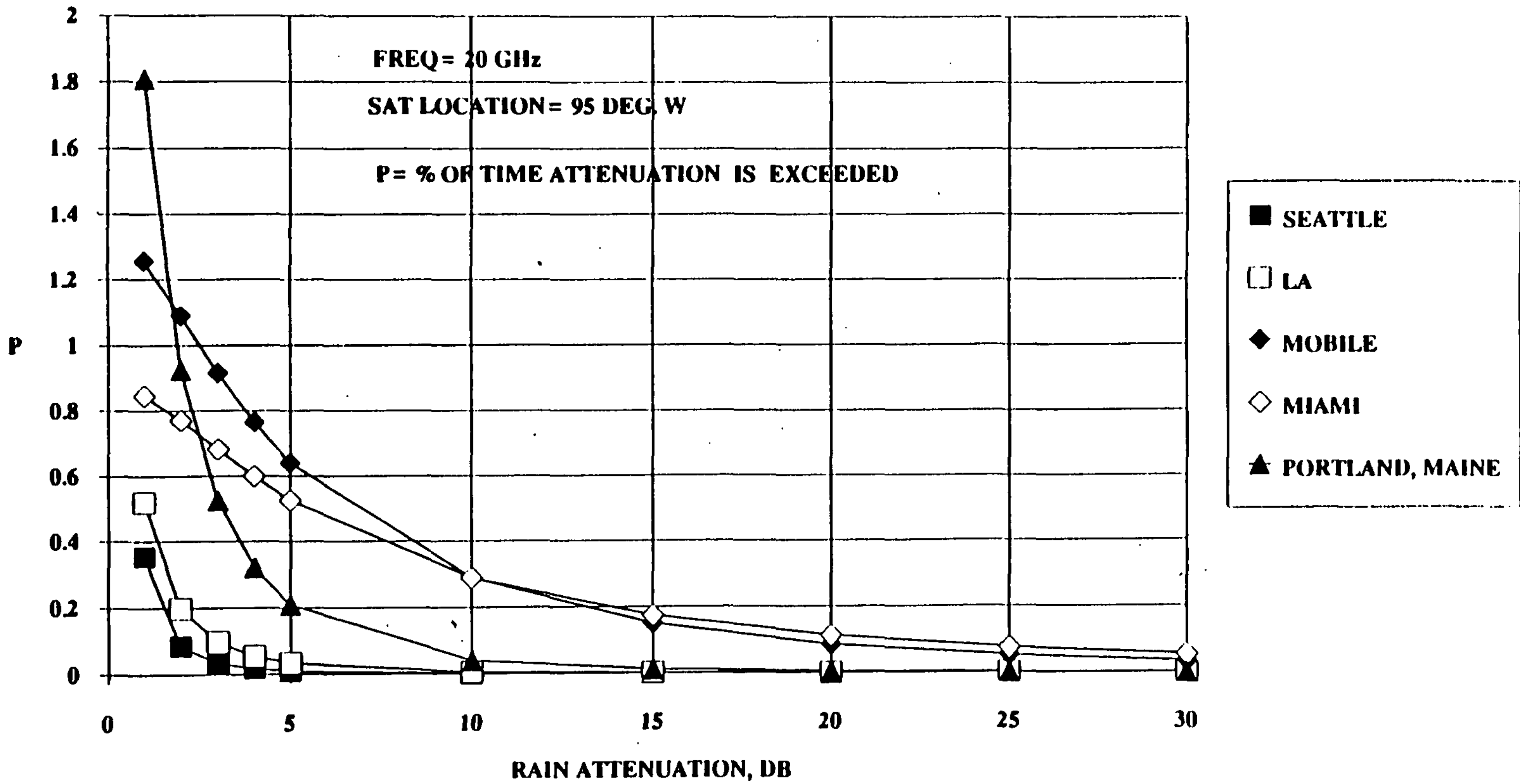


Figure 1.10. Rain Attenuation at 20 GHz for Selected Locations

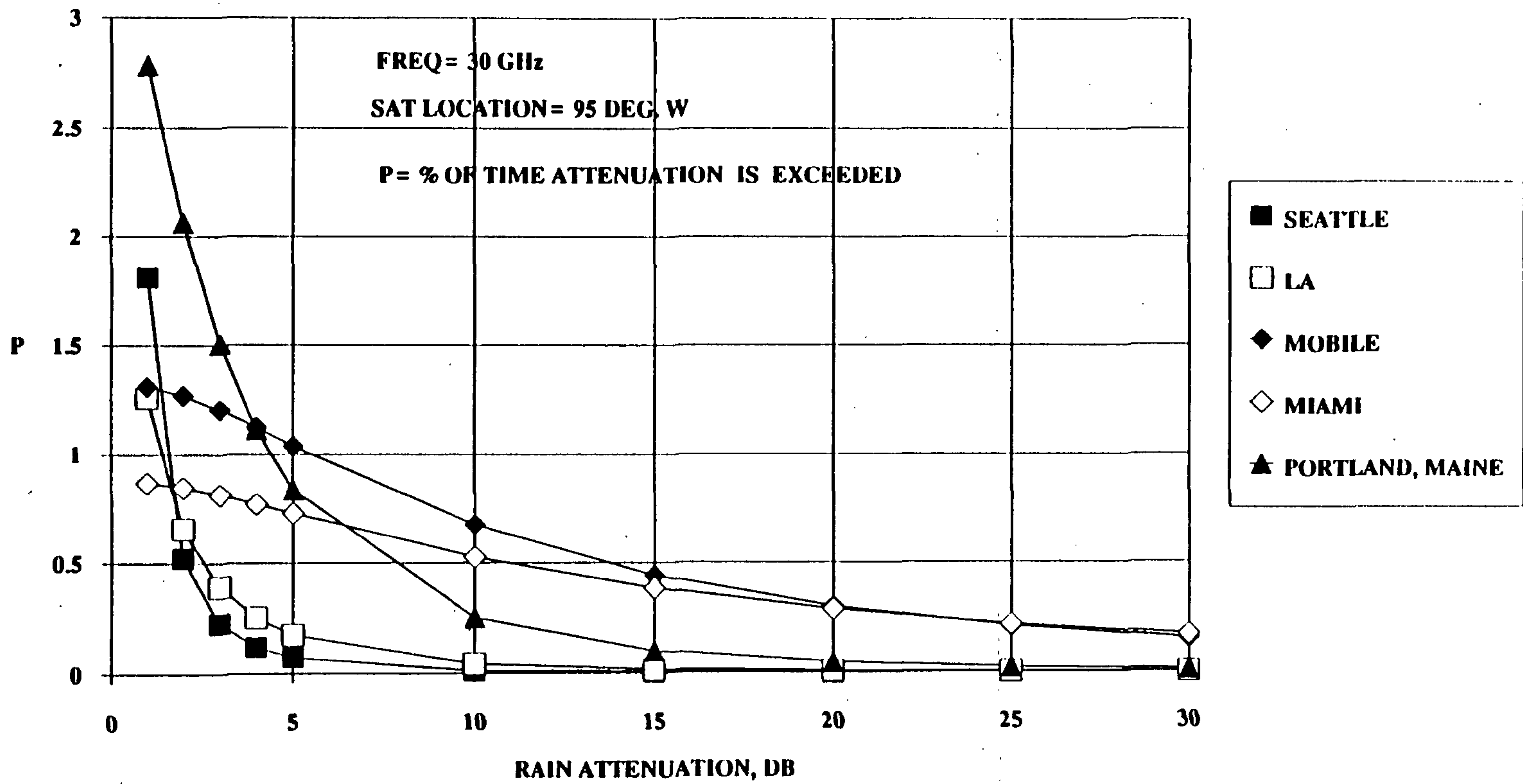


Figure 1.11. Rain Attenuation at 30 GHz for Selected Locations

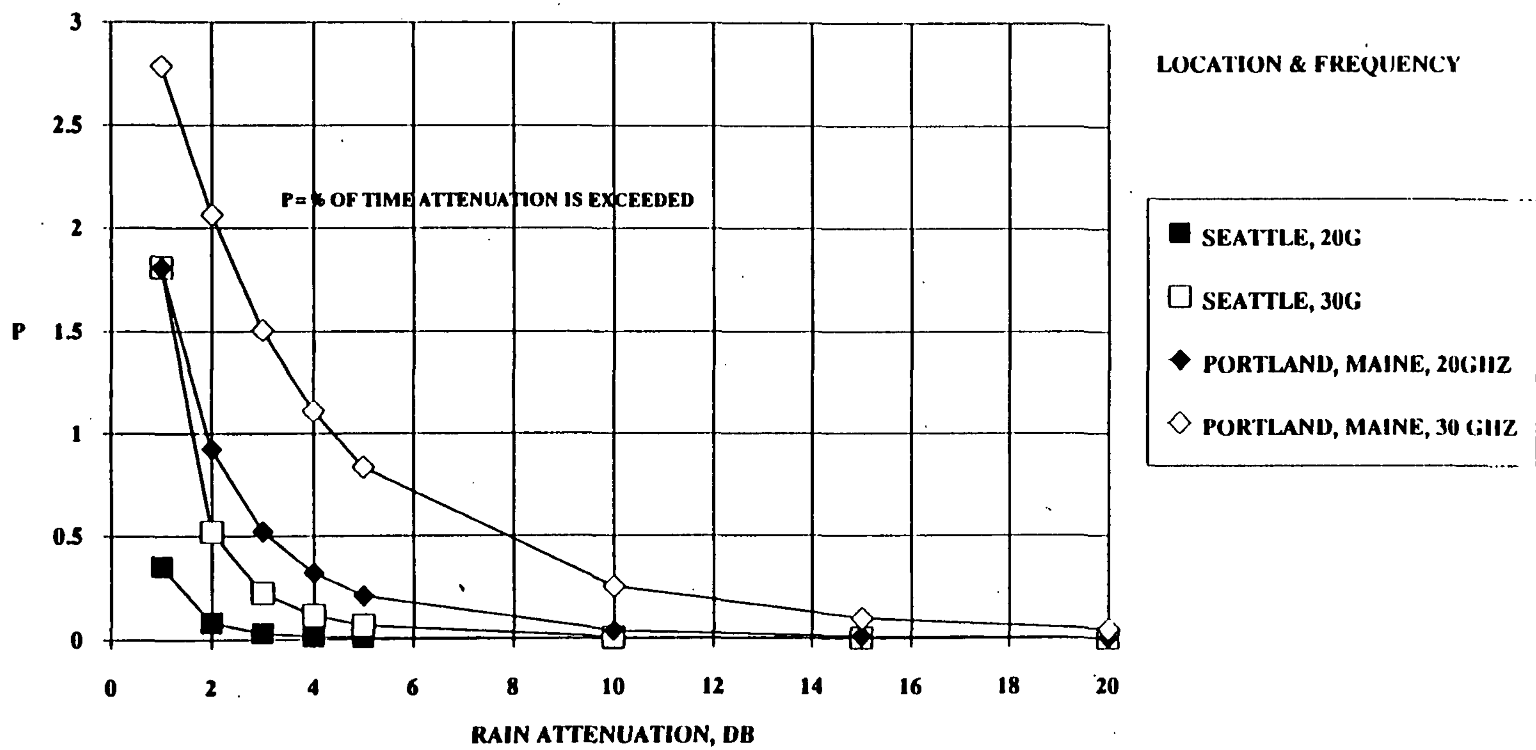


Figure 1.12. Percentage of Time vs. Rain Attenuation at 20 and 30 GHz for Selected Locations (Seattle, and Portland, Maine)

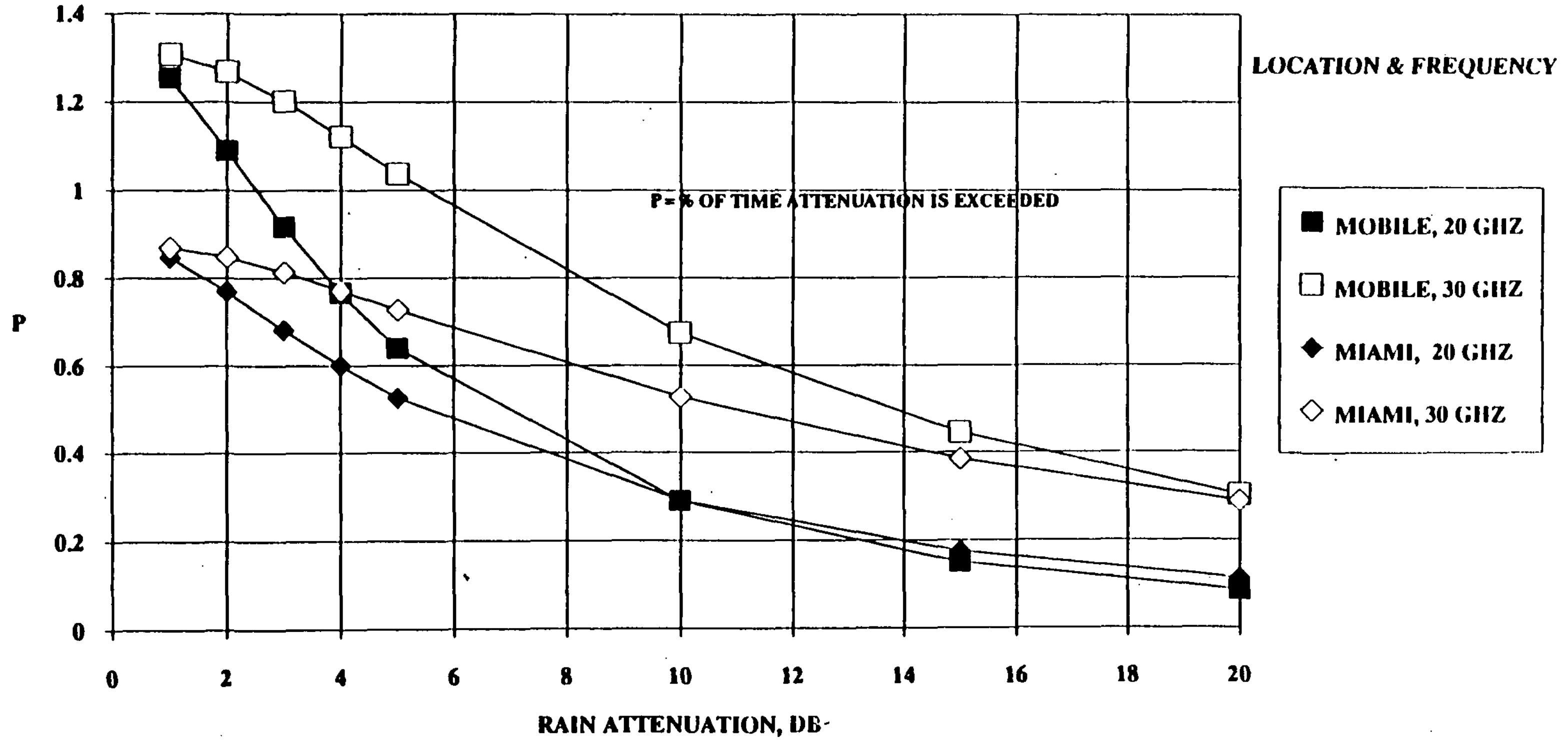


Figure 1.13. Percentage of Time vs. Rain Attenuation at 20 and 30 GHz for Selected Locations (Mobile and Miami)

Table 1.1. Relative Capacities and Bandwidth Requirements for CDMA and FDMA [7]

ACCESS SCHEMES	LINK Eb/NO dB	CODING (CONVOLUTIONAL)	CAPACITY (#CHANNELS) RETURN	FORWARD	BANDWIDTH (MHz) UP-LINK	DN-LINK	TOTAL	SAT RF POWER SPLIT(TOT/F/R)
FDMA (RET)/ TDMA (FWD)	3	R=1/2, K=7	8072	8216	111.8	110.3	222.1	410/390/20 W
"	2.3	R=1/3, K=7	9483	9653	183.4	181	364.4	410/390/20 W
CDMA (RET)/ TDMA (FWD)	2.3	R=1/3, K=7	10143	8452	65.1	183	248.1	410/335/75 W
"	1.5 (R)/ 2.3 (F)	SUP. ORTH.(K=10)/ R=1/3, K=7	10142	9331	69.1	180	249.1	410/375/35 W
....	....	....	....	....	....	....	....	....
FDMA (RET)/ TDMA (FWD)	3	R=1/2, K=7	10493	10433	142.3	143	285.3	520/494/26 W
"	2.3	R=1/3, K=7	12328	12258	233.6	234.6	468.2	520/494/26 W
CDMA (RET)/ TDMA (FWD)	2.3	R=1/3, K=7	12171	10565	78.6	206.4	285	520/425/95 W
"	1.5	R=1/3, K=9	13894	13523	99.8	258.2	358	520/470/50 W
"	"	"	19069	11411	85.1	225	310.1	520/390/130 W
"	1.5 (R)/ 2.3 (F)	S. ORTH.(K=11)/ R=1/3, K=7	17851	11411	101.8	356.3	458.1	520/460/60 W

Note: For a 10:1 data-to-voice traffic ratio, a 1.4 s average message delay, 2% voice blocking probability, 90 s/call/user/hr, 1000 bits/data message, one channel can servean average of 100 users

Table 1.2

Rain Attenuation, SNR Degradation, and Compensation Techniques

	FREQ (GHZ)	ATTEN-UATION (DB)	OVERALL SNR DEGRADATION (DB)	COMPENSATION TECHNIQUES[1]
FORWARD:				
UPLINK	30	2.5	0	UPLINK POWER CONTROL
DOWNLINK	20	1.0	1.5	WITHIN NORMAL LINK MARGIN
RETURN:				
UPLINK	30	2.5	2.5	WITHIN NORMAL LINK MARGIN
DOWNLINK	20	1.0	<0.1	NEGLIGIBLE EFFECTS ON THE OVERALL SNR

(1) To achieve 98% link availability for BPTs.

Table 1.3. Return Link Budget for BPTs (4.8 kbps Voice, Clear Sky, 20-Degree Elevation, 1.0E-3 BER, R=1/2, and K=7)

		USER TO SAT					SAT TO SUPPLIER				
	PDF	DESIGN	FAV TOL	ADV TOL	MEAN	VAR (X.01)	DESIGN	FAV TOL	ADV TOL	MEAN	VAR (X.01)
TRANSMITTER PARAMETERS	---	-------	----	----	-------	------	-------	----	----	-------	------
1)XMIT POWER,DBW	TRI	-7.80	.3	.3	-7.80	1.50	-15.00	.30	.30	-15.00	1.50
2)XMIT CIRCUIT LOSS,DB	REC	-.50	.1	.4	-.65	2.08	-.50	.10	.40	-.65	2.08
3)ANTENNA GAIN,DBI	TRI	22.80	.5	.5	22.80	4.17	26.90	.50	.50	26.90	4.17
4)EIRP,DBW ((1)+(2)+(3))		14.50			14.35		11.40			11.25	
5)POINTING LOSS,DB	TRI	-1.55	.68	.88	-1.62	10.20	.00	.00	.00	.00	.00
PATH PARAMETERS											
6)SPACE LOSS,DB		-214.03			-214.03		-210.51			-210.51	
(FREQUENCY,GHZ/GHZ =		30.00					20				)
(RANG= 40000 KM).											
7a)ATMOSPHERIC ATTN, DB	TRI	-.70	.50	.50	-.70	4.17	-.90	.40	.40	-.90	2.67
7b)RAIN ATTN, DB	TRI	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
8)E.O.B.LOSS,DB	TRI	-4.00	1	1	-4.00	4.17	-3.00	.50	.50	-3.00	4.17
9)MULTIPATH LOSS,DB	GAU	.00	0	0	.00	.00	.00	.00	.00	.00	.00
10)SHADOWING LOSS,DB	DEL	.00	0	0	.00		.00	.00	.00	.00	
RECEIVER PARAMETERS											
11)POLARIZATION LOSS,DB	TRI	-.50	0	0	-.50	.67	-.50	.20	.20	-.50	.67
12)ANTENNA GAIN,DBI	TRI	52.50	1	1	52.50	16.67	57.50	1.00	1.00	57.50	16.67
13)POINTING LOSS,DB	TRI	-1.23	0	0	-1.23	.00	-.09	.02	.02	-.09	.01
14)RECEIVED SIGNAL POWER,DBW		-155.01			-155.23		-146.10			-146.25	
(SUM OF LINES 4 - 13)											
15)SYSTEM TEMPERATURE,DBK	GAU	29.07	.30	.61			27.15	.62	.95		
(CIRCUIT LOSS,DB =		-1.50	0	0			-1.00	.10	.40		)
(RCVR N.F. ,DB =		3.00	0	0			3.00	.20	.20		)
(EXTERNAL ANT TEMP,K =		280.00	0	0			81	20	18		)
(INTERNAL ANT TEMP,K =		.00	0	0			.00	0	0		
(RAIN INDUCED TEMP,K =		.00	0	0			.00	0	0		
16)RECEIVED NO,DBW/HZ	GAU	-199.53	.30	.61	-199.38	2.30	-201.45	.62	.95	-201.28	6.78
((15)-228.6 DBW/HZ)											
(BANDWIDTH,KHZ =		20.00					20.00				)
CHANNEL PERFORMANCE											
17)RCVD C/NO,DB-HZ ((14)-(16))		44.52			44.15		55.34			55.03	
18)EFFECTIVE C/NO,DB-HZ		44.50			44.13		55.16			54.86	
(OVERALL C/I,DB =	GAU	26.00	1	1	26.00	11	26.00	1.00	1.00	26.00	11.11)
(INTERBEAM ISOLATION =		26.00	1.00	1.00			99.00	1.00	1.00	99.00	)
(INTERSAT. ISOLATION =		99.00	.50	.50			99.00	.50	.50	99.00	)
(INTERMOD ISOLATION =	TRI	99.00	1.00	1.00			26.00	1.00	1.00	26.00	)
(TURNAROUND C/NO =	GAU						44.50			44.13	57.03)
(NO(UP)/NO(REQUIRED) =		.75		.25			.75				)
19) END-TO-END C/NO, DB-HZ							43.91			43.78	
20) MODEM/RADIO LOSS, DB=	TRI	.00			.00		-1.00	.30	.30	-1.00	1.50)
21)REQUIRED C/NO,DB-HZ		41.06			41.06		39.81			39.81	
(REQUIRED EB/NO,DB							3.00				)
		--------			--------	------	------			------	-----
22)PERFORMANCE MARGIN,DB		3.44			3.07	.76	3.09			2.97	1.04
((19)+(20)-(21))						(1 SIG)					(1 SIG)

Table 1.4. Forward Link Budget for BPTs (4.8 kbps Equivalent Voice/Data Channels, Clear Sky, 20-Degree Elevation, 1.0E-5 BER, R=1/2, and K=7)

		SUPPLIER TO SAT.					SAT TO USER				
	PDF	DESIGN	FAV TOL	ADV TOL	MEAN	VAR (X.01)	DESIGN	FAV TOL	ADV TOL	MEAN	VAR (X.01)
TRANSMITTER PARAMETERS	---										
1)XMIT POWER,DBW	TRI	-3.00	.30	.30	-3.00	1.50	-6.80	.30	.30	-6.80	1.50
2)XMIT CIRCUIT LOSS,DB	REC	-1.00	.10	.40	-1.15	2.08	-1.50	.10	.40	-1.65	2.08
3)ANTENNA GAIN,DBI	TRI	57.50	1.00	1.00	57.50	16.67	52.50	1.00	1.00	52.50	16.67
4)EIRP,DBW ((1)+(2)+(3))		53.50			53.35		44.20			44.05	
5)POINTING LOSS,DB	TRI	-.09	.02	.02	-.09	.01	-1.23	.05	.05	-1.23	.04
PATH PARAMETERS											
6)SPACE LOSS,DB		-214.03			-214.03		-210.51			-210.51	
(FREQUENCY,GHZ/GHZ =		30.00					20				)
(RANG= 40000 KM)											
7a)ATMOSPHERIC ATTN, DB	TRI	-.70	.50	.50	-.70	4.17	-.90	.40	.40	-.90	2.67
7b)RAIN ATTN, DB	TRI	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
8)E.O.B.LOSS,DB	TRI	-3.00	.50	.50	-3.00	4.17	-4.00	.50	.50	-4.00	4.17
9)MULTIPATH LOSS,DB	GAU	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
10)SHADOWING LOSS,DB	DEL	.00	.00	.00	.00		.00	.00	.00	.00	
RECEIVER PARAMETERS											
11)POLARIZATION LOSS,DB	TRI	-.50	.20	.20	-.50	.67	-.50	.20	.20	-.50	.67
12)ANTENNA GAIN,DBI	TRI	26.90	.50	.50	26.90	4.17	19.30	.50	.50	19.30	4.17
13)POINTING LOSS,DB	TRI	.00	.00	.00	.00	.00	-.70	.29	.40	-.74	2.00
14)RECEIVED SIGNAL POWER,DBW		-137.92			-138.07		-154.34			-154.53	
(SUM OF LINES 4 - 13)											
15)SYSTEM TEMPERATURE,DBK	GAU	28.06	.30	.61			28.23	.60	.86		
(CIRCUIT LOSS,DB =		-.50	.10	.40			-.50	.10	.40		)
(RCVR N.F. ,DB =		3.00	.20	.20			3.50	.20	.20		)
(EXTERNAL ANT TEMP,K =		280.00	0	0			107	20	18		)
(INTERNAL ANT TEMP,K =		.00	0	0			119.60	18	19		
(RAIN INDUCED TEMP,K =		.00	0	0			.00	0	0		
16)RECEIVED NO,DBW/HZ	GAU	-200.54	.30	.61	-200.39	2.32	-200.37	.60	.86	-200.24	5.91
((15)-228.6 DBW/HZ)											
(BANDWIDTH,KHZ =		20.00					20.00				)
CHANNEL PERFORMANCE											
17)RCVD C/NO,DB-HZ ((14)-(16))		62.62			62.32		46.03			45.71	
18)EFFECTIVE C/NO,DB-HZ		62.24			61.96		45.98			45.67	
(OVERALL C/I,DB =	GAU						22.99	1.00	1.00	22.99	11.11)
(INTERBEAM ISOLATION =							26.00	1.00	1.00	26.00	)
(INTERSAT. ISOLATION =							99.00	.50	.50	99.00	)
(INTERMOD ISOLATION =	TRI	30.00	1.00	1.00	30.00	16.67	26.00	1.00	1.00	26.00	)
(TURNAROUND C/NO =	GAU						62.24			61.96	52.41)
(NO(UP)/NO(REQUIRED) =		.10					.10				)
19) END-TO-END C/NO, DB-HZ							45.83			45.57	
20) MODEM/RADIO LOSS, DB=	TRI	.00			.00		-1.50	.30	.30	-1.50	1.50)
21)REQUIRED C/NO,DB-HZ		51.31			51.31		41.31			41.31	
(REQUIRED EB/NO,DB							4.50				)
		--------			--------	------	------			------	-----
22)PERFORMANCE MARGIN,DB		10.93			10.65	.72	3.02			2.76	1.02
((19)+(20)-(21))						(1 SIG)					(1 SIG)

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Table 1.5

Salient Features of the Baseline System Design

OPERATING FREQUENCY	
UPLINK	30 GHZ
DOWNLINK	20 GHZ
COVERAGE CONCEPT	
SAT/SUPPLIERS	CONUS BEAM
SAT/USERS	142 SPOTBEAMS
MULTIPLE ACCESS	
SUPPLIERS	TDMA
USERS	FDMA
GENERIC SERVICES	VOICE AND DATA
DATA RATES	
FORWARD (NORMAL)	100 KBPS (BPT) 300 KBPS (EPT)
RETURN (NORMAL)	4.8 KBPS (BPT)
RAIN COMPENSATION	
FORWARD	UPLINK POWER CONTROL & VARIABLE DATA RATE
RETURN:BPTs	VARIABLE DATA RATE
RETURN:EPTs	UPLINK POWER CONTROL & VARIABLE DATA RATE
LINK AVAILABILITY	98% FOR BPTs @ 4.8 KBPS >98% FOR EPTs
INTERBEAM POWER MANAGEMENT	9-BEAM POWER MANAGEMENT
FREQUENCY REUSE CAPABILITY	16 TIMES (FOR SPOTBEAMS)
SYSTEM CAPACITY*	
RAW DUPLEX CHANNELS	2800 (100% DUTY CYCLE), OR
DUPLEX VOICE CHANNELS	7500 (VOX=35%)

NOTE:
* System capacity is given in terms of the number of equivalent channels at 4.8 kbps each assuming that all user terminals are BPTs.

Table 1.6

Summary of the Satellite Design

SPOTBEAM	
ANTENNA SIZE (TRANSMIT)	3 M
(RECEIVE)	2 M
NUMBER OF SPOTBEAMS	142
ANTENNA GAIN	52.5 DBI
ANTENNA BEAMWIDTH	0.35 DEG
SYSTEM G/T	23.4 DB/K
AVERAGE EIRP/BEAM	58.7 DBW
CONUS BEAM	
ANTENNA GAIN	27.0 DB
ANTENNA BEAMWIDTH	7.7 DEG
SYSTEM G/T	- 1.2 DB/K
EIRP	46.1 DBW
SATELLITE MASS (GTO)	6500 LB
SATELLITE POWER (EOL)	4.0 kW

Table 1.7

Design Requirements for the BPT

ANTENNA GAIN @20 GHZ	19.3 DBI
ANTENNA GAIN @30 GHZ	22.8 DBI
ANTENNA TRACKING/COVERAGE CAPABILITY	
AZIMUTH	360.0 DEG
ELEVATION	15-60 DEG
RECEIVE G/T	-9.0 DB/K
TRANSMIT POWER	0.17 W
NORMAL DATA RATE	
RECEIVE	100 KBPS
TRANSMIT	4.8 KBPS
OTHER REQUIREMENTS	
SIZE	HANDHELD
MODEM	VARIABLE RATE

APPENDIX A

IMPACTS OF NONUNIFORM USER DISTRIBUTION ON SATELLITE CAPACITY

Miles K. Sue

1.0 INTRODUCTION

User distribution is not uniform throughout CONUS. This presents a challenge to the design of a CONUS coverage system. Fixed multiple beams with frequency reuse is a technology that has often been suggested for CONUS-coverage satellite systems providing services such as mobile and personal communications. For simplicity, most satellites are designed to provide a fixed but equal eirp for each spotbeam, i.e., the same HPA output power for all beams. In other words, these satellites are designed for a uniform user distribution. When the distribution is nonuniform, saturation may occur in some beams while other beams may have unused capacity, consequently reducing the system's effective capacity. This problem is more acute for systems with narrow spotbeams. For systems with relatively large beams, this problem is less severe due to the averaging effects. The problem of nonuniform user distribution was addressed in [11] using a simplified triangular probability density function (pdf) to model the user distribution. The results of that study are summarized here.

2.0 ANALYSIS

There are two adverse effects. The first is a reduction of system capacity. The second is that users in some beams may be denied services. This happens when the number of users in a beam exceeds the designed capacity for that beam. The system designer is forced to trade capacity utility for service quality, as illustrated in Figure A.1. This figure shows the effects of nonuniform user density (number of users per beam) on the effective capacity (or satellite utility) for a system designed for a uniform distribution. The vertical axis gives the potential system utility normalized to the utility for a uniform distribution as a function of two parameters: Alpha and Beta. These parameters characterize the user distribution and the transponder design. Alpha relates the user density to the transponder design. Specifically, it gives the fraction of beams in which the number of users exceeds the design value. Beta is a user distribution parameter; it is a measure of the spread between the most probable user density and the maximum density. It takes on values between 0 and 1. When Beta is 1, it implies that the probable value equals the maximum value. As indicated by Figure A.1, the reduction is significant for small values of Beta.

Figure A.2 is similar to Figure A.1, showing the relative capacity (or satellite utility) as a function of the variance of user density. As expected, a larger variance will result in a lower capacity.

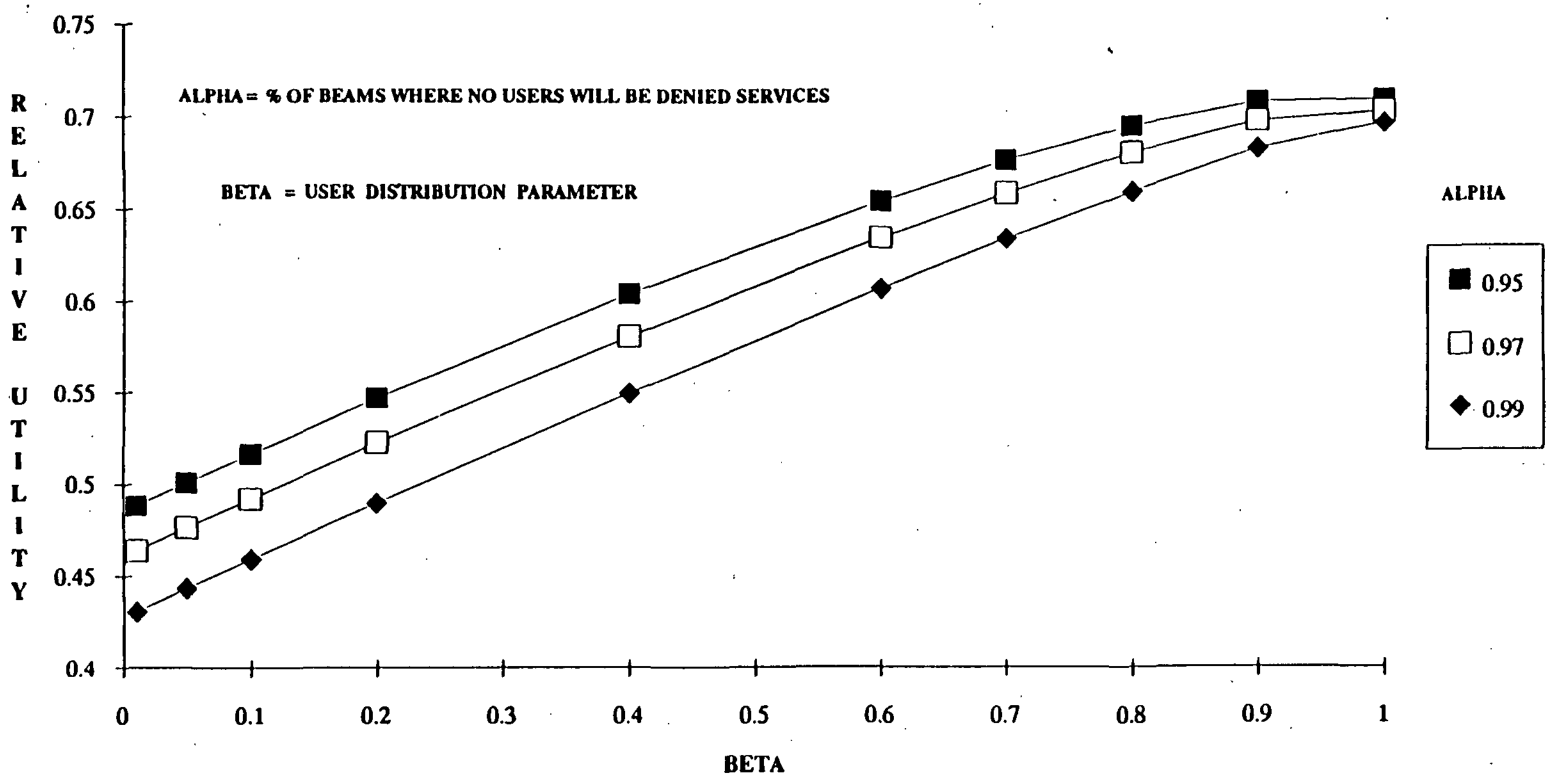

Figure A.1. Relative Satellite Capacity (Utility) vs. User Distribution

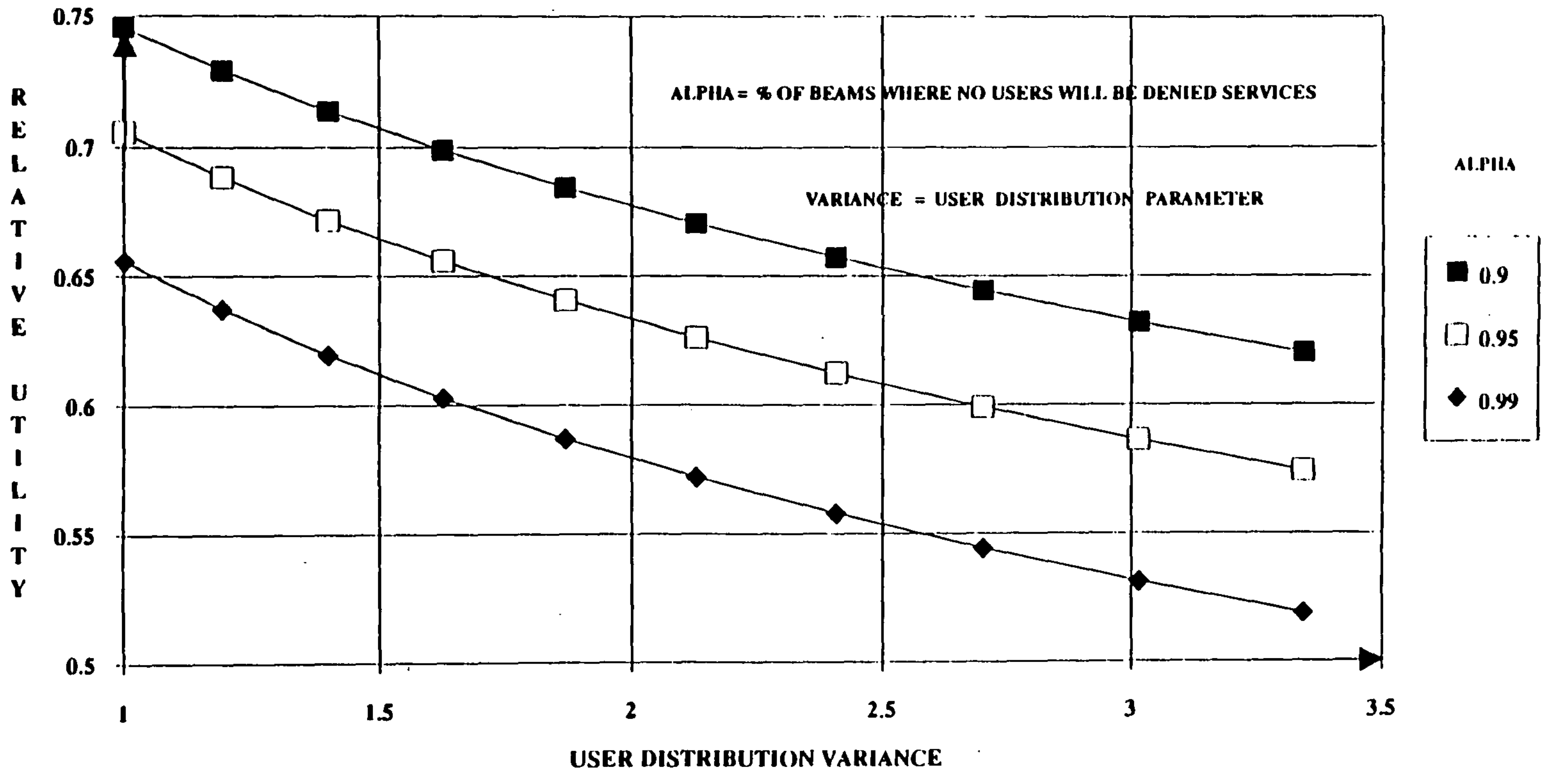

Figure A.2. Relative Satellite Capacity (Utility) vs. Variance of User Density

APPENDIX B

USER TERMINAL RADIATION LEVEL ESTIMATES

(Derived from Dessouky and Jamnejad [12])

1.0 INTRODUCTION

The current design requires the user terminal to have a 0.17-W transmitter and a transmit antenna with about 23-dBi gain. The resulting eirp is 14.5 dBW. While these values are preliminary and subject to future revision, it is necessary to estimate the radiated power flux density in order to insure that safety standards will be complied with.

2.0 CURRENT SAFETY STANDARD

The current ANSI standard for frequency above 1.5 GHz is 5 mW per square centimeter averaged over a 6-minute period. This standard includes a safety factor of 10 or more. At 30 GHz, the eye, particularly the cornea, is most susceptible to radiation damage due to the lack of blood circulation which drains the deposited heat. Independent experiments recently conducted by the USAF School of Aerospace Medicine using cat's eyes have suggested that incident densities up to 100 mW/cm^2 did not cause any harm [9]. Although this kind of study may eventually result in a relaxation of the acceptable radiation level, the PASS design goal is to meet the current safety standard.

3.0 RADIATION LEVELS VS. ANTENNA SIZE AND TRANSMIT POWER

To estimate the radiation density, a plot has been created and shown in Figure B.1, obtained from Chapter 5. This plot gives the normalized radiation density as a function of the normalized distance from the antenna for selected antenna gain, along with an upper bound of peak radiation level. The radiation density is normalized to the radiated RF power (in watts) and the square of the operating frequency (in GHz). The distance from the antenna is given in terms of the axial distance in wavelengths. To obtain the actual radiation density (mW/square cm), the normalized value is multiplied by the square of the operating frequency (GHz), and by the radiated RF power (watts). For example, the peak radiation level for a 25-dBi antenna at 30 GHz occurs 8 wavelengths (8 cm) from the antenna. The peak density is equal to 153xP, where P (watts) is the radiated power. If P is .2 watts, the peak radiation density is 30.6 mW. Chapter 5 contains a more detailed discussion of the antenna radiation level.

The estimates above give only the radiation density. Other factors, including exposure time and transmitter duty cycle, should be considered in order to determine whether the user terminal radiation level complies with established safety standards.

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4.0 ESTIMATED RADIATION LEVEL FOR PASS USER TERMINALS

The current user terminal is designed to have a 23-dBi transmit antenna, 0.17-W transmitter power, and correspondingly, 14.5-dBW eirp. Using the design values and assuming a typical voice traffic scenario (i.e., a 90-second call with 35% duty cycle), the peak radiation density produced by the user terminal under these conditions is estimated to be 3.6 mW averaged over a 6-minute period, which complies with the current safety standard. The peak radiation density occurs at a point on the antenna boresight about 6 cm from the antenna aperture. The radiation density drops off rapidly as the distance from the aperture increases. The peak radiation density can be further reduced by employing a larger user antenna. If we increase the antenna gain, for example, from 23 to 25 dBi and maintain the same eirp, the resulting peak radiation level, which occurs at about 8 cm from the antenna aperture, would be reduced to about 1 mW/cm^2, averaged over a 6-minute interval.

In summary, by carefully choosing the design parameters and operating scenarios, PASS user terminals can meet the current safety standard.

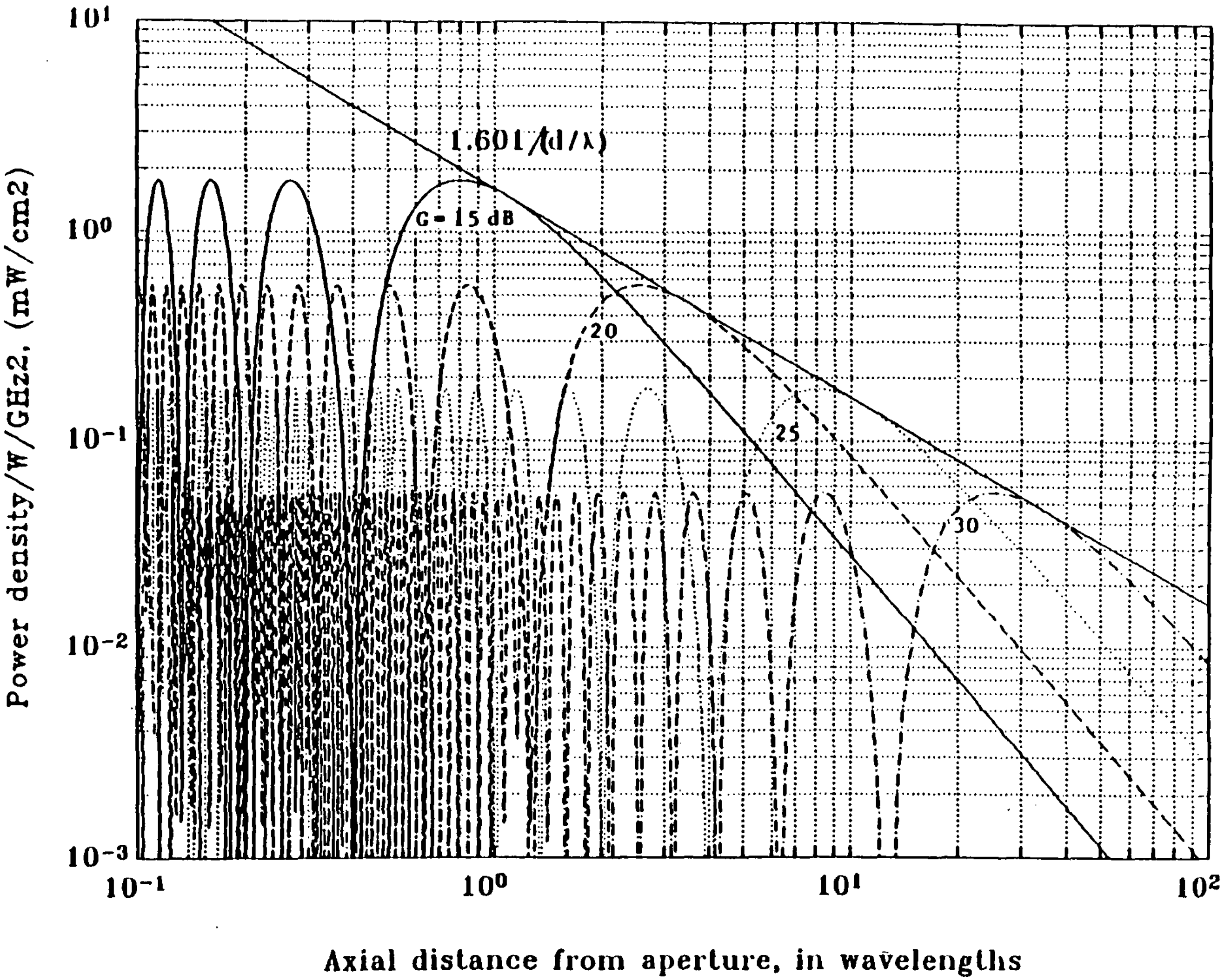

Figure B.1. Power Density vs. Axial Distance for Uniformly Illuminated Aperture Antenna (Obtained from Chapter 5)

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APPENDIX C

PASS RAIN ATTENUATION COMPENSATION TECHNIQUES AND AN ASSESSMENT OF SERVICE AVAILABILITY

Miles K. Sue

1.0 INTRODUCTION

PASS is a satellite-based communications system, currently designed to operate in the 20/30 GHz bands. These bands are chosen because of the ample available bandwidth and the potential for developing small terminals, both of which are key to the success of PASS. These bands, unfortunately, are sensitive to rain effects. This appendix discusses the rain compensation techniques proposed for small terminals and examines their impacts on link performance.

2.0 PASS RAIN COMPENSATION TECHNIQUES

As stated in Chapter 1, a combination of uplink power control and an adjustable data rate is employed in the current design to combat rain attenuation. Uplink power control is applicable to the uplinks from the suppliers who are equipped with large, fixed earth stations. When increased uplink power from the suppliers fails to fully compensate for rain degradation, the data rate will be reduced to close the link. Uplink power control will not be employed by the small personal terminals due to their limited power capability. Instead, only a variable data rate scheme will be used. During rain, the data rate will be reduced by a factor equal to multiples of 2.

3.0 DESIRED SERVICE AVAILABILITY AND ESTIMATED RAIN ATTENUATION

PASS's main objective is to provide personal communications. The design goal is to maintain 95% to 98% availability for the basic personal communications services, i.e., 4.8 kbps voice. This goal is based on a number of factors, including the nature of services, users' willingness to accept occasional outages or delays, the practicality of providing the required rain margin, the resulting system complexity, and costs.

The rain attenuation corresponding to 98% availability has been estimated to be 1.0 dB at 20 GHz and 2.5 dB at 30 GHz, based on five selected locations representing the four corners of CONUS and one southern location, as described in Chapter 1.

4.0 FORWARD LINK ANALYSIS

The forward link is downlink limited, i.e., the overall (end-to-end) C/N_o is essentially determined by the downlink C/N_o, as indicated by Table 1.4. The end-to-end clear-sky link margin is about 3.0 dB with 1-sigma variation of 1 dB.

In the forward direction, rain attenuation is more severe on the uplink than on the downlink. Fortunately, the uplink rain attenuation (2.5 dB) can be fully compensated for by uplink power control. Hence, it will not affect the overall link performance.

Although the downlink rain attenuation is smaller, it has two adverse effects: it causes an increase in system noise temperature in addition to signal attenuation. For systems with a very low system noise temperature, the first effect can be more pronounced than the second and can result in significant performance degradation. The operating system noise temperature of the small PASS personal terminals is in the neighborhood of 650 k. The relatively high noise temperature makes these terminals insensitive to the rain-induced increase in sky noise temperature, as shown in Figure C.1. This figure shows the total signal-to-noise ratio (SNR) degradation as a function of rain attenuation for selected values of the receiving system noise temperature. The total SNR degradation includes the combined effects of signal attenuation and increased system noise temperature. As evident in Figure C.1, the total SNR degradation is caused mainly by signal attenuation for the typical PASS user terminals.

Two key parameters affect the service availability. The first is the clear-sky link variation due to all possible variations of link parameters with the exception of rain attenuation, e.g., transmit power, antenna pointing error, thermal noise, etc. The clear-sky link variation in units of dB, x, can be modeled as a random variable having a gaussian probability density function (pdf) with mean μ_x and variance σ_x^2. The second parameter is the rain attenuation, y, which has the well-known log-normal pdf. Ignoring the effects caused by the increase in system noise temperature, the total link attenuation due to the combined effects of x and y is given by

$$z = \begin{cases} x & \text{no rain} \\ x+y & \text{during rain} \end{cases} \qquad \text{Eq. (1)}$$

The pdf of x, $p_x(x)$, is given by

$$p_x = \frac{1}{\sqrt{2\pi}\,\sigma_x} \exp\left(-(x-\mu_x)^2/\,2\,\sigma_x^2\right) \qquad \text{Eq. (2)}$$

The pdf of y which can be derived from its log-normal pdf is given by

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$$p_y(y) = \frac{1}{\sqrt{2\pi}\,\sigma_y\, y} \exp(-(\ln(y) - \mu_{\ln(y)})^2 / 2\,\sigma^2_{\ln(y)}) \qquad \text{Eq. (3)}$$

where $\mu_{\ln(y)}$ is the mean of ln(y), which happens to equal the natural logarithm of the median of y, and $\sigma^2_{\ln(y)}$ is the variance of ln(y).

Assuming that x and y are independent, the conditional pdf of z during rain is then given by

$$p_z(z|rain) = p_x(x) * p_y(y) \qquad \text{Eq. (4)}$$

where * denotes convolution. In the absence of rain, the conditional pdf of z is identical to that of x. The total probability of z is obtained by averaging the two conditional probabilities with and without rain,

$$p_z(z) = (1-p_o)\, p_x(x) + p_o\, p_z(z|rain) \qquad \text{Eq. (5)}$$

where P_o is the probability that rain occurs at any point along the propagation path. The link availability for a given link margin can then be obtained by integrating $p_z(z)$.

The above analysis has been applied to estimate the service availability for three locations: Mobile, Miami, and Portland (Maine). The first step is to determine the rain attenuation statistics and the clear-sky link variation statistics. The rain attenuation statistics have been computed using Manning's rain model and by assuming that the satellite is located at 95 degrees west longitude. The statistics for the clear sky link variation have been computed using a spread-sheet link design program by specifying the favorable and adverse tolerances and the associated pdf for each link variable. The statistics for the clear-sky link variation can be obtained from the link budget table and are tabulated in Table C.1, along with the rain attenuation statistics.

Figure C.2 shows, as an example, the pdf of x, the pdf of y, the conditional pdf of z during rain, the total pdf of z, and their relationships for Portland, Maine. The link availability can be obtained from Figure C.3, which gives the percentage of time that the total attenuation on the link exceeds a given link margin. As indicated, the 3.0-dB link margin would provide approximately 99% availability. It should be noted, however, that the effect of increased system noise temperature has not been included in Figure C.3. For the range of service availability targeted for basic personal communications, increased system noise temperature will not result in more than 0.4-dB degradation based on the five locations examined. Allowing pessimistically 0.5 dB to account for the effect of increased system noise temperature, the resulting link availability would be approximately 98%.

5.0 RETURN LINK ANALYSIS

The return link is from the user to the supplier, via the satellite. A clear sky link budget is shown in Table 1.3, with a clear-sky link margin of 3.0 dB and σ_x equal to 1.0 dB. The return link is different from the forward link in that it is basically uplink limited instead of downlink limited. Rain attenuation on the downlink, which is less than 1.0 dB approximately 98% of the time, would have negligible impacts (less than 0.1 dB) on overall link performance.

Service availability for the return link is thus mainly determined by uplink rain attenuation and variations in link parameters. Ignoring the contributions of downlink rain attenuation, service availability for the return link has been estimated using Eqs. (1)-(5) and results are shown in Figure C.4. The rain attenuation and link variation statistics are tabulated in Table C.2. Figure C.4 shows that the 3-dB link margin would be adequate 98% of the time.

6.0 HIGHER AVAILABILITY FOR CRITICAL SERVICES

The foregoing analyses have determined the availability of basic personal communications services at the nominal data rate of 4.8 kbps. There are services offered by PASS, such as emergency communications, that require a higher availability. The variable data rate scheme is designed to satisfy these needs. By reducing the data rate from 4.8 kbps to 2.4 kbps, the link availability can be increased to about 99%, as indicated by Figures C.3 and C.4. A further reduction below 2.4 kbps would result in an even higher service availability, although the improvement becomes increasingly negligible.

7.0 CONCLUSIONS

Service availability for PASS has been estimated to be 98% at 4.8 kbps and 99% at 2.4 kbps based on the three locations examined. While an expanded study that includes more locations would be needed to fully establish PASS service reliability, the analysis of the three selected locations, comprising areas with heavy rain as well as areas with low elevation angles, has provided a quick assessment of PASS's rain compensation strategy and the resulting service quality. Results indicate that the impacts of rain attenuation for PASS-like systems are moderate and can be mitigated without relying on complicated on-board baseband processing technologies.

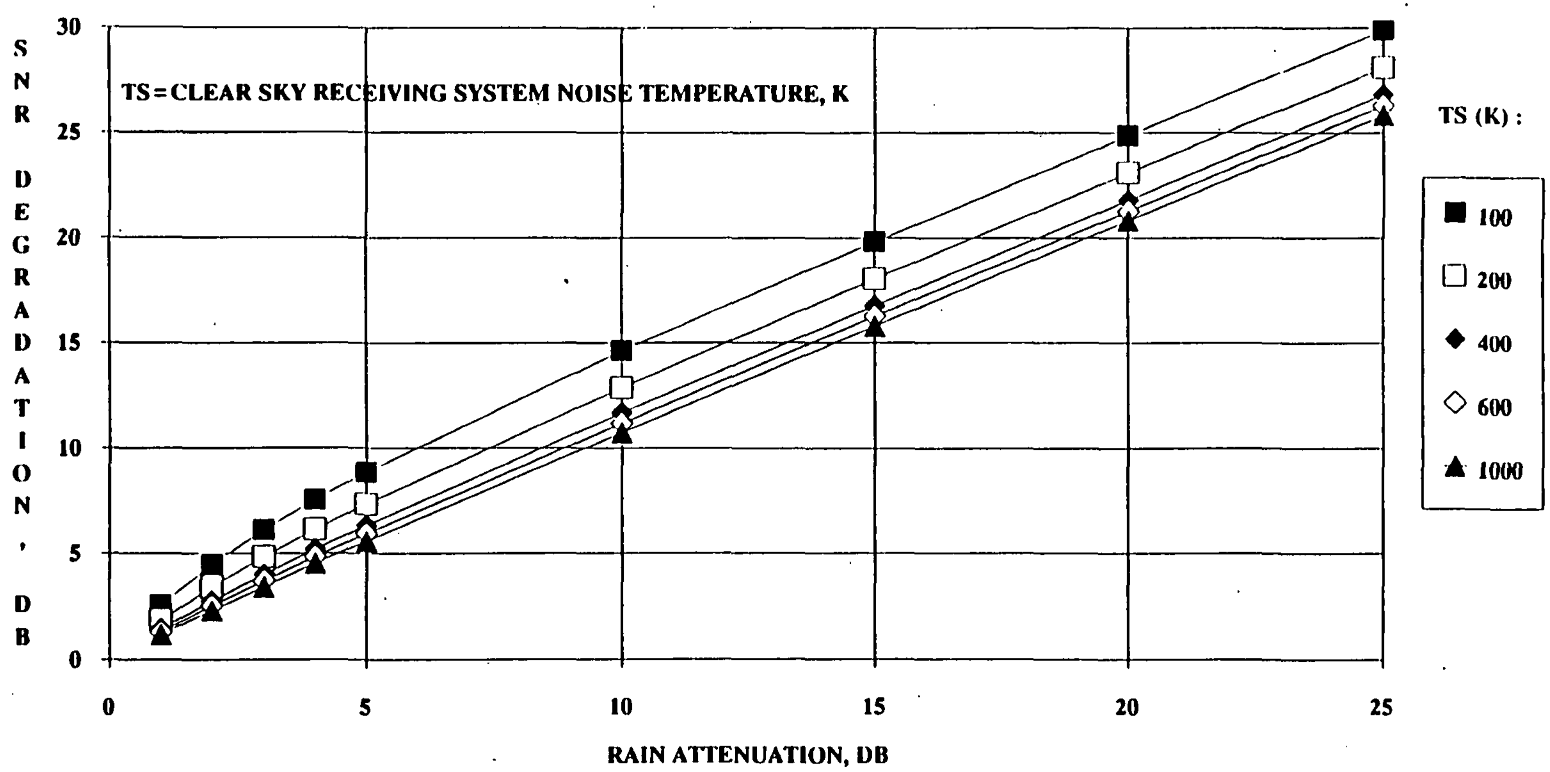
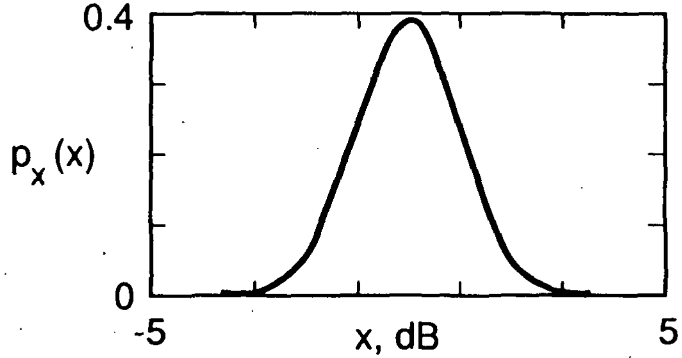
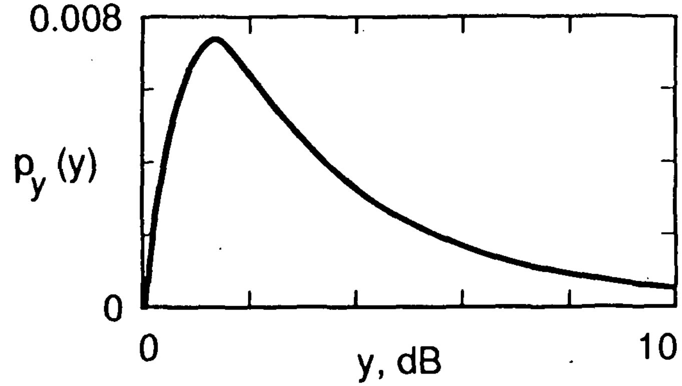


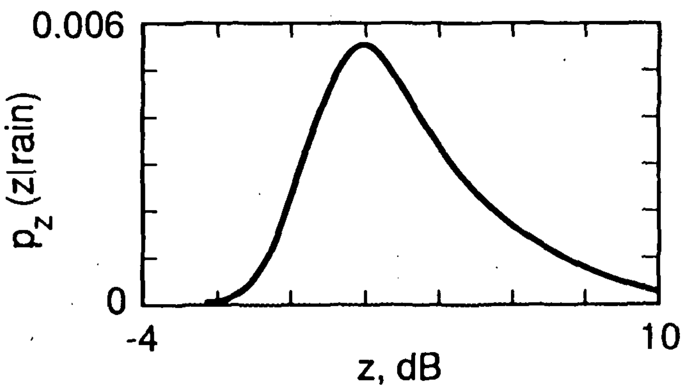
Figure C.1. Total SNR Degradation vs. Rain Attenuation with Clear-Sky System Noise Temperature as a Parameter



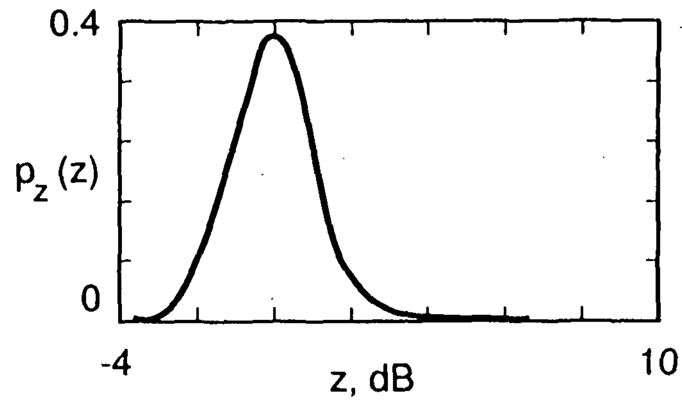
a. pdf of the Clear-Sky Link Variations, x.



b. pdf of Rain Attenuation, y.



c. pdf of the Total Link Attenuation, z, Conditioned on Rain: $p_z(z|rain) = p_x(x) * p_y(y)$



d. Total pdf of z, Averaged Over Rain and no Rain Cases: $p_z(z) = (1-P_o)\ p_x(x) + P_o\ p_z(z|rain)$; P_o = Probability of Attenuation

Figure C.2. An Illustration of $p_x(x)$, $p_y(y)$, $p_z(z)$, and Their Relationships

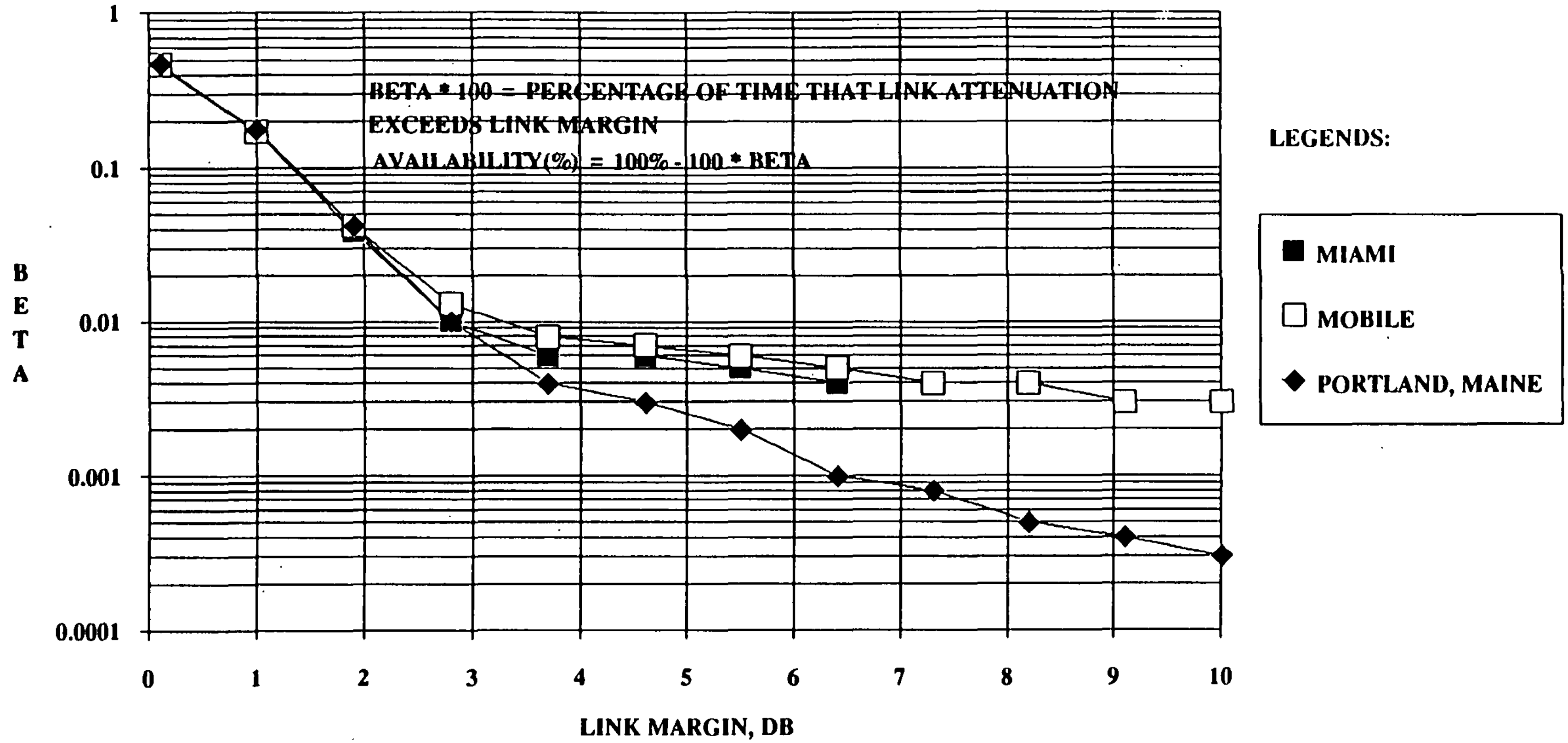


Figure C.3. Percentage of Time That the Total Link Attenuation Exceeds the Link Margin for the Forward Link

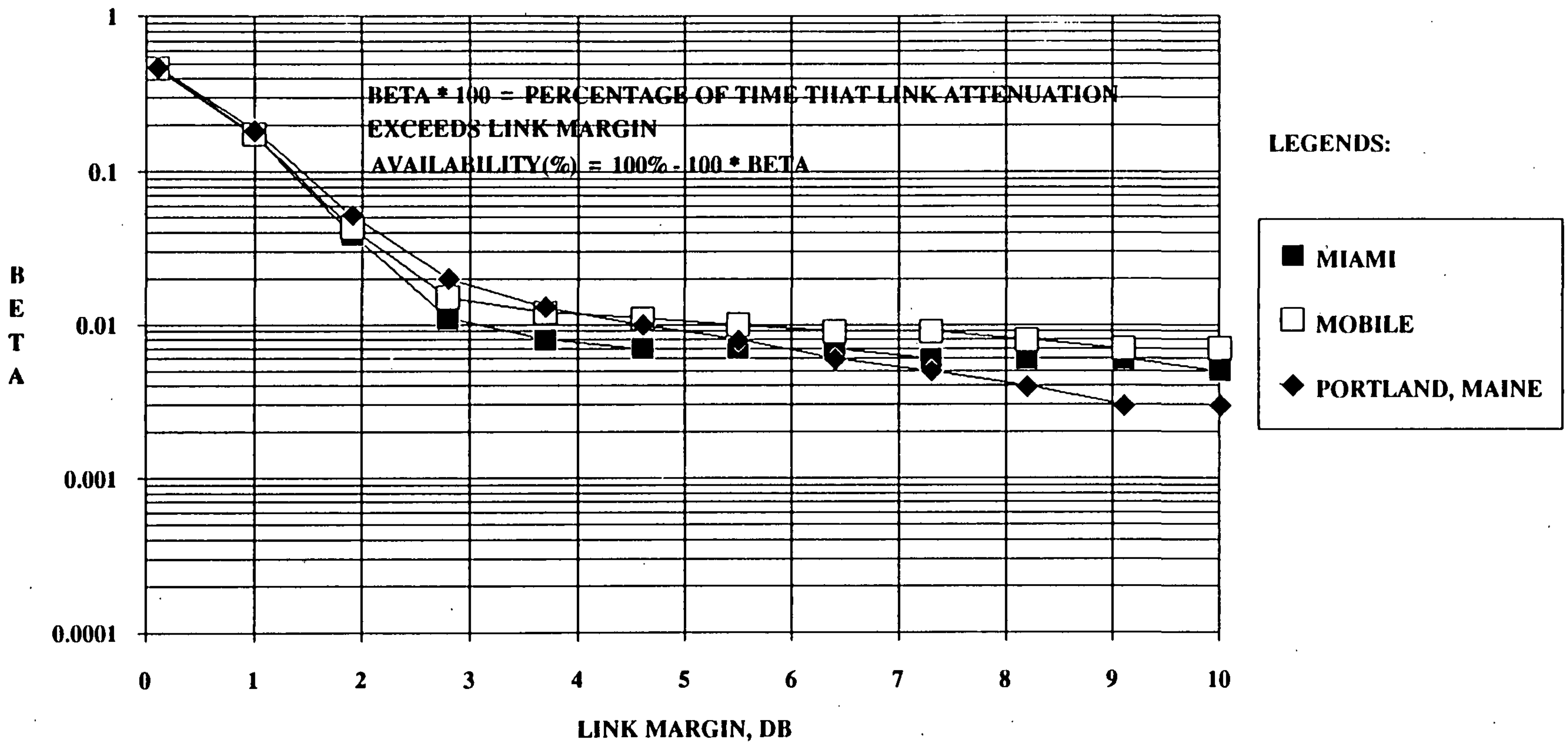


Figure C.4. Percentage of Time That the Total Link Attenuation Exceeds the Link Margin for the Return Link

Table C.1.

Key Parameter Values for the Forward Link

KEY PARAMETERS	MIAMI, FLORIDA	MOBILE, ALABAMA	PORTLAND, MAINE
$\mu_{ln(y)}$, dB	12.9	10.3	2.8
σ_y, dB	0.98	0.89	0.89
P_o, %	0.9	1.3	3.2
μ_x, dB	0.0	0.0	0.0
σ_x, dB	1.0	1.0	1.0

Table C.2.

Key Parameter Values for the Return Link

KEY PARAMETERS	MIAMI, FLORIDA	MOBILE, ALABAMA	PORTLAND, MAINE
$\mu_{ln(y)}$, dB	6.5	4.8	1.2
σ_y, dB	1.0	0.9	1.0
P_o, %	0.9	1.3	3.2
μ_x, dB	0.0	0.0	0.0
σ_x, dB	1.0	1.0	1.0

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