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PROPAGATION EFFECTS ON SPREAD-SPECTRUM MOBILE-SATELLITE SYSTEMS

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ABSTRACT

In contrast to the situation at L band, wide bandwidths of 500 MHz or more have been allocated for mobile-satellite service at frequencies between 20 and 50 GHz. These broad bandwidths are well suited for the use of spread spectrum. Certain system considerations about the use of such high frequencies for mobile-satellite service are mentioned first, and attention is then given to propagation effects on high-frequency broad-band systems. Attenuation due to rain is a constraint at 20 to 50 MHz but would not be a serious problem if outages occurring for one to three percent of the time, depending on location, are considered to be acceptable. Procedures are available for estimating rain attenuation for percentages of time from 0.001 to 1. Clear-air absorption becomes a significant factor above 40 GHz but should not exceed 2 dB at a 10 deg elevation angle and frequencies below 40 GHz. Spread spectrum provides a form of frequency diversity that helps to minimize the effects of multipath. An experimental program would be needed to determine the performance of spread-spectrum systems in the presence of diffuse scatter and shadowing by trees.

1. INTRODUCTION

The World Administrative Radio Conference for Mobile Services of October 1987 (WARC-MOB-87) allocated 3 MHz and 4 MHz bands for both downlink and uplink voice service by land mobile-satellite systems at frequencies between 1530 and 1660.5 MHz. The 3 MHz bands are shared with maritime mobile-satellite service, and the 4 MHz bands are unshared except for 0.5 MHz shared with radio astronomy. Also there are allocations for non-speech low-bit-rate data. These allocations represent a step forward but are small compared to the 500 MHz and wider bands allocated for mobile-satellite service between 20 and 50 GHz. Table 1 lists allocations for mobile-satellite service within, or close to, the 20 to 50 GHz range. The desirable 19.7 to 20.2 GHz and 29.5 to 30.0 GHz ranges are available for mobile-satellite use on only a secondary basis, it is true, and the equally appealing 20.2 to 21.2 GHz and 30.0 to 31.0 bands are allocated for governmental use in the United States. The potential of these broad-band allocations for commercial service is nevertheless worthy of attention. Spread-spectrum systems have a low susceptibility to interference and tend to not cause significant interference. Indeed spread spectrum is characterized by what is referred to as a low probability of intercept (Proakis, 1983). Spread spectrum could well be used for mobile service in the 19.7 to 20.2 and 29.5 to 30 GHz bands without interfering with fixed service that has the primary allocation for these bands.

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Table 1. Allocations for Mobile Satellite Service, 20 to 50 GHz

Frequency (GHz)	Service	Allocation
19.7-20.2	Downlink (Sec.)	Non-government in U.S.
20.2-21.2	Downlink (Primary)	Government in U.S.
29.5-30.0	Uplink (Sec.)	Non-government in U.S.
30.0-31.0	Uplink (Primary)	Government in U.S.
39.5-40.5	Downlink (Primary)	Gov. & Non-gov. in U.S.
43.5-45.5	Uplink (Primary)	Government in U.S.
45.4-47.0	Uplink (Primary)	Gov. & Non-gov. in U.S.
50.4-51.4	Uplink (Sec.)	Gov. & Non-gov. in U.S.

2. SYSTEM CONSIDERATIONS

This paper is devoted to the role of propagation in a possible high-frequency (20 GHz or higher) mobile-satellite system. Certain other aspects of such a system are discussed briefly in this section. We do not present definitive treatments of these other topics but believe that they should be mentioned to provide a suitable background.

Antennas are crucial elements of mobile-satellite systems. It is desirable to employ phased-array antennas on land vehicles used for land mobile-satellite systems, in order to keep the antennas pointed at the satellite as the vehicles turn and tilt. But phased-array antennas tend to be costly--at L band and probably equally or more so above 20 GHz. In considering possible systems operating above 20 GHz, one approach could be to use a first-generation L Band system as a reference and assume that the antenna gains above 20 GHz should be the same as at L Band. Analysis shows, however, that keeping antenna gain constant with frequency puts the higher frequencies at a power disadvantage. That is, the ratio of received to transmitted power, P_R/P_T, decreases with frequency when constant gain, G_RG_T, is maintained (Fig. 1). Another possible approach, maintaining antenna areas, A_RA_T, constant with frequency, gives a power advantage to the higher frequencies (Fig. 2). But a satellite antenna as large above 20 GHz as the antennas planned for L band would present major practical problems and tend to be very costly. The satellite antenna and power problems could be solved by keeping the satellite antenna gain constant and the land-vehicle antenna area constant with frequency. In this case there is no advantage from the power viewpoint of either high or low frequencies. But the cost of maintaining the vehicle phased-array antenna area constant with frequency may still present a problem, and it may be necessary to move from constant area of the vehicle antenna towards constant gain. By such a procedure, a suitable tradeoff may be found between antenna costs and power considerations.

A favorable point is that, if constant gain for the satellite antenna is maintained as a function of frequency, the satellite antenna will tend to be relatively small and lightweight above 20 GHz. It may then be feasible to increase the power transmitted from the satellite to compensate for the power handicap otherwise encountered at high frequencies when constant gain is maintained.

The spread-spectrum technique could be applied to a single 4 MHz bandwidth, such as that allocated for land mobile-satellite use at L band. Analysis in such a case would indicate that a certain number, A, of signals could be carried simultaneously. Utilizing the wide bandwidths above 20 GHz, the same number A could also be carried in a 4 MHz bandwidth, or perhaps a somewhat wider bandwidth such as 5 MHz would be used. In addition some number, B, of 4 or 5 MHz channels could be employed. Then the total number of signals that could be carried would be A times B. Spread spectrum has been of interest in military circles for a considerable period of time (Sass, 1983). In recent years commercial non-military applications have been increasing (Parker, 1984). A number of papers have attempted to define the role of spread spectrum and to determine the number of simultaneous signals that can be accommodated in spread-spectrum channels characterized by certain parameters (Yue, 1983). The advance program for this Mobile Satellite Conference of May 3-5, 1988 lists two papers on these topics. Continuing attention needs to be given to these matters. One general conclusion is that spread spectrum is most suitable for thin-route applications, and land mobile-satellite service falls into this category.

3. PROPAGATION CONSIDERATIONS

The logic of using 30-20 GHz frequencies for satellite service, as planned for the ACTS program for example, is well established by now and it does not seem necessary to further justify it. The situation is somewhat different for fixed and mobile-satellite service, however, and propagation problems become more severe very far above 30 GHz. Power control (increasing transmitted powers as needed) and forward error correction are measures planned to mitigate signal degradation due to rain for ACTS. Power control could also be used in mobile-satellite service, and a spread-spectrum system may be able to employ forward error correction or measures having much the same effect. It seems only realistic to expect that land mobile-satellite service, however, will not be able to achieve the low outage percentage (0.01) commonly expected for fixed service. For land mobile-satellite service it may be quite reasonable to accept outage percentages of 1 to 3, depending on location. If such outage percentages are accepted, rain would not present a serious problem for land mobile-satellite service even without employing sophisticated techniques to combat attenuation due to rain.

Procedures are available for estimating attenuation due to rain exceeded for percentages of time from 0.001 to 1. The CCIR procedure is described in CCIR Report 564 (CCIR, 1986a). Even though interest may lie in a percentage other than 0.01, attenuation A for a percentage of 0.01 is calculated first by using

$$A = \alpha_p L r_p \quad \text{dB} \tag{1}$$

where α_p is an empirically derived attenuation constant in dB/km, L is path length through rain in km, and r_p is a path reduction factor that takes account of the fact that intense rain tends to be localized and can not be expected to occur with the same high intensity along the entire length of the path. The path length L can be determined from $H = L/\sin\theta$ for values of θ above 10 deg where θ is elevation angle and H is the height of the 0 deg C isotherm, taken in the CCIR 1986 model to be given in km by

$$H = 4.0 - 0.075\,(\phi - 36^\circ) \qquad \phi \geq 36^\circ \tag{2}$$

with H equal to 4.0 km for latitude $\phi < 36^\circ$. The path reduction factor r_p is given by

$$r_p = 1/(1 + 0.045\,D) \tag{3}$$

where D is the horizontal projection of H. Attenuation exceeded for a percentage p other than 0.01 is computed from the value $A_{0.01}$ for 0.01 percent by use of

$$A_p = A_{0.01}\,(0.12)\,p^{-(0.546 + 0.043 \log p)} \quad \text{dB} \tag{4}$$

It develops that the attenuation exceeded for a percentage of time of one is 0.12 of that exceeded for a percentage of 0.01. The constant α_p is determined by using the relation

$$\alpha_p = aR^b \qquad \text{dB/km} \tag{5}$$

where information for determining a and b are given in CCIR Report 721 (CCIR, 1986b). Values of rain rate R in mm/h exceeded for a percentage of time of 0.01 can be estimated from worldwide plots provided in CCIR, 1986c and reproduced by Flock (1988).

An alternative procedure that was presented in earlier versions of the CCIR model involved using tables giving rain rates R exceeded for various percentages of time and calculating attenuation directly using these rain rates. The values of rain rate obtained by this procedure for a percentage of 0.01 and for a percentage of 1 are given in Table 2. The table demonstrates how very much smaller the rain rates exceeded for a percentage of time of 1 are than the rain rates exceeded for a percentage of time of 0.01.

It should be kept in mind that attenuation is accompanied by an increase in noise and that the degradation in signal-to-noise ratio due to rain, clouds, or atmospheric gases is due to both attenuation and the accompanying increase in noise.

Clouds become a significant factor for frequencies of about 20 GHz and higher. For example, for the rather extreme case of clouds 4 km in thickness containing 1 g/m^3 of water , an attenuation of 3.9 dB and an increase in noise temperature of about 160 K are encountered at 30 GHz (Slobin, 1982). Clouds occur for a larger percentage of time than intense rain and tend to be relatively more important when emphasis is given to effects occurring for one percent of the time or more instead of 0.01 percent.

Table 2. Rain Rates (mm/h) Exceeded for 0.01 and 1 Percent of the Time for Regions A to P of CCIR Model

Region	Rate, 0.01	Rate, 1	Region	Rate, 0.01	Rate, 1
A	8	<0.5	H	32	2
B	12	1	J	35	8
C	15	2	K	42	2
D	19	3	L	60	2
E	22	1	M	63	4
F	28	2	N	95	5
G	30	3	P	145	12

Clear air absorption becomes a factor above about 40 GHz as shown in Fig. 3 (Smith, 1982). Attenuation due to the clear air should not exceed 2 dB, however, for an elevation angle of 10 deg and frequencies below 40 GHz.

The broad bandwidths employed in spread-spectrum systems tend to minimize the effects of multipath, a common source of signal degradation in land mobile-satellite systems. Multipath effects can be expected when driving on broad interstate highways, etc. A number of experimental studies, however, have tended to emphasize the importance of shadowing by trees instead of multipath effects (Vogel and Smith, 1985; Goldhirsh and Vogel, 1986). It appears that additional experimental efforts are needed to determine the performance of spread-spectrum systems in the presence of diffuse scatter and shadowing by trees.

4. CONCLUSION

The broad bandwidths allocated for the mobile-satellite service at frequencies above 20 GHz suggest that serious consideration should be given to the exploitation of these frequencies by the use of spread spectrum, for commercial as well as governmental applications.

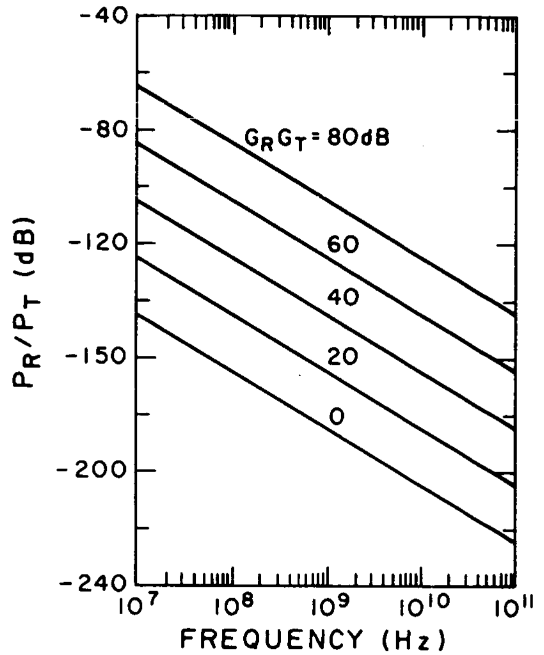

Fig. 1. P_R/P_T as a function of frequency and $G_R G_T$

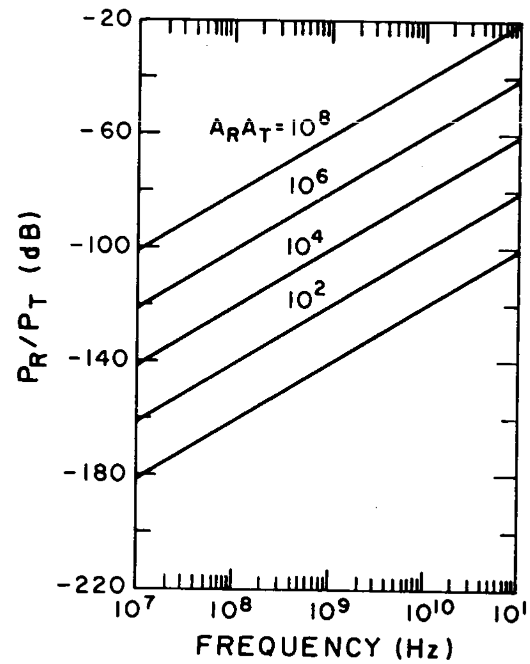

Fig. 2. P_R/P_T as a function of frequency and $A_R A_T$

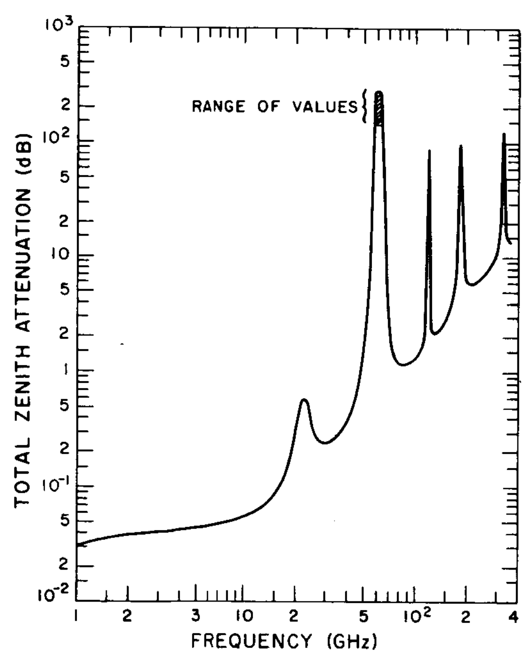

Fig. 3. Vertical one-way attenuation through atmosphere for a water vapor content of 7.5 g/m^3 at the surface

REFERENCES

CCIR 1986a. Propagation data and prediction methods required for earth-space telecommunication systems, Report 564-3. Volume V, Propagation in Non-ionized Media, Recommendations and Reports of the CCIR, 1986 (Geneva: Int. Telecomm. Union).

CCIR 1986b. Attenuation by hydrometers, in particular precipitation, and other atmospheric particles, Report 721-2. Volume V, Propagation in Non-ionized Media, Recommendations and Reports of the CCIR, 1986 (Geneva: Int. Telecomm. Union).

CCIR 1986c. Radiometeorological data, Report 563-3. Volume V, Propagation in Non-ionized Media, Recommendations and Reports of the CCIR, 1986 (Geneva: Int. Telecomm. Union).

Flock, W.L. 1988. Propagation Effects on Satellite Systems at Frequencies Below 10 GHz, NASA Reference Publication 1108(02). (Washington, DC: National Aeronautics and Space Administration).

Goldhirsh, J. and W.J. Vogel 1987. Roadside tree attenuation measurements at UHF for landmobile satellite systems. IEEE Trans. Antennas Propagat. AP-35: pp. 589-596, May.

Parker, E. B. 1984. Micro earth stations as personal computer accessories. Proc. IEEE. 72: pp. 1526-1531, Nov.

Proakis, J.G. 1983. Digital Communications. (New York: McGraw-Hill).

Sass, P.F. 1983. Propagation measurements for UHF spread spectrum mobile communications. IEEE Trans. Veh. Technol. VT-32: pp. 168-176, May.

Slobin, S.D. 1982. Microwave noise temperature and attenuation of clouds. Radio Science. 17: pp. 1443-1454, Nov. -Dec.

Smith, E.K. 1982. Centimeter and millimeter wave attenuation due to atmospheric oxygen and water vapor. Radio Science. 17: pp. 1455-1464, Nov.-Dec.

Vogel, W.J. and E.K. Smith 1985. Propagation Considerations in Land Mobile Satellite Transmission, MSAT-X Report No. 105. (Pasadena: Jet Propulsion Laboratory).

Yue, O. 1983. Spread spectrum mobile radio, 1977-1982. IEEE Trans. Veh. Technol. VT-32: pp. 98-105, Feb.