THE FACTS ABOUT Ku BAND SATELLITE TRANSMISSION FOR CABLE TELEVISION

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ABSTRACT

This article treats the subject of Ku Band satellite TV transmissions from the viewpoint of the ground segment or the receiving earth station. It is, therefore, intended as a tutuorial for cable television engineers who are planning or will plan to receive the programming available from Ku Band satellites. Uplink and satellite performance parameters are discussed and included only to the extent that they affect the overall performance and serve as a benchmark for design of the receiving earth station.

Ku Band transmission has its pluses and minuses in comparison to the more familiar C Band transmission. The advantages and disadvantages are discussed without bias. The main thrust of this paper is; once given a Ku Band transmission, and a range of parameters on the signal from the satellite, how does one go about accommodating this signal to provide quality programming to subscribers?

The primary advantage of Ku Band is that it does not share the same frequencies on a co-equal basis with terrestrial microwave systems. It is, therefore, essentially a clear channel. The only terrestrial users are Local Television Transmission Services (LTTS) which operate on a secondary basis. This means that the earth station can be located anywhere as long as there is line of sight and clearance to the satellite orbital arc. The FCC will not even accept application for license in this band for receiving stations. This does not mean that a receiving station is totally free from interference. The receiving station must have sufficient discrimination against other Ku Band satellites in the orbital arc.

The primary disadvantage of Ku Band is that it is subject to weather related fading to a greater extent than C Band. The fading is explained and it will be shown that the reliability or availability of a signal of whatever quality desired can be controlled by design of the receiving earth station, usually in a cost-effective manner.

In addition, the article will discuss certain precautions to be taken in installing the hardware used in the receiving earth stations.

WHAT IS Ku BAND?

Ku Band is an old radar designation for frequencies in the range of 12 to 15 GHz. In the world of communication satellites, it denotes the frequency of two classes of satellite service. There is a Broadcast Satellite Service (BSS) which operates from 17.3 to 17.8 GHz in the uplink and 12.2 to 12.7 GHz in the downlink. There are no satellites currently flying utilizing the BSS band but several construction permits have been issued (and revoked) by the FCC. The second class of service is the Fixed Satellite Service (FSS). The FSS utilizes 14.0 to 14.5 GHz in the uplink, and 11.7 to 12.2 GHz in the downlink. The BSS band is regulated by the Mass Media Bureau of the FCC and the FSS band is regulated by the Common Carrier Bureau of the FCC. This paper deals with the FSS, Ku Band and in particular the downlink since cable operations will, for the most part, be on the receiving end of the satellite transmission.

The band 11.7 to 12.2 GHz is very nearly three times the frequency band 3.7 to 4.2 GHz of C Band. Therefore, the wavelength is 1/3 that of C Band. A parabolic antenna at Ku Band will have a beamwidth about 1/3 of the beamwidth of a C Band antenna with the same diameter. Since the gain of an antenna is proportional to the square of the frequency, a Ku Band antenna will have about 10 dB more gain than a C Band antenna with the same diameter. A 3 meter (10 ft.) diameter antenna at Ku Band is electrically equivalent to a 9 meter (30 ft.) diamter antenna at C Band.

THE CLEAR CHANNEL

No FCC License for The Earth Station at Ku Band

The frequency band 11.7 to 12.2 GHz is set aside by the FCC primarily for satellite downlink. There are a very limited number of licenses (about 50) issued to common carriers for use in the Local Television Transmission Servive (LTTS) which operate in this same frequency band on a secondary or noninterfering basis. Since the possiblity of interference is so small, the FCC does not license receive only earth stations in this band. The FCC will not even accept applications for license of receive earth stations. It would be prudent when planning a Ku Band earth station in the 11.7 to 12.2 GHz band to notify the common carrier LTTS licensee in your area. The geographic coordinates of the station and the antenna used should be given in the notification.

This "clear" channel of operation provides a great deal of freedom to anyone planning a Ku Band earth station. Any site that can support the antenna with a clear unobstructed view of the geostationary arc can be used. It need not be co-located with a C Band station although it could be.

Satellite Power

Since there are no primary terrestrial transmitters to interfere with satellite receiving earth stations, there are no primary terrestrial receivers to be victims of interference from a satellite. Ku Band satellites can, therefore, concentrate more power on the earth than C Band ones. Early Ku Band satellites have about 20 watt transmitters on board. The RCA K1 and K2 satellites have 45 watt transmitters. The RCA K3 and K4 to be launced in 1989 or 1990 will have 60 watt transmitters. The BSS satellites will have either 100 watt or 230 watt transmitters.

Interference From Adjacent Satellites

Although the Ku Band satellite service does not share frequencies on a co-equal basis with terrestrial service, there are a multiplicity of satellites in the orbital arc operating at the same frequencies. A receiving station must depend on the discrimination of its antenna to protect it from interference from other satellites. Furthermore, there does not currently exist a "standard" frequency and polarization plan at Ku Band. The consequence of this non-standarization is that polarization isolation cannot be counted on in planning an earth station.

From a practical standpoint, it would be prudent for the earth station planner to purchase an antenna meeting the FCC sidelobe envelope requirements of Para. 25.209 of the FCC Rules and Regulations. An antenna of 2.4 meters diameter or greater meeting these requirements should provide adequate protection from adjacent satellite interference.

PRECIPITATION

Ku Band transmission is subject to deeper fades and more frequent fades than C Band transmission. This is because the shorter wavelength (2.5 centimeters vs 7.5 centimeters) is affected more than the longer wavelength. Satellite links need not provide the same level of protection (fade margin) as terrestrial links, since only a small portion of the path passes through the earth's atmosphere. However, unlike C Band service, effects of precipitation must be included in the planning of a Ku Band service.

The effects of precipitation have been thoroughly studied, and solid engineering prediction models for rain fades exist which have been experimentally verified in a large number of cases. Rain fades are dependent on rain rate and the length of the path through rain. In the case of satellite transmission, the path length depends on how much atmosphere the signal passes through, or the elevation angle of the antenna. It follows, therefore, that rain fades will depend on local conditions and the location of the earth station with respect to the satellite.

Effects of Snow

The effects of snow in the atmosphere are not nearly so bad as rain regardless of the rate of snowfall. However, an uneven accumulation of snow in the dish can cause a serious de-focusing effect which will reduce the antenna gain and increase the sidelobes. It can also cause mispointing effects, further reducing the gain on the mechanical boresight axis. In this regard, the effects are not much different than at C Band, especially for dry snow. The effects of wet snow are far more degrading than dry snow. It is obvious that a dry snow condition will always degrade to a wet snow condition when the inevitable thaw occurs, if the accumulation is allowed to stay in the dish.

The net effect for those cable operators whose philosophy it has been to sweep the snow out of antennas when pictures degrade, is to be more vigilant. A good rule of thumb is to be alert to potential problems if the weather prediction is for more than two inches of snow. The alternative, for reliability, is to equip the antenna with an automatic snow removal heating system at some additional expense.

Effects of Rain

Several models exist to predict attenuation due to rain[1]. The Crane Global Attenuation Model[2] is recommended for use in planning satellite systems because it is quantitative and has been proven accurate. The Global Model relates point rain rate (for which much statistical data exists) to attenuation at various frequencies. The Global Model correlates well with measured attenuation data[3]. Figures 1 and 2 show the rain rate climate regions worldwide and for the Continental United States (CONUS) in particular. Figures 3 through 9 provides data for all of the rain rate regions in the CONUS. In the following section, it will be shown how these charts can be used in the design of earth stations in the Ku Band. For those who wish to "fine tune" a reliability prediction, use reference 2, if rain rate data exists for the site planned for your earth station.

LINK ANALYSIS

The link analysis and examples given in this paper apply to the RCA K1 satellite at 85° west longitude. The modulation prameters used in this satellite for transmission to cable systems has been optimized to provide a reasonable compromise between clear weather signal to noise ratio, and fade margin. In the transmissions from this satellite, the deviation of the main carrier by video is 9.2 MHz, and if subcarrier is used for audio, the deviation of the main carrier by the subcarrier is 2 MHz. The receiver to accommodate these signals should have a bandwidth of approximately 24 MHz.

For an FM receiver operating above threshold, the video signal-to-noise ratio (peak luminance signal to rms noise) can be expressed by:

$$(S/N)_V = 6\ m^2\ (\frac{B}{fm})\quad (C/N)_{PD}\ (PW)..........(1)$$

where,

$(C/N)_{PD}$ is predetection carrier-to-noise ratio:

m is modulation index $(\frac{\Delta F}{fm})$

ΔF is deviation of main carrier by video

B is predetection bandwidth

fm is highest modulation frequency (4.2 MHz for NTSC)

(pw) is combined pre-emphasis and weighting improvement factor (12.8 dB for U.S. and CCIR standards)

Substituting appropriate values for ΔF and B, this equation reduces to:

$$(S/N)_V = [(C/N)_{PD} + 35]\ (db).............(2)$$

The predetection carrier-to-noise ratio is:

$$(C/N)_{PD} = (C/N)_U \oplus (C/N)_D \oplus (C/I)_T........(3)$$

where,

$\oplus$ denotes power summation:

$(C/I)_T$ is total carrier-to-interference power ratio

$(C/N)_U$ is Uplink C/N

$(C/N)_D$ is Downlink C/N

Clear Weather $(C/N)_D$ is:

$$(C/N)_D = [(EIRP)_S + G_R - T_R - A_D - (k+B)]dB..(4)$$

where,

$(EIRP)_S$ is satellite EIRP - dBW

G_R is Receiveing antenna gain -dB

T_R is Receiving system noise temperature -dB°K

A_D is downlink clear weather space loss = 205 dB

k is Boltzmanns constant = -228.6 dBW/°K

B is bandwidth - dBHz = 73.8 dBHz

Substituting and assuming the use of an LNA or LNB with 2.5 dB noise figure, and antenna noise temperature of 40°K:

$$(C/N)_D = [(EIRP)_S + G_R - 74.8]\ dB.........(5)$$

In a rain fade, the carrier-to-noise is modified by adding two addition factors:

$$(C/N)_{DF} = [(EIRP)_S + G_R - Fade - 74.8]\ dB..(6)$$

should be greater than 8 dB to remain above threshold.

where,

Fade = L_R + T_e, L_R is rain attenuation (in dB),

and

T_e is change in system noise temperature and is expressed by:

$$T_e = 10 \log \left[\frac{T_R + T_0 \frac{(L_R - 1)}{L_R}}{T_R} \right] dB$$

where,

L_R is rain attenuation (in numeric)

T_0 is ambient temperature (290°K). The sum of L_R and T_e represents the total fade in rain.

Equation (6) is the expression that a designer of a receiving earth station has to work with. He (or she) must know the satellite EIRP for the site. Satcom K1 EIRP footprint is given in figure 10. He can then determine what size antenna to use for a desired S/N, and reliability.

Since the S/N is dependent on $(C/N)_{PD}$, and equation (6) is $(C/N)_D$ in 24 MHz bandwidth, it is necessary to combine equations (3) and (6):

$$(C/N)_{PD} = [EIRP_S + G_R - (L_R + T_e + 74.8)] \oplus (C/N)_U \oplus (C/I)_T$$

A reasonable assumption for $(C/I)_T$ is 26 dB.

A reasonable assumption for $(C/N)_U$ is 26 dB.

Therefore:

$$(C/N)_{PD} = [EIRP_S + G_R - (L_R + T_e + 74.8)] \oplus 23\ dB...(7)$$

DESIGN EXAMPLE

Location of earth station site: Latitude 33°N. Longitude 97°W. (near Dallas, TX)
Desired $(S/N)_V$ in clear sky: 53 dB
Desired availability: 99.95%

1. From equation (2), for a $(S/N)_V$ = 53 dB, $(C/N)_{PD}$ = 18 dB.
2. From equation (7), for a $(C/N)_{PD}$ = 18 dB, $(C/N)_D$ = 19.6 dB.

3. Station is in rain rate region D2 (Figure 2). At this point a calculation of the antenna elevation angle must be made. Use the following formula:

$$EL = - \arctan \left(\frac{\cos\theta \cos\alpha - R/D}{\sin\theta / \sin AZ}\right) \quad \text{(degrees)}$$

where,

$$AZ = 180° + \arctan \left(\frac{\tan\theta}{\sin\alpha}\right) \quad \text{(degrees)}$$

α is earth station latitude
θ is relative longitude or satellite longitude minus earth station longitude ($\theta < 90°$)
R is radius of earth (3,957 miles)
D is radius of satellite orbit (26,244 miles)

With satellite at 85° W.L., solution of this equation yields an elevation angle of 49°.

From figure 6, rain attenuation is 5.1 dB for 99.95% availability.

$$T_e = 10 \log \frac{265 + 290 \left(\frac{3.24 - 1}{3.24}\right)}{265} = 2.4 \text{ dB}$$

Total fade is 5.1 + 2.4 = 7.5 dB.

From figure 10, EIRP is 47 dBW.

Using equation (5), and substituting:

For $(C/N)_D$ = 19.6 dB, the antenna gain should be:

$$G_R = (C/N)_D - EIRP + 74.8$$
$$= 19.6 - 47 + 74.8 = 46.4 \text{ dB.}$$

It should be noted that this value of gain will also satisfy equation (6) for minimum faded $(C/N)_D$ of 8 dB.

$(C/N)_D$ faded = 19.6 - 7.5 = 12.1 dB.

This analysis shows that a 2.3 meter diameter antenna will satisfy the requirement of $(S/N)_V$ of 53 dB in clear weather, with greater than 99.95% availability at this site.

In this case the $(S/N)_V$ was the critical limiting design factor. In some other region where the rain rate or elevation angle is less favorable, the critical design factor for dish size might be availability.

It can be shown that a target value of 99.95% availability (4.38 hours per year) can be obtained everywhere in the CONUS (except Southern Florida) using a 3.0 meter antenna with Satcom K1. In Southern Florida a 3.0 meter antenna will provide 99.90% availability to a $(C/N)_{PD}$ of 8.0 dB.

OTHER FACTORS

There are several precautions that must be taken for a successful installation at Ku Band. Remember, the wavelength of the Ku band frequency is 1/3 that of C Band. It follows, therefore, that much tighter tolerances are required in the microwave portion of the earth station. The components have been designed for these tighter tolerances, but mishandling or poor practice at installation could destroy these tolerances and thereby cause considerable degradation. For example, do not attempt to use a C Band dish, install a Ku Band feed, and expect performance as if it were a Ku Band design. Use antennas from reliable manufacturers. The RMS deviation from a paraboloidal surface should be less than 0.025 inches.

Extreme care should be exercised in assembly of a sectionalized dish. Don't force fit anything. Mating holes should line up without force fit. Don't overtorque or undertorque bolts.

REFERENCES

1. R. Kaul, et al., A Propagation Effects Handbook for Satellite Systems Design, NASA Report N80-25520 (ORI, Inc. Technical Report 1679), March 1980.

2. R. K. Crane, "Prediction of Attenuation by Rain," IEEE Transactions on Communications, Vol. COM-28, No. 9, September 1980, pp. 1717-1733.

3. L. J. Ippolito, "Radio Propagation for Space Communications Systems," Proceedings of the IEEE, Vol. 69, No. 6, June 1981, pp. 697-727.

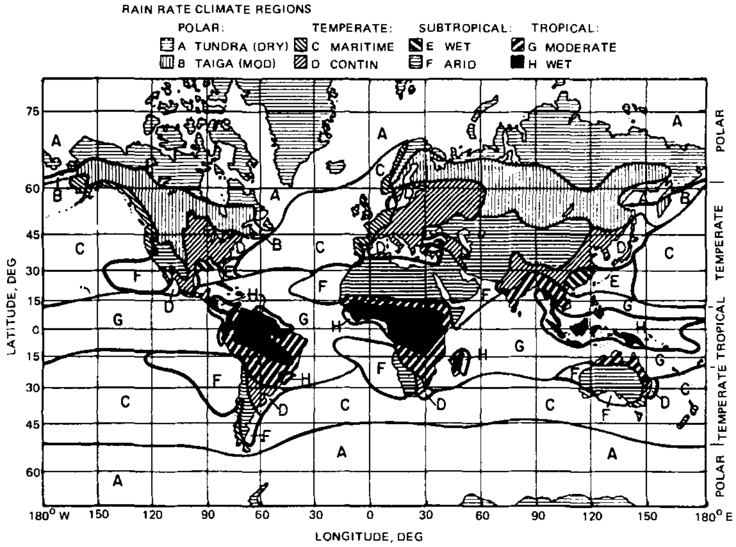


FIGURE 1. RAIN RATE CLIMATE REGIONS FOR THE GLOBAL RAIN ATTENUATION MODEL

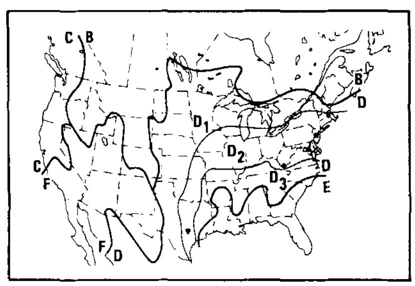


FIGURE 2. RAIN RATE CLIMATE REGIONS FOR THE CONTINENTAL U.S. SHOWING THE SUBDIVISION OF REGION D

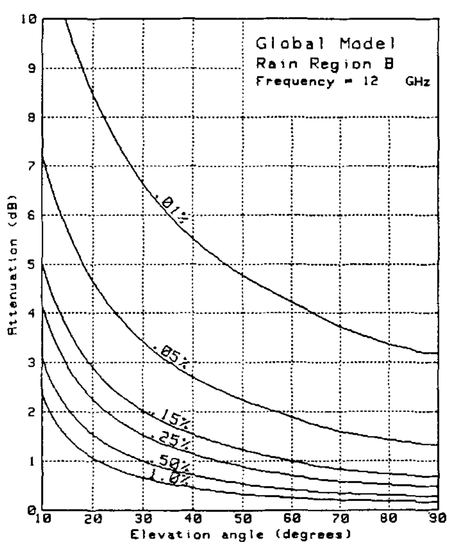


FIGURE 3. RELIABILITY DATA
RAIN RATE REGION B

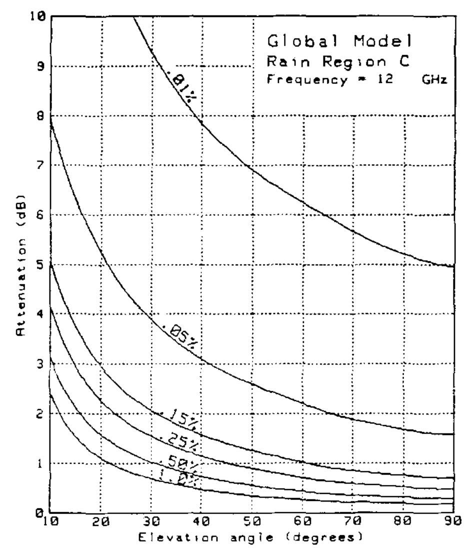


FIGURE 4. RELIABILITY DATA
RAIN RATE REGION C

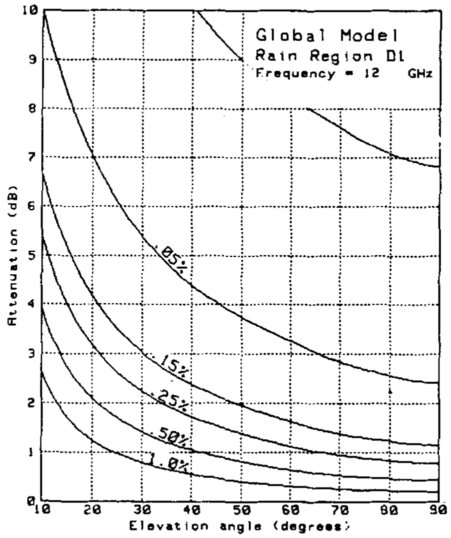


FIGURE 5. RELIABILITY DATA
RAIN RATE REGION D1

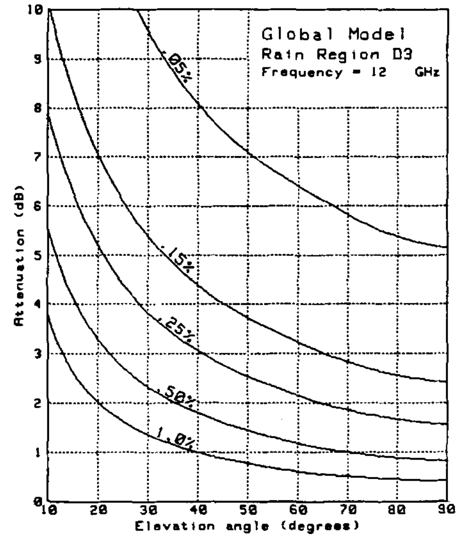


FIGURE 7. RELIABILITY DATA
RAIN RATE REGION D3

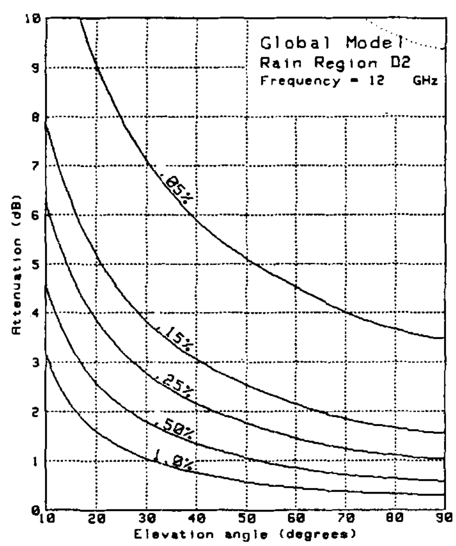


FIGURE 6. RELIABILITY DATA
RAIN RATE REGION D2

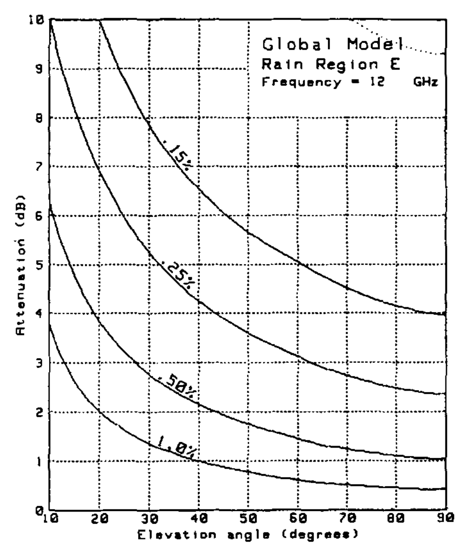


FIGURE 8. RELIABILITY DATA
RAIN RATE REGION E

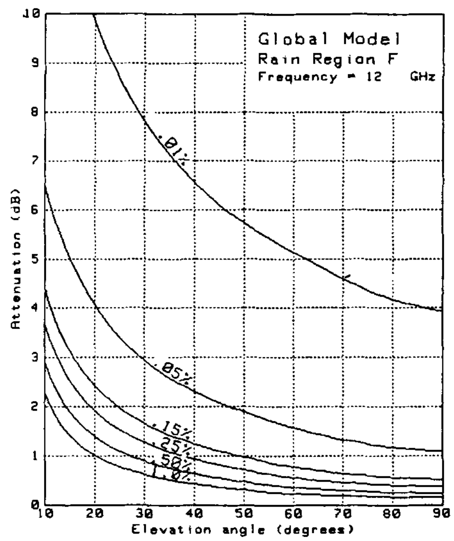
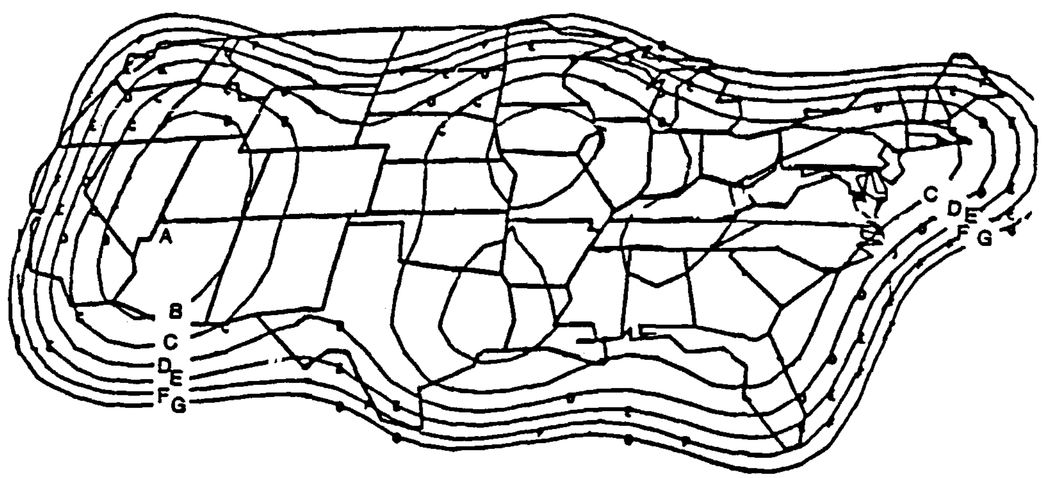
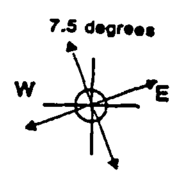


FIGURE 9. RELIABILITY DATA
RAIN RATE REGION F





EIRP (dBW)
Contour Legend

A	48.1 dBW
B	47.1 dBW
C	46.1 dBW
D	45.1 dBW
E	44.1 dBW
F	43.1 dBW
G	42.1 dBW

FIGURE 10. SATCOM K1 CONUS BEAM
EIRP CONTOURS