Link Budget Design Software
for Satellite Communications

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(ABSTRACT)

A software package is developed for communication design engineers that allows for quick and accurate evaluations of established and proposed link designs. The package is designed to be used with geostationary satellites. The computer program is written in Microsoft Basic and uses an Apple Macintosh personal computer. The software package is particularly useful in the design of K and Ku Band satellite systems. The adverse effect of rain is significant for this frequency range. The program determines the rain attenuation loss and the increase in the system noise temperature due to rain. The rain induced cross-polarization discrimination is also calculated for systems that operate with frequency reuse. The program also provides a link design for a rain attenuated downlink based upon a specified carrier-to-noise ratio. The software package also calculates basic link budget equations, derives adjacent satellite system interference, and performs

baseband analog analysis. The software program finally determines the communication system availability. A link design for three commercial satellites is shown using the computer program. The communications design software package is a very useful tool for it provides rapid response that will save the designer valuable time in the design process.

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Introduction

The satellite communications design software allows a communications engineer to test and evaluate link budget designs for geostationary satellites effectively and efficiently. The design computer program has ten options. These options include:

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2.0 Rain Margin Determination
3.0 Atmospheric Absorption Estimate
4.0 Atmospheric Attenuation Calculation
5.0 Path Diversity Gain
6.0 Link Budget Calculations
7.0 Baseband Performance Calculations
8.0 Adjacent Satellite Interference Calculations
9.0 System Availability
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The azimuth and elevation to a satellite must be determined to specify the location of the satellite when referenced from a particular site. The elevation is determined from the subsatellite point and the earth station location. The central angle and the path distance from the ground site to the satellite is also found. The azimuth is obtained from the half perimeter and vertex angle of the azimuth triangle. This method, developed by Warren L. Stutzman, provides a rapid and convenient approach to azimuth calculations.

The effects of rain are significant for frequencies greater than ten gigahertz. As more Ku band (12.5 - 18.0 GHz), K band (18.0 - 26.5 GHz), and Ka band (26.5 - 40.0 GHz) satellite systems are established the communications engineer must include rain attenuation loss in the link design. Rain attenuation becomes significant for frequencies above 10 GHz. Three methods are used to figure out the rain margin. These include the *Crane global* model, the Sam model and the International Radio Consultative Committee (CCIR) model. The noise system increase due to rain is determined next. Finally the effect of rain depolarization is calculated for each rain attenuation model.

The atmospheric absorption estimate is based upon a mathematical model of empirical data. The resulting formula allows the designer to calculate the atmospheric loss based upon the elevation angle and carrier frequency. The model provides accurate results but is only valid for the limited frequency range between 1 and 15 GHz and elevation angles between 0 and 90°.

The atmospheric attenuation calculation provides a more accurate calculation of the effects of oxygen and water vapor upon satellite communication. This model is also not limited to the stringent frequency range as the previous estimate. The calculation is determined from existing atmospheric surface conditions including surface water vapor density, temperature and humidity. Atmospheric attenuation represents a small loss when compared to rain attenuation. However atmospheric attenuation is subsequently used to find a receiver's system noise temperature.

Path site diversity gain results when two earth stations located in close proximity use the same satellite transponder. The diversity gain helps in offsetting losses because of rain. This is due to the situation where one site is affected by a rain storm, but the other site is not. Therefore sustained communication is allowed between the two sites. The site diversity gain is calculated using two models. The Hodge model essentially determines the gain increase from the site separation distance and the rain attenuation loss. A later improved model also includes the effects of frequency, elevation and the baseline-to-path gain.

The link budget equations are used to determine the carrier-to-noise ratio for the uplink, downlink and the combined total. The effects of intermodulation, carrier interference and polarization discrimination are also included. These equations allow the communications engineer to determine the optimal design based upon equipment operating characteristics and the specified cost allowance.

Baseband performance calculations are used to analyze FDM-FM-FMDA multichannel systems, single channel per carrier systems and FM-FDMA television. The carrier-to-noise and signal-to-noise ratios are determined for the appropriate system. In addition the program will determine the multichannel rms frequency deviation and the number of channels for a given telephone system.

The adjacent satellite carrier-to-interference calculation determines the effect that two different satellite systems would have upon one another. The separation angle between two satellites as observed from an earth station is determined. This angle is obtained from the subsatellite points and the path distance from the earth station to each satellite. The angular separation is used to figure out the interference of an interfering satellite with the interfered receive station. In addition the interference of an interfering earth station into an interfered satellite is also found. The effect of spectral interference for multicarrier systems is included in the final interference calculations.

The system availability is determined for a satellite communications system. The availability of a particular piece of ground equipment is derived from its mean time before failure and its mean time to repair. These are statistical parameters that define the operational capability of a particular unit. The terminal availability is established from the product of each of its major component's availability. Both the transmit and receive terminal availability is found. The link availability is determined from a rain rate threshold percentage. This threshold is determined from the uplink and downlink rain rate percentages. The system availability is found once the satellite availability is included. The system availability is obtained from the product of the terminal availabilities, link availability and the satellite availablity. The expected number of failures per year and hours outage per year is also determined.

The rain induced cross-polarization interference determines the loss due to rain upon systems that use frequency reuse. Rain depolarization has the effect of reducing the orthogonal polarization between the communication waves. The discrimination is calculated from the rain attenuation, the effective path length and transmission coefficients. The transmission coefficients are derived from attenuation and phase shift coefficients. The horizontal and vertical cross-polarization discrimination is calculated. The carrier-to-cross polarization discrimination for circularly polarized waves is also found.

A link budget design example using three commercial satellites is shown. The satellites used are the Satellite Business Systems (SBS) satellite, the GTE Spacenet satellite and GTE Gstar satellite. The link assumes the downlink is affected by rain attenuation. The design is based upon a minimum required carrier-to-noise ratio for a FM video signal. The design determines the required HPA output power, the transmit antenna diameter and the receive station gain to noise temperature ratio.

Chapter 1.0

Azimuth and Elevation Angle Determination

The determination of the azimuth and elevation angle is necessary to plan and design a communications link with a satellite. These parameters specify the location of the satellite from the earth's station point of view. The elevation angle is a crucial parameter for several aspects of the link budget design including rain attenuation, atmospheric attenuation, and site diversity gain calculations.

The elevation angle is determined from the subsatellite point and the earth station location. The subsatellite point is found by drawing a vector from the center of the earth to the satellite. The intersection of the vector with the surface of the earth defines the subsatellite point. The subsatellite point and the ground station location are specified in degrees latitude and longitude. Figure 1.1 shows the geometry of the system used to find the elevation angle. The symbol r_s represents the vector from the satellite to the center of the earth. The symbol d represents the vector from the earth station to the satellite called the path distance. The symbol r_e represents the vector from the center of the earth to the earth's surface. Therefore r_e denotes the radius of the earth. These three vectors lie in a plane and form a triangle. The angle Ω is the central angle

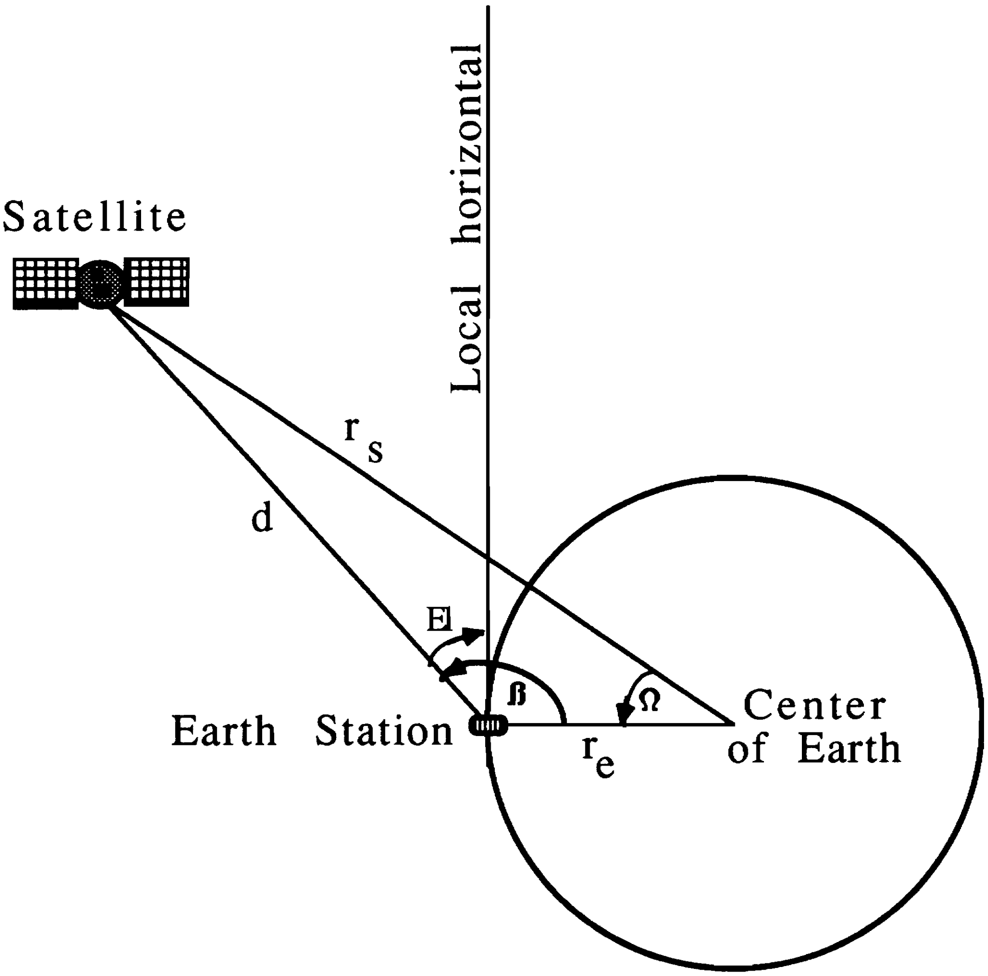

Figure 1.1 Elevation Angle Determination Geometry

between the earth station and the satellite. The central angle is determined from the subsatellite point and ground station latitude and longitude. The cosine of the central angle is given by[1]

$$\cos(\Omega) = \cos(L_e)\cos(L_s)\cos(l_s - l_e) + \sin(L_e)\sin(L_s). \qquad (1.1)$$

The symbols L_e and l_e represent the latitude and longitude of the earth station respectively. The symbols L_s and l_s represent the latitude and longitude of the subsatellite points. The law of cosines is used to calculate the slant path distance d. The magnitude of this vector is shown by

$$d = r_s[(1 + (r_e/r_s)^2 - 2(r_e/r_s)\cos(\Omega))]^{0.5} \qquad (1.2)$$

The elevation angle El is shown by

$$El = \beta - 90. \qquad (1.3)$$

The angle ß is the angle measured between the radius of the earth and the path distance. The elevation angle is measured from the local horizontal to the slant path distance. The difference between these two angles is ninety degrees shown in

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[1] Timothy Pratt and Charles W. Bostian, *Satellite Communicatios*, New York: Macmillan Publishing Company, 1986, pp 22 - 25.

Figure 1.1. The law of sines is used to relate the angles Ω and β. The resulting relationship is shown by

$$r_s/\sin(\beta) = d/\sin(\Omega) \tag{1.4}$$

Equations 1.2, 1.3 and 1.4 are then combined to form

$$\cos(El) = \sin(\Omega)/[(1 + (r_e/r_s)^2 - 2(r_e/r_s) \cos(\Omega))]^{0.5} \tag{1.5}$$

The previous elevation equations are modified for the special case of geosynchronous satellites. The subsatellite latitude, L_s, for this type of satellite is zero. The radius of the earth is 6370 km and the geosynchronous orbital radius is 42,242 km. The geosynchronous version of Equation 1.1 is given by

$$\cos(\Omega) = \cos(L_e) \cos(l_s - l_e). \tag{1.6}$$

The path distance (equation 1.2) to a geostationary satellite is therefore described by

$$d = 42{,}242[1.02274 - 0.301596 \cos(\Omega)]^{0.5}. \tag{1.7}$$

The elevation angle (equation 1.5) to a geostationary satellite is given by

$$\cos(El) = \sin(\Omega)/[\ 1.02274 - 0.301596 \cos(\Omega)]^{0.5}. \qquad (1.8)$$

The geostationary central angle, path distance and elevation angle equations are implemented in Microsoft Basic. The program is written to allow an operator to enter the subsatellite point longitude, l_s, and the earth station location, l_e and L_e. Equations 1.6 through 1.7 are then used to solve for the central angle, path distance and finally the elevation angle.

The azimuth determination is based upon the spherical triangle.[2] The trigonometry of the spherical triangle is shown in Figure 1.2. The vertices' labels are given by S, E and M. The symbol S represents the subsatellite point. The symbol E represents the earth station. The remaining symbol M represents the point where the longitude line of the earth station crosses the equator. The arcs of the triangle are labeled Ω, c, and a. The arc labeled by Ω is the central angle. The arc labeled by c is given by

$$c = |\ L_e - L_s\ |. \qquad (1.9)$$

The arc labeled by a is shown by

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[2] Timothy Pratt and Charles W. Bostian, *Satellite Communicatios*, New York: Macmillan Publishing Company, 1986, pp 25 - 29.

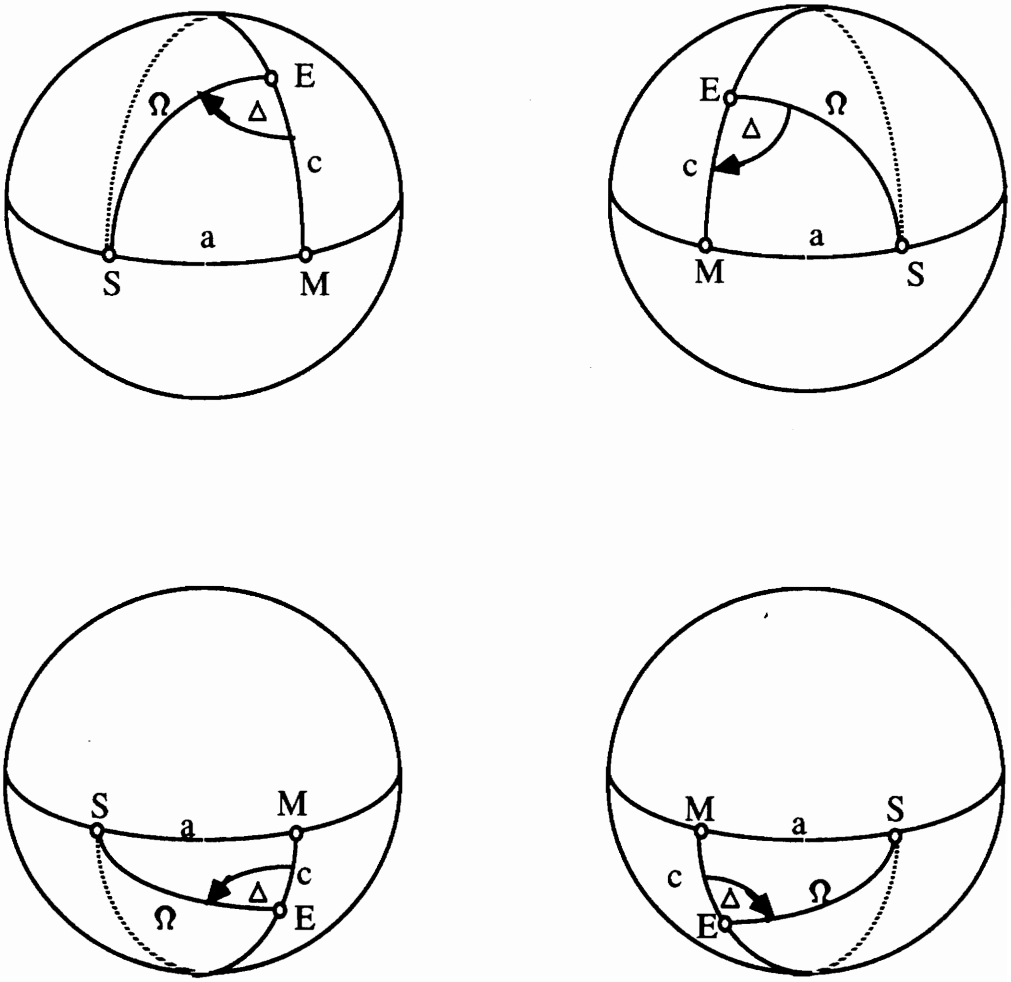

Figure 1.2 Azimuth Calculation Spherical Trigonometry

$$a = | l_s - l_e |. \tag{1.10}$$

The half perimeter of the spherical triangle is defined as

$$s = 0.5(a + c + \Omega). \tag{1.11}$$

The half perimeter is used to determine the vertex angle Δ. The vertex angle can be determined from

$$\tan^2(\Delta/2) = [\sin(s-\Omega) \sin(s - c)]/[\sin(s) \sin(s - a)]. \tag{1.12}$$

Thus the vertex angle is given by

$$\Delta=2 \tan^{-1}\{[\sin(s-\Omega)\sin(s-|L_e|)]/[\sin(s)\sin(s-| l_e - l_s |)]\}^{0.5}. \tag{1.13}$$

The vertex angle is used to determine the azimuth from the earth station to the satellite. Table 1.1 shows the equations necessary to figure out the azimuth from the vertex angle based upon the geometry of the system.

The geometry of the satellite system is input into the design software computer program by the operator. The program calculates the half perimeter of the triangle from the central angle, subsatellite point longitude and earth station location longitude and latitude. The vertex angle is determined

Table 1.1 Azimuth Calculations from Spherical Triangle Angle Δ

Situation Geometry	Equation
Subsatellite Point Southwest of Earth Station	$Az = 180^\circ + \Delta$
Subsatellite Point Southeast of Earth Station	$Az = 180^\circ - \Delta$
Subsatellite Point Northwest of Earth Station	$Az = 360^\circ - \Delta$
Subsatellite Point Northeast of Earth Station	$Az = \Delta$

from which the azimuth is found based upon the user's geometry selection.

Chapter 2.0

Rain Margin Determination

Three rain attenuation prediction models are implemented by the communications design computer software. The first model implemented is the *Crane global* model.[3] The Crane model is an accurate model that is easily determined using a calculator. The Crane model is an estimate of the "total time" that the rain attenuation is expected to exceed a given amount. This estimate is found for a certain slant path over a one year period. The rain attenuation loss, L_r, in dB is given by

$$L_r(\mathrm{dB})=(aR_p{}^bL/D)[(e^{(ubD)}-1)/ub] \quad \text{for} \quad 0 \le D \le d, \qquad (2.1)$$

and by

$$L_r(\mathrm{dB})=(aR_p{}^bL/D)\{[(e^{(ubD)}-1)/ub][x^be^{(vbd)}/vb]+[x^be^{(vbD)}/vb]\} \qquad (2.2)$$

for $d \le D \le 22.5$ km.

The parameters a and b are frequency dependent coefficients. The analytical expressions that approximate their value are

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[3] Tri T. Ha, *Digital Satellite Communications*, New York: Macmillan Publishing Company, 1986, pp 157 - 165.

shown by

$$a = 4.21 \times 10^{-5} f^{2.42} \quad \text{for } 2.9 \le f \le 54 \text{ GHz}, \tag{2.3}$$

$$a = 4.09 \times 10^{-2} f^{0.699} \quad \text{for } 54 \le f \le 180 \text{ GHz}, \tag{2.4}$$

$$b = 1.41\, f^{-0.0779} \quad \text{for } 8.5 \le f \le 25 \text{ GHz, and} \tag{2.5}$$

$$b = 2.63\, f^{-0.272} \quad \text{for } 25 \le f \le 164 \text{ GHz}. \tag{2.6}$$

The parameter f represents the uplink or downlink frequency in gigahertz. The variable R_p is the point rain rate that may be exceeded for P percent of the year (mm/h). The point rain rate is dependent upon the rain climate regions. The world Crane global rain climate regions are shown in Figure 2.1. The expanded rain climate regions for the United States are given in Figure 2.2. The appropriate rain region is selected based upon the earth station location. Then Table 2.1 is entered using the selected region. Table 2.1 shows the point rain rate distribution values for a specific percent of year that the rain rate is exceeded. The point rain rate R_p is obtained for the selected percent of year the rain rate is exceeded.

Figure 2.3 and 2.4 shows the geometry for the rain attenuated satellite communications link. The parameter L is the slant path length in kilometers. This distance is given by

$$L = D/\cos(El) \quad \text{for } El \ge 10^{\circ}, \tag{2.7}$$

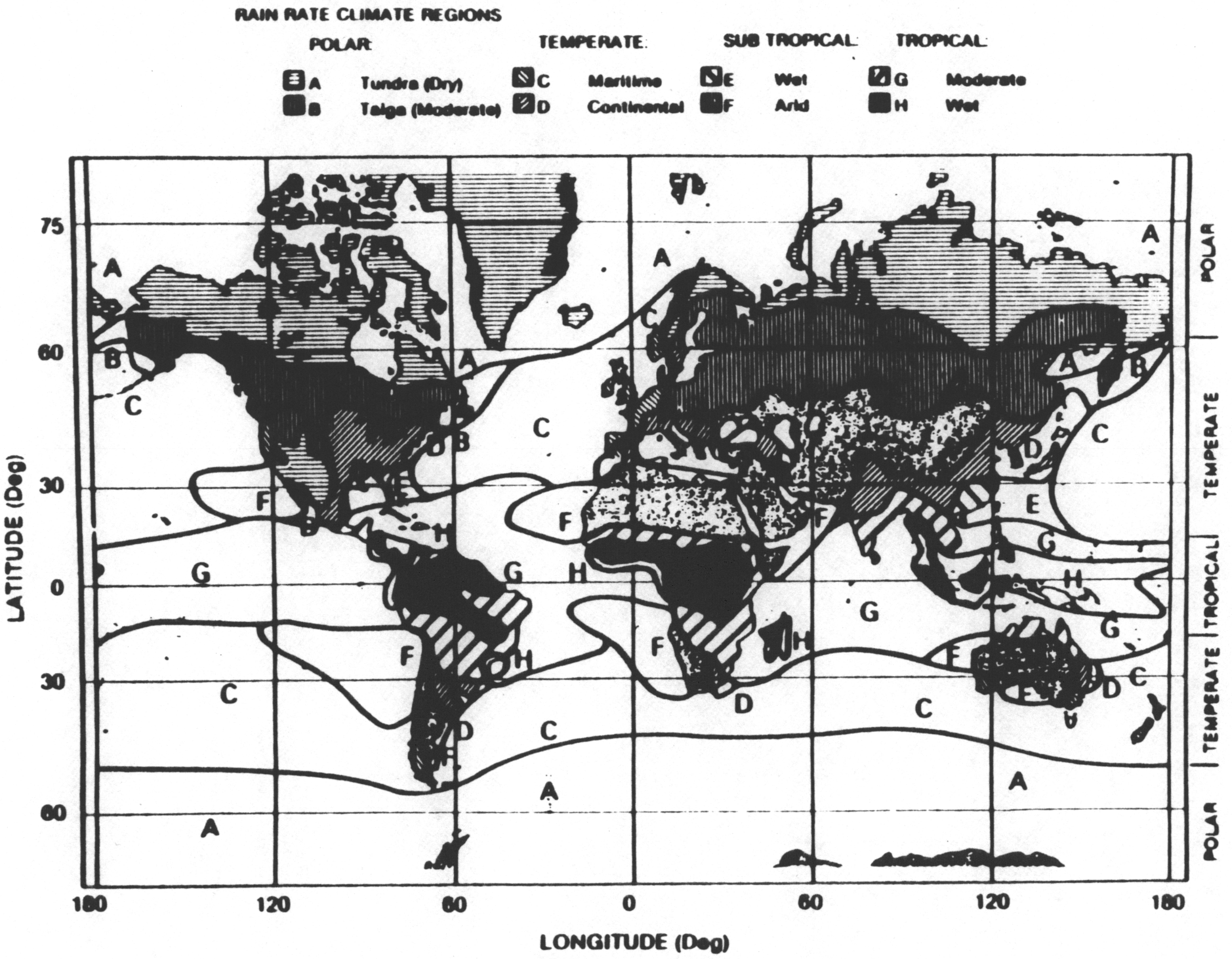

Figure 2.1 Crane Global World Rain Climate Regions

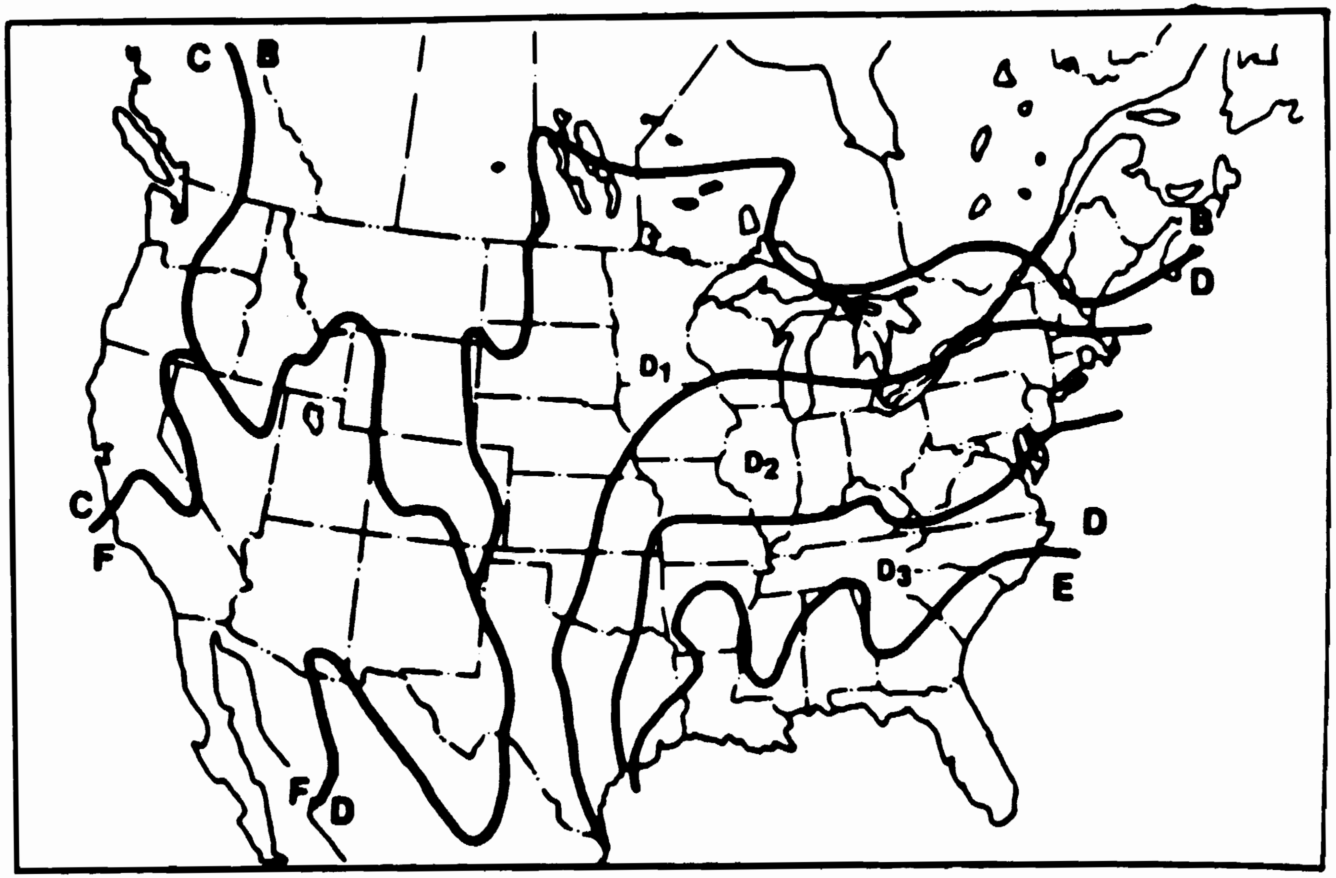

Figure 2.2 Crane Global United States Rain Climate Regions

Table 2.1 Point Rain Rate Distribution Values

Percent of year $P\%$	Rain climate region												Minutes per year	Hours per year
	A	B_1	B	B_2	C	D_1	$D = D_2$	D_3	E	F	G	H		
0.001	28.5	45	57.5	70	78	90	108	126	165	66	185	253	5.26	0.09
0.002	21	34	44	54	62	72	89	106	144	51	157	220.5	10.5	0.18
0.005	13.5	22	28.5	35	41	50	64.5	80.5	118	34	120.5	178	26.3	0.44
0.01	10.0	15.5	19.5	23.5	28	35.5	49	63	98	23	94	147	52.6	0.88
0.02	7.0	11.0	13.5	16	18	24	35	48	78	15	72	119	105	1.75
0.05	4.0	6.4	8.0	9.5	11	14.5	22	32	52	8.3	47	86.5	263	4.38
0.1	2.5	4.2	5.2	6.1	7.2	9.8	14.5	22	35	5.2	32	64	526	8.77
0.2	1.5	2.8	3.4	4.0	4.8	6.4	9.5	14.5	21	3.1	21.8	43.5	1,052	17.5
0.5	0.7	1.5	1.9	2.3	2.7	3.6	5.2	7.8	10.6	1.4	12.2	22.5	2,630	43.8
1.0	0.4	1.0	1.3	1.5	1.8	2.2	3.0	4.7	6.0	0.7	8.0	12.0	5,260	87.7
2.0	0.1	0.5	0.7	0.8	1.1	1.2	1.5	1.9	2.9	0.2	5.0	5.2	10,520	175
5.0	0.0	0.2	0.3	0.3	0.5	0.0	0.0	0.0	0.0	0.0	1.8	1.2	26,298	438

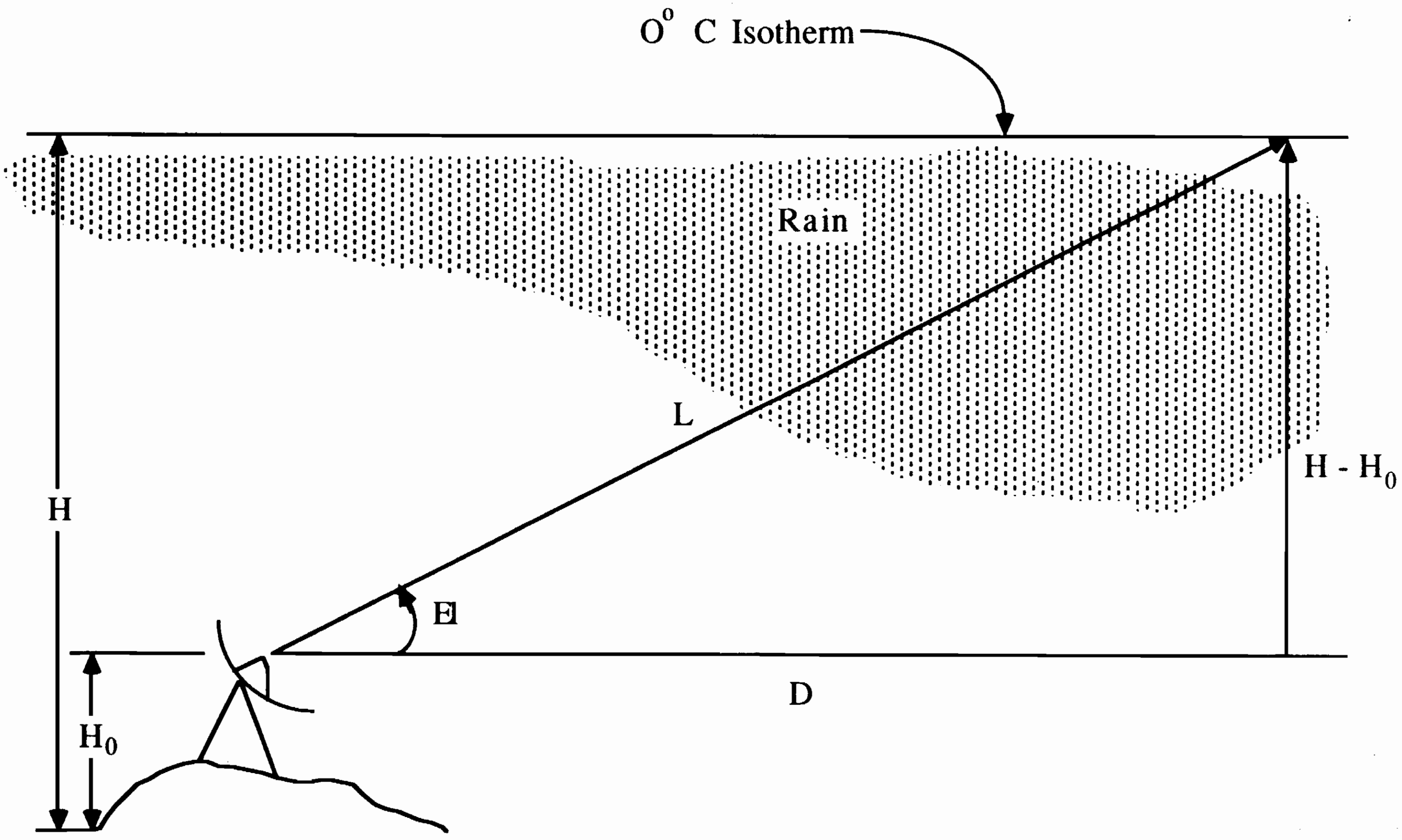

Figure 2.3 Surface Projected path length D for El $\geq 10^o$

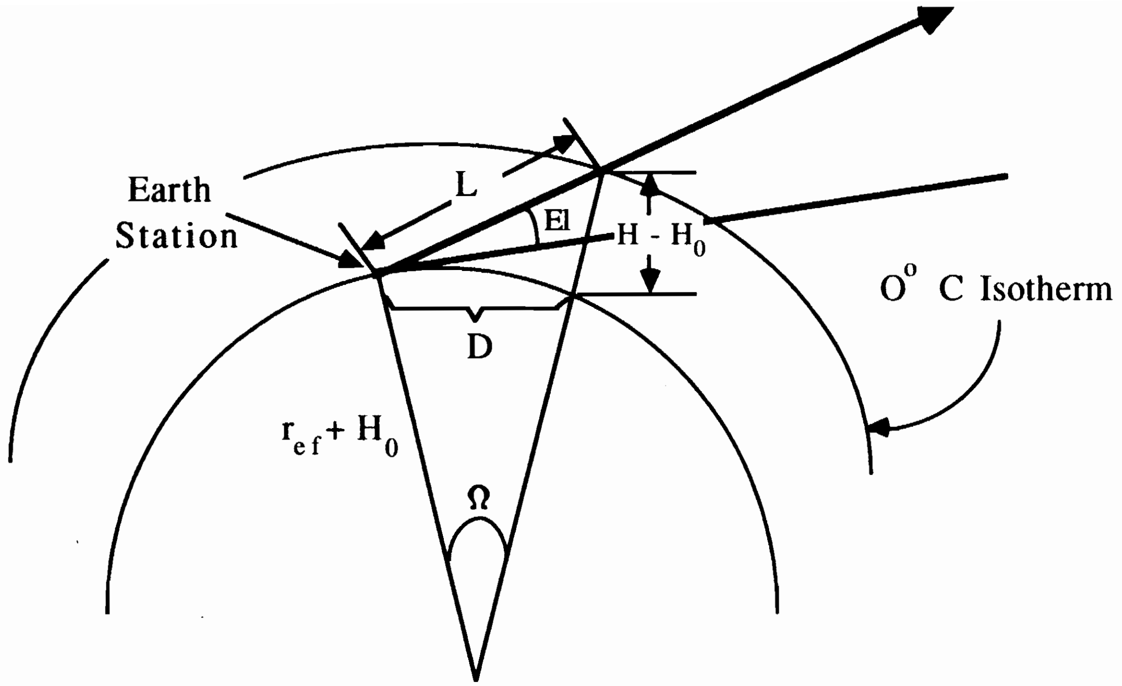

Figure 2.4 Surface Projected Path Length D for El < 10^o

and by

$$L=-(r_{ef}+H_0)\sin(El)+\{(r_{ef}+H_0)^2\sin^2El + 2r_{ef}(H-H_0)+H^2-H_0^2\}^{0.5} \quad (2.8)$$

for $El<10^{\circ}$.

The parameter D is the surface projected path length and El is the elevation angle. The variable r_{ef} is the effective earth's radius, which is equal to 8500 km. The effective earth's radius takes into account the oblateness of the earth. The parameter H_0 is the height of the earth station above sea level. The height of the 0°C isotherm is given by H. This isotherm is equal to the vertical extent of the rain. Above this height liquid water does not exist. This value is obtained from Figure 2.5 using the earth station latitude and the percent of year rain rate is exceeded as the inputs. The surface projected length D is given by

$$D = H-H_0/\tan(El) \qquad \text{for } El \geq 10^{\circ}, \qquad (2.9)$$

and by

$$D= (r_{ef} + H_0)\Omega \qquad \text{for } El < 10^{\circ}. \qquad (2.10)$$

The central angle Ω is given by equation 1.6 and also is expressed as

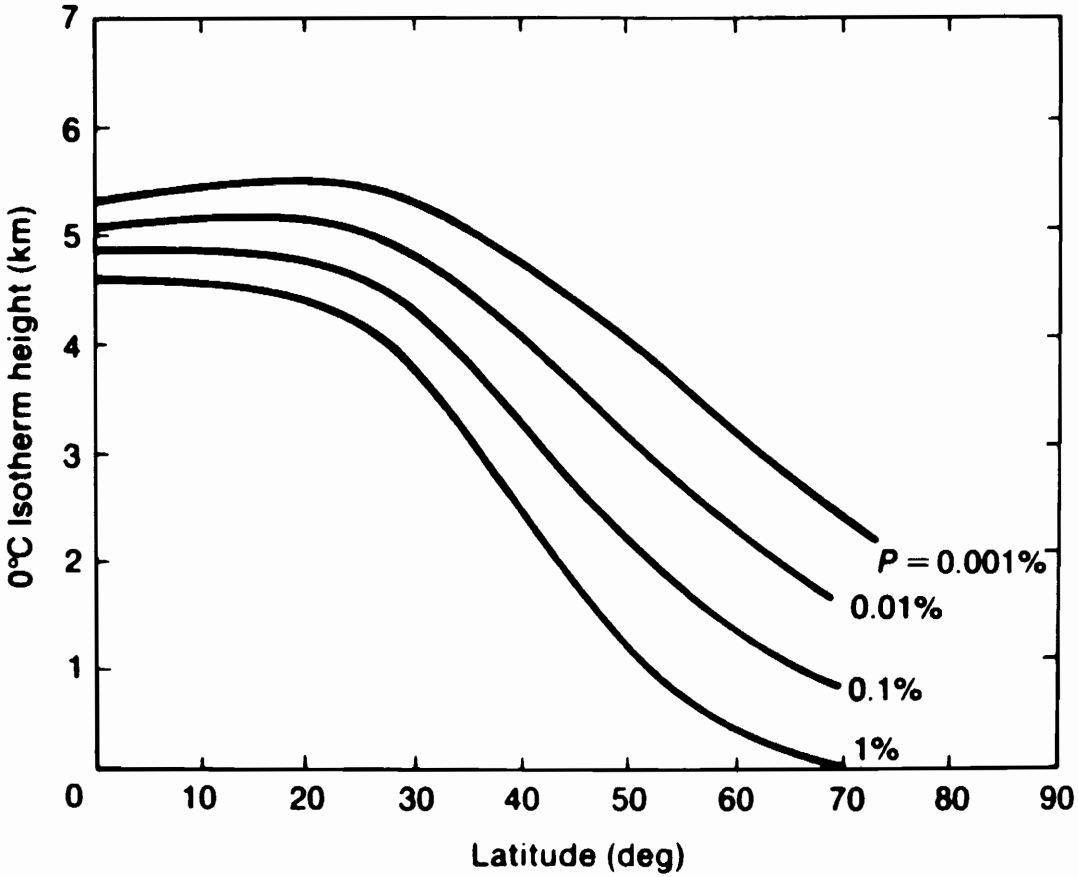

Figure 2.5 Height of 0° C Isotherm

$$\Omega = \sin^{-1}\{L\cos(El)/(r_{ef} + H)\} \qquad (2.11)$$

where L, the slant path, is given in equation 2.8 for $El < 10^{\circ}$. Figure 2.3 shows the projected path for elevation angles greater than or equal to ten degrees. The slant path is found from the definition of the cosine angle and is given in equation 2.7. Figure 2.4 shows the projected path for elevation angles less than ten degrees. In this situation the curvature of the earth must be included. The law of sines is used to obtain

$$L/\sin\Omega = r_{ef} + H/\sin(90^{\circ} + El). \qquad (2.12)$$

The central angle Ω is given by

$$\Omega = \sin^{-1}(L\cos(El)/(r_{ef} + H_o + H - H_o)). \qquad (2.13)$$

Note that this result reduces to equation 2.11. The law of cosines is used to solve for the slant path. This results in

$$L^2 + (r_{ef} + H_0)^2 - 2(r_{ef} + H_0)L\cos(90^{\circ} + El) = (r_{ef} + H)^2. (2.14)$$

The above equation is used to solve for the slant path distance L, the results of which are given in equation 2.8. The final constants in equations 2.1 and 2.2, u, v, x, and d are functions of the point rain rate and are given by

$$d = 3.8 - 0.6 \ln R_p, \tag{2.15}$$

$$x = 2.3 R_p^{-0.17}, \tag{2.16}$$

$$v = 0.026 - 0.03 \ln R_p, \text{ and} \tag{2.17}$$

$$u = \ln[x\, e^{(vd)}/d]. \tag{2.18}$$

The Sam model[4] is the second rain attenuation model implemented by the design computer program. This model was developed by NASA to provide a simple method of determining the rain attenuation loss. This model is used to determine the slant path length L. The slant path is derived from the earth station height above sea level H_0, the elevation angle El, and the effective vertical rain height H_e. The Sam model path length geometry is shown by Figure 2.6. The slant path in km is given by

$$L = H_e - H_0/\sin(El). \tag{2.19}$$

The effective vertical height H_e is directly related to the height of the zero degree isotherm H. This relationship is shown by

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[4] Timothy Pratt and Charles W. Bostian, *Satellite Communicatios*, New York: Macmillan Publishing Company, 1986, pp 327 - 338.

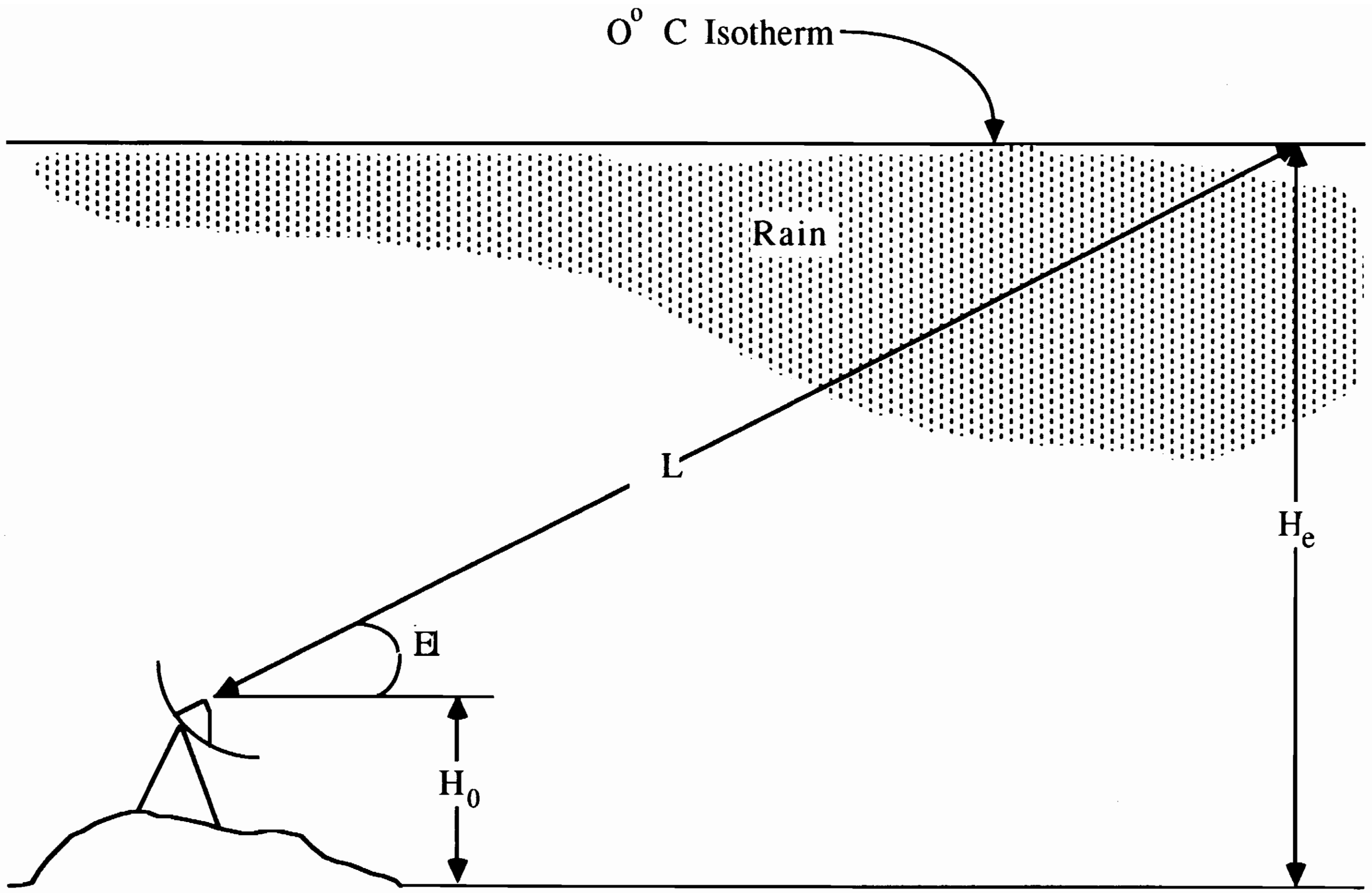

Figure 2.6 Sam Model Rain Attenuation Geometry

$$H_e = H \qquad \text{for } R_p \leq 10 \text{ mm/h}, \qquad (2.20)$$

and by

$$H_e = H + \log(R_p/10) \qquad \text{for } Rp > 10 \text{mm/h}. \qquad (2.21)$$

The 0°C isotherm is estimated from the station latitude and is given by

$$H = 4.8 \qquad \text{for } |Le| \leq 30°, \qquad (2.22)$$

and by

$$H = 7.8 - 0.1|Le| \quad \text{for } |Le| > 30°. \qquad (2.23)$$

The point rain rate distribution, R_p, can be obtained from Table 2.1. The Sam model attenuation is given by

$$A(P) = a[R_p]^b L \text{ for } R_p \leq 10 \text{ mm/h}, \qquad (2.24)$$

and by

$$A(P)=a[R_p]^b\{1-e^{-[\partial b\ \ln(R_p/10) L \cos(El)]}/\partial \ln(R_p/10)\ \cos(El)\} \quad (2.25)$$

for $R_p > 10$ mm/h.

The parameters a and b are the frequency dependent coefficients given in equations 2.3 through 2.6. The empirical quantity ∂ is 1/22. The parameter P is the percent of year rain rate is exceeded associated with the point rain rate R_p.

The last rain attenuation model analyzed is the International Radio Consultative Committee (CCIR) model.[5] This model is based on predicting the attenuation associated with a 0.01% rain rate. Additional attenuation losses are found from scaling the 0.01% rain rate attenuation to the required rain rate percentage. This CCIR model is only valid for the range of percentages between 0.001 and 0.1%. The rain attenuation for the 0.01% basis percentage is determined from the frequency dependent coefficients a, b, and the point rain rate distribution Rp. In addition the slant path L_s, and the path reduction factor r_p are used also to find the 0.01% basis percentage. The attenuation loss in dB for the basis percentage is expressed by

$$A_{0.01} = a\,[R_p]^b\,L_s\,r_p. \tag{2.26}$$

The slant path Ls is given by

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[5] Timothy Pratt and Charles W. Bostian, *Satellite Communicatios*, New York: Macmillan Publishing Company, 1986, pp 339 - 340.

$$Ls = H_r - H_0/\sin(El) \quad \text{for } El \geq 10^{\circ}, \tag{2.27}$$

and by

$$Ls=2(H_r-H_0)/\{[\sin^2(El)+2(H_r-H_0)/8500]^{0.5}+\sin(El)\} \text{ for } E<10^{\circ}. \tag{2.28}$$

The parameter Hr is the rain height in km and is shown by

$$Hr = 5.1 - 21.5 \log\{1 + 10^{[(|Le| - 27)/25]}\}. \tag{2.29}$$

The parameter H_0 is the station height above sea level. The CCIR modifies the path length by a reduction factor which accounts for the spatial nonuniformity of the rain rate. The path length reduction factor r_p is shown by

$$r_p = 90/(90 + 4L_G) \quad \text{where } L_G \text{ is expressed as} \tag{2.30}$$

$$L_G = L_s\cos(El). \tag{2.31}$$

The scaled attenuation loss is shown by

$$A_p = A_{0.01}(P/0.01)^{-z}. \tag{2.32}$$

The exponent z is expressed as

$$z = 0.33 \qquad \text{for } 0.001 \le P \le 0.01\text{, and} \tag{2.33}$$

$$z = 0.41 \qquad \text{for } 0.01 \le P \le 0.1. \tag{2.34}$$

The models implemented show three methods of determining rain attenuation loss. The Crane global and the CCIR model both include the effect of low elevation angles upon the rain attenuation. However the Sam model modifies the 0°C isotherm by the rain rate. In addition the Sam model provides an estimate of the isotherm from the earth station latitude. Similarly the CCIR model also estimates the vertical rain height from the earth station latitude. The CCIR model presented is only valid between a limited percentage range. A more complicated procedure is required for attenuation losses outside this range.

Rain increases the earth station antenna noise temperature besides attenuating satellite communication signals.[6] The thermal radiation that the earth station antenna sees is greater due to the thermal effect of the raindrops. The increase in the noise temperature T_n in degrees Kelvin is shown by

$$T_n = 280\ (\ 1 - e^{-A/4.34}). \tag{2.35}$$

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[6] Timothy Pratt and Charles W. Bostian, *Satellite Communicatios*, New York: Macmillan Publishing Company, 1986, pp 342 - 343.

The parameter A is the rain attenuation in dB. The increase in the antenna noise temperature is calculated for each rain attenuation model.

Rain also adversely affects the orthogonal polarization of communication systems that implement frequency reuse. Rain depolarization is the electromagnetic scattering of the transmission and reception signal waves. The shape of the raindrop also is an important factor in the effect rain has upon the communication signal. The CCIR model for rain depolarization is implemented. This treats the shape of the raindrop as an oblate spheroid. The oblate shape results due to air resistance effects upon the raindrop. The attenuation upon vertically polarized waves differ from those that are horizontally polarized. This results in vertical and horizontal components. These components when recombined result in cross polarized components. Depolarization is not only dependent upon the raindrop shape, but also on the size and orientation of the raindrops. The volume of water present in the slant path is also a significant factor in the depolarization determination. Rain depolarization is much more difficult to model than rain attenuation because of the number of factors that affect depolarizaton. The CCIR statistical model relates rain attenuation to depolarization and is shown by

$$XPD = U - V \log(A). \tag{2.36}$$

The parameter XPD represents the rain depolarization loss in dB. The variables U and V are given by

$$U = 30 \log(f) - 40 \log[\cos(El)] - 20 \log[\sin(2t)] \text{ and} \tag{2.37}$$

$$V = 20. \tag{2.38}$$

The parameter t represents the angle between the received electric field and local horizontal. The parameter f is the carrier frequency. There is some controversy concerning the values for variables U and V. Olsen and Nowland proposed a revision to the value of V,[7] which is shown by

$$V = 20 \qquad \text{for } 8 \le f \le 15 \text{ GHz and} \tag{2.39}$$

$$V = 23 \qquad \text{for } 15 < f \le 33 \text{ GHz.} \tag{2.40}$$

There has also been debate over whether the coefficient of the log frequency term in U should be 30 or 20. The computer program uses the CCIR quick reference model given in equations 2.36 through 2.38.

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[7] J. A. Bennet, " Drop-Size distribution: cross-polarization discrimination and attenuation for propagation through rain," *Comsat Technical Review*, vol. 14, no. 1, pp113 - 135, Spring 1984.

Chapter 3.0

Atmospheric Absorption Estimate

A quick and simple procedure is developed that determines the atmospheric gaseous absorption for frequencies between 1 and 15 GHz and for elevation angles between 0 and 90°.[8] The only inputs are the uplink/downlink frequency and the elevation angle. The procedure derives analytic expressions from empirical data through a curve-fitting technique. Two standards of relevant atmospheric parameters are used in the derivation of the analytic equations. The data points are obtained and plotted for both standards. Table 3.1 shows the specific parameters for standards A and B. Figure 3.1 shows the surface specific attenuation, y_s, versus frequency. The curve fit for the surface condition of standard A is given by

$$y_s = 0.00466\ e^{0.1362f}. \tag{3.1}$$

The curve fit for the standard B surface conditions is shown by

$$y_s = 0.00442\ e^{0.1178f}. \tag{3.2}$$

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[8] D. V. Rogers, "Estimating Atmospheric Absorption at 1 to 15 GHz," Comsat Technical Review, vol. 13, no. 1, pp 157 - 163, Spring 1983.

Table 3.1 Atmospheric Estimate Standard Atmospheric Conditions

Atmospheric Parameters	Standard A	Standard B
Vapor Concentration	11.1 g/m^3	7.5 g/m^3
Surface Temperature	14.6 °C	20.0 °C

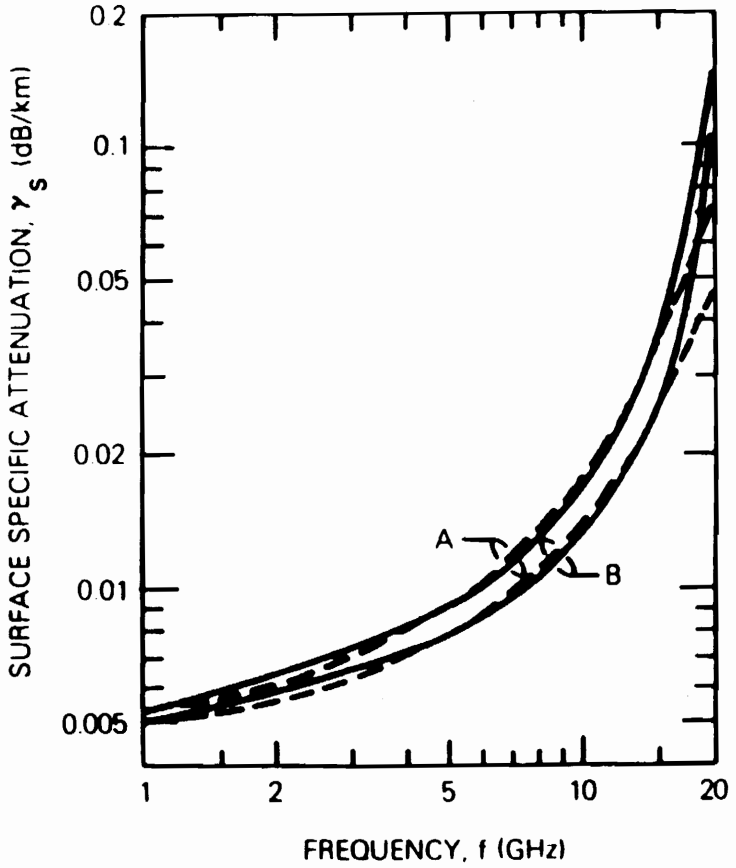

Figure 3.1 Surface Specific Attenuation vs Frequency (solid lines) and Corresponding Curve Fits (dashed lines)

The effective path length L_e is given by

$$L_e = H_a/\sin(El) \text{ for } El > 10^\circ \text{, and by} \tag{3.3}$$

$$L_e = 2H_a/\{[\sin^2(El) + 2\, H_a/R_{ef}\,]^{0.5} + \sin(El)\} \text{ for } El \leq 10^\circ. \tag{3.4}$$

Note that these equations have the same format as equations 2.27 and 2.28. The parameter H_a is the scale height of the atmosphere. The variable R_{ef} is the effective earth's radius (8500 km). The path elevation angle is again represented as El. The scale height is determined from the total zenith attenuation A_v and the surface specific attenuation y_s. The scale height in km is expressed as

$$H_a = A_v/y_s. \tag{3.5}$$

The total zenith attenuation versus frequency for standards A and B is shown in Figure 3.2. The total zenith is a vertical measurement initiated at the earth station height above sea level. These zenith data points are then used to generate a curve of the scale height versus frequency shown in Figure 3.3. A curve fit is performed upon this figure. The resulting scale height is given by

$$H_a = 6.01e^{-0.048f}, \qquad \text{for standard A conditions} \tag{3.6}$$

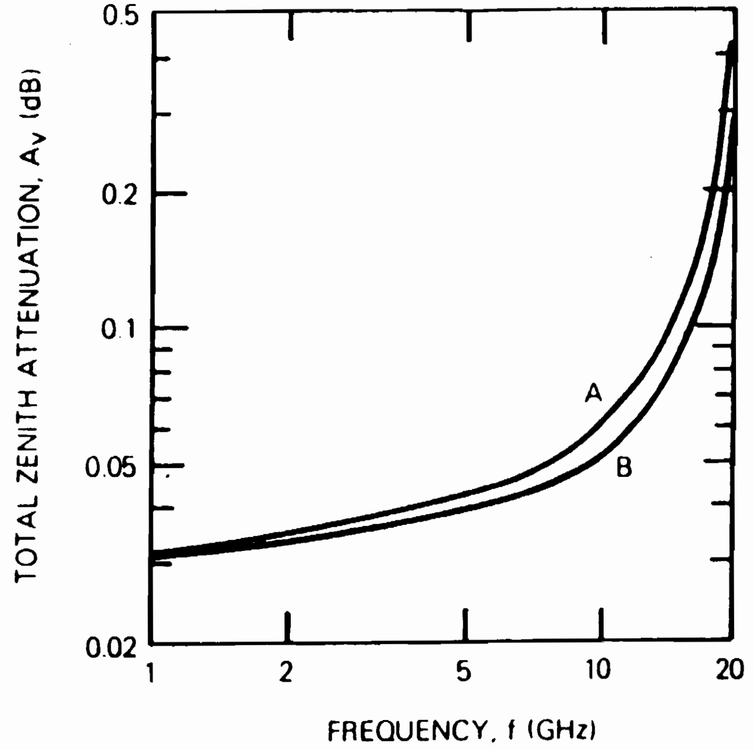

Figure 3.2 Total Zenith Attenuation vs Frequency (solid lines) and Corresponding Curve Fits (dashed lines)

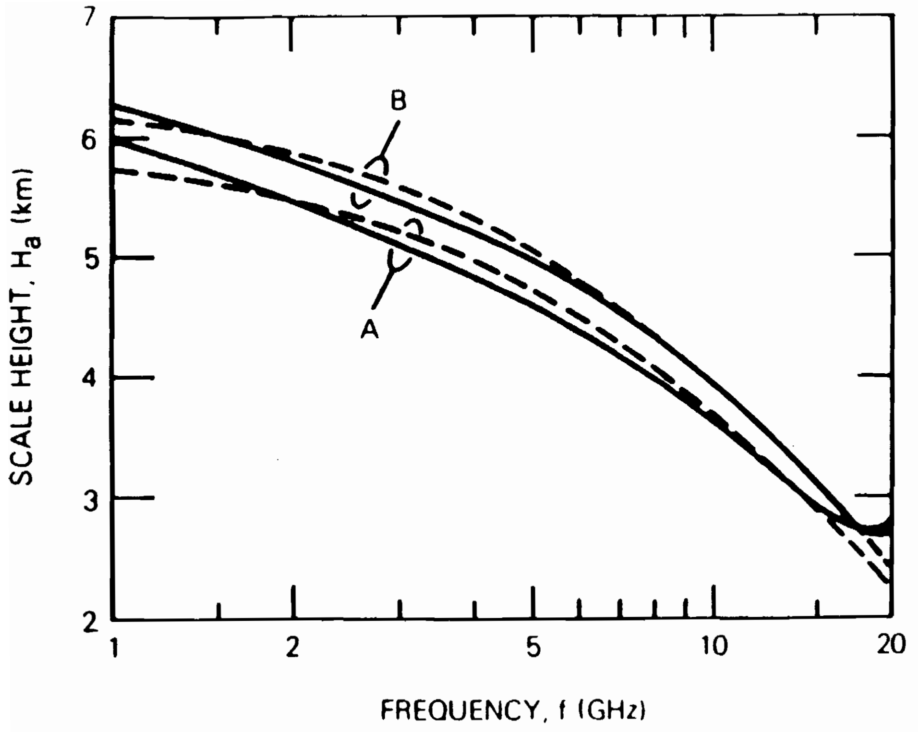

Figure 3.3 Scale Height vs Frequency(solid lines) and Corresponding Curve Fits (dashed lines)

and by

$$Ha = 6.43e^{-0.0487f} \quad \text{for standard B conditions.} \tag{3.7}$$

The atmospheric absorption, A_a, in dB is given by

$$A_a = y_s L_e. \tag{3.8}$$

The atmospheric attenuation is derived from equations 3.1 through 3.4 and equations 3.7 and 3.8.

The computer program calculates an estimate of the atmospheric attenuation based upon the empirically derived formulas. The operator selects the appropriate standard and then inputs the frequency and path elevation. Figures 3.1 and 3.3 show the exponential curve fit with the empirical data. Note that the deviation between the two curves becomes significant for frequencies above 15 GHz and less than 1 GHz. The program ensures that the frequency and elevation selected is within the specified limits.

Chapter 4.0

Atmospheric Attenuation Calculation

The atmospheric attenuation calculation provides greater accuracy over the atmospheric absorption estimate. The attenuation calculation is also not subject to the stringent frequency limits as was the estimate method. The procedure for determining atmospheric attenuation is based upon scaling affected parameters from those established at a standard condition to the existing operating condition.[9] The atmospheric loss L_a is given by

$$L_a = [L_a' + c_T(21 - T_o) + b_p(p_o - 7.5)]/\sin(El). \qquad (4.1)$$

The zenith one-way attenuation is represented by the parameter L_a'. The values for the zenith attenuation are listed in Table 4.1. The altitude is the station height above sea level. Figure 4.1 may be also used to determine the total (one-way) zenith attenuation. These values are obtained for a moderately humid atmosphere. The atmospheric conditions that apply include a surface water vapor of 7.5 g/m^3 and a surface temperature of 21°C. The temperature correction coefficient c_T is given in Table 4.2. The

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[9] Tri T. Ha, *Digital Satellite Communications*, New York: Macmillan Publishing Company, 1986, pp 89 - 93.

Table 4.1 Typical One-Way Clear Air Total Zenith Attenuation Values

	Altitude (km) Earth Station Height				
Frequency (GHz)	0	0.5	1.0	2.0	4.0
10	0.053	0.047	0.042	0.033	0.02
15	0.084	0.071	0.061	0.044	0.023
20	0.28	0.23	0.18	0.12	0.05
30	0.24	0.19	0.16	0.10	0.045
40	0.37	0.33	0.29	0.22	0.135
80	1.30	1.08	0.90	0.62	0.30
90	1.25	1.01	0.81	0.52	0.22
100	1.41	1.14	0.92	0.59	0.25

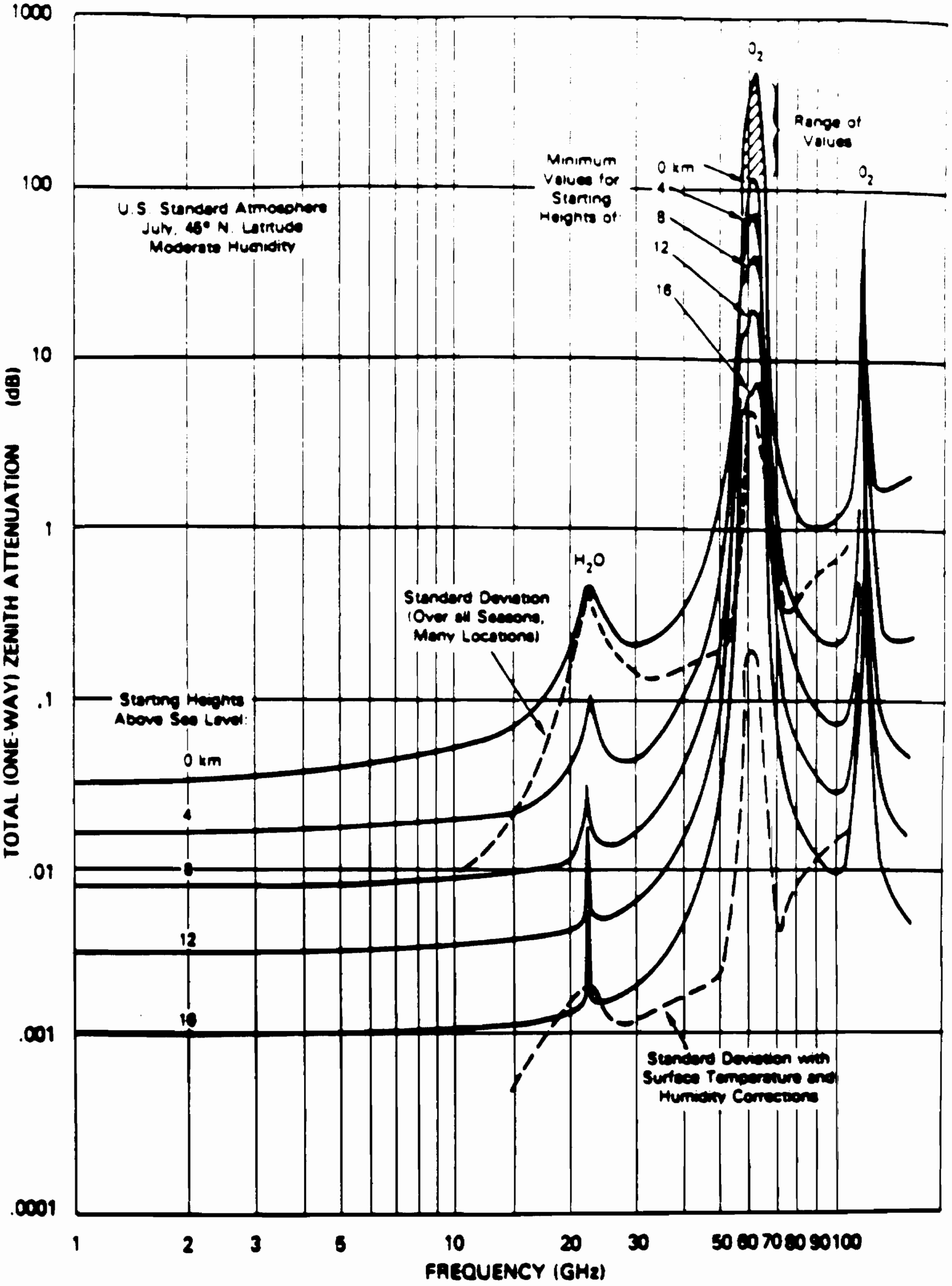

Figure 4.1 Atmospheric Attenuation

parameter T_o represents the surface water temperature in degrees centigrade. The term $c_T(21 - T_o)$ accounts for the difference between the surface water temperature and the standard, which is 21°C. The parameter b_p represents the water vapor density correction coefficient. The density correction factors are also listed in Table 4.2. The parameter p_o represents the surface water vapor density. The term $b_p(p_o-7.5)$ accounts for the difference between the surface water vapor density and the standard, which is 7.5 g/m^3. The vapor density is given by

$$p_o = h\, e_s/0.46(T_o+273). \qquad (4.2)$$

The variable h is the relative humidity. The term e_s is the saturated partial pressure of water vapor (N/m^2) corresponding to a local surface temperature of T_o. An approximation of the partial pressure is given by

$$es = 206.43e^{[\,0.0354T_o(^oF)]}. \qquad (4.3)$$

The design computer program determines the atmospheric loss from equations 4.1 through 4.3. However the operator is given the option of entering the saturated water vapor directly as opposed to calculating an estimate. The saturated partial

Table 4.2 Water Vapor Density and Temperature Correction Coefficients

Frequency (GHz)	Water Vapor Density Correction b_p	Temperature Correction c_T
10	2.10×10^{-3}	2.60×10^{-4}
15	6.34×10^{-3}	4.55×10^{-4}
20	3.46×10^{-2}	1.55×10^{-3}
30	2.37×10^{-2}	1.33×10^{-3}
40	2.75×10^{-2}	1.97×10^{-3}
80	9.59×10^{-2}	5.86×10^{-3}
90	1.22×10^{-1}	5.74×10^{-3}
100	1.50×10^{-1}	6.30×10^{-3}

pressure of water vapor can be obtained from saturated steam tables.[10]

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[10] Gordon J. Van Wylen and Richard E. Sonntag, *Fundamentals of classical thermodynamics*, New York: John Wiley and Sons, Inc., 1976, pp 645 - 650.

Chapter 5.0

Path Site Diversity

The effects of rain can significantly impede a communications link between the earth station and the satellite. Site path diversity is one method of reducing the probability of communication outages because of rain. Two earth stations are located in close proximity such that they are can communicate through the same transponder. Since heavy rain occurs in spatially limited areas, there is a good chance that both sites will not be equally affected. This probability increases with site separation distance. Site diversity is a method of determining the link budget gain when the communications system employs two sites. The diversity gain increase in dB is estimated from an empirical model, developed by Hodge,[11] and is shown by

$$G_D = a'(1 - e^{-b'd}). \tag{5.1}$$

The coefficients a' and b' are given by

$$a' = L_r - 3.6(1 - e^{-0.24L_r}) \quad \text{and} \tag{5.2}$$

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[11] Timothy Pratt and Charles W. Bostian, *Satellite Communicatios*, New York: Macmillan Publishing Company, 1986, pp 345 - 346.

$$b' = 0.46(1 - e^{-0.26L_r}). \quad (5.3)$$

The parameter L_r is the rain attenuation loss in dB. The parameter d is the site separation in km.

Another empirical model includes the effects of the frequency, elevation angle and the baseline-to-path angle.[12] The diversity gain of this model is expressed as

$$G_D = G_d G_f G_{El} G_\mu. \quad (5.4)$$

The term G_d is shown by

$$G_d = a(1 - e^{-bd}). \quad (5.5)$$

The coefficients a and b are expressed by

$$a = 0.64L_r - 1.6(1 - e^{-0.11L_r}), \text{ and} \quad (5.6)$$

$$b = 5.85(1 - e^{-0.98L_r}). \quad (5.7)$$

The frequency gain G_f is shown by

$$G_f = 1.64e^{-0.025f}. \quad (5.8)$$

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[12] Timothy Pratt and Charles W. Bostian, *Satellite Communicatios*, New York: Macmillan Publishing Company, 1986, pp 346 - 347.

The elevation gain, G_{El}, is given by

$$G_{El} = 0.00492El + 0.834. \qquad (5.9)$$

The baseline-to-path is represented by G_{μ} and is expressed as

$$G\mu = 0.00177\mu + 0.887. \qquad (5.10)$$

The baseline is the straight line that joins the two sites. The baseline-to-path angle μ is determined from the law of cosines. This angle is given by

$$\cos^{-1}(\mu) = (d^2 + d_1^2 - d_2^{2)} / 2\, d\, d_1. \qquad (5.11)$$

The path distance from the first earth station to the satellite is represented by d_1. The path distance from the second earth station to the satellite is represented by d_2. The variable d represents the site separation distance.

The computer program implements both models. The program calculates the elevation angle and distance of each site to the satellite. The program also estimates the separation distance based upon each earth station latitude and longitude location when the exact distance is not known. One degree of latitude is equal to 60 nautical miles or 69 statute miles. The degrees of longitude vary. One degree of longitude equals one degree of latitude at the equator. At 45° north latitude one degree of longitude equals 49 statute miles. At one mile from the pole one degree of longitude is only 30 yards. The program assumes the earth station is in the 45° north latitude region and equates one degree of longitude as 49 miles. When the exact separation distance is known, the designer can input that separation distance directly. The operator inputs the satellite and site positions, the link frequency, and the separation distance when its value is available. The diversity gain is then determined using equations 5.1 through 5.11.

Chapter 6.0

Link Budget Calculations

The goal of a satellite system is to ensure the communications link is reliable and sustainable. Satellite link budget equations provide a method that predicts the ability of a system to support satisfactory communications. The performance characteristics are determined for both the satellite uplink and downlink. The design of the system uplink ensures the ground station is able to transmit a signal of sufficient power in order for the satellite to receive that signal. A major component in the design of the uplink portion is the earth station antenna. The transmit antenna gain, G_{Tx}, is given by

$$G_{Tx} = n_T(4\pi A/w^2). \tag{6.1}$$

The variable n_T is the total efficiency of the antenna. Some factors that affect the antenna efficiency are the main reflector illumination efficiency, the reflector surface tolerance efficiency, the phase efficiency, and the spillover efficiency. The subreflector and support structure blocking efficiency and the feed system dissipative efficiency also add to the total antenna efficiency.[13] The total efficiency is generally taken to be about sixty percent. The parameter A represents the aperture area of the antenna. This is the cross sectional area of the dish. The remaining variable w is the free space wavelength that is equal to the ratio of the speed of light in m/sec^2 and frequency in hertz. The speed of light is equal to 3 x 10^8 m/sec^2. The transmit antenna gain equation is rewritten in dB format and is shown by

$$G_{Tx} = 20\log(10.5\ f_u\ D_{Tx}) + 10\log(n_T). \tag{6.2}$$

The variable f_u is the uplink frequency in GHz. The variable D_{Tx} is the antenna diameter in meters. The receive antenna gain has the same format as the transmit gain. The receive antenna gain is given by

$$G_{Rx} = 20\log(10.5\ f_d\ D_{Rx}) + 10\log(n_T). \tag{6.3}$$

The variable f_d is the downlink frequency and D_{Rx} is the receive antenna diameter.

The free space loss accounts for the way energy is spread out as the electromagnetic waves travel from the transmitting

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[13] Tri T. Ha, *Digital Satellite Communications*, New York: Macmillan Publishing Company, 1986, pp 77.

source through the medium of space.[14] The free space loss is represented by L_{fs} and is shown by

$$L_{fs} = [w/4\pi d]^{-2}. \tag{6.4}$$

The variable d represents the path distance from the earth station to the satellite. The free space loss, in the dB format, is given by

$$L_{fs} = 92.45 + 20\log(f_{GHZ}) + 20\log(d_{km}). \tag{6.5}$$

The frequency is entered in GHz and the path distance in km. The constant term 92.45 accounts for the speed of light value, and the 4π term. This constant allows the operator to enter the frequency in units of gigahertz and the path distance in units of kilometers.

The system noise temperature is calculated to find the carrier-to-noise ratio. The system noise temperature is comprised of the antenna noise temperature, the low noise amplifier temperature, the line noise temperature and the line loss. Noise temperature is a concept that provides a means of calculating the thermal noise generated by active and passive

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[14] Timothy Pratt and Charles W. Bostian, *Satellite Communicatios*, New York: Macmillan Publishing Company, 1986, pp 110.

devices in the receiving system.[15]

The antenna noise temperature is determined from the ambient and atmospheric noise temperature, the sky noise temperature and the sidelobe noise temperature. The atmospheric noise temperature T_{atm} is given by

$$T_{atm} = T_o(1 - 1/L_{atm}), \text{ where} \tag{6.6}$$

T_o is the ambient noise temperature in degrees Kelvin and L_{atm} is the atmospheric attenuation loss in ratio. The ambient noise temperature is usually 290°K. The atmospheric loss in ratio is shown by

$$L_{atm}=10^{[L_a(dB)/10]}. \tag{6.7}$$

The sky noise temperature T_{sky} is obtained from Figure 6.1. This figure shows the sky noise temperature versus frequency.[16]

Transmission waveforms contain some energy in the generated sidelobes. The energy within these sidelobes can cause some noise interference to adjacent systems in addition to

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[15] Timothy Pratt and Charles W. Bostian, *Satellite Communicatios*, New York: Macmillan Publishing Company, 1986, pp 113 - 117.

[16] Louis J. Ippolito, R. D. Kaul and R. G. Wallace, Propagation *Effects Handbook for Satellite Systems Design* (NASA Reference Publication 1082), Washington D.C. : National Aeronautics and Space Administration, 1981 pp 334.

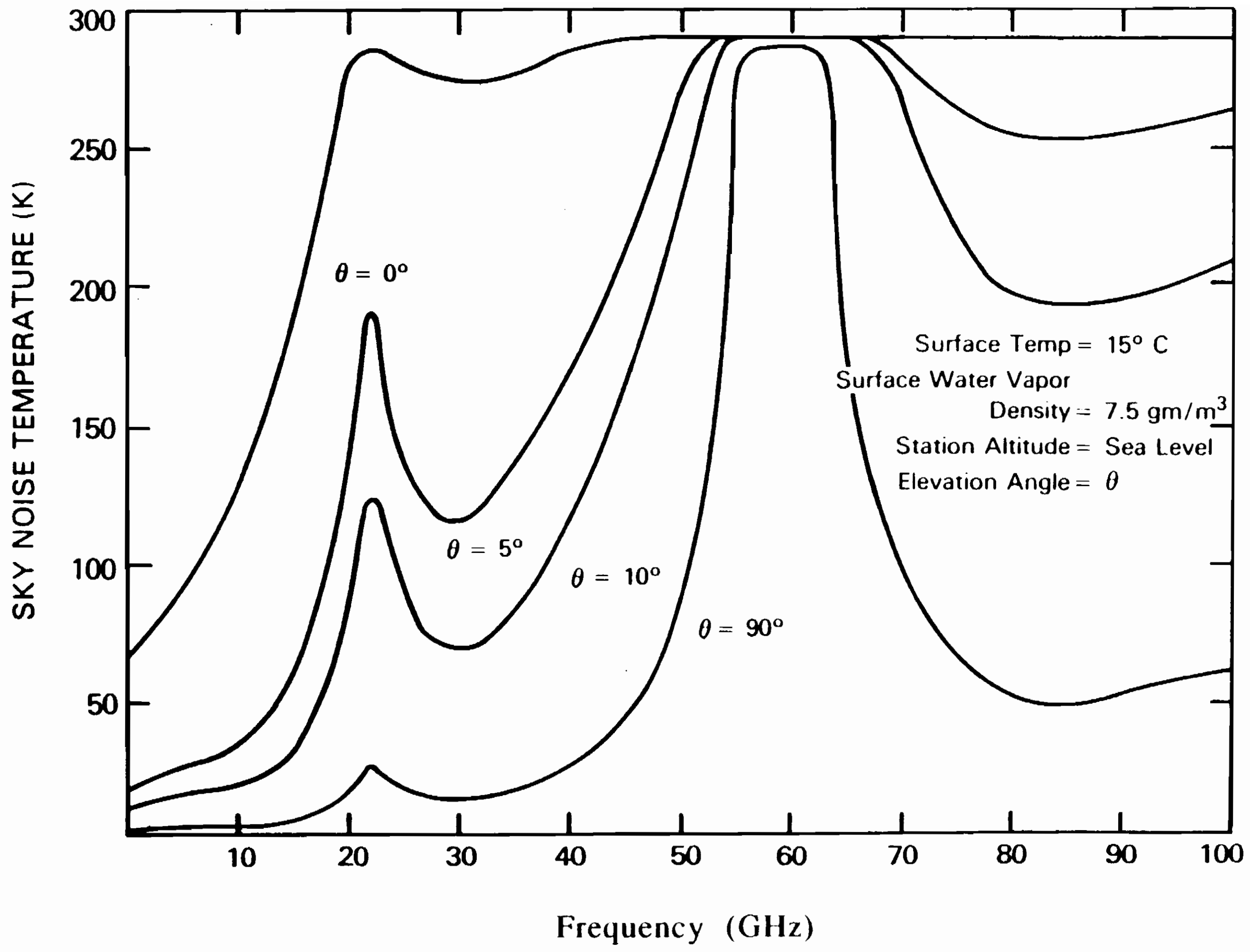

Figure 6.1 Sky Noise Temperature due to Clear Atmosphere

increasing the noise temperature of its own satellite system. The temperature noise caused by the sidelobes T_{sdlb} is typically 20°K. The antenna noise temperature is given by

$$T_{ant} = T_{sky}/L_{atm} + T_{atm} + T_{sdlb}. \tag{6.8}$$

Figure 6.2 shows the receive system noise temperature components. The effective antenna noise temperature is given by

$$T_{ant,eff} = T_{ant}/L_{line}. \tag{6.9}$$

The effective line temperature noise is shown by

$$T_{line,eff} = T_{line}[1 - 1/L_{line}]. \tag{6.10}$$

The parameter T_{line} represents the noise temperature associated with the receive channel. The corresponding line losses are shown by L_{line}. The line losses in equations 6.9 and 6.10 are in ratio. The amplifier stages are shown in Figure 6.3. The noise temperature of the first stage's low noise amplifier is represented by the parameter T_{LNA} and its gain by G_{LNA}. The noise temperature of the second stage's low noise amplifier is shown by $T2_{LNA}$ and its gain by $G2_{LNA}$. The noise temperature of the third stage's low noise amplifier is expressed by $T3_{LNA}$

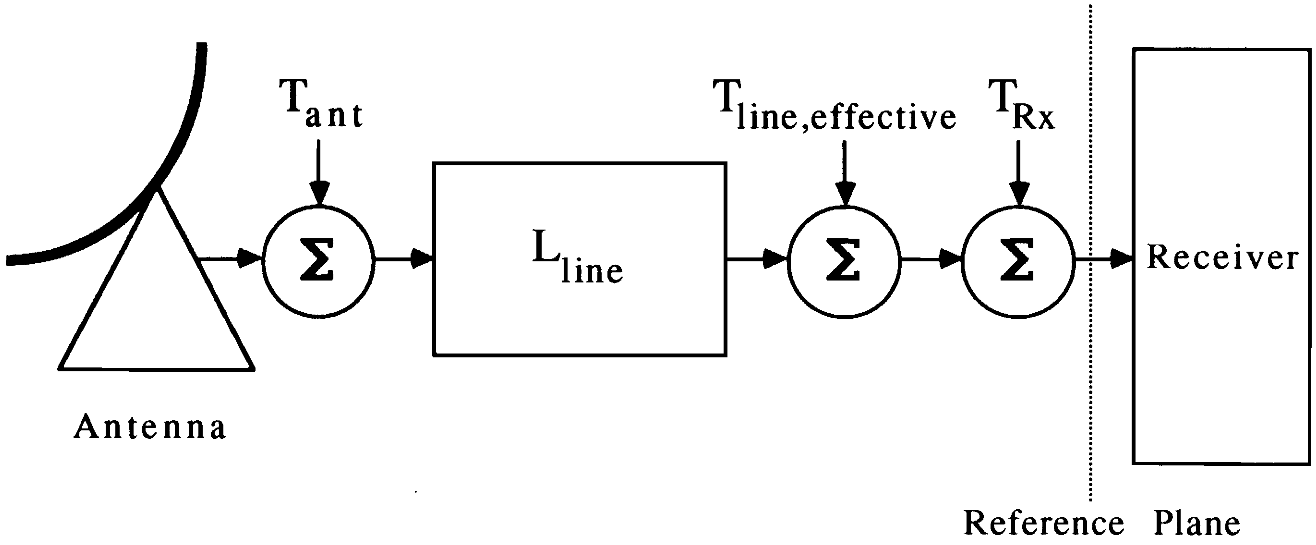

Figure 6.2 System Noise Temperature Components

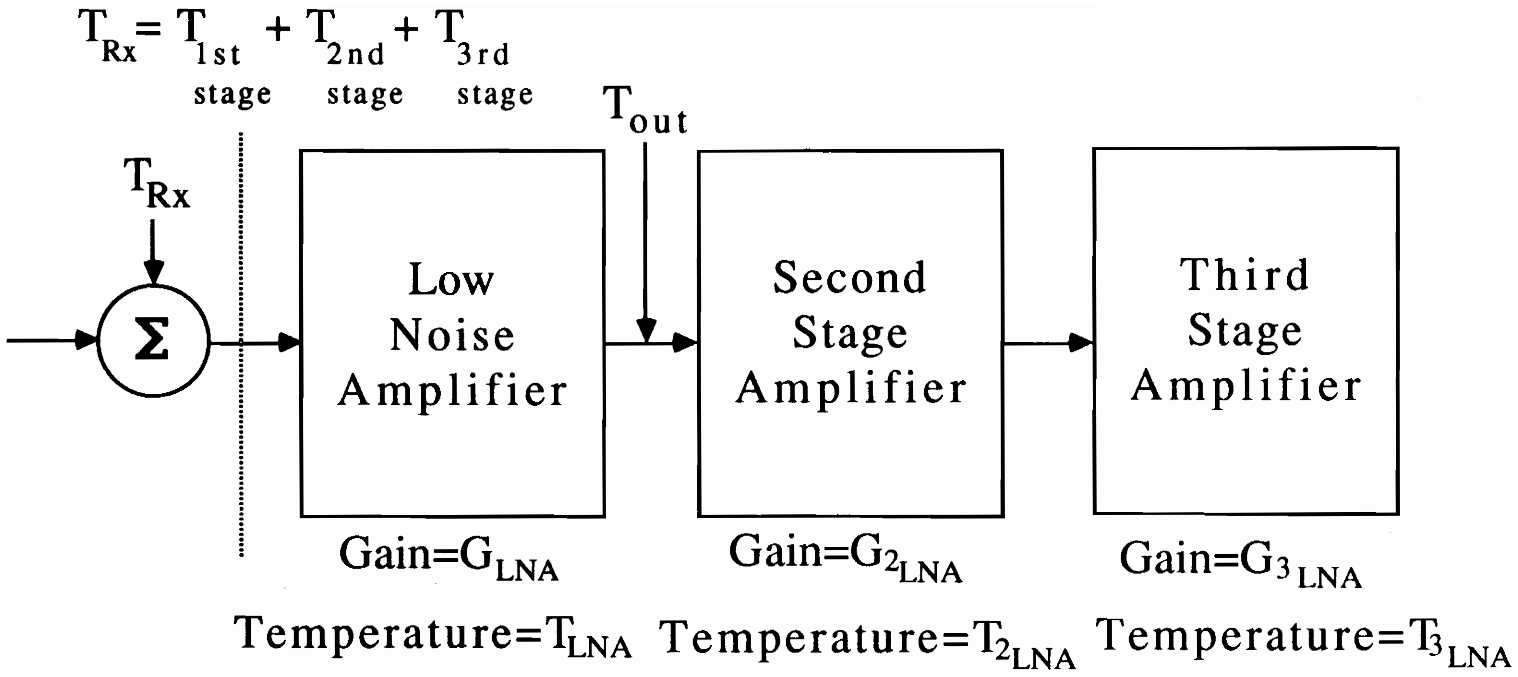

Figure 6.3 Receive Antenna System Amplifier Stages

and its gain by $G3_{LNA}$. This convention would continue for the total number of stages contained within the receiver. The receiver noise temperature is given by

$$T_{Rx} = T_{LNA} + T2/G_{LNA} + T3/G2_{LNA}\, G_{LNA} + \ldots \qquad (6.11)$$

The second and third stage gain is usually much greater than one thus the receive temperature is shown by

$$T_{Rx} \approx T_{LNA} \qquad (6.12)$$

The total noise temperature is therefore expressed by

$$T_{sys} = T_{ant} + T_{line}(L_{line} - 1) + T_{LNA}L_{line}. \qquad (6.13)$$

The receiver antenna G/T ratio is the ratio between the receiver antenna gain and the system noise temperature at the output of the antenna. The G/T ratio is given by

$$G/T = G_{Rx}/T_{ant} + T_{line}(L_{line} - 1) + T_{LNA}L_{line}. \qquad (6.14)$$

The downlink carrier-to-noise ratio is now determined. The general format for the carrier-to-noise density ratio is given by

$$C/kT = [P_{tx}\,G_{tx}/(L_{fs}L_{atm}k)][G_{rx}/T_{rx}]. \qquad (6.15)$$

The constant k is Boltzmann's constant and is equal to 1.38×10^{-23} J/K. The product term $P_{tx}\,G_{tx}$ can be expressed as $EIRP_{tx}$, the effective isotropic radiated transmit power. The term P_{tx} represents the transmit power. The term G_{tx} represents the transmit antenna gain. Equation 6.15 is rewritten in the dB format for the downlink. The downlink Carrier-to-Noise density ratio is given by

$$C/kT_d = EIRP_{sat,s}|_{dB} - Lfs_d|_{dB} - Latm|_{dB} - M_d|_{dB} - OBO|_{dB} + G/T|_{dB}$$
$$-10\log(n_{carrT}) + 228.6 \qquad (6.16)$$

The transmit EIRP for the downlink originates from the satellite. The parmeter $EIRP_{sat,s}$ represents the satellite transmit saturation isotropic radiated transmit power. The parameter OBO represents the satellite amplifier output back-off. The satellite traveling wave tube amplifier (TWTA) must be backed off from the saturated operating point in a multicarrier system. The multicarriers generate intermodulation products which cause non linear distortion in the amplifiers for frequency division multiple access (FDMA) systems. The parameter M_d, the downlink margin, accounts for equipment degradation from operational use and performance loss due to the effects of age. The parameter n_{carrT} represents the number of carriers within the transponder. The downlink carrier-to-noise ratio is found from the carrier-to-noise density ratio and the carrier bandwidth B_W. The carrier-to-noise (C/N_d) ratio downlink is shown by

$$C/N_d = C/kT_d - 10\log(B_W). \tag{6.17}$$

The parameter B_W represents the carrier bandwidth in Hertz.

The uplink carrier-to-noise ratio computations are accomplished in a similar manner to that of the downlink. The downlink carrier-to-noise density ratio, equation (6.15), is rewritten with the appropriate uplink parameters. The uplink carrier-to-noise density ratio is given by

$$C/kT_u = EIRPsate_{tx}|_{dB} - Lfs_u|_{dB} - Latm|_{dB} - M_u|_{dB} - IBO|_{dB} + \\ + G/T_{sat}|_{dB} - 10\log(n_{carrE}) + 228.6 \tag{6.18}$$

The parameter $EIRPsate_{tx}$ represents the saturation transmit power for the transmit terminal. The actual transmit power is given by

$$EIRPe_{tx} = EIRPsate_{tx} - IBO \tag{6.19}$$

The parameter $EIRP_{etx}$ represents the EIRP of the transmit earth station. The transmit station EIRP is shown also by

$$EIRP_{etx} = HPA|_{dB} + L_{wvgd}|_{dB} + G_{tx}|_{dB} \qquad (6.20)$$

It is determined from the output of the high power amplifier (HPA) and the transmit antenna gain (G_{tx}). A factor that affects the HPA is the waveguide loss, L_{wvgd}. The waveguide loss increases the required transmit output power. The term IBO represents the input back-off. This is the amount the satellite TWTA input voltage is backed off from the saturation point to ensure linear amplifier operation. This reduces the adverse effects of intermodulation interference generated in the satellite TWTA. The G/T term is the ratio of the satellite receive gain and the satellite noise temperature. An additional factor that affects the uplink carrier-to-noise density ratio is the number of carriers in a multicarrier system. The parameter n_{carrE} represents the number of carriers transmitted by the earth station. The number carriers transmitted by the ground site, n_{carrE}, is not necessarily equal to the number of carriers in the satellite transponder, n_{carrT}. The satellite may have additional users which would increase the number of carriers in the satellite transponder. The uplink carrier-to-noise (C/N_u) ratio is given by

$$C/N_u = C/kT_u - 10\log(B_w). \tag{6.21}$$

The uplink carrier-to-noise ratio can be also calculated from the satellite saturation flux density as opposed to the transmit station EIRP. The uplink carrier-to-noise density ratio may be found from

$$C/kT = Flux_c + (G/T)_{sat} - 10\log(4\pi/w^2) - Mu + 228.6. \tag{6.22}$$

The parameter $Flux_c$ is the satellite saturation carrier flux density. The flux density is related to the transmit station EIRP. This relationship is given by

$$Flux_c = EIRP_{etx}/4\pi d^2 L_{atm} n_{carr}. \tag{6.23}$$

The station transmit power is calculated from equation 6.23 when the saturated flux density is given. The transmit power is shown by

$$P_{tx} = Flux_c 4\pi d^2 L_{atm} n_{carr}/G_{tx}. \tag{6.24}$$

The communications design computer program uses the basic link budget equations to determine satellite system performance. Specific equations are used based upon the operator selection. The designer uses this section to determine the uplink, downlink and total carrier-to-noise ratio. The software package does not compute the intermodulation interference. The intermodulation interference calculations are specific to the satellite system hardware design. This interference depends on the number of carriers, the power level of the carriers and the placement of the carriers. Also the particular TWTA transfer characteristics are included in the intermodulation interference calculations. The operator is given the option of entering the intermodulation interference when its value is known. The operator also may use the program to calculate the required transmit power for a specified transmit antenna diameter. The appropriate HPA power is found for its associated transmit antenna diameter when the transmit EIRP is held constant. The antenna size is varied from one to twelve meters. The operator may also chose an option that determines the required HPA power, transmit antenna diameter and the receiver station G/T ratio for a rain attenuated downlink.

Chapter 7.0

Baseband Performance Calculations

The required signal-to-noise ratios are determined from specified carrier-to-noise ratios and vice versa. In a frequency modulated scheme with multiple channels the signal-to-noise ratio[17] in dB is shown by

$$S/N = (C/N) + 10\log(B_{IF}/b) + 20\log(f_{rms}/f_{max}) + P + W. \quad (7.1)$$

The parameter Δf_{rms} is the 0 dbm test tone rms deviation for sinusoidal modulation. The maximum frequency is designated by f_{max}. The psophometric weighting factor is shown by P. This weighting factor is used to increase the signal-to-noise ratio that allows the receiver or human listener to respond differently to noise in different parts of the audio spectrum. The preemphasis factor W also improves the signal-to-noise ratio. Preemphasis and deemphasis filters are used to reduce the high frequency content of the modulating signal. Noise at the high-frequency end of the input spectrum is demodulated with a greater output than noise at the low frequency end. The filters are used to suppress this greater output thereby improving the signal-to-

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[17] Timothy Pratt and Charles W. Bostian, *Satellite Communicatios*, New York: Macmillan Publishing Company, 1986, pp 164 - 167.

noise ratio. The parameter b is the channel bandwidth. The transmission bandwidth B_{IF} is determined by Carson's rule. The bandwidth is shown by

$$B_{IF} = 2(f_{\Delta} + f_{max}). \qquad (7.2)$$

Bandwidth calculations are determined for frequency division multiplexing/frequency modulation (FDM/FM) telephone signals using equation 7.1.[18] The channel bandwidth for a telephone system is typically 3.1 kHz. The FDM peak frequency is represented by f_{Δ}. The peak frequency is related to the 0 dbm test tone rms frequency deviation, Δf_{rms}. This relationship is given by

$$f_{\Delta} = gl\Delta f_{rms}. \qquad (7.3)$$

The parameter g is the peak-to-rms ratio more commonly known as the peak factor. The peak factor is typically 3.16 for a large number of telephone channels. When a small number of channels is implemented a value of 6.5 may be used for the peak factor. The FDM loading factor, l is given by

$$l = \log^{-1}[(-1 + 4\log(n))/20] \qquad \text{for } n < 240, \text{ and} \qquad (7.4)$$

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[18] Timothy Pratt and Charles W. Bostian, *Satellite Communicatios*, New York: Macmillan Publishing Company, 1986, pp 167 - 174.

$$l = \log^{-1}[(-15 + 10\log(n))/20] \qquad \text{for } n \geq 240. \qquad (7.5)$$

The term $l\Delta f_{rms}$ is referred to as the rms frequency deviaton. The parameter n is the number of telephone channels. The maximum frequency is also related to the number of telephone channels. This relationship is given by

$$f_{max} = 4200n. \qquad (7.6)$$

This relationship is useful in determining the number of telephone channels that a particular system can support. The number of channels for a proposed satellite is based upon a given carrier-to-noise and signal-to-noise ratio.

The signal-to-noise ratio for a single channel per carrier (SCPC)[19] is given by

$$S/N = (3/2)(C/N)(B_{IF}/f_{max})(\Delta f/f_{max})^2. \qquad (7.7)$$

The parameter Δf is the peak test-tone deviation. The Carson's rule bandwidth B_{IF} is shown by

$$B_{IF} = 2(\Delta f + f_{max}). \qquad (7.8)$$

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[19] Tri T. Ha, *Digital Satellite Communications*, New York: Macmillan Publishing Company, 1986, pp 202 - 203.

The carrier-to-noise ratio is calculated from the signal-to-noise ratio using equation 7.7.

The FM-FDMA television performance is expressed in terms of peak-to-peak luminance signal-to-noise ratio.[20] The television signal-to-noise ratio is given by

$$(S/N)_{p-p} = 6(C/N)(B_{IF}/f_{max})(\Delta f_{rms}/f_{max})^2 \text{ P W}. \qquad (7.9)$$

Typical parameters for FM-FDMA television for fixed satellite service are, $f_{max} = 4.2$ MHz, $\Delta f_{rms} = 13.8$ MHz, $B_{IF} = 36$ MHz, and PW = 12.8 dB. Typical parameters for Direct Broadcast Systems (DBS) television channels are, $f_{max} = 4.2$ MHz, $\Delta f_{rms} = 7.8$ MHz, BIF = 24 MHz, and PW = 12.8 dB. The output signal-to-noise ratio is given by

$$(S/N) = (C/N)+1.76+10\log(B_{IF}/f_{max})+20\log(\Delta f_{rms}/f_{max})+P+W.^{21} \qquad (7.10)$$

The baseband FDM-FM-FMDA performance calculations are used to figure out the signal-to-noise and carrier-to-noise ratios for multichannel systems. The operator selects whether to calculate the carrier-to-noise ratio using the FDM multichannel

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[20] Tri T. Ha, *Digital Satellite Communications*, New York: Macmillan Publishing Company, 1986, pp 204.

[21] Timothy Pratt and Charles W. Bostian, *Satellite Communicatios*, New York: Macmillan Publishing Company, 1986, pp 176 - 179.

rms frequency deviation ($1\Delta f_{rms}$) or the FDM peak frequency (f_{Δ}). The operator can select to determine the multichannel rms frequency from the signal and carrier to noise ratio, maximum baseband frequency, bandwidth and loading factor. The operator can also chose to find the number of telephone channels. The next portion of the program provides SCPC-FM-FMDA signal and carrier to noise ratio calculations. The remaining option determines FM-FMDA television signal to noise ratio calculations.

Chapter 8.0

Adjacent Satellite Interference Calculations

A satellite can interfere with an adjacent system when the power contained within a sidelobe interferes with the receive signal of the adjacent earth station. Conversely the transmission signal of one earth station can interfere with the adjacent satellite receiver. The Federal Communications Commission (FCC) has set guidelines to minimize this type of interference. The regulations specify that the sidelobe envelope level relative to the normalized peak gain must meet with the following criteria:

$$G(\partial) = 29 - 25\log(\partial) \qquad \text{for } 1 \leq \partial \leq 48^{\circ} \text{ and} \qquad (8.1)$$

$$G(\partial) = -13 \qquad \text{for } 48^{\circ} < \partial. \qquad (8.2)$$

The parameter ∂ is equal to the angular separation between two geostationary satellites as observed by the earth station. The separation angle is determined from the path distance from the earth station to the satellites and the separation distance between the satellites.[22] Figure 8.1 shows the system geometry used to determine the satellite separation distance. The satellite separation distance d_{sep} is derived by using the law of cosines

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[22] Tri T. Ha, *Digital Satellite Communications*, New York: Macmillan Publishing Company, 1986, pp 142 - 147.

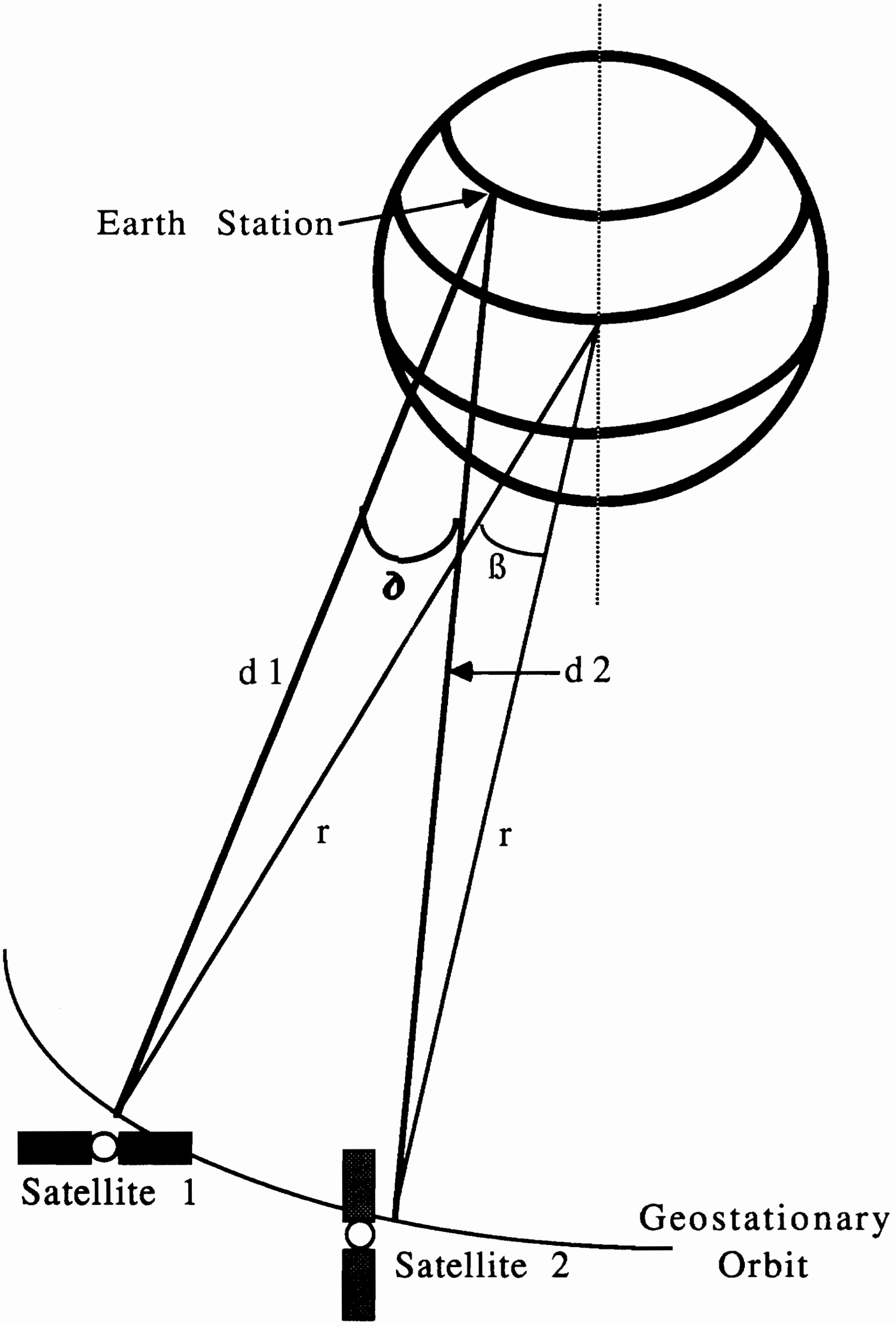

Figure 8.1 Adjacent Satellite Interference Geometry

and is shown by

$$d_{sep}^2 = d1^2 + d2^2 - 2\ d1\ d2\cos(\partial). \qquad (8.3)$$

The parameter d1 represents the distance from the earth station to one of the satellites. The parameter d2 represents the distance from the same earth station to the adjacent satellite. The separation distance is also calculated from the geostationary radius r and the separation angle between the two satellites, ß, measured at the center of the earth. The second separation distance calculation is shown by

$$d_{sep}^2 = 2r^2 - 2r^2\cos(\beta). \qquad (8.4)$$

Equations 8.3 and 8.4 are combined to determine ∂. The separation angle seen by the earth station is therefore given by

$$\partial = \cos^{-1}[\{d1^2 + d2^2 - 2r^2(1 - \cos(\beta))\}/2\ d1\ d2]. \qquad (8.5)$$

The carrier-to-interference ratio is determined in a similar manner as the link budget carrier-to-noise ratios. The uplink carrier-to-interference is shown by

$$(C/I)u = (EIRP1\ IBO1) - (EIRP2 - IBO2) + G_{Tx_2} - (29 - 25\log(\partial)) + \\ + Gu - Gu' \qquad (8.6)$$

The postscripts 1 and 2 refer to two satellite systems. Earth station 2 transmissions are interfering with satellite 1 reception. The parameter EIRP1 is the effective isotropic radiated power of earth station 1. EIRP2 is the effective isotropic radiated power of earth station 2. Note that the saturated flux density may be used in place of the EIRP in equation 8.6. The variable IBO is the input back off for each respective satellite. The parameter G_{Tx2} is the on axis transmit antenna gain of the interfering earth station(2). The term Gu - Gu' is the differential antenna gain. The term Gu' represents the satellite antenna gain of the interfered satellite(1) in the direction of the interfering earth station(2).

The carrier-to-interference ratio of the downlink is shown by

$$(C/I)d = (EIRP_{sat,s}1-OBO1)-(EIRP_{sat,s}2-OBO2) + G_{Rx} + \\ - (29-25\log(\partial)) \qquad (8.7)$$

The interfered satellite is satellite 1. The transmission of satellite 2, the interfering satellite, is degrading the reception of earth station 1 from its respective satellite. The parameter $EIRP_{sat,s}$ is the saturation EIRP of the associated satellite. The output back-off for each satellite is described by the term OBO.

The parameter G_{Rx} is the on-axis antenna gain of earth station 1, the interfered site.

When a system employs multiple carriers per transponder the carrier to interference equations (8.6 and 8.7) must be modified. The interference equations must include the carrier power spectral density interference of both satellite systems. The carrier power spectral density relative to the carrier power is determined for the interfered signal. This value is then modified by the carrier bandwidth of the interfering signal. The results are included in the carrier-to-interference equations.

Figure 8.2 shows the power spectral densities for three types of carriers, quadrature phase shift keying (QPSK), FDM-FM and TV-FM.[23] The one-sided power spectral density S for a QPSK carrier is given by

$$S = 10 \log(2CT_b). \tag{8.8}$$

The carrier power in an infinite bandwidth is represented by C. The term T_b is the bit duration and is equal to the reciprocal of the bit rate. The QPSK carrier is normally filtered such that its bandwidth B is given by

$$B = T_b/0.6. \tag{8.9}$$

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[23] Tri T. Ha, *Digital Satellite Communications*, New York: Macmillan Publishing Company, 1986, pp 149 - 151.

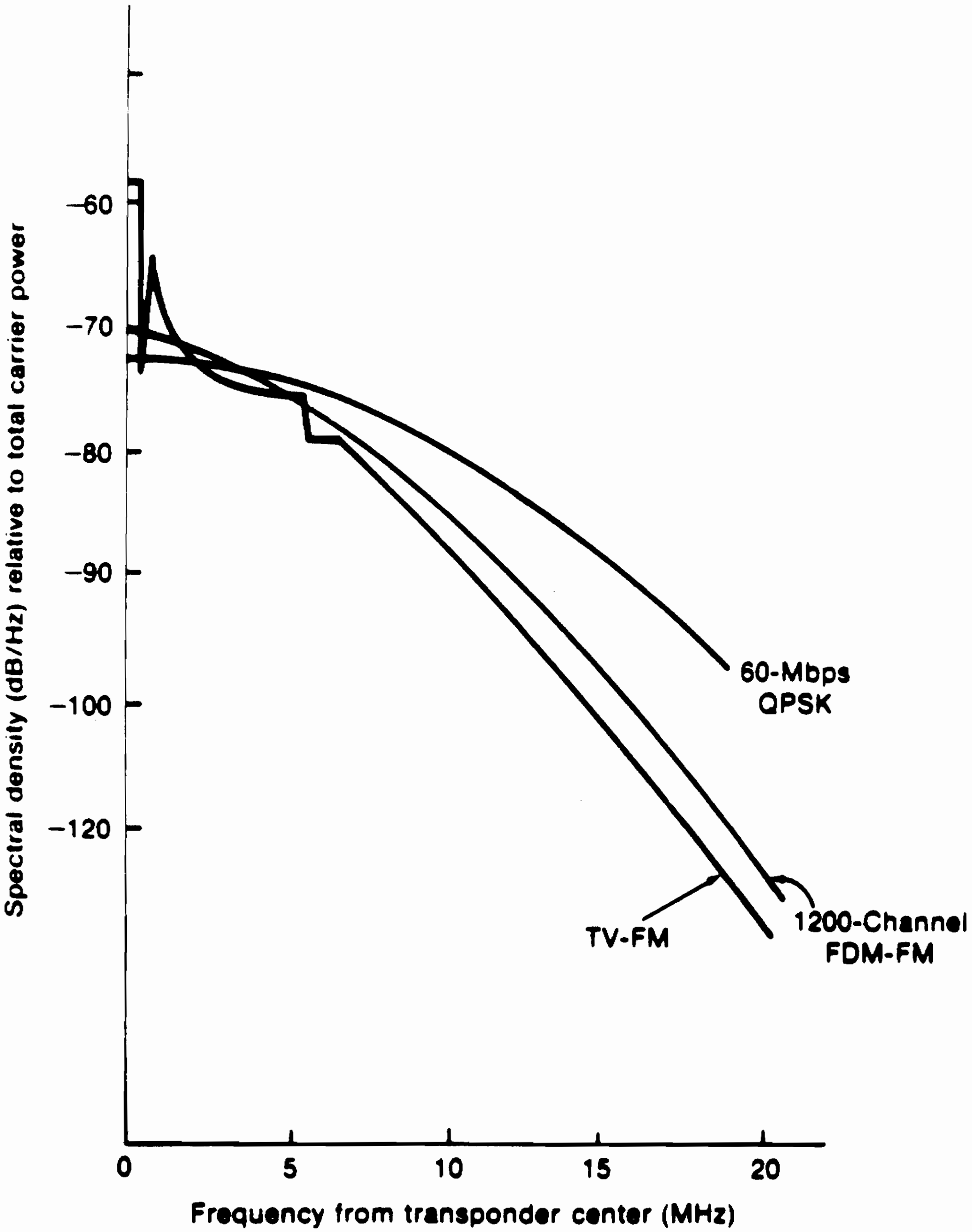

Figure 8.2 Power Spectral Densities of QPSK, FDM-FM and TV-FM Carriers

For example, the associated bandwidth for a 60 Mbps system is 36 MHz. The total carrier power in the carrier bandwidth is approximately 67% of the carrier power in an infinite bandwidth. Therefore equation 8.8 reduces to

$$S = 10\log(2T_b/0.67). \qquad (8.10)$$

The one sided spectral density of a FDM-FM carrier is given by

$$S = C/2\sqrt{(2\pi(\Delta)^2)}. \qquad (8.11)$$

The variable Δ represents the rms multichannel deviation (Hz) and is equal to the product of the multichannel loading factor, l and the 0-dbm rms test-tone deviation, Δf_{rms}. Most of the carrier power is captured within the carrier bandwidth as opposed to a QPSK carrier. The power spectral density of a TV-FM carrier is approximated to be a constant around the carrier frequency. The constant is -59 dB/Hz relative to the carrier power. Similar to the FDM-FM carrier, most of its power is also captured within the carrier bandwidth.

The operator inputs the subsatellite point and earth station location for both systems. The angular separation as viewed from first earth station is computed. The operator may then enter the appropriate parameters for each system to determine the interference of the reference system into another. The operator also may determine the interference from another system into the reference.

Chapter 9.0

System Availability

An important consideration in the satellite link design is system outages.[24] These outages may be due to rain, which can cause significant degradation for frequencies above 10 GHz. Also, outages can be caused by equipment failure and the time it takes to complete the repair. Another consideration which affects station outage time is planned maintenance. This preventive maintenance is required for some equipment and enables the unit to operate with sustained peak performance. Two important concepts that aid the designer in the determination of the system outage is the mean time before failure (MTBF), and the mean time to repair (MTTR)[25]. The mean time before failure is the period from the start of equipment operation until the unit experiences failure. The mean time to repair is the time it takes to complete repairs to the unit and restore it to operational status. These times are statistical in nature and are based upon data collection and studies on past performance. The unit availability is calculated from these mean times and is given by

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[24] Tri T. Ha, ***Digital Satellite Communications***, New York: Macmillan Publishing Company, 1986, pp 177 - 178.

[25] Ernest Simo, ***Satellite Communications and VSATS***, Dallas, Texas: Space-2000, 1989, pp A-3.1 - A-3.14.

$$A_{unit} = MTBF_{unit}/(MTBF_{unit} + MTTR_{unit}). \qquad (9.1)$$

The failure rate, Lamda is the reciprocal of the mean time before failure (MTBF). The unit availability can be expressed in terms of the failure rate and is shown by

$$A_{unit} = 1/\{ 1 + (Lamda_{unit})(MTTR_{unit})\}. \qquad (9.2)$$

The terminal availability is determined by calculating the availability of each of its units. The components that comprise the earth station terminals include the outdoor unit, the indoor unit, the antenna and interfacility link.[26] The terminal availability is found from the product of each of its respective unit availabilities. The terminal availability, A_{Term} is given by

$$A_{Term} = A_{ODU}\, A_{IDU}\, A_{ANT}\, A_{IFL}. \qquad (9.3)$$

The parameter A is the availability of that particular unit. The term ODU is the outdoor unit and the term IDU represents the indoor unit. The antenna is shown by ANT and the interfacility link by IFL. The expected number of failures per year can be calculated from Lamda, the failure rate. The number of failures

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[26] Ernest Simo, *Satellite Communications and VSATS*, Dallas, Texas: Space-2000, 1989, pp 4.1 - 4.34.

for a particular terminal in one year is found from the product of two terms. The first term is the summation of the failure rates for each of its components. The second term is the number of hours in a year. The outage hours is determined from the unavailability of a unit. The unavailability is given by $1 - A_{unit}$. The product of the unavailability and the number of hours in a year result in the outage hours per year. The outage hours per year, Hr_X is expressed by

$$Hr_X = (8760)(1-A_{unit})/100. \tag{9.4}$$

The system availability is obtained from the product of the transmit and receive terminal availability, the link availability, and the satellite availability. The link availability is obtained from the percent of year rain rate is exceeded, P. The average probability threshold, P_b is equal to the sum of the percent of year rain rate exceeded for the uplink probability, downlink probability and joint probability. The joint probability (rain on both uplink and downlink) is normally not available and is usually neglected when the individual uplink and downlink probabilities are small. If P_e is the link outage when rain attenuation exceeds P_b the link availability is given by

$$A_{Link} = 1 - P_e/100. \tag{9.5}$$

The system availability is shown by

$$A_{SYS} = A_{Term_{TX}} A_{Term_{RX}} A_{Link} A_{Sat}. \tag{9.6}$$

Note that the earth station failure, satellite failure, and link outage are mutually independent.

The availability of a redundant system is also determined. The availability of a redundant unit depends upon either unit or both being on line. The availability when one unit on line is $A_{unit}(1 - A_{unit})$. The availability when both units are on line is $A_{unit}(A_{unit})$. Thus the redundant availability for the case where one or both units are on line is shown by

$$A_{Red} = 2A_{unit}(1-A_{unit}) + A_{unit}^2 = A_{unit}(2 - A_{unit}). \tag{9.7}$$

The design software determines the availability of ground station components based upon the mean time before failure and the mean time to repair. The availability of the transmit and receive terminal is obtained from the product of each individual component availability. The operator enters the link outage P_e to find the link availability. Finally the system availability is determined once the satellite availability is included.

Chapter 10.0

Rain Induced Cross-Polarization Discrimination

Many satellite systems use frequency reuse to double the operating capacity. Frequency reuse allows two users in a given geographical area to operate with the same frequency. Frequency reuse is implemented with either spatial diversity or polarization diversity. Spatial diversity is used when two users are located in different geographical regions. Polarization diversity is used when both users are in the same geographical region. One user operates with horizontal polarization. The other user operates with vertical polarization. The isolation between the orthogonal polarizations must be sufficient to minimize cross-polarization interference. However rain can have the effect of degrading this isolation due to its depolarizing effect.[27] Figure 10.1 shows an oblate raindrop. Air resistance causes the raindrop to take on this oblate shape. The angle Ω is the canting angle and is the tilt angle of the raindrop with respect to the local horizontal. The interaction of a linear polarized waveform causes amplitude and phase attenuation of its horizontal and vertical components. The attenuated waves can be expressed in terms of a matrix shown in Figure 10.2. The

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[27] Tri T. Ha, *Digital Satellite Communications*, New York: Macmillan Publishing Company, 1986, pp 170 - 177

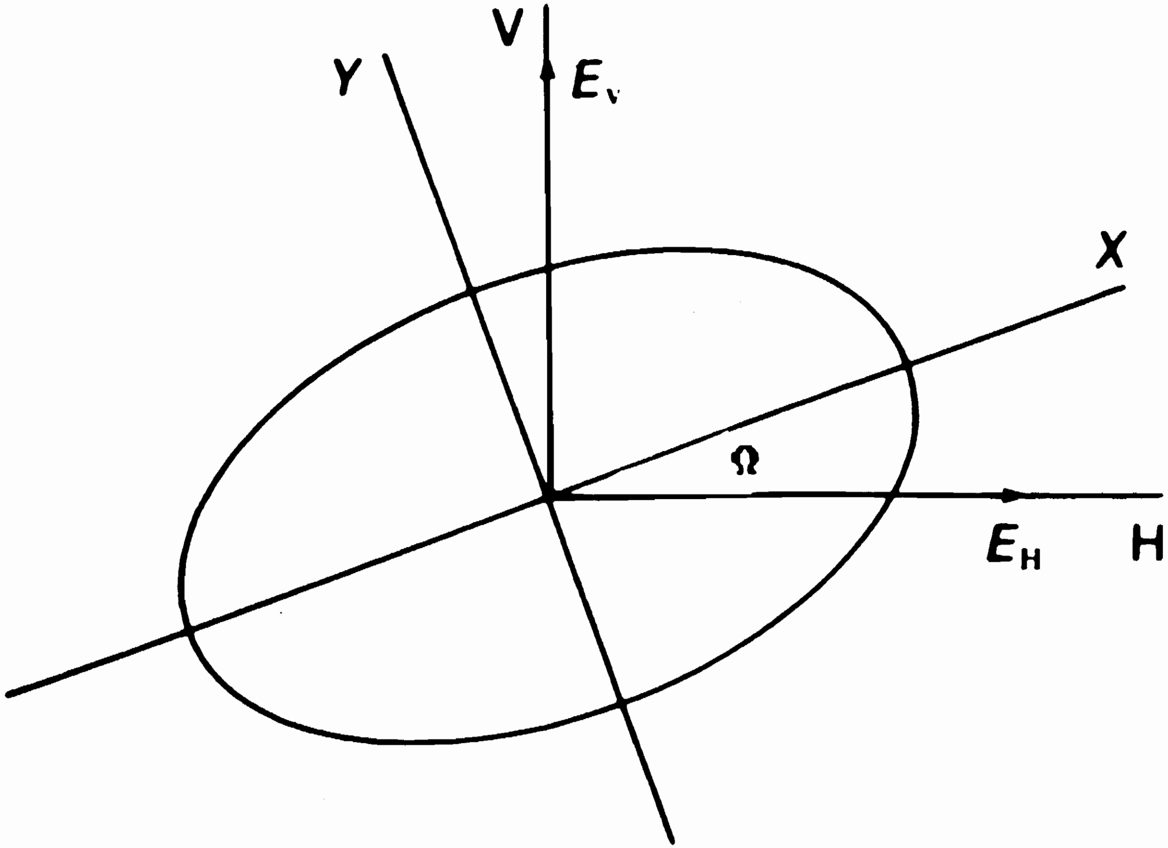

Figure 10.1 Oblate Raindrop

$$\begin{bmatrix} E'_H \\ E'_V \end{bmatrix} = \begin{bmatrix} \cos(\Omega) & \sin(\Omega) \\ \sin(\Omega) & \cos(\Omega) \end{bmatrix} \begin{bmatrix} T_x & 0 \\ 0 & T_y \end{bmatrix} \begin{bmatrix} \cos(\Omega) & \sin(\Omega) \\ \sin(\Omega) & \cos(\Omega) \end{bmatrix} \begin{bmatrix} E_H \\ E_V \end{bmatrix}$$

Figure 10.2 Wave Component Transformation Matrix resulting attenuation wave components are given by

$$E_H' = \{T_x \cos^2(\Omega) + T_y \sin^2(\Omega)\}E_H + \{(T_x - T_y)\sin(\Omega)\cos(\Omega)\}E_V \text{ and} \quad (10.1)$$

$$E_V' = \{(T_x - T_y)\sin(\Omega)\cos(\Omega)\}E_H + \{T_x \sin^2(\Omega) + T_y \cos^2(\Omega)\}E_V. \quad (10.2)$$

The parameters E_H and E_V represent the horizontal and vertical components of the transmission waves. The terms E_H' and E_V' represent the attenuated wave components. The parameters T_x and T_y are the transmission coefficients over an effective rainfall slant path length L_e. The transmission coefficients are given by

$$T_x = e^{-(A_x - j\beta_x)L_e}, \text{ and} \quad (10.3)$$

$$T_y = e^{-(A_y - j\beta_y)L_e}. \quad (10.4)$$

The rainfall slant path is determined from the *Crane global* model rain attenuation L_r and is given by

$$L_e = L_r(dB)/aR_p^b. \quad (10.5)$$

The constants a and b are the frequency dependent coefficients. The point rain rate is given by R_p. The attenuation coefficients are given by A_x and A_y that are in units of nepers/km. The phase coefficients are given by β_x and β_y that are in units of rad/km.

The cross-polarization discrimination is the ratio of power received from the principal polarization to that received by the orthogonal polarization from the same signal. This is equal to the carrier-to-cross polarization interference ratio when the vertical and horizontal components have the same power. The horizontal and vertical cross-polarization discrimination is shown by

$$X_H = 20\log\{ [\ |(Tx/Ty)+\tan^2\Omega|\ ] / [\ |(Tx/Ty-1)\tan\Omega|\ ] \}, \text{ and} \quad (10.6)$$

$$X_V = 20\log\{ [\ |(Tx/Ty)\tan^2\Omega+1|\ ] / [\ |(Tx/Ty-1)\tan\Omega|\ ] \}. \quad (10.7)$$

The transmission coefficient ratio is shown by

$$T_x/T_y = e^{(-\Delta A - j\Delta\beta)Le}, \text{ where} \quad (10.8)$$

$$\Delta A = A_x - A_y \quad \text{and} \quad (10.9)$$

$$\Delta\beta = \beta_x - \beta_y. \quad (10.10)$$

The differential attenuation ΔA is obtained from Figure 10.3. Figure 10.3 is the plot of differential attenuation versus frequency. Note that the attenuation units are listed in this figure as dB/km. This is equivalent to 8.686 nepers/km. The differential phase shift is obtained from Figure 10.4. Figure 10.4 is the plot of differential phase versus frequency. Note that the phase units in Figure 10.4 are listed as deg/km. These units must be converted to rad/km to use equations 10.6 and 10.7.

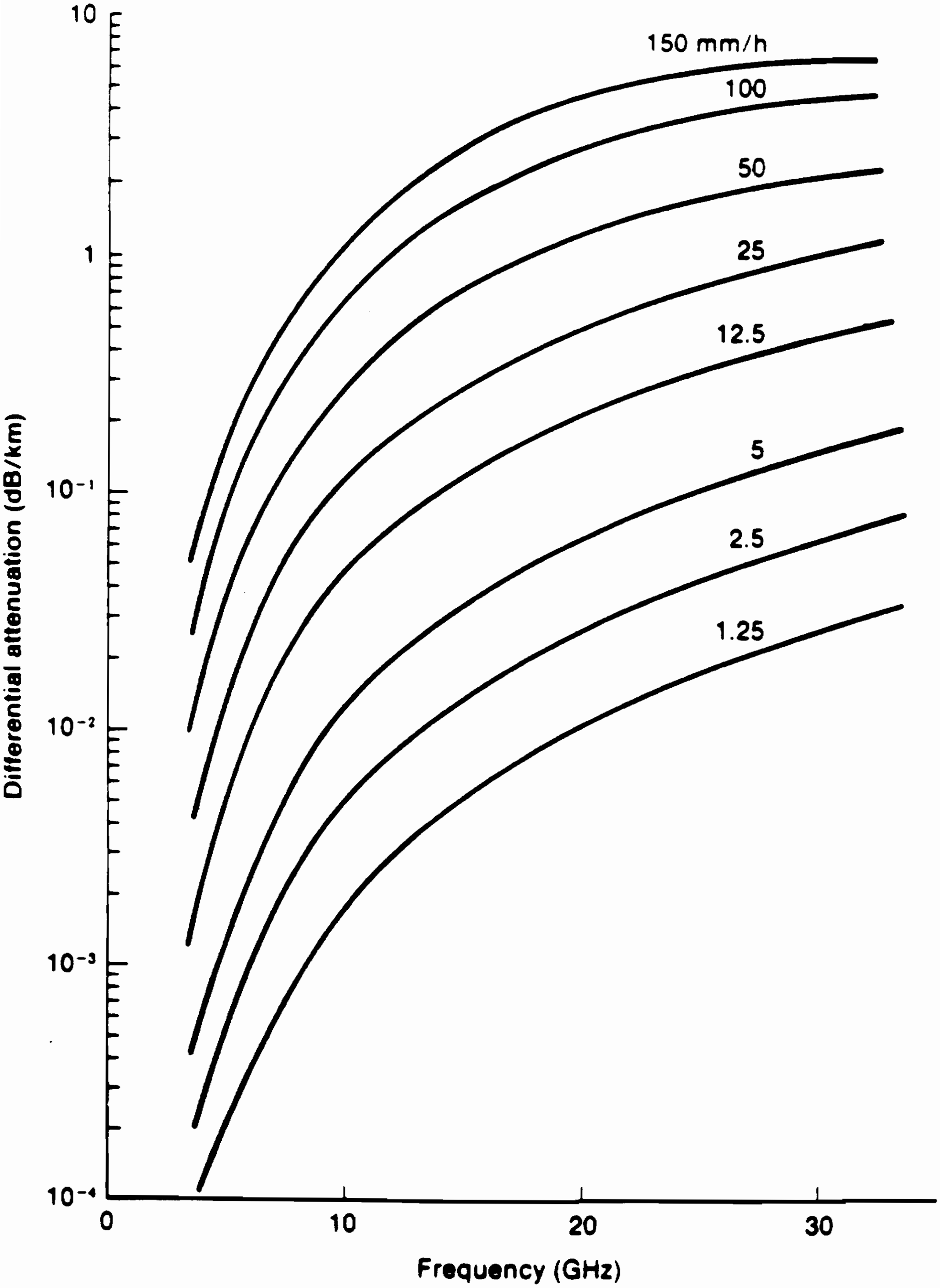

Figure 10.3 Differential Attenuation

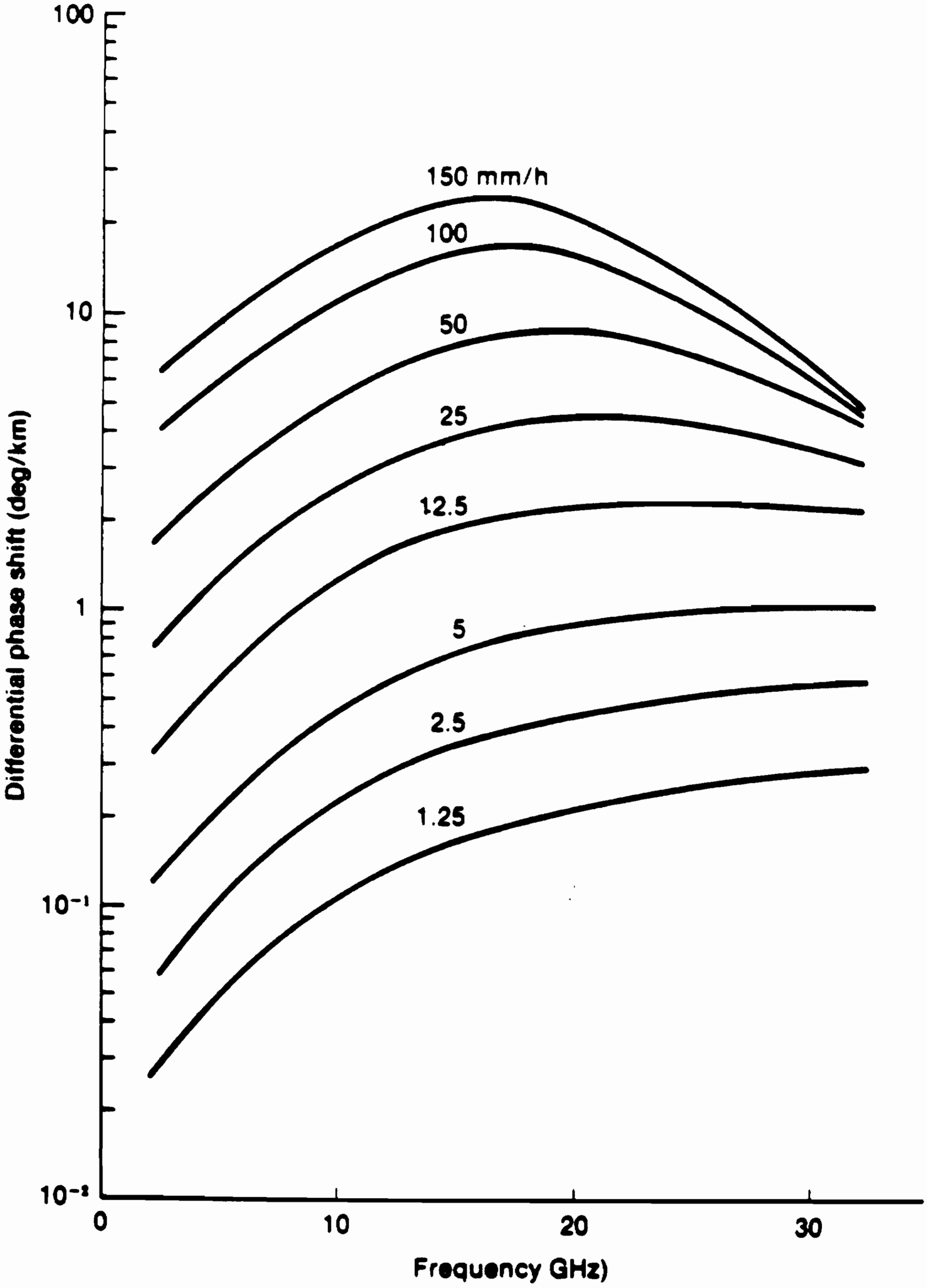

Figure 10.4 Differential Phase shift

Figures 10.3 and 10.4 give the differential attenuation and phase for the case where the angle between the direction of propagation and raindrop symmetry Y axis is ninety degrees. This angle is represented by the symbol μ. The differential attenuation and phase for the earth station is estimated from Figures 10.3 and 10.4 when the angle μ is not ninety degrees. The operational differential attenuation is given by

$$\Delta A = \cos^2(El)\ (\Delta A\ |_{\mu=90^o}). \qquad (10.11)$$

The operational differential phase attenuation is given by

$$\Delta \beta = \cos^2(El)\ \Delta \beta|_{\mu=90^o}. \qquad (10.12)$$

The parameter $(\Delta A\ |_{\mu=90^o})$ is obtained from Figure 10.3. The term $(\Delta \beta|_{\mu=90^o})$ is obtained from Figure 10.4. The path elevation is represented by variable El.

When the polarized waves are not aligned to the local horizontal and vertical, the rain canting angle Ω is replaced with the rain canting component angle ς. The canting component angle ς is obtained from the polarization tilt angle, ∂. The rain canting component angle, ς is given by

$$\varsigma = \Omega + \partial. \qquad (10.13)$$

The rain canting angle Ω in equations 10.6 and 10.7 is replaced by ς when the waves have a polarization tilt. Finally the right and left hand cross-polarization discrimination for orthogonal circular polarizations is given by

$$X_C = 20 \log[|T_x/T_y + 1|]/[|T_x/T_y - 1|]. \qquad (10.14)$$

Chapter 11.0

Communications Link Budget Design

The communications link budget design software package is used to design three satellite links. The first design is implemented with the Satellite Business Systems (SBS) satellite.[28] Satellite Business Systems is a specialized common carrier that provides a wide range of telecommunications services. SBS operates four Ku-band satellites. The technical specifications for the SBS satellites are listed in Table 11.1. The subsatellite point is 95°W. The satellite link is designed based upon a required carrier-to-noise ratio. It is assumed that rain attenuation exists on the downlink.[29] The link will be used for FM video. The maximum frequency is 4.2 MHz. The peak frequency deviation is 13.8 MHz. The resulting Carson's bandwidth is 36 MHz. The FM detector threshold is 10 dB. A 6 dB margin is allocated for equipment degradation and propagation effects. Thus the required Carrier-to-noise ratio is 16 dB. The transmit station is at Blacksburg, Virginia. The transmit earth station specifications are as follows:

Longitude	80.438°W

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[28] Alfred T. Barnes, *The 1985 Satellite Directory* 7th Annual Edition, Bethseda Md: Phillips Publishing Inc., 1985, pp 28 - 30.

[29] Tri T. Ha, *Digital Satellite Communications*, New York: Macmillan Publishing Company, 1986, pp 178 - 185.

Table 11.1: SBS Satellite Technical Characteristics

Owner:	Satellite Business Systems
Frequency Band:	12/14 GHz
Receive: Transmit:	14.025-14.466 11.725-12.166
Transponder Bandwidth:	43 MHz
Polarization:	Linear
Antenna Coverage: (Beam Edge EIRP)	43.7 dBW
Receive Coverage (G/T):	+/- 2 dB/K
Single Carrier Saturation Flux Density:	-76 to -82 dB/m^2
Number of Transponders:	10
TWTA Power Output:	20 Watts
Design Life:	7 years
Services (FSS):	Voice,data,video

Latitude	37.229°N
Height above sea level	0.640 km
0°C isotherm	3.9 km

The receive station is at Vienna, Virginia. The receive earth station specifications are as follows:

Longitude	77.22°W
Latitude	38.91°N
Height above sea level	0.150 km
0°C isotherm	3.6 km

Table 11.2 lists typical input output back-off relationships for a satellite traveling wave tube amplifier (TWTA). The earth stations will use a 14/12 GHz satellite link. The satellite and earth station cross-polarization discrimination is assumed to be 30 dB. The carrier-to-adjacent satellite interference ratio is 32 dB for both the uplink and downlink. The carrier-to-adjacent channel interference ratio is assumed to be 29 dB for both the uplink and downlink. The atmospheric and tracking loss is assumed to be 1.5 dB for both the uplink and downlink. The clear sky TWTA input back-off is 3 dB. The clear sky TWTA output back-off is 0.3 dB.

The design process is begun by establishing the allocation of outages. Since most satellites are downlink-limited a greater outage is planned for the downlink. The percent rain rate exceeded for the uplink is established at 0.05%. The percent rain

Table 11.2 Typical Input-Output Back-off Relationship of A Satellite TWTA

Input Back-off (dB)	Output Back-off (dB)	
20	10	
18	09	
16	7.5	
14	06	
12	4.7	
09	2.5	
06	1.0	
03	0.3	
00	00	{Saturation
-2	0.2	{Overdrive
-4	0.7	{Overdrive

rate exceeded for the downlink is set at 0.1% yielding a two to one ratio. Table 2.1 is used to obtain the point rain rate based upon the given percentages. The point rain rate that corresponds to a 0.05% rain rate exceeded is 22 mm/h. The point rain rate that corresponds to a 0.1% rain rate exceeded is 15 mm/h.

The computer program is used to determine the azimuth, elevation, rain margin and rain induced cross-polarization interference for linear frequency reuse. The transmit station azimuth and elevation is 203.24° and 44.21° respectively. The Crane global rain attenuation at Blacksburg is 4.6 dB. The associated system temperature increase is 182.92°. The rain cross-polarization discrimination is 21.65 dB and 21.89 dB for horizontal and vertical polarizations.

The receive station azimuth and elevation is 207.05° and 41.31° respectively. The Crane global rain attenuation at Blacksburg is 2.45 dB. The associated system temperature increase is 120.67°. The rain cross-polarization discrimination is 23.66 dB and 23.85 dB for horizontal and vertical polarizations.

The link is computed based upon the required carrier-to-noise ratio. The link characteristics are first designed assuming uplink rain only. Then the link is designed assuming downlink rain only. The receive station G/T ratio is then determined for the condition with rain affecting the downlink. The receive antenna gain, transmit antenna gain, transmit antenna diameter and HPA output power is found. The transmit antenna gain is related to the receiver gain by the squared ratio of the uplink and downlink frequencies. This relationship is valid when both antenna total efficiencies are equal.

The uplink carrier-to-noise ratio with uplink rain only is 22.07 dB. This is determined from the basic link budget equation including the rain attenuation loss. The uplink carrier-to-noise interference ratio is determined assuming that rain does not occur at the interfering source. This interference then consists of the carrier-to-adjacent satellite interference, carrier-to-adjacent channel interference and satellite antenna cross-polarization. The uplink carrier-to-noise ratio is also reduced by the uplink rain attenuation. The uplink carrier-to-noise interference ratio assuming uplink rain only less the uplink rain attenuation is 20.8 dB. The uplink carrier-to-noise plus interference ratio assuming uplink rain only is therefore 18.38 dB. The downlink carrier-to-noise plus interference ratio with uplink rain only is calculated from the required carrier-to-noise ratio minus the uplink carrier-to-noise plus interference ratio. The required carrier-to-noise ratio is 16 dB. The downlink carrier-to-noise plus interference ratio is 19.75 dB. The downlink carrier-to-interference ratio with uplink rain only is determined from the carrier-to-adjacent satellite interference, carrier-to-adjacent channel interference and the satellite antenna and earth station cross-polarization. This downlink interference must be modified by the difference between the clear sky output back-off and the rain affected output back-off. The rain affected back-off results when the effect of rain attenuation is applied to the clear sky input back-off for rain on the uplink. The downlink carrier-to-interference ratio with uplink rain only is 22.2 dB. The downlink carrier-to-interference ratio is subtracted from the carrier-to-noise plus interference ratio. The resulting downlink carrier-to-noise ratio is 22.83 dB. The G/T of the receive station with uplink rain only is determined from the downlink carrier-to-noise ratio by using link budget equations. The G/T is 34.86 dB/K. The transmit station EIRP is determined from the satellite flux density and the atmospheric and tracking loss. The EIRP is 81.98 dBW.

The uplink carrier-to-noise plus interference ratio with downlink rain only is determined from the uplink carrier-to-noise plus interference ratio plus the uplink rain margin. The uplink carrier-to-noise plus interference ratio is 22.98 dB. The downlink carrier-to-noise plus interference ratio with downlink rain only is determined from the difference between the required carrier-to-noise ratio and the uplink carrier-to-noise plus interference ratio. The downlink carrier-to-noise plus interference ratio is 16.97 dB. The downlink carrier-to-interference ratio with downlink rain is determined from the carrier-to-adjacent satellite interference and the carrier-to-adjacent channel interference. In addition the satellite antenna and earth station cross-polarization, and the rain depolarization characteristic are also included. The downlink carrier-to-interference ratio is 20.86 dB. The downlink carrier-to-noise ratio with downlink rain only is determined from the difference between the downlink carrier-to-noise ratio plus interference ratio and the downlink carrier-to-interference ratio. The downlink carrier-to-noise ratio with downlink rain only is 19.25 dB. The receive station G/T with downlink rain is determined from the downlink carrier-to-noise ratio by also using link budget equations. The receive station G/T with downlink rain is 33.32 dB. The system temperature is determined from the G/T with uplink rain only and the G/T with downlink rain only. In addition the system temperature increase due to rain must also be included. The system temperature is determined to be 152.09°K based upon the system increase of 120.67° because of rain. The receive gain is determined from the receive station clear sky G/T and the system temperature. The receive gain is determined to be 56.68 dB. The transmit gain is determined from the receive gain and the square of the uplink and downlink ratios. The transmit gain is 58 dB. Therefore the transmit antenna diameter is 7.2 m. The associated HPA is 250.3 W. More iterations may be performed to optimize antenna size, system noise temperature and HPA power requirements. However the EIRP and receive station clear sky G/T must remain constant. Also the receive station rain G/T value must be greater than or equal to the one obtained in the previous link design.

The second satellite link design uses the GTE Spacenet Corporation Spacenet satellite. The Spacenet satellite is designed for single and multicarrier applications for both analog and digital modulation schemes. Table 1.3 shows the Spacenet satellite specifications. The subsatellite point is 69°W. The Satellite link is obtained using the same design method that was used for the SBS satellite.[30] The link design is again used for FM video, but is implemented with different specifications. The maximum frequency is 4 MHz. The peak frequency deviation is 9.0 MHz. The resulting Carson's bandwidth is 26 MHz. The FM detector threshold is 10 dB. A 3 dB margin is allocated for equipment degradation and propagation effects. Thus the required carrier-to-noise ratio is 13 dB. The transmit station is again established at Blacksburg, Virginia. The receive earth station is located at Vienna, Virginia. The earth station location specifications are listed in the SBS link budget calculation. Table 11.2 gives the typical input output back-off relationships for a satellite TWTA and is used also for the Spacenet satellite. The

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[30] Alfred T. Barnes, *The 1985 Satellite Directory* 7th Annual Edition, Bethseda Md: Phillips Publishing Inc., 1985, pp 18, 21.

Table 11.3: Spacenet Satellite Technical Characteristics

Owner:	GTE Corporation
Frequency Band:	12/14 GHz (Ku Band)
Receive: Transmit:	14.000-14.500 11.700-12.200
Transponder Bandwidth:	72 MHz
Polarization:	Linear
Antenna Coverage: (Beam Edge EIRP)	39.7 to 44.8 dBW (Ku Band)
Receive Coverage (G/T):	-0.2 to +4.2 dB/K
Single Carrier Saturation Flux Density:	-94 to -86.6 dB/m^2
Number of Transponders:	6
TWTA Power Output:	16 Watts
Design Life:	11.5 years
Services (FSS):	Voice,data,video

earth stations will use a 14/12 GHz satellite link. The satellite and earth station cross-polarization discrimination is assumed to be 30 dB. The carrier-to-adjacent satellite interference ratio is 32 dB for both the uplink and downlink. The carrier-to-adjacent channel interference ratio is assumed to be 29 dB for both the uplink and downlink. The atmospheric and tracking loss is assumed to be 1.5 dB for both the uplink and downlink. The clear sky TWTA input back-off is 3 dB. The clear sky TWTA output back-off is 0.3 dB.

The design process is again started by establishing the allocation of outages. The same rain percentages are used. The percent rain rate exceeded for the uplink is established at 0.05%. The percent rain rate exceeded for the downlink is set at 0.1%. The point rain rate that corresponds to a 0.05% rain rate exceeded is 22 mm/h. The point rain rate that corresponds to a 0.1% rain rate exceeded is 15 mm/h. The computer program is used to determine the azimuth, elevation, rain margin and rain induced cross-polarization interference for linear frequency reuse. The transmit station azimuth and elevation is 198.49° and 45.20° respectively. The Crane global rain attenuation at Blacksburg is 4.52 dB. The associated system temperature increase is 181.21°. The rain cross-polarization discrimination is 22.10 dB and 22.33 dB for horizontal and vertical polarizations. The receive station azimuth and elevation is 192.95° and 44.16° respectively. The Crane global rain attenuation at Blacksburg is

2.32 dB. The associated system temperature increase is 115.84°. The rain cross-polarization discrimination is 24.94 dB and 25.10 dB for horizontal and vertical polarizations.

The link budget design results for uplink rain only are summarized as follows:

Uplink carrier-to-noise ratio is 15.76 dB
Uplink carrier-to-interference ratio is 20.87 dB
Uplink carrier-to-noise ratio plus interference ratio is 14.60 dB
Downlink carrier-to-noise plus interference ratio is 18.13 dB
Downlink carrier-to-interference ratio is 22.7 dB
Downlink carrier-to-noise ratio is 19.99 dB
Receive earth station G/T is 32.26 dB/K
Transmit station EIRP is 74.37 dBW

The link budget design results for downlink rain only are given as follows:

Uplink carrier-to-noise plus interference ratio is 19.11 dB
Downlink carrier-to-noise plus interference ratio is 14.22 dB
Downlink carrier-to-interference ratio is 21.49 dB
Downlink carrier-to-noise ratio is 15.12 dB
Receive earth station G/T is 28.31
Clear sky system temperature is 78.14°K
Receive antenna gain is 51.19 dB
Transmit antenna gain is 52.53 dB
Transmit antenna diameter is 3.8 m

HPA output power is 152.7 W

The third satellite design implements the Gstar satellite.[31] GTE Spacenet is the operator of this satellite. The Gstar satellite is also used for both analog and digital modulation schemes. The satellite can support a wide variety of users including television programmers, government agencies and businesses. The Gstar subsatellite point is 103°W. The Gstar technical specifications are given is Table 11.4. The Satellite link is obtained using the same previous design method. The link will be used for FM video. The maximum frequency is 4 MHz. The peak frequency deviation is 9.0 MHz. The resulting Carson's bandwidth is 26 MHz. The FM detector threshold is 10 dB. A 1 dB margin is allocated for equipment degradation and propagation effects. Thus the required Carrier-to-noise ratio is 11 dB. The transmit station is at Blacksburg, Virginia. The receive earth station is located at Vienna, Virginia. The earth station location specifications are listed in the SBS satellite link budget calculation. Table 11.2 is again used to illustrate the operating characteristic of a typical TWTA. The earth stations will use a 14/12 GHz satellite link. The satellite and earth station cross-polarization discrimination is assumed to be 30 dB. The carrier-to-adjacent satellite interference ratio is 32 dB for both the uplink and downlink. The carrier-to-adjacent channel

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[31] Alfred T. Barnes, *The 1985 Satellite Directory* 7th Annual Edition, Bethseda Md: Phillips Publishing Inc., 1985, pp 19, 22.

Table 11.4: Gstar Satellite Technical Characteristics

Owner:	GTE Corporation
Frequency Band:	12/14 GHz (Ku Band)
Receive:	14.000-14.500
Transmit:	11.700-12.200
Transponder Bandwidth:	54 MHz
Polarization:	Linear
Antenna Coverage: (Beam Edge EIRP)	45 dBW {1/2 CONUS} {east region}
Receive Coverage (G/T):	-1.0 to +2.0 dB/K
Single Carrier Saturation Flux Density:	-92 to -95 dB/m^2
Number of Transponders:	16
TWTA Power Output:	16 Watts
Design Life:	10 years
Services (FSS):	Voice,data,video

interference ratio is assumed to be 29 dB for both the uplink and downlink. The atmospheric and tracking loss is assumed to be 1.5 dB for both the uplink and downlink. The clear sky TWTA input back-off is 3 dB. The clear sky TWTA output back-off is 0.3 dB.

The design process is again started by establishing the allocation of outages. The same rain percentages are used. The percent rain rate exceeded for the uplink is established at 0.05%. The percent rain rate exceeded for the downlink is set at 0.1%. The point rain rates retain the same value as the previous calculations. The computer program is used to determine the azimuth, elevation, rain margin and rain induced cross-polarization interference for linear frequency reuse. The transmit station azimuth and elevation is 214.48° and 40.77° respectively. The Crane global rain attenuation at Blacksburg is 4.88 dB. The associated system temperature increase is 189.14°. The rain cross-polarization discrimination is 20.15 dB and 20.44 dB for horizontal and vertical polarizations. The receive station azimuth and elevation is 217.56° and 37.62° respectively. The Crane global rain attenuation at Blacksburg is 2.64 dB. The associated system temperature increase is 127.59°. The rain cross-polarization discrimination is 22.07 dB and 22.29 dB for horizontal and vertical polarizations.

The link budget design results for uplink rain only are summarized as follows:

Uplink carrier-to-noise ratio is 12.19 dB

Uplink carrier-to-interference ratio is 20.51 dB

Uplink carrier-to-noise ratio plus interference ratio is 11.60 dB

Downlink carrier-to-noise plus interference ratio is 19.89 dB

Downlink carrier-to-interference ratio is 22.6 dB

Downlink carrier-to-noise ratio is 23.22 dB

Receive earth station G/T is 32.70 dB/K

Transmit station EIRP is 69.04 dBW

The link budget design results for downlink rain only are listed as follows:

Uplink carrier-to-noise plus interference ratio is 16.48 dB

Downlink carrier-to-noise plus interference ratio is 12.44 dB

Downlink carrier-to-interference ratio is 19.96 dB

Downlink carrier-to-noise ratio is 13.29 dB

Receive earth station G/T is 23.91

Clear sky system temperature is 19.42°K

Receive antenna gain is 45.59 dB

Transmit antenna gain is 46.93 dB

Transmit antenna diameter is 2.0 m

HPA output power is 174.43 W

The communications design computer program is useful in establishing a satellite link design from a specific location to a geosynchronous satellite. The SBS satellite can support a greater bandwidth than the GTE satellites. The GTE satellites are designed with a reduced margin and lower bandwidth. The Gstar satellite has the lowest margin due to the saturation flux density and the rain attenuation. The program also shows the significance of rain attenuation. Several satellites were attempted using these earth station locations that resulted in a low elevation angle. The resulting rain induced cross-polarization interference caused the final carrier-to-noise ratio to be less than the minimum required. The designer then has several options. The design constraints will determine whether he may use a different satellite, or a different earth station location. He can also chose alternate antenna sizes, HPAs with varying output power or different low noise amplifiers. Another option is to establish another site to take advantage of site path diversity. Many of these options are constrained by the designer's operating costs. The design software allows the operator to figure out and evaluate several options quickly and easily.

Conclusion

The design of an efficient and effective satellite system is a complicated process. The designer must take several factors into consideration. The communication signals are affected by free space loss, atmospheric attenuation and rain attenuation. Other factors include cross polarization discrimination, system interference, carrier interference and intermodulation distortion interference. The communications link budget software package accumulates much of the information a designer would use in establishing a basic design. The program allows the designer to evaluate systems and derive operating characteristics in a shorter time. Thus the designer has more time to investigate these other factors or begin new projects.

The software package also can be a valuable training aid. It allows the design student the ability to evaluate several designs without wasting time in mathematical computations. The student can then observe how rain attenuation effects different frequencies. The student can see how a low elevation angle is severely affected by rain and how an alternate site may improve the link design.

The communications link budget software package is limited in that it does not compute the intermodulation ratios for specific input and output back-offs. This would be a valuable tool to figure out what input back-off value should be selected that results in the maximum carrier-to-noise ratio. Another option that could improve the usefulness of the software package would be the addition of a data base. The data base would be composed of the vendor technical information. It would list the vital statistics of the product such as operating specifications, design life, manufacturer and cost. Thus the design is optimized operationally and practically.

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Appendix

The appendix contains the code for the communications link budget software package. The computer program is written in Microsoft Basic. The program is run on Apple Macintosh Computers.

```
   REM***A communications link budget design software package allows an engineer
   REM***to determine link budget parameters in order to optimize the design

50 DIM  diff(255)
100 CLS
105 PRINT " Communications Engineer Design Software Package "
110 PRINT " Is the PC connected to  line printer?"
120 INPUT " Enter Y or N ";respptr$
125 lone#=0
130 cenanr = 0
135 CLS
200 PRINT " Satellite Communications Link Budget Calculations "
300 PRINT " Select the Desired Calculation Option "
400 PRINT " 1: Elevation Angle Determination (Geostationary) "
500 PRINT " 2: Rain Margin Determination "
520 PRINT " 3: Atmospheric Absorption Estimate "
540 PRINT " 4: Atmospheric Attenuation Calculation"
560 PRINT " 5: Path Diversity Gain
570 PRINT " 6: Link Budget Calculations
580 PRINT " 7: Baseband Performance Calculations"
590 PRINT " 8: Satellite Carrier Interference"
595 PRINT " 9: System Availability"
598 PRINT "10: Rain Induced Cross-Polarization Interference"


600 INPUT "        Input the Option Number ";opt$
700 IF opt$ = "1" GOTO 1000
800 IF opt$ = "2" GOTO 2000
850 IF opt$ = "3" GOTO 3000
875 IF opt$ = "4" GOTO 4000
890 IF opt$ = "5" GOTO 5050
900 IF opt$ = "6" GOTO 7000
910 IF opt$ = "7" GOTO 10000
920 IF opt$ = "8" GOTO 12000
930 IF opt$ = "9" GOTO 13500
935 IF opt$ = "10" GOTO 2002

1000 PRINT " Elevation Angle Determinaton (Option 1)"
1002 IF respptr$ ="N" OR respptr$="n" GOTO 1010
1004 LPRINT "  Subsatellite Point                          Earth Station"
1006 LPRINT "     Lat     Long         City,State   Lat   Long    Path Distance(km)   Azim
uth   Elevation"
1010 PRINT " Input the Subsatellite Coordinates"

     REM***lons# is the variable for the Longitude of the Subsatellite Point in degree
s
     REM***lonsd$ is the variable for the direction of the Subsatellite Point Longitud
e
```

```
1020 INPUT " Input the Subsatellite Point Longitude in Degrees"; lons#
1030 INPUT " Input the Subsatellite Point Longitude Direction ( E or W)";lonsd$
1040 PRINT " (The Subsatellite Latitude for a geosynchronous satellite is 0 degrees)"

     REM*** The program is written for a geosynchronous orbit therefore the
     REM*** the Subsatellite Latitude inputs are not required.
     REM*** INPUT "Input the Subsatellite Latitude in Degrees";lats#
     REM*** INPUT "Input the Subsatellite Latitude in Direction( N or S)";latsd$

1070 PRINT " Input the Earth Station Coordinates"

     REM***lone# is the variable for the longitude of the Earth Station in degrees
     REM***loned$ is the variable for the direction of the Earth Station longitude
     REM***late# is the variable for the latitude of the Earth Station
     REM***lated$ is the variable for the direction of the Earth Station latitude
     REM***citst$ is the variable for the city, state or country of the Earth Station

1080 INPUT " Input the Earth Station Longitude in Degrees"; lone#
1090 INPUT " Input the Earth Station Longitude Direction ( E or W)";loned$
1100 INPUT " Input the Earth Station Latitude in Degrees";late#
1110 INPUT " Input the Earth Station Latitude Direction ( N or S)";lated$
1115 PRINT " Input the Earth Station Location (City,State or Country)"
1117 INPUT " (12 characters, No punctuation)";citst$

     REM***The geosynchronous orbit radius is 42,242 km
     REM***The mean equatorial radius of the earth is 6378.155 km

1120 PRINT " The geosynchronous orbit is 42,242 km"

     REM***The Longitude direction of the satellite and the Earth Station
     REM***must be the same in order to determine the longitude difference

1130 IF lonsd$ = loned$  GOTO 1330
1140 IF lons#>180 GOTO 1200
1150 IF lone#>180 GOTO 1250

1200  lons#=360-lons#
1210 lonsd$=loned$
1220 GOTO 1330

1250 lone#= 360-lone#
1260 loned$ = lonsd$

     REM*** The absolute value of the longitude difference is calculated
     REM*** and converted to radians
     REM*** londif is the longitude difference between the the subsatellite point and
     REM*** the Earth Station
     REM*** londifr is the longitude difference in radians

1330  londif=ABS(lons#-lone#)
1350  londifr  =  londif*3.141592654#/180
```

```
     REM***cdif is the cosine of the longitude difference in radians
     REM***later# is the Earth Station latitude converted to radians
     REM***clate is the cosine of the Earth Station latitude

1370 cdif = COS (londifr)
1390  later#=late#*3.141592654#/180
1400 clate = COS(later#)

     REM***ccenan is the cosine of the central angle
     REM***The central angle is the between the Earth Station and the
     REM***satellite.  The angle is measured between the r(e) (radius
     REM***to the Earth Station) and r(s) (radius to the satellite). The
     REM***angle vertex is the center of the earth


1420 ccenan = clate*cdif
1440 x=ccenan

     REM***x is a dummy variable which is used to determine the central
     REM***angle in radians.  Microsoft Basic for the Macintosh uses the
     REM***arctangent function to calculate the inverse cosine
     REM***The resulting inverse cosine is in radians and is then converted to
     REM***degrees
     REM***cenanr is the central angle in radians
     REM***cenand is the central angle in degrees

1450 cenanr = -ATN(x/SQR(-(x*x)+1))+1.5708
1470 cenand = cenanr*180/3.141592654#
1480 PRINT " The central angle is ";cenand" degrees"

     REM***d is the distance from the earth station to the satellite
     REM***cel is the cosine of the elevation angle
     REM***Y is a dummy variable used to determine the inverse cosine
     REM***for the cosine of the elevation angle,cel
     REM***celr is the elevation angle in radians
     REM***eld# is the elevation angle in degrees
     REM***The function CSNG returns the single precision equivalent
     REM***of its argument

1490 d= 42242!*SQR(1.02274-.301596*COS(cenanr))
1500 PRINT " The distance from the earth station to the satellite is";d"km."
1510 cel = SIN(cenanr)/SQR(1.02274-.301596*COS(cenanr))
1520 Y = cel
1530 celr = -ATN(Y/SQR(-(Y*Y)+1))+1.5708
1540 eld# = celr*180/3.141592654#
1550 PRINT " The elevation angle is ";CSNG(eld#) " degrees"

     REM***This portion of the program calculates the azimuth angle
     REM***The Warren L. Stutzman Azimuth determination method is
     REM***selected
```

```
     REM***The geostationary subsatellite point latitude is zero

1560 lats# = 0

     REM***latdiff is the latitude difference between the subsatellite
     REM***and the Earth Station.  For a geosynchronous satellite,
     REM***the latdiff is simply the earth station latitude
     REM***lattdiffr is the latitude difference in radians

1570 latdiff = ABS(lats#-late#)
1600  latdiffr  =  latdiff*3.141592654#/180

     REM***hptsr is the half-perimeter of the azimuth triangle
     REM***vertxar is the argument vertex angle of the azimuth
     REM***triangle in radians
     REM***vertxr is the vertex angle of the azimuth triangle in radians
     REM***vertxd is the vertex angle of the azimuth triangle in degrees

1610 hptsr = .5*(latdiffr + londifr + cenanr)
1620 vertxar = SQR((SIN(hptsr-cenanr)*SIN(hptsr  -latdiffr))/(SIN(hptsr)*SIN(hptsr-
londifr)))
1630 vertxr = 2*ATN(vertxar)
1640  vertxd  =  vertxr*180/3.141592654#

     REM***The vertex angle is used to determine the azimuth triangle based
     REM***on the geometry situation between the satellite and the Earth station
     REM***Az is the variable for the azimuth angle

1660 PRINT" If the subsatellite point is southwest of the earth station enter SW"
1670 PRINT" If the subsatellite point is southeast of the earth station enter SE"
1680 PRINT" If the subsatellite point is northwest of the earth station enter NW"
1690 INPUT" If the subsatellite point is northeast of the earth station enter NE";optaz
$
1700 IF optaz$ = "sw" OR optaz$ = "SW" OR optaz$="sW" OR optaz$ = "Sw" THEN Az = 1
80  +vertxd
1702 IF optaz$ = "se" OR optaz$ = "SE" OR optaz$="sE" OR optaz$ = "Se" THEN Az = 180
 + vertxd
1704 IF optaz$ = "nw" OR optaz$ = "NW" OR optaz$="nW" OR optaz$ = "Nw" THEN Az = 3
60 - vertxd
1706 IF optaz$ = "ne" OR optaz$ = "NE" OR optaz$="nE" OR optaz$ = "Ne" THEN Az = vert
xd
1710 PRINT " The Azimuth angle is ";Az

     REM***The final results are tabulated and sent to the line printer

1712 IF respptr$ ="N" OR respptr$="n" GOTO 1760
1720 LPRINT "     ";CSNG(lats#)"   ";CSNG(lons#);lonsd$"         ";citst$"   ";CSNG(lat
e#);lated$" ";CSNG(lone#);loned$"      ";d"     ";Az;CSNG(eld#)

     REM*** The remaining section concludes this module with giving the user
     REM*** several ootions.  The user can reoeat this section or continue with the ne
```

```
x t
    REM*** The operator may return to the initiation panel or terminate the program

1760 INPUT " Do you desire to continue (Enter Y OR N) ";resp1$
1770 IF resp1$ = "Y" OR resp1$ = "y" GOTO 1772
1771 IF resp1$ ="N" OR resp1$ = "n" GOTO 14000


1772 PRINT " Do you desire to continue with azimuth and elevation calculations?"
1774 INPUT " Enter (Y or N)";resp2a$
1776 IF resp2a$ = "Y" OR resp2a$ = "y" GOTO 1010
1778 IF resp2a$ = "N" OR resp2a$ = "n" GOTO 1780

1780 PRINT " Do you desire to continue with the rain margin determination"
1782 INPUT " Enter (Y or N)";resp2$
1784 IF resp2$ = "Y" OR resp2$ = "y" GOTO 2000

1792 GOTO 125


    REM***The second module of the communications software package
    REM***is used to calculate the rain attenuation loss.  This is particularly
    REM***important when designing systems that use frequencies over 10 GHz.
    REM***First the rain margin attenuation is determined.  Next the increase
    REM***in the earth station antenna noise temperature is calculated.
    REM***The rain induced polarization loss is then determined.
    REM***Three methods are used to calculate the rain attenuation, the
    REM***Crane global model, the SAM model and the International Radio
    REM***Consultative Committee (CCIR model).

    REM***The Crane Global model is model is the first to be calculated

2000 PRINT " Rain Margin Determination (Option Number 2)"
2001 GOTO 2004
2002 PRINT " Rain-Induced Cross-Polarization Interference "
2003 GOTO 2008
2004 IF respptr$ ="N" OR respptr$="n" GOTO 2008
2005 LPRINT " Subsatellite Point    Earth Station    P%  Freq    Rain Attenuation(
db)/Temp increase"
2007 LPRINT "      Long       City,State  Lat  Long        CRANE     SAM      CCIR
"


    REM*** The elevation angle is necessary to determine the rain attenuation
    REM*** If the elevation angle was not determined in the previous section
    REM*** then the angle will be determined in this option
    REM*** If the earth station latitude is not equal to zero then the elevation
    REM*** would have already been calculated in option I.

2008 IF lone# <> 0  GOTO 2124
```

```
        REM*** The following variables are explained in the previous module.
        REM*** Although the satellite and Earth Station latitude and longitude
        REM*** points are not specifically used, they are necessary in order to
        REM*** obtain some of required inputs.

2010 PRINT " Input the Subsatellite Coordinates"
2020 INPUT " Input the Subsatellite Point Longitude in Degrees"; lons#
2030 INPUT " Input the Subsatellite Point Longitude Direction ( E or W)";lonsd$
2040 PRINT " (The Subsatellite Latitude for a geosynchronous satellite is 0 degrees)"

       REM***These equations are only valid for the special case of a geosynchronous
       REM***satellite.  The Subsatellite Latitude is zero and need not be entered.
       REM***INPUT  "Input the Subsatellite Latitude in Degrees";lats#
       REM***INPUT "Input the Subsatellite Latitude in Direction( N or S)";latsd$

2070 PRINT " Input the Earth Station Coordinates"
2080 INPUT " Input the Earth Station Longitude in Degrees"; lone#
2090 INPUT " Input the Earth Station Longitude Direction ( E or W)";loned$
2100 INPUT " Input the Earth Station Latitude in Degrees";late#
2105 INPUT " Input the Satellite Latitude Direction ( N or S)";lated$
2108 PRINT " Input the Earth Station Location (City,State or Country)"
2110 INPUT " (12 characters, No punctuation)";citst$


        REM*** The elevation is required to determine the rain attenuation loss.  If the
        REM*** angle is unknown it can be determined in the first option.
        REM*** If the angle is known, it is converted to radians

2112 PRINT " If the elevation is unknown it can be determined in option I"
2114 PRINT " Do You know the value of the elevation angle?"
2116 INPUT " Enter Y or N";respev$
2118 IF respev$ = "N" OR respev$ ="n" GOTO 1120
2120 INPUT " Input the Elevation Angle";eld#
2122  celr  =  eld#*3.141593/180

        REM***ho# is the height of the earth station in kilometers above sea level
        REM***freq# is the frequency of interest.  It can be either the uplink or the
        REM***downlink frequency depending on which link is being evaluated

2124 INPUT " Input the height of the earth station above sea level in km";ho#
2126 PRINT " The height of the earth station above sea level is";CSNG(ho#)"km."
2152 INPUT " Input the Frequency (Downlink/Uplink) in GHz";freq#
2160 PRINT " The Frequency of interest is ";CSNG(freq#)"GHz."

        REM***The rain climate region is determined from the figures "Rain climate
        REM***region in a Crane global model" (Figure 2.1)and "Rain climate regions in th
e United
        REM***States" (Figure 2.2).  The earth station location is required in order to sel
ect the
        REM***appropriate  region.
```

```
2170 PRINT " Select the rain climate region (Figure 2.1/Figure 2.2)"

      REM***Once the rain climate region is determined, the point rain rate distributio
n values
      REM***can be selected from the table "Point rain rate distribution values (mm/h
) versus
      REM***percent of year rain rate is exceeded" (Table 2.1)

2180 PRINT " Select the point rain rate distribution for that region (Table 2.1)"

      REM***prre# is the percent of year rain rate is exceeded
      REM***prrd# is the associated point rain rate distribution value for
      REM***the specific rain climate region

2190 INPUT " Input the percent of year rain rate is exceeded";prre#
2200 INPUT " Input the point rain rate distribution value";prrd#

      REM***h# is the height of the zero degree isotherm (vertical extent of the rain)
      REM***This height is determined from the figure " Height of 0 degree C isotherm
".
      REM***(Figure 2.5) The earth station latitude is required to determine the isothe
rm height

2222 PRINT " Input the 0 degree isotherm height corresponding to the"
2224 INPUT " probability of occurrence in km (Figure 2.5).";H#
2226 PRINT " The height of the 0 degree C isotherm is";CSNG(H#)"km."

      REM*** If the elevation angle is greater than or equal to 10 degrees the the surfa
ce
      REM*** projected path length is calculated from the height of the earth station,
 the
      REM*** 0 degree C isotherm, and the elevation angle
      REM*** dpl is the surface path projected length

2227 IF eld# < 10 GOTO 2230
2228 dpl = (H# - ho#)/TAN(celr)
2229 GOTO 2240

      REM***If the elevation angle is less than 10 degrees the projected path length is

      REM***calculated from r(ef), the effective earth's radius, the earth station heigh
t,
      REM***and the central angle.  The central angle is calculated in Option 1.  If the
central
      REM***angle was not determined this module will perform the required calculati
ons.
      REM***The central angle is determined from the elevation angle, the effective ea
rth's
      REM***radius, the 0 degree C isotherm, and the earth station height.

2230 IF cenanr <> 0 GOTO 2238
```

```
2231 z1=COS(celr)/(8500 + H#)
2232 z2 = -(8500+ho#)*SIN(celr)
2233 z3= SQR((8500+ho#)^2*SIN(celr)^2+17000*(H#-ho#)+H#^2-ho#^2)
2234 z= z1*(z2+z3)

     REM***cenanr is the variable for the central angle in radians

2236 cenanr = ATN(z/SQR(-(z*z)+1))
2238 dpl = (8500 + ho#)*cenanr

     REM***The frequency dependent coefficients a and b are based on
     REM***raindrop characteristics.  They can be approximated from
     REM***the frequency in gigahertz (Ghz)

2240 IF freq#>=2.9 AND freq#<=54 GOTO 2250
2242 IF freq#>=54 AND freq#<=108 GOTO 2256

2250 A = .0000421*freq#^2.42
2252 GOTO 2258
2256 A = .0409*freq#^.699

2258 IF freq#>=8.5 AND freq#<=25 GOTO 2270
2260 IF freq#>=25 AND freq#<=164 GOTO 2276

2270 B = 1.41*freq#^(-.0779)
2272 GOTO 2290
2276 B = 2.63*freq#^(-.272)

     REM***dcon,xcon,v, and u are constants which are derived from
     REM***point rain rate distribution

2290 dcon = 3.8 - .6* LOG(prrd#)
2300 xcon = 2.3*prrd#^(-.17)
2310 v=.026-.03*LOG(prrd#)
2320 u = LOG((xcon*EXP(v*dcon)))/dcon

     REM***l is the slant path.  Its value is determined from the surface
     REM***projected path length, and the elevation angle when that angle is
     REM***greater than or equal to 10 degrees

2331 IF eld#>= 10 GOTO 2340

     REM***When the elevation angle is less than 10 degrees , the slant path length
     REM***is determined from the effective earth's radius, the earth station height,
     REM***the 0 degree C isotherm and the elevation angle

2332 z2 = -(8500+ho#)*SIN(celr)
2333 z3= SQR((8500+ho#)^2*SIN(celr)^2+17000*(H#-ho#)+H#^2-ho#^2)
2334 l = z2+z3
2335 GOTO 2360
2340 l=dpl/COS(celr)
```

```
     REM*** When the surface projected path length is less than
     REM*** the dcon constant then the rain attenuation loss calculation
     REM*** is determined from the equation at address 2374

2360 IF dpl >= 0 AND dpl<= dcon GOTO 2370
2362 IF dpl >= dcon AND dpl <= 22.5 GOTO 2380
2370 var1a = (A*(prrd#^B)*l)/dpl
2372 var2a = (EXP(u*B*dpl) -1)/(u*B)
2374 lossra= var1a*var2a
2376 PRINT "The Crane Global rain attenuation is";lossra"dB."

     REM***Tb1 is the earth station antenna noise temperature increase due to
     REM***the effects of rain.  It is determined from the rain attenuation loss.

2377 Tb1 = 280*(1-EXP(-lossra/4.34))
2378 PRINT "The noise temperature increase of the Crane model is";Tb1"K."
2379 GOTO 2394

     REM***When the surface projected path length is less than 22.5 Km and
     REM***greater than the dcon constant, then the rain attenuation loss calculation
     REM***is determined from equation at address 2388


2380 var1b = (A*(prrd#^B)*l)/dpl
2382 var2b = (EXP(u*B*dcon) -1)/(u*B)
2384 var3b = xcon^B*EXP(v*B*dcon)/(v*B)
2386 var4b = xcon^B*EXP(v*B*dpl)/(v*B)
2388 lossra = var1b*(var2b-var3b+var4b)
2390 PRINT " The Crane Global rain attenuation is";lossra"dB."

     REM***Tb1 is the earth station antenna noise temperature increase due to
     REM***the effects of rain.  It is determined from the rain attenuation loss.

2391 Tb1 = 280*(1-EXP(-lossra/4.34))
2392 PRINT " The noise temperature increase of the Crane model is";Tb1"K."
2393 IF opt$ = "10" GOTO 2474

     REM***The SAM model is then used to calculate the rain attenuation loss.
     REM***This model was developed by NASA to provide a simple technique
     REM***for calculator use.
     REM***hi is the 0 degree C isotherm.  The SAM model uses an estimation
     REM***technique based on the earth station latitude.  When the latitude is less
     REM***than or equal to 30 degrees the isotherm is a constant (4.8 km).  When the
 latitude
     REM***is greater than 30 degrees the isotherm is calculated from the earth stat
ion latitude.

2394 IF late# <=30 THEN hi = 4.8 ELSE hi = 7.8 - .1*late#

     REM***he is the effective rain height.  The Sam model calculates this height
```

```
      REM***from hi, the 0 degree C isotherm and the point rain rate distribution
      REM***value.  When the rain rate is less than or equal to 10 mm/h then the
      REM***effective rain height is equal to the 0 degree C isotherm.  When the
      REM***rain rate is greater than 10, then the effective height is a function of
      REM***the rain rate and the isotherm height.

2396 IF prrd# <= 10 THEN he =hi ELSE he = hi + LOG(prrd#/10)/2.3026

      REM***lp is the slant path length in the rain.  The slant path is calculated from
      REM***the effective rain height, the earth's station height above sea level and
      REM***elevation  angle.
      REM***As in the Crane global model ho# is the earth station height above sea lev
el
      REM***and celr is the elevation angle in radians.

2400 lp = (he-ho#)/SIN(celr)

       REM***The rain attenuation is calculated from the raindrop temperature
       REM***coefficients, the point rain rate distribution, and the slant path length.
       REM***When the rain rate is greater than 10 mm/h then the elevation angle is
       REM***included in the calculation.

2402 IF prrd# <= 10 THEN GOTO 2408
2404 ap = A*(prrd#)^B*((1 - EXP(-(1/22)*B*LOG(prrd#/10)*lp*COS(celr)))/((1/22)*B
*LOG(prrd#/10)*COS(celr)))
2406 GOTO 2409
2408 ap = A*(prrd#)^B*lp
2409 PRINT " The SAM model rain attenuation is";ap"dB."

      REM***Tb3 is the earth station antenna noise temperature increase due to
      REM***the effects of rain.  It is determined from the rain attenuation loss
      REM***for the SAM model.

2410 Tb3 = 280*(1-EXP(-ap/4.34))
2411 PRINT " The noise temperature increase of the SAM model is";Tb3"K."


      REM***The CCIR model is based upon a prediction of the rain attenuation
      REM***loss expected for the 0.01% rain rate and then scaling it to other
      REM***percentages.  This model is used for percentages between .001 through
      REM***0.1%.

      REM***The rain height for the CCIR model is calculated from the earth station
      REM***latitude
      REM***hr is the rain height

2412 hr=5.1 - 2.15*LOG(1 + 10^((late# - 27)/25))/2.302585093#

      REM***ls is the variable for the CCIR model slant path length.  The slant
      REM***is calculated from the rain height,hr, the earth station height above
      REM***sea level.ho#.and the elevation anole.
```

```
     REM***When the elevation angle is less than 10 degrees the effective earth's
     REM***radius is included.

2413 IF eld# >=10 GOTO 2416
2414 ls= 2*(hr-ho#)/SQR((SIN(celr)^2 + (2*(hr-ho#))/8500) + SIN(celr)
2415 GOTO 2417

     REM***When the elevation angle is greater than or equal to zero the
     REM***slant path is calcualted from the rain height, the earth station
     REM***height above sea level and the elevation angle.

2416 ls= (hr-ho#)/SIN(celr)

     REM***lg is the horizontal projection of the slant path ls in kilometers

2417 lg = ls*COS(celr)

     REM***rp is the path length reduction factor.  It accounts for the spatial
     REM***nonuniformity of the rain rate.  rp is calculated from the
     REM***horizontal projection

2418 rp = 90/(90 + 4*lg)

     REM***The 0.01% rain attenuation is calculated from the frequency coefficients
     REM***a and b, the slant path length and the path length reduction factor.  The
     REM***point rain rate distribution value is included also.  The rain rate for a 0.01
% is 49 mm/h.

2420 a01 = A*(49)^B*ls*rp

     REM***The rain attenuation is predicted from the 0.01% value.  The scale factor
     REM***is calculated from the percentages from 0.001% through 0.1%.

2421 IF prre#>=.001 AND prre#<=.01 THEN GOTO 2430
2422 IF prre#>.01 AND prre#<=.1 THEN GOTO 2425
2423 PRINT " The CCIR model cannot be used for a percentage of ";prre#
2424 GOTO 2437
2425 apc = a01*(prre#/.01)^-.41

     REM***Tb4 is the earth station antenna noise temperature increase due to
     REM***the effects of rain.  It is determined from the rain attenuation loss for
     REM***the CCIR model.

2426 Tb4 = 280*(1-EXP(-apc/4.34))
2427 PRINT " The CCIR mode rain attenuation is";apc"dB."
2428 PRINT " The noise temperature increase of the CCIR model is";Tb4"K."

2429 GOTO 2434
2430 apc = a01*(prre#/.01)^ -.33

     REM***Tb4 is the earth station antenna noise temoerature increase due to
```

```
        REM***the effects of rain.  It is determined from the rain attenuation loss
        REM***for the CCIR model.

2431 Tb4 = 280*(1-EXP(-apc/4.34))
2432 PRINT " The CCIR mode rain attenuation is";apc"dB."
2433 PRINT " The noise temperature increase of the CCIR model is";Tb4"K."


2434 IF respptr$ ="N" OR respptr$="n" GOTO 2437
2435 LPRINT "     ";CSNG(lons#);lonsd$"          ";citst$"    ";CSNG(late#);lated$"    ";CSNG
(lone#);loned$"   ";CSNG(prre#)"  ";CSNG(freq#);
2436 LPRINT USING"####.#";lossra;Tb1;ap;Tb3;apc;Tb4

        REM***The software package gives two methods for determining the cross-polar
ization
        REM***discrimination.  The first method is the CCIR approximation.  There is som
e uncertainty
        REM***as to the appropriate values for the coefficients.  However for quick estim
ates this method
        REM***gives near results.  The second method will determine the horizontal and
vertical  cross-
        REM***polarization discrimination components in dB for orthogonal linear polari
zations.  The carrier-
        REM***to-cross polarization interference is calculated for orthogonal circular p
olarizations.

2437 PRINT " The rain depolarization is calculated for nominal rain attenuation"
2438 PRINT " values between and including 3 through 30 dB."
2439 PRINT " Do you desire to calculate the rain depolarization loss or the"
2440 INPUT " rain induced cross-polarization discrimination interference ";resp3a$
2441 IF resp3a$ = "Y" OR resp3a$ = "y" GOTO 2443
2442 IF resp3a$ ="N" OR resp3a$ = "n" GOTO 2867
2443 PRINT " If you desire to calculate the approximate rain depolarization loss enter
 ap"
2444 PRINT " If you desire to calculate the vertical, horizontal, and circular rain induc
ed"
2445 INPUT " cross-polarization discrimination interference (Option 10), enter ac";res
p3b$

2446 IF resp3b$ = "ap" OR resp3b$ = "AP" OR resp3b$ ="aP" OR resp3b$ = "Ap" GOTO 24
48
2447 IF resp3b$ = "ac" OR resp3b$ = "AC" OR resp3b$ ="aC" OR resp3b$ = "Ac" GOTO 24
74

        REM***tau is the variable which represents the angle between the received
        REM***electric field and the local horizontal

2448 PRINT " Input the angle between the received electric field and the"
2449 INPUT " local horizontal.  (For circular polarization enter 45 deg.)";tau#

        REM***taur is the angle between the received electric field and the local horizon
```

```
tal
       REM*** in radians

2450  taur=3.141592654#*tau#/180

       REM***The CCIR approximation is valid for the nominal attenuation range from
       REM***three through thirty dB.

2452  uxpd=(30/LOG(10))*LOG(freq#)-(40/LOG(10))*COS(celr)-(20/LOG(10))*LOG(SIN
(2*taur))

      REM***The CCIR rain depolarization loss is determined for the Crane, SAM, and CC
IR models

2453 IF lossra>=3 AND lossra<30 THEN GOTO 2456

2454 PRINT " The rain depolarization loss cannot be calculated for the Crane model."
2455 GOTO 2458

      REM***The rain depolarization for the Crane global model

2456  xpd1=uxpd-(20/LOG(10))*LOG(lossra)
2457 PRINT " The rain depolarization loss for the Crane model is ";xpd1"dB."
      IF respptr$ ="N" OR respptr$="n" GOTO 2458
      LPRINT "                    The rain depolarization loss for the Crane model is ";xpd1"
dB."
2458 IF ap>=3 AND ap<30 THEN GOTO 2461

2459 PRINT " The rain depolarization loss cannot be calculated for the SAM model."
2460 GOTO 2463

       REM***The rain depolarization for the SAM model

2461  xpd2=uxpd-(20/LOG(10))*LOG(ap)
2462 PRINT " The rain depolarization loss for the SAM model is ";xpd2"dB."
      IF respptr$ ="N" OR respptr$="n" GOTO 2463
      LPRINT "                    The rain depolarization loss for the SAM model is ";xpd2"dB
."
2463 IF apc>=3 AND apc<30 THEN GOTO 2466

2464 PRINT "The rain depolarization loss cannot be calculated for the CCIR model."
2465 GOTO 2867

       REM***The rain depolarization for the CCIR model

2466  xpd3=uxpd-(20/LOG(10))*LOG(apc)
2467 PRINT " The rain depolarization loss for the CCIR model is ";xpd3"dB."
      IF respptr$ ="N" OR respptr$="n" GOTO 2472
      LPRINT "                    The rain depolarization loss for the CCIR model is ";xpd3"d
B."
2472 GOTO 2867
```

```
      REM***The next section calculates the horizontal,vertical and carrier-to-
      REM***cross rain discrimination interference
      REM***lep is the variable that represents the effective path length.  It is defined
      REM***as the ratio of the total path attenuation (lossra) to the rain attenuation
per
      REM***unit length

2474 lep = lossra/(A*(prrd#)^B)

      REM***difat90# is the variable which represents the differential attenuation fo
r the case
      REM***where the angle between the direction of propagation and the raindrop sy
mmetry Y
      REM***axis is ninety degrees.  This value is obtained from the figure " Differenti
al Attenuation"
      REM***(Figure 10.3)

2475 PRINT " Input the Differential attenuation for the case where the"
2476 PRINT " angle between the direction of propagation and the raindrop"
2477 INPUT " symmetry Y axis is 90 degrees (Figure 10.3)";difat90#

      REM***difph90# is the variable which represents the differential phase shift fo
r the case
      REM***where the angle between the direction of propagation and the raindrop sy
mmetry Y
      REM***axis is ninety degrees.  This value is obtained from the figure " Differenti
al Phase Shift"
      REM***(Figure 10.4)

2478 PRINT " Input the Differential phase shift for the case where the"
2479 PRINT " angle between the direction of propagation and the raindrop"
2480 INPUT " symmetry Y axis is 90 degrees (Figure 10.4)";difph90#

      REM***poltr is the polarization tilt angle
      REM***rncntang is the rain canting angle in degrees
      REM***cntangr is the variable which represents the sum of the
      REM***polarization tilt and the rain canting angle
      REM***cntangr is in radians

2482 INPUT " Input the polarization tilt angle in degrees ";polt#
          poltr = polt#*3.141592654#/180

2483 INPUT " Input the rain canting angle in degrees ";rncntang#
          rncntangr = rncntang#*3.141592654#/180


2484 cntangr = rncntangr + poltr

      REM***difat is the variable which represents the differential attenuation
      REM***difph is the variable which represents the differential phase shift
```

```
2485 difat = COS(celr)^2*difat90#/8.686
2486 difph = COS(celr)^2*difph90#*3.141592654#/180

     REM***The variables real and imag represent the real and imaginary components
of
     REM***the Tx/Ty ratio.  Tx and Ty are the transmission coefficients over an effec
tive
     REM***rainfall path.

2488 real = EXP(-difat*lep)*(COS(difph*lep))
2490 imag = EXP(-difat*lep)*(SIN(difph*lep))

     REM***numlv is the variable which represents the numerator of the vertical cros
s
     REM***polarization discrimination in dB for linear polarizations.
     REM***numlh is the variable which represents the numerator of the horizontal cr
oss
     REM***polarization discrimination in dB for linear polarizations.
     REM***denoml is the variable which represents the denominator of both the vert
ical and
     REM***horizontal discrimination for linear polarizations.

     REM***numc is the variable which represents the numerator of the carrier-to-cr
oss polarization
     REM***for circular polarizations.
     REM***denomc is the variable which represents the denominator of the carrier-t
o-cross polarization
     REM***for circular polarizations.

     REM***The absolute value is obtained by taking the square root of the sum of
     REM***the squares of the real and imaginary terms.

2492 numlv = SQR(((real*TAN(cntangr)^2)+1)^2 + (imag*TAN(cntangr)^2))
2494 numlh = SQR((real+TAN(cntangr)^2)^2 + imag^2)
2496 denoml = SQR(((real-1)*TAN(cntangr))^2 + (imag*TAN(cntangr))^2)

2498 numc = SQR((real + 1 )^2 + imag^2)
2500 denomc = SQR((real - 1)^2 + imag^2)

     REM***Xh is the variable which represents the horizontal cross polarization disc
rimination
     REM***Xv is the variable which represents the vertical cross polarization discri
mination
     REM***Xc is the variable which represents the carrier-to- cross polarization dis
crimination

2502 Xh = 20*(1/LOG(10))*LOG(numlh/denoml)
2504 Xv = 20*(1/LOG(10))*LOG(numlv/denoml)
2506 Xc = 20*(1/LOG(10))*LOG(numc/denomc)
```

```
2508 PRINT " The orthogonal linear horizontal polarization is ";Xh"dB."
2510 PRINT " The orthogonal linear vertical polarization is ";Xv"dB."
2512 PRINT " The orthogonal circular polarization is ";Xc"dB."

2514 IF respptr$ ="N" OR respptr$="n" GOTO 2530
2516 LPRINT "                    The orthogonal linear horizontal polarization is ";Xh"dB."
2518 LPRINT "                    The orthogonal linear vertical polarization is ";Xv"dB."
2520 LPRINT "                    The orthogonal circular polarization is ";Xc"dB."
2530 IF opt$ = "2" THEN GOTO 2867

2540 INPUT " Do you desire to continue (Enter Y OR N) ";resp3a$
2560 IF resp3a$ = "Y" OR resp3a$ = "y" GOTO 2564
2562 IF resp3a$ ="N" OR resp3a$ = "n" GOTO 14000

2564 PRINT " Do you desire to calculate another Rain-Induced "
2565 PRINT " Cross-Polarization Interference"
2566 INPUT " Enter (Y or N)";resp4a$
2567 lone# = 0
2568 IF resp4a$ = "N" OR resp4a$ = "n" GOTO 125
2570 IF resp4a$ = "Y" OR resp4a$ = "y" GOTO 2002


2867 INPUT " Do you desire to continue (Enter Y OR N) ";resp3$
2870 IF resp3$ = "Y" OR resp3$ = "y" GOTO 2882
2871 IF resp3$ ="N" OR resp3$ = "n" GOTO 14000
2882 PRINT " Do you desire to calculate another rain margin"

2890 INPUT " Enter (Y or N)";resp4$
2892 IF resp4$ = "N" OR resp4$ = "n" GOTO 2900
2894 IF resp4$ = "Y" OR resp4$ = "y" GOTO 2895
2895 PRINT " Do you desire to use the same satellite"
2896 INPUT " and earth station coordinates (Enter Y or N)";resp5$

2897 IF resp5$ = "Y" OR resp5$ = "y" GOTO 2152
2898 IF resp5$ = "N" OR resp5$ = "n" GOTO 2010
2900 PRINT " Do you desire to calculate Atmospheric Absorption "
2910 PRINT " Estimate?"
2920 INPUT " Enter (Y or N)";resp6$
2930 IF resp6$ = "n" OR resp6$ = "N"  GOTO 125
2940 IF resp6$ = "y" OR resp6$ = "Y" GOTO 3000

     REM***The next module estimates the atmospheric attenuation due to
     REM***atmospheric gaseous absorption.  The estimate is valid for
     REM***frequencies between 1 through 15 Ghz and from elevation angles
     REM***0 through 90 degrees.

3000 PRINT " Atmospheric Absorption Estimate"
3020 PRINT " Option Number 3"
3030 IF respptr$ ="N" OR respptr$="n" GOTO 3040
3032 LPRINT "     Standard    Frequency    Elevation    Atmospheric Attenuation(dB)"
```

```
     REM***The estimate can be used with either one of two standards.  These
     REM***standards provide two sets of atmospheric parameters.

3040 PRINT " This estimate can be calculated using two standards"
3060 PRINT " of  relevant atmospheric parameters.  These parameters"
3080 PRINT " include the surface water vapor concentration (g/m^3)  and"
3100 PRINT " surface temperature (C)."
3120 PRINT " Standard A: [vapor] = 11.1, T =14.6 C"
3140 PRINT " Standard B: [vapor] = 07.5, T = 20.0 C"
3160 PRINT " Standard B is most often used for CCIR reference purposes."
3170 PRINT " The approximation is valid for frequencies between 1 - 15 Ghz"

3182 IF freq# <> 0 GOTO 3185

     REM***The program checks to verify whether a specific frequency has been
     REM***specified.  If not the user may enter the desired frequency.
     REM***The estimate is only valid for frequencies between one and fifteen
     REM***degrees.  The program ensures this criteria is met and alerts the operator
     REM***when it is not.

3184 INPUT " Input the Frequency (Downlink/Uplink)";freq#
3185 IF freq#<1 OR freq#>15 GOTO 3700

3186 IF eld# <> 0 GOTO 3190

     REM***The program checks to verify whether an elevation angle has been
     REM***specified.  If not the user may enter the desired angle.
     REM***The estimation is only valid for elevation angles between zero through 90
     REM***degrees.  The program ensures this criteria is met and alerts the operator
     REM***when it is not.

3187 INPUT " Input the elevation angle";eld#
3188 IF eld#<0 OR eld#>90 GOTO 3700
3189  celr=eld#*3.141593/180

     REM***The operator is given the option of selecting which standard best
     REM***meets with the design requirements

3190 INPUT " Input the desired Standard (Enter A or B)";stnd$

3200 IF stnd$ = "a" OR stnd$ = "A" GOTO 3500
3220 IF stnd$ = "b"OR stnd$ ="B" GOTO 3300
3240 IF stnd$<> "b" OR stnd$<>"B" GOTO 3190

     REM***This section of the program uses Standard B parameters to calculate
     REM***the gaseous attenuation.
     REM***ys is the variable for the specific attenuation (dB/km) at the earth's surf
ace
     REM***ha is the scale height and is defined as the ratio between the total vertic
al
     REM***(zenith) attenuation in dB caused by gaseous absorption and the specific a
```

```
ttenuation.

3300 ys = .00442*EXP(.1178*freq#)
3320 ha = 6.43*EXP(-.048*freq#)
3340 GOTO 3540

     REM***This section of the program uses Standard A parameters to calculate
     REM***the gaseous attenuation.
     REM***ys is the variable for the specific attenuation (dB/km) at the earth's surf
ace
     REM***ha is the scale height and is defined as the ratio between the total vertic
al
     REM***(zenith) attenuation in dB caused by gaseous absorption and the specific a
ttenuation.

3500 ys = .00466*EXP(.1362*freq#)
3520 ha = 6.01*EXP(-.0485*freq#)

     REM***ra is the variable which represents the effective slant path length in km.
 ra is a
     REM***function of the elevation angle, scale height and the effective earth's rad
ius.

3540 IF eld# >10 GOTO 3580
3560  ra=2*ha/(SIN(celr)^2 + SQR(2*ha/8500)  +SIN(celr))
3570 GOTO 3600
3580 ra= ha/SIN(celr)

     REM***Ata is the variable which represents the slant path attenuation for the at
mospheric gases
     REM***(water vapor and molecular oxygen)

3600 Ata = ys*ra
3620 PRINT " The Atmospheric Absorption Estimate loss  is ";Ata "dB."
3622  IF respptr$ ="N" OR respptr$="n" GOTO 3626
3624 LPRINT"       "stnd$;"       "CSNG(freq#);"        "CSNG(eld#);"         "CSNG(A
ta)

     REM***The variables of frequency and elevation angle are initialized for subsequ
ent calcualtions

3626 freq# = 0
3628 eld# = 0

3640 INPUT " Do you desire to continue (Enter Y OR N) ";resp7$
3660 IF resp7$ = "Y" OR resp7$ = "y" GOTO 3664
3662 IF resp7$ ="N" OR resp7$ = "n" GOTO 14000

3664 PRINT " Do you desire to calculate another atmospheric absorption estimate"
3666 INPUT " Enter (Y or N)";resp8$
3668 IF reso8$ = "N" OR reso8$ = "n" GOTO 125
```

```
3670 IF resp8$ = "Y" OR resp8$ = "y" GOTO 3184

3700 PRINT " The estimation is only valid for frequencies between 1 through 15 Ghz"
3720 PRINT " and for elevation angles between 0 through 90 degrees."
3730 freq# = 0
3735 eld# = 0
3740 GOTO 3184

     REM***This module of the program presents an alternate method of calculating
     REM***the atmospheric loss due to attenuation.

4000 PRINT " Atmospheric Attenuation Calculation (Option Number 4)"
4002 IF respptr$ ="N" OR respptr$="n" GOTO 4010
4004 LPRINT" Frequency  Temperature  Density {Temp corr} {Den corr} {Zenith att}  Ele
vation {Atmos loss dB}"

4010 PRINT " The standard atmospheric parameters used for this "
4020 PRINT " calculation are as follows:"
4030 PRINT " Surface temperature = 21 degrees C"
4040 PRINT " Water vapor concentration = 7.5 g/m^3"
4060 PRINT " Standard Latitude = 45 deg North, July "

     REM***Although the frequency is not specifically used in any of the
     REM***calculations it is required as an input to find the zenith one-way
     REM***attenuation

4070 INPUT " Input the frequency (Uplink/Downlink) in Ghz";freq#

     REM***lap# is the variable which represents the zenith one-way attenuation
     REM***for a moderately humid atmosphere.  Typical values can be obtained from
     REM***either the table "Typical one-way clear-air total zenith attenuation value
s"
     REM***(Table 4.1) or from the figure "Atmospheric Attenuation" (Figure 4.1).

4080 PRINT " Input the one way typical clear-air total zenith"
4100 INPUT " attenuation value in dB (Table 4.1 or Figure 4.1).";lap#

     REM***bp# is the variable which represents the water density correction coeffic
ient.
     REM***Typical values may be found in the table "Water vapor density and temper
ature
     REM***correction  coefficients  (Table  4.2)

4150 INPUT " Input the water vapor density correction factor (Table 4.2) ";bp#

     REM***ct# is the variable which represents the temperature correction factor.
     REM***Typical values may be found in the table "Water vapor density and temper
ature
     REM***correction  coefficients

4200 INPUT " Input the temperature correction coefficient (Table 4.2) ";ct#
```

```
     REM***T0# is the surface temperature in degrees centigrade.  The factor
     REM***ct#(21-T0#) accounts for the suface temperature difference from
     REM***21 degrees centigrade

4340 INPUT" Input the surface temperature (C). ";T0#

     REM***eld# is the variable which represents the elevation angle
     REM***celr is the elevation angle in radians
     REM***If the elevation angle has not been specified the operator
     REM***may enter its value

4342 IF eld# <> 0 GOTO 4350
4344 INPUT "Input the elevation angle in degrees ";eld#
4346  celr=eld#*3.141593/180

     REM***p0# is the variable which represents the surface water vapor density (g/
m^3)
     REM***The factor bp#(p0#-7.5) accounts for the difference between the local su
rface
     REM***water vapor density and 7.5 g/m^3.

     REM***The program gives the operator the option of entering the exact water vap
or density
     REM***if known or of estimating the density.  The density is found from the rela
tive humidity,
     REM***the local surface temperature and the saturated partial pressure of wate
r vapor at that
     REM***local temperature.
     REM***If the saturated partial pressure is not known it may also be estimated fr
om the surface
     REM***temperature in degrees Fahrenheit

4350 PRINT " Input the surface water vapor density. Enter 0 "
4400 INPUT " if the exact value is unknown";p0#
4440 IF p0# <> 0 GOTO 4680

     REM***hum# is the variable which represents the relative humidity
     REM***es# is the variable which represents the saturated patial pressure of
     REM***water vapor.

4460 PRINT " An estimate of the surface water vapor follows"
4480 INPUT " Input the relative humidity (eg hum=60% = .6)";hum#
4490 PRINT " Input the saturated partial pressure of water vapor (N/m^2)"
4500 PRINT " corresponding to the local surface temperature"
4540 PRINT " Enter 0 if the water vapor saturated partial pressure will"
4580 INPUT " be estimated";es#
4600 IF es#<> 0 GOTO 4660

     REM***T0F is the conversion of T0# in degrees centigrade to Fahrenheit.
     REM***The estimated saturated patial pressure is calculated using T0F.
```

```
4640 TOF =(T0#)*9/5 + 32
4650 es# = 206.43*EXP(.0354*TOF)

     REM***The surface water vapor density is calculated from the ideal gas law

4660  p0#  =  (hum#)*(es#)/(.461*(T0#+273))

      REM***latta is the variable which represents the atmospheric attenuation loss
in dB

4680 latta  =  (lap#  +  (bp#)*((p0#)-7.5)  +  (ct#)*(21-T0#))/SIN(celr)

4700 PRINT " The Atmospheric attenuation loss is "; latta"dB."
4702  IF respptr$ ="N" OR respptr$="n" GOTO 4740
4704 LPRINT "   "CSNG(freq#);"   "CSNG(T0#);"   "CSNG(p0#);"  "CSNG(ct#);"    "CSN
G(bp#);"    "CSNG(lap#);"      "CSNG(eld#);"    "CSNG(latta)

4740 INPUT "Do you desire to continue (Enter Y OR N) ";resp9$
4760 IF resp9$ = "Y" OR resp9$ = "y" GOTO 4764
4762 IF resp9$ ="N" OR resp9$ = "n" GOTO 14000

4764 PRINT "Do you desire to calculate another Atmospheric Attenuation Calculation"
4766 INPUT "Enter (Y or N)";resp10$
4768 IF resp10$ = "N" OR resp10$ = "n" GOTO 125
4770 IF resp10$ = "Y" OR resp10$ = "y" GOTO 4070

     REM***Rain induced attenuation can greatly affect satellite operation at and
     REM*** above 10 GHz.  Path (Site) diversity is one means of overcoming
     REM***this problem.  Path diversity is accomplished by using two earth stations
     REM***located approximately 5 to 30 Km apart.  When one of the stations is affe
cted
     REM***by rain the other would not be affected.   This reduces the probability of o
utage.
     REM***This module calculates the path diversity gain when two sites
     REM***are implemented versus one.

    REM***The earth station coordinates for both sites are entered
    REM***lone1# is the variable which represents the longitude in degrees of the fir
st  station
    REM***lone1d$ is the variable which represents the direction of longitude for the
  first  station
    REM***late1# is the variable which represents the latitude in degrees of the firs
t  station
    REM***late1d$ is the variable which represents the direction of latitude for the
first  station

5050 IF respptr$ ="N" OR respptr$="n" GOTO 5070
5055 LPRINT "  Subsatellite Point  Earth Station 1  Earth Station 2  Sep Dis Rain loss(d
B) Diversity Gain(dB)"
5060 LPRINT "      Long          Lat  Long       Lat  Long                     Hodge   Improv
```

```
ed "

5070 INPUT " Input the Subsatellite Point Longitude in Degrees"; lons#
5072 INPUT " Input the Subsatellite Point Longitude Direction ( E or W)";lonsd$

5075 PRINT " Input the Site 1 Earth Station Coordinates "
5080 INPUT " Input the Site 1 Earth Station Longitude in Degrees"; lone1#
5090 INPUT " Input the Site 1 Earth Station Longitude Direction ( E or W)";loned1$
5100 INPUT " Input the Site 1 Earth Station Latitude in Degrees";late1#
5110 INPUT " Input the Site 1 Satellite Latitude Direction( N or S)";lated1$

    REM***eld1# is the variable which represents the elevation angle of the first ear
th  station
    REM***The elevation angle and path distance are calculated in the same manner a
s they are in Option 1
    REM***celr1 is the variable which represents the elevation angle in radians

5112 IF lonsd$ = loned1$  GOTO  5128
5114 IF lons#>180 GOTO  5118
5116 IF lone1#>180 GOTO  5124

5118   lons#=360-lons#
5120  lonsd$=loned1$
5122  GOTO  5128

5124   lone1#= 360-lone1#
5126  loned1$ = lonsd$
5128  londif1=ABS(lons#-lone1#)
          londifr1 = londif1*3.141592654#/180
       cdif1 = COS  (londifr1)
           later1#=late1#*3.141592654#/180
       clate1 = COS(later1#)
         ccenan1 = clate1*cdif1
       x1=ccenan1
        cenanr1 = -ATN(x1/SQR(-(x1*x1)+1))+1.5708
          cenand1 = cenanr1 *180/3.141592654#
      PRINT " The central  1  angle is ";cenand1" degrees"
       d1= 42242!*SQR(1.02274-.301596*COS(cenanr1))
      PRINT " The distance from the earth station 1 to the satellite is";d1"km."
       cel1 = SIN(cenanr1)/SQR(1.02274-.301596*COS(cenanr1))
       Y1 = cel1
       celr1 = -ATN(Y1/SQR(-(Y1*Y1)+1))+1.5708
          eld1# = celr1*180/3.141592654#
      PRINT " The elevation angle  1 is ";CSNG(eld1#) " degrees"


    REM***The  path length from the second site to the satellite is then calculated
    REM***The program follows the same method as for the first earth station calcu
lation
    REM***lone2# is the variable which represents the longitude in degrees of the se
cond  station
```

```
     REM***lone2d$ is the variable which represents the direction of longitude for th
e second station
     REM***late2# is the variable which represents the latitude in degrees of the sec
ond station
     REM***late2d$ is the variable which represents the direction of latitude for the
 second station

5150 PRINT " Input the Site 2 Earth Station Coordinates "
5152 INPUT " Input the Site 2 Earth Station Longitude in Degrees"; lone2#
5154 INPUT " Input the Site 2 Earth Station Longitude Direction ( E or W)";loned2$
5156 INPUT " Input the Site 2 Earth Station Latitude in Degrees";late2#
5158 INPUT " Input the Site 2 Satellite Latitude Direction( N or S)";lated2$


     REM***eld2# is the variable which represents the elevation angle of the first ear
th station
     REM***The elevation angle is calculated in the same way as is in Option 1
     REM***celr2 is the variable which represents the elevation angle in radians

5160 IF lonsd$ = loned2$ GOTO 5176
5162 IF lons#>180 GOTO 5166
5164 IF lone2#>180 GOTO 5172

5166  lons#=360-lons#
5168 lonsd$=loned2$
5170 GOTO 5176

5172  lone2#= 360-lone2#
5174 loned2$ = lonsd$
5176  londif2=ABS(lons#-lone2#)
         londifr2 = londif2*3.141592654#/180
      cdif2 = COS (londifr2)
         later2#=late2#*3.141592654#/180
      clate2 = COS(later2#)
        ccenan2 = clate2*cdif2
      x2=ccenan2
      cenanr2 = -ATN(x2/SQR(-(x2*x2)+1))+1.5708
        cenand2 = cenanr2 *180/3.141592654#
     PRINT " The central 2 angle is ";cenand2" degrees"
      d2= 42242!*SQR(1.02274-.301596*COS(cenanr2))
     PRINT " The distance from the earth station 1 to the satellite is";d1"km."
      cel2 = SIN(cenanr2)/SQR(1.02274-.301596*COS(cenanr2))
      Y2 = cel2
      celr2 = -ATN(Y2/SQR(-(Y2*Y2)+1))+1.5708
        eld2# = celr2*180/3.141592654#
     PRINT " The elevation angle 2 is ";CSNG(eld2#) " degrees"


     REM***ratt# is the variable which represents the rain attenuatio loss.
     REM***This loss is calculated in OPTION 2
     REM***freq# is the variable which represents the frequency
```

```
5180 INPUT " Input the rain attenuation loss in dB (Option 2).";ratt#
5223 INPUT " Input the Frequency (Downlink/Uplink)";freq#

     REM***The next section of the program is used to estimate the separation distan
ce between
     REM***the two earth stations.  The straight line separation distance is estimate
d from the
     REM***longitude and latitude values of both sites.  The longitude and latitude dif
ference
     REM***between the stations is determined and converted to kilometers.  The sep
aration distance
     REM***is determined from the square root of the sum of the squares.
     REM***One degree of latitude is equal to 69 statute miles.  One degree of longitu
de varys.
     REM***The program uses one degree of longitude as 49 statute miles.  This is the
 value for one
     REM***degree of longitude at 45 degrees north latitude.
     REM***The operator is given the option of entering the exact separation distance
 when its value
     REM***is known.

5400 IF loned1$=loned2$ THEN GOTO 5750
5450 IF lone1#>180 THEN GOTO 5550
5500 IF lone2#>180 THEN GOTO 5650
5550 lone1# = 360 - lone1#
5600 loned1$=loned2$

5650 lone2#= 360 - lone2#
5700 loned2$ = loned1$
5750 londiff = ABS(lone1#-lone2#)

5850 IF lated1$=lated2$ THEN GOTO 6200
5900 IF late1#>180 THEN GOTO 6000
5950 IF late2#>180 THEN GOTO 6100
6000 late1# = 360 - late1#
6050 lated1$=lated2$

6100 late2#= 360 - late2#
6150 lated2$ = lated1$
6200 latdiff = ABS(late1#-late2#)

6225 PRINT " Input the separation difference between the two sites."
6230 PRINT " Input zero if you desire an approximation based on the "
6235 INPUT "  site coordinates in km";dps#
6240 IF dps#<> 0 GOTO 6325
6300 dps#=(SQR((latdiff*69)^2 + (londiff*49)^2))*1.609347
6325 PRINT " The separation distance between the two sites is "CSNG(dps#)"km."

     REM***The baseline-to-path angle is calculated from the separation distance,
     REM***and the oath distance of both sites.  The Law of Cosines is used to
```

```
     REM***determine this value
     REM***cbp is the variable which represents the cosine of the baseline-to-path a
ngle

6340 IF dps#> 30 GOTO 6655
6350 cbp=(dps#^2 +d1^2-d2^2)/(2*dps#*d1)

6355 IF ABS(cbp) > = 1 GOTO 6635

     REM***db is a dummy variable and is used to determine the baseline-to-path ang
le
     REM***delta is the variable which represents delta, the baseline-to-path angle i
n radians
     REM***cbpang is the variable which represents the baseline-to-path angle in deg
rees

6380 db=cbp
6400 delt = -ATN(db/SQR(-(db*db) + 1)) + 1.5708
6450  cbpang=delt*180/3.141592654#

     REM***acoef and bcoef are coefficients that are a function of the rain attenuatio
n.
     REM***Gd the separation distance gain
     REM***Gf is the variable which represents the frequency gain
     REM***GE is the variable which represents the elevation gain
     REM***Gdel is the variable which represents the baseline-to-path gain

6570  acoef  =  .64*ratt#-1.6*(1-EXP(-.11*ratt#))
6580  bcoef  =  .58*(1-EXP(-.98*ratt#))
6590  Gd=acoef*(1-EXP(-bcoef*dps#))
6600  Gf=1.64*EXP(-.025*freq#)
6610 GE=.00492*eld1# + .834
6620 Gdel=.000177*cbpang + .887

     REM***GSDi is the variable which represents the improved site diversity gain.
     REM***This uses a later and more detailed model.

6630 GSDi = Gd*Gf*GE*Gdel

      REM***The Hodge Model is also used to compute the diversity gain and is compar
ed
      REM***with the later and more detailed model

6635 aprm = ratt# - 3.6*(1-EXP(-.24*ratt#))
6640 bprm = .46*(1-EXP(-.26*ratt#))
6645 GSDh = aprm*(1-EXP(-bprm*dps#))

6648 PRINT " The Hodge site diversity gain is";GSDh"dB."
6649 PRINT " The Improved model site diversity gain is";GSDi"dB."

6651 IF respotr$ ="N" OR respotr$="n" GOTO 6670
```

```
6652 LPRINT "      "   ;CSNG(lons#);lonsd$"            ";CSNG(late1#);lated1$;CSNG(lone
1#);loned1$"     "CSNG(late2#);lated2$;CSNG(lone2#);loned2$;CSNG(dps#)"km     ";CSNG
(ratt#)"     ";
6653 LPRINT USING  "###.###";GSDh;GSDi
6654 GOTO 6670

6655 PRINT" The maximum separation distance for the Hodge model"
6660 PRINT " used for the Site diversity gain calculation is 30 km. "

6670 INPUT "Do you desire to continue (Enter Y OR N) ";resp11$
6672 GSDh = 0
6674 GSDi = 0
6680 IF resp11$ = "Y" OR resp11$ = "y" GOTO 6684
6682 IF resp11$ ="N" OR resp11$ = "n" GOTO 14000

6684 PRINT "Do you desire to calculate another Path Diversity Gain "
6686 INPUT "Enter (Y or N)";resp12$
6688 IF resp12$ = "N" OR resp12$ = "n" GOTO 125
6690 IF resp12$ = "Y" OR resp12$ = "y" GOTO 5070

     REM***This module of the program is used to execute Link Budget Equations
     REM***Carrier-to-noise ratios are calculated from the earth station EIRP or HPA
 power
     REM***Carrier-to-noise ratios are calculated from the carrier flux density
     REM***Rain attenuated downlink design is performed
     REM***Earth station power calculations are performed

7000 PRINT " Link Budget Calculations"
7002 PRINT " Enter 1 for C/N calculations given transmit power or EIRP of the earth st
ation"
7004 PRINT " Enter 2 for C/N calcualtions given Satellite Flux Saturation Density"
7006 PRINT " Enter 3 for Rain Attenuated Downlink Link Design "
7008 PRINT " Enter 4 for Earth Station power calculations given "
7015 INPUT " Satellite Saturation Flux Density ";optLBc$
7016 IF optLBc$ = "2" GOTO 8175
7018 IF optLBc$ = "3" GOTO 8300
7020 IF optLBc$ = "4" GOTO 8125

      REM***The user is allowed to enter the transmit gain or
      REM***calculate the transmit antenna gain
      REM***frequp# is the variable for the uplink frequency
      REM***antdiup# is the variable for the uplink ground antenna in meters
      REM***effup# is the variable for the uplink ground antenna efficiency

7050 INPUT " Input the uplink frequency in Ghz";frequp#
7055 PRINT " Input the earth station transmit gain if known"
7057 PRINT " Enter A if you desire to calculate the transmit gain"
7058 INPUT " Enter B if you desire to input the transmit gain";Gtxa$
7059 IF Gtxa$ ="A" OR Gtxa$ = "a"  GOTO 7065
7060 INPUT  " Input the earth station transmit gain";Gtx
7062 GOTO 7150
```

```
      REM***The transmit antenna gain is calculated

7065 INPUT " Input the uplink ground antenna diameter in meters";antdiup#
7070 INPUT " Input the uplink ground antenna effieciency";effup#

      REM***gtx is the variable for the transmit antenna gain

7100 Gtx = 20*(1/LOG(10))*LOG(10.5*frequp#*antdiup#) + 10*(1/LOG(10))*LOG(effu
p#)
7150 PRINT " The uplink antenna transmit gain is";Gtx"dB."

      REM***The user is allowed to enter the receive gain, enter the earth station
      REM***G/T ratio or calculate the transmit antenna gain

      REM***freqdn# is the variable for the downlink frequency
      REM***antdidn# is the variable for the receiver antenna diameter in meters
      REM***effdn# is the variable for the ground receive antenna efficiency

7170 INPUT " Input the downlink frequency in Ghz";freqdn#
7175 PRINT " Input the earth station receive gain if known"
7176 PRINT " Enter A if you desire to calculate the receive gain"
7177 PRINT " Enter B if you desire to enter the receive gain"
7178 INPUT " Enter C if the G/T of the receive earth station is known";Grxa$
7179 IF Grxa$ = "A" OR Grxa$ = "a" GOTO 7190
7180 IF Grxa$ = "C"  OR Grxa$ = "c" GOTO 7330
7182 INPUT " Input the earth station receive gain ";Grx
7184 GOTO 7240

      REM***The receiver antenna gain is calculated

7190 INPUT " Input the downlink ground antenna diameter in meters";antdidn#
7210 INPUT " Input the downlink ground antenna effieciency";effdn#

      REM***grx is the variable for the receiver antenna gain

7230 Grx = 20*(1/LOG(10))*LOG(10.5*freqdn#*antdidn#) + 10*(1/LOG(10))*LOG(effd
n#)
7240 PRINT " The downlink antenna receiver gain is";Grx"dB."

      REM***lfsup is the variable which represents the uplink free space loss
      REM***lfsdn is the variable which represents the downlink free space loss

7330 IF optLBc$ = "2" GOTO 7370

      REM***dup is the variable which represents the uplink path distance

7335 INPUT " Input the uplink path distance to the satellite in km";dup
7340 lfsup= 92.45 + 20*(1/LOG(10))*LOG(frequp#) + 20*(1/LOG(10))*LOG(dup)
7360 PRINT " The uplink free space loss is ";lfsup"dB."
```

```
      REM***ddn is the variable which represents the downlink path distance

7370 INPUT " Input the downlink path distance to the earth station":ddn
7380 lfsdn= 92.45 + 20*(1/LOG(10))*LOG(freqdn#) + 20*(1/LOG(10))*LOG(ddn)
7400 PRINT " The downlink free space loss is ":lfsdn"dB."

7405 INPUT " Input the downlink atmospheric attenuation loss in dB.":latta

7420 IF Grxa$ = "B"  OR Grxa$ = "b" OR Grxa$ ="A" OR Grxa$ = "a"  GOTO 7500
7450 INPUT " Enter the G/T of the receive earth station.";GTrx
7460  GOTO 7840

      REM***The system noise temperature is calculated

      REM***The antenna noise temperature is calculated first
      REM***TTo# is the variable which represents the ambient noise temperature
      REM***Tsky# is the variable which represents the sky noise temperature
      REM***Tsdlb# is the variable which represents the sidelobe noise temperature

      REM***The atmospheric attenuation is optained from Option 3 or 4 or the user
      REM***enters this attenuation value.  The attenuation loss is converted to
      REM***to a ratio

      REM***The user is allowed to enter the system noise tempetature directly

7500 PRINT " Input the system antenna noise temperature"
7508 INPUT " Enter 0 if you desire to calculate the system noise temperature";Tsysant
7510 IF Tsysant < > 0 GOTO 7800

7512 INPUT " Input the the ambient noise temperature (approximately 290 K)";TTo#
7514 INPUT " Input the sky noise temperature in degrees Kelvin.";Tsky#
7516 INPUT " Input the sidelobe noise temperature in degrees Kelvin.";Tsdlb#

      REM***lattar is the downlink atmospheric attenuation in ratio

7548 Latm = latta
7550 lattar = 10^(latta/10)

      REM***Tatm is the variable which represents the atmospheric noise temperature
      REM***Tatm is calcualted from the ambient noise temperature and the atmosphe
ric
      REM***attenuation

7560 Tatm = TTo#*(1 - 1/lattar)
7570 PRINT " The atmospheric noise temperature is ";Tatm
7575 GOTO 7640

      REM***Tant is the antenna noise temperature

7640 Tant = Tsky#/lattar + TTo#*(1-1/lattar) + Tsdlb#
7645 PRINT " The antenna noise temoerature is":Tant"dB."
```

```
      REM***Tlna# is the variable which represents the low noise amplifier noise temperature
      REM***Tline# is the variable which represents the line noise temperature
      REM***Lline# is the variable which represents the line loss

      REM***The user may enter the low noise amplifier noise temperature directly in
      REM***degrees Kelvin or low noise amplifier noise figure in dB.

      REM***NFlna is the variable that represents the low noise amplifier noise figure
      REM***The low noise temperature is calculated from the noise figure

7650 PRINT " Enter T to input the low noise amplifier temperature in degrees Kelvin"
7655 INPUT " Enter N to input the low noise amplifier noise figure in db.":LNA$
7660 IF LNA$ = "T" OR  LNA$ = "t" GOTO 7700

7665 INPUT " Input the low noise amplifier noise figure in dB.";NFlna
7670  Tlna#=  (10^(NFlna/10)-1)*290
7680 GOTO 7720

7700 INPUT " Input the low noise amplifier noise temperature.";Tlna#
7720 INPUT " Input the line noise temperature.";Tline#
7740 INPUT " Input the line loss in dB. ";Lline#

      REM***Lliner is the variable which represents the line loss in ratio

7760 Lliner  =  10^(Lline#/10)

      REM***Tsysant is the system antenna noise temperature

7780 Tsysant= Tant + Tline#*(Lliner - 1)+Tlna#*Lliner
7800 PRINT " The system antenna noise temperature is ";Tsysant"dB."

     REM***GTrx is the G/T of the receiver antenna

7820 GTrx = Grx - 10*(1/LOG(10))*LOG(Tsysant)
7840 PRINT " The G/T of the receiver earth station antenna is ";GTrx"dB/K"

      REM***EIRPsat# is the variable which represents the EIRP of the satellite
      REM***Margd# is the variable which represents the downlink margin
      REM***OBO# is the variable which represents the output backoff
      REM*** ncarrT# is the variable which represents the number of carriers in the transponder

7850 INPUT " Input the saturation EIRP for the satellite.";EIRPsat#
7860 INPUT " Input the Link Budget downlink Margin.";Margd#
7870 INPUT " Input the output back off.";OBO#
7875 INPUT " Input the number of carriers in the satellite transponder. ";ncarrT#
7878 Latm = latta

      REM***CKTd is the variable which reoresents the downlink carrier to noise densi
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ty ratio

7880 CKTd = EIRPsat# + GTrx - lfsdn - Latm +  228.6012091#- Margd#-OBO#-(10 LOG
(10))*LOG(ncarrT#)
7890 PRINT " The carrier-to-noise density ratio (C/KT) downlink is ":CKTd"dBHz"
7892 IF optLBc$ = "2" GOTO 8084

     REM***GTsat# is the variable which represents the G/T of the satellite
     REM***Margu# is the variable which represents the budget uplink margin
     REM***Ptx is the variable which represents the transmit HPA power
     REM***wvgl# is the variable which represents the waveguide loss
     REM***IBO# is the variable which represents the input backoff
     REM***ncarr# is the variable which represents the number of carriers transmitt
ed from the site
     REM***Latmup is the variable which represents the uplink atmospheric loss

8000 INPUT " Input the G/T of the satellite in dB/K.";GTsat#
8020 INPUT " Input the Link Budget uplink Margin in dB.";Margu#
8030 INPUT " Input the wave guide loss in dB.";wvgl#
8035 INPUT " Input the input back off in dB. ";IBO#
8040 INPUT " Input the uplink atmospheric attenuation loss in dB." ;Latmup

8045 PRINT " Enter P to input the earth station transmit HPA power"
8050 INPUT " Enter E to input the earth station saturation EIRP";EStx$
8052 IF EStx$ = "P" OR EStx$ = "p" GOTO 8055
8053 INPUT "Input the earth station saturation EIRP in dBW.";EIRPtx
8054 GOTO 8070
8055 INPUT " Input the Transmit HPA power in W.";Ptx

     REM***EIRPtx is the variable which represents the earth station EIRP
     REM***EIRPes is the variable which represents the earth station saturation EIRP

8060 EIRPtx = 10*(1/LOG(10))*LOG(Ptx) + wvgl# + Gtx
8070 PRINT " The EIRP of the earth station is";EIRPtx
8075 EIRPes = EIRPtx +IBO#
8078 PRINT " The saturation EIRP of the earth station is ";EIRPes
8079 INPUT " Input the number of carriers transmitted from the site. ";ncarr#

     REM***CKTu is the variable which represents the uplink carrier to noise density
ratio

8080 CKTu = EIRPes + GTsat# - lfsup - Latmup +  228.6012091#- Margu#-IBO#-(10/LO
G(10))*LOG(ncarr#)

     REM***The total carrier-to-noise density  ratio is determined
     REM***CKTt represents the total carrier-to-density ratio
     REM***CIKt represents the carrier-to-intermodulation density ratio
     REM***CAkt represents the carrier-to-adjacent density ratio

8082 PRINT " The carrier-to-noise density ratio (C/KT) uplink is ";CKTu"dBHz"
8084 INPUT " Inout the carrier-to-intermodualtion noise densitv ratio":CIkt
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```
8086 INPUT " Input the carrier-to-adjacent noise density ratio";CAkt

8088 CKTt = (10/LOG(10))*LOG(1/(10^(-CKTd/10) + 10^(-CKTu/10) + 10^(-CIkt/10) + 1
0^(-CAkt/10)))
8090 PRINT " The total carrier-to-noise denstiy ratio is ";CKTt "dB-Hz."

     REM***BWc represents the carrier bandwidth in megahertz
     REM***CNt is the total carrier-to-noise ratio in dB

8091 INPUT " Input the carrier bandwidth in MHz";BWc
8092 CNt = CKTt - (10/LOG(10))*LOG(BWc*10^6)
8093 PRINT " The total carrier-to-noise density is ";CNt"dB."
8094 IF optLBc$ = "2" GOTO 9750

     REM***Flux is the variable for the uplink carrier flux density
     REM***The carrier flux density is calculated from the earth station
     REM***saturation EIRP, uplink path distance and uplink atmospheric loss

8095 Flux=EIRPes-10/LOG(10)*LOG(4*3.141592654#*dup*dup*10^6)-Latmup-(10/LOG
(10))*LOG(ncarr#)
8096 PRINT " The uplink carrier flux density is ";Flux"dBW/m^2"
8097 GOTO 9750

     REM***This portion of the program will calculate the power required for a given
 antenna
     REM***size based upon the satellite flux saturation density

8125 INPUT " Input the satellite flux saturation density";Flux#
8128 INPUT " Input the wave guide loss.";wvgl#
8130 INPUT " Input the uplink frequency in Ghz";frequp#
8132 INPUT " Input the uplink ground antenna efficiency";effup#
8134 INPUT " Input the slant path distance to the satellite in km";dup
8140 INPUT " Input the atmospheric attenuation loss in dB.";Latmup

     REM***Ptxdb is the variable which represents the transmit power in dB
     REM***Ptx is the variable which represents the transmit power in watts

8141 INPUT " Input the input back off ";IBO
8142 INPUT " Input the number of carriers transmitted from the site. ";ncarr#
8143 PRINT " Ant Diam     HPA(dB)     HPA(W) "

8144 IF respptr$ ="N" OR respptr$="n" GOTO 8150
8145 LPRINT " Ant Diam     HPA(dB)     HPA(W) "

8150 FOR antdiup# =1 TO 12 STEP .2
8151 Ptxdb = Flux#-(20/LOG(10))*LOG(10.47197551#*frequp#*antdiup#) -(10/LOG(1
0))*LOG(effup#)+(10/LOG(10))*LOG(4*3.141592654#)+(20/LOG(10))*LOG(dup*10^3)+
Latmup+(10/LOG(10))*LOG(ncarr#)-IBO+wvgl#
8152 Ptx = 10^(Ptxdb/10)
8153 PRINT antdiup#"     ";Ptxdb"     ";Ptx
```

```
8154 IF respptr$ ="N" OR respptr$="n" GOTO 8156
8155 LPRINT " "antdiup#"      ":Ptxdb"     ":Ptx
8156 NEXT antdiup#
8158 GOTO 9750

     REM***The uplink carrier-to-noise density is determined from the
     REM***uplink carrier flux density

8175 INPUT " Input the satellite flux saturation density":Flux#
8180 INPUT " Input the G/T of the satellite.":GTsat#
8185 INPUT " Input the Link Budget uplink Margin.";Margu#
8195 INPUT " Input the input back off in dB. ";IBO#
8200 INPUT " Input the number of carriers transmitted from the site. ":ncarr#
8215 INPUT " Input the uplink atmospheric attenuation loss in dB.":Latmup
8235 INPUT " Input the uplink frequency in Ghz";frequp#
8240 CKTu = Flux# + GTsat# - (10/LOG(10))*LOG(4*3.141592654#*frequp#*frequp#
.09) - Latmup +  228.6012091#- Margu# -IBO#-(10/LOG(10))*LOG(ncarr#)
8245 PRINT " The carrier-to-noiese density ratio (C/KT) uplink is ";CKTu"dBHz"

     REM***The downlink carrier-to-noise density ratio is determined from the
     REM***the previous section

8250 GOTO 7170

     REM***The following section determines the link budget design for a rain attenu
ated
     REM***downlink.  The link budget is first determined for the rain on uplink only.
     REM***Then the link budget is determined for the rain attenuated downlink based
 upon
     REM***the values found for the previous case.

8300 PRINT " Rain Attenuated Downlink Budget Design "
8301 INPUT " Input the wave guide loss in dB.";wvgl#
8302 INPUT " Input the earth station antenna efficiencies ";eff#
8303 INPUT " Input the path distance from the transmit station to the satellite (km). "
;dtxsat#
8304 INPUT " Input the Uplink atmospheric losses and antenna tracking losses (dB). ";L
atmup#
8306 INPUT " Input the Uplink Frequency in GHz. ";frequp#
8308 INPUT " Input the carrier Bandwidth in MHz. ";BW#
8310 INPUT " Input the Satellite Transponder Saturation Power Flux Density (dBW/m^2
). ";Flux#
8312 INPUT " Input the Satellite antenna gain-to-noise temperature ratio. ";GTsat#
8313 INPUT " Input the Satellite saturation EIRP ";EIRPsats
8314 INPUT " Input the clear sky TWTA input back-off. ";IBOc#
8316 INPUT " Input the clear sky TWTA output back-off. ";OBOc#
8318 INPUT " Input the downlink atmospheric losses and antenna tracking losses (dB).
";Latmdn#
8320 INPUT " Input the path distance from the satellite to the receive earth station. ";
dsatrv#
8321 INPUT " Inout the Downlink Freauencv in GHz. ";freadn#
```

```
     REM***The interference parameters are entered
     REM***Clui# is the uplink carrier-to-adjacent satellite interference into an adj
acent satellite system (satellite)
     REM***Cldi# is the downlink carrier-to-adjacent satellite interference into an a
djacent satellite system (earth station)
     REM***Clchu# is the uplink carrier-to-adjacent channel interference
     REM***Clchd# is the downlink carrier-to-adjacent channel interference
     REM***Cantplz# is the satellite antenna cross polarization discrimination
     REM***Cresplz# is the receive earth station cross polarization discrimination
     REM***Cluf# is the uplink interference from an adjacent satellite system (earth
 station)
     REM***Cldf# is the downlink interference from an adjacent satellite system (sa
tellite)
     REM***Xpol# is the downlink rain induced cross polarization discrimination

8322 INPUT " Input the Carrier-to-Adjacent Satellite interference ratio uplink ";Clui#
8324 INPUT " Input the Carrier-to-Adjacent Satellite interference ratio downlink ";Cld
i#
8326 INPUT " Input the Carrier-to-Adjacent Channel interference ratio uplink ";Clchu#
8328 INPUT " Input the Carrier-to-Adjacent Channel interference ratio downlink ";Clch
d#
8330 INPUT " Input the satellite antenna cross-polarization discrimination ";Cantplz#
8332 INPUT " Input the receive earth station antenna cross-polarization discriminatio
n ";Cresplz#
8334 INPUT " Input the adjacent earth station interference uplink ";Cluf#
8336 INPUT " Input the adjacent satellite interference downlink ";Cldf#
8338 INPUT " Input the receive earth station rain depolarization characteristic ";Xpol#

     REM***Iraup# is the uplink rain attenuation loss
     REM***Iradn# is the downlink rain attenuation loss
     REM***sytpdel# is the delta system temperature, the temperature increase in th
e system
     REM***noise temperature due to the downlink rain
     REM***CNreq# is the required carrier-to-noise ratio

8340 INPUT " Input the uplink rain attenuation loss in dB. ";Iraup#
8342 INPUT " Input the downlink rain attenuation loss in dB. ";Iradn#
8343 INPUT " Input the system noise temperature increase associated with downlink r
ain only ";sytpdel#
8344 INPUT " Input the required Total Link Carrier-to-Noise ratio ";CNreq#

     REM***EIRPes is the variable which represents the earth station saturation EIRP

8352 EIRPes = Flux# + 70.9921 + (20/LOG(10))*LOG(dtxsat#) + Latmup#

     REM***CNur is the uplink carrier-to-noise ratio with uplink rain only
     REM***CItu is the uplink total carrier-to-interference ratio with uplink rain onl
y
     REM***CIur is the rain affected uplink total carrier-to-interference ratio with u
plink rain only
```

```
8354 CNur = EIRPes - 92.442 - (20/LOG(10))*LOG(dtxsat#*frequp#) + GTsat#- 228.6 -
IBOc#-Latmup#-Iraup# - (10/LOG(10))*LOG(BW#*1000000!)
8356 CItu =(10/LOG(10))*LOG(1/(10^(-CIui#/10) + 10^(-CIchu#/10) +10^(-Cantplz#/10
) +10^(-CIuf#/10)))
8358 CIur = CItu - Iraup#

     REM***CNIur is the uplink carrier-to-noise plus interference ratio with rain on u
plink
     REM***CNId is the downlink carrier-to-noise plus interference ratio with rain on
 uplink

8360 CNIur = (10/LOG(10))*LOG(1/(10^(-CNur/10) + 10^(-CIur/10)))
8361 IF CNreq# < CNIur GOTO 8363
8362 PRINT " The minimum required C/N is too great for these parameters"
     GOTO 9750
8363 CNId = (10/LOG(10))*LOG(1/(10^(-CNreq#/10) -10^(-CNIur/10)))

      REM***IBOr is the TWTA input back-off that the satellite sees when the uplink i
s affected by rain

      IBOr =IBOc#+ Iraup#

     REM***OBOr# is the associated TWTA output back-off which results from the ra
in
     REM***affected TWTA input back-off

     PRINT " Input the associated TWTA Output Back-off for an Input Back-off of ";IBO
r
     INPUT " Enter this Output  Back-off ";OBOr#
     OBOdif = OBOr# - OBOc#

     REM***CItd is the total downlink carrier-to-interference ratio with uplink rain
only
     REM***CNd is the carrier-to-noise ratio with uplink rain only

8364 CItd = ((10/LOG(10))*LOG(1/(10^(-CIdi#/10) + 10^(-CIchd#/10) + 10^(-Cantplz#/
10) + 10^(-Cresplz#/10) + 10^(-CIdf#/10)))) - OBOdif
8365 IF CNId < CItd GOTO 8367
8366 PRINT " The minimum required C/N is too great for these parameters"
     GOTO 9750


8367 CNd = (10/LOG(10))*LOG(1/(10^(-CNId/10) - 10^(-CItd/10)))

    REM***GTresc is the clear sky receive earth station G/T ratio (rain on uplink only
)
    REM***EIRPtx is the variable which represents the earth station EIRP

8368 GTresc = CNd - EIRPsats + 92.442 + (20/LOG(10))*LOG(dsatrv#*freqdn#) -228.6
 + (10/LOG(10))*LOG(BW#*1000000!) + OBOr# + Latmdn#
```

```
8370 EIRPtx = EIRPes - IBOc#

     REM***CNIu is the uplink carrier-to-noise ratio plus interference ratio with dow
nlink rain only
     REM***CNIdr is the downlink carrier-to-noise plus interference ratio with down
link rain only
     REM***CIdr is the downlink carrier-to-interference ratio with downlink rain onl
y
     REM***CNdr is the downlink carrier-to-noise ratio with downlink rain only

8372 CNIu = CNIur + Iraup#
8373 IF CNreq# < CNIu GOTO 8375
8374 PRINT " The minimum required C/N is too great for these parameters"
     GOTO 9750

8375 CNIdr = (10/LOG(10))*LOG(1/(10^(-CNreq#/10) - 10^(-CNIu/10)))
8376 CIdr  = (10/LOG(10))*LOG(1/(10^(-CIdi#/10) + 10^(-CIchd#/10) + 10^(-Cantplz#/
10) + 10^(-Cresplz#/10) + 10^(-CIdf#/10) + 10^(-Xpol#/10)))
8377 IF CNIdr < CIdr GOTO 8379
8378 PRINT " The minimum required C/N is too great for these parameters"
     GOTO 9750

8379 CNdr = (10/LOG(10))*LOG(1/(10^(-CNIdr/10) -10^(-CIdr/10)))

     REM***GTresr is the receive earth station G/T ratio with downlink rain
     REM***GTdif is the G/T ratio difference between the clear sky and rain attenuat
ed condition

8380 GTresr = CNdr - EIRPsats + 92.442 + (20/LOG(10))*LOG(dsatrv#*freqdn#) -228.6
 + (10/LOG(10))*LOG(BW#*1000000!) + OBOc#+ Latmdn#+ Iradn#
8382 GTdif = GTresc - GTresr

     REM***systmp is the clear sky system temperature

8384 systmp = sytpdel#/(10^(GTdif/10) - 1)
8386 Grx = GTresc + (10/LOG(10))*LOG(systmp)

     REM***The transmit antenna gain is calculated with the assumption that both an
tennas have
     REM***the same efficiency

8388 Gtx = Grx + (20/LOG(10))*LOG(frequp#/freqdn#)
8389 antdiup#= (10^((Gtx - (10/LOG(10))*LOG(eff#))/20))/(10.5*frequp#)
8390 Ptxdb = EIRPtx -Gtx + wvgl#
8392 Ptx = 10^(Ptxdb/10)

8395 PRINT " The link budget design with uplink rain only"
8400 PRINT " The uplink carrier-to-noise ratio is";CNur"dB."
8405 PRINT " The uplink carrier-to-interference ratio is";CIur"dB."
8410 PRINT " The uplink carrier-to-noise ratio plus interference ratio is";CNIur"dB."
8415 PRINT " The downlink carrier-to-noise ratio olus interfernce ratio is":CNId"dB."
```

```
8420 PRINT " The downlink carrier-to-interference ratio is";CItd"dB."
8425 PRINT " The downlink carrier-to-noise ratio is".CNd"dB."
8430 PRINT " The clear sky receive earth station G/T is ";GTresc"dB/K."
8432 PRINT " The transmit station EIRP is";EIRPtx"dBW."

8435 PRINT " The link budget design with downlink rain only "
8440 PRINT " The uplink carrier-to-noise plus interference ratio is"; CNIu"dB."
8445 PRINT " The downlink carrier-to-noise plus interference ratio is"; CNIdr"dB."
8450 PRINT " The downlink carrier-to-interference ratio is";CIdr"dB."
8455 PRINT " The downlink carrier-to-noise ratio is";CNdr"dB."
8460 PRINT " The rain attenuated downlink receive earth station G/T is";GTresr"dB/K."
8465 PRINT " The receive antenna gain is " ;Grx"dB."
8470 PRINT " The transmit antenna gain is ";Gtx"dB."
8475 PRINT " The transmit antenna diameter is ";antdiup#"m."
8480 PRINT " The HPA output power is";Ptx"W."

8490 IF respptr$ ="N" OR respptr$="n" GOTO 9750
8495 LPRINT " The link budget design with uplink rain only"
8500 LPRINT " The uplink carrier-to-noise ratio is";CNur"dB."
8505 LPRINT " The uplink carrier-to-interference ratio is";CIur"dB."
8510 LPRINT " The uplink carrier-to-noise ratio plus interference ratio is";CNIur"dB."
8515 LPRINT " The downlink carrier-to-noise ratio plus interfernce ratio is";CNId"dB."
8520 LPRINT " The downlink carrier-to-interference ratio is";CItd"dB."
8525 LPRINT " The downlink carrier-to-noise ratio is";CNd"dB."
8530 LPRINT " The clear sky receive earth station G/T is ";GTresc"dB/K."
8532 LPRINT " The transmit station EIRP is";EIRPtx"dBW."

8535 LPRINT " The link budget design with downlink rain only "
8540 LPRINT " The uplink carrier-to-noise plus interference ratio is"; CNIu"dB."
8545 LPRINT " The downlink carrier-to-noise plus interference ratio is"; CNIdr"dB."
8550 LPRINT " The downlink carrier-to-interference ratio is";CIdr"dB."
8555 LPRINT " The downlink carrier-to-noise ratio is";CNdr"dB."
8560 LPRINT " The rain attenuated downlink receive earth station G/T is";GTresr"dB/K
."
8565 LPRINT " The receive antenna gain is " ;Grx"dB."
8570 LPRINT " The transmit antenna gain is ";Gtx"dB."
8575 LPRINT " The transmit antenna diameter is ";antdiup#"m."
8580 LPRINT " The HPA output power is";Ptx"W."

9750 INPUT "Do you desire to continue (Enter Y OR N) ";resp13$
9760 IF resp13$ = "Y" OR resp13$ = "y" GOTO 9780
9770 IF resp13$ ="N" OR resp13$ = "n" GOTO 14000

9780 PRINT "Do you desire to calculate an additional Link Budget "
9790 INPUT "Enter (Y or N)";resp14$
9800 IF resp14$ = "N" OR resp14$ = "n" GOTO 125
9810 IF resp14$ = "Y" OR resp14$ = "y" GOTO 7000

     REM***This section of the program is used to calcuate baseband performance cri
teria
     REM***The ooerator is aiven several ootions to suooort these calculations
```

```
10000 PRINT " Baseband Performance Calculations"
10001 PRINT " Enter 1a for FDM-FM-FDMA multichannel C/N calculations."
10002 PRINT " Enter 1b for FDM-FM-FDMA multichannel S/N calculations."
10003 PRINT " Enter 1c for FDM multichannel rms frequency deviation calculation."
10004 PRINT " Enter 1d for the determination of the number of channels."
10005 PRINT " Enter 1e for telephone performance specifications."
10006 PRINT " Enter 2a for Single channel per carrier C/N calculations.
10007 PRINT " Enter 2b for Single channel per carrier S/N calculations."
10008 PRINT " Enter 3 for FM-FDMA television calculations"
10009 INPUT " Please input the desired suboption:";optbb$
10010 IF optbb$ = "1a" OR optbb$ ="1A" OR optbb$ = "1b" OR optbb$ = "1B" GOTO 10016
10012 IF optbb$ = "2a" OR optbb$ ="2A" OR optbb$ = "2b" OR optbb$ = "2B" GOTO 11300
10013 IF optbb$ = "1c" OR optbb$ = "1C" GOTO 10050
10014 IF optbb$ = "1d" OR optbb$ = "1D" GOTO 10260
10015 IF optbb$ = "1e" OR optbb$ = "1E" GOTO 10325
10016 IF optbb$ = "3" GOTO 11500

      REM***IF bandwidth calculations are performed using Carson's Rule
      REM***fmfdm# is the variable for the maximum FDM baseband frequency

10018 PRINT " The IF bandwidth is calculated using Carson's rule"
10020 INPUT " Input the maximum FDM baseband frequency in khz.";fmfdm#

      REM***The user is given the option of of calculating the IF bandwidth from the
      REM*** FDM peak frequency or from the FDM multichannel rms frequency deviat
ion

10022 PRINT " The IF bandwidth can be calculated from the FDM peak frequency"
10024 PRINT " or from the FDM multichannel rms frequency deviation."
10026 INPUT " Enter 1 for FDM peak frequency or 2 for FDM rms frequency deviation";op
tfdm$
10028 IF optfdm$ ="1" GOTO 10038
10030 IF optfdm$ <> "2" GOTO 10026

      REM***frfdm# is the variable for the FDM mulitchannel rms frequency deviation
      REM***fpfdm# is the variable for the FDM peak frequency deviation

10032 INPUT " Input the FDM multichannel rms frequency deviation in khz.";frfdm#
10034  fpfdm#=frfdm#*3.16
10036 GOTO 10040
10038 INPUT " Input the FDM peak frequency deviation in khz.";fpfdm#

       REM***IFbw is the intermediate freqency bandwidth.  It is calculated from
       REM***Carson's rule.  The 2000 accounts for peak frequency deviation and
       REM***and the maximum baseband frequency being entered in kilohertz

10040  IFbw=2000*(fmfdm#+fpfdm#)

       REM***IFbwm is the intermediate frequency in Megahertz
```

```
10042 IFbwm = IFbw/1000000!
10045 PRINT " The IF Bandwidth is";IFbwm "Mhz."

      REM***ntelch# is the number of telephone channels in the carrier

10050 INPUT " Input the number of telephone channels in the FDM-FM carrier";ntelch#
10060 IF ntelch# < 240 GOTO 10090

      REM***loadfac is the variable which represents the FDM loading factor
      REM***The calculation for this term is a factor of the number of telephone
      REM***channels

10070 loadfac =10^(((-15 + 10/LOG(10)*LOG(ntelch#))/20))
10080 GOTO 10100
10090 loadfac = 10^(((-1 + 4/LOG(10)*LOG(ntelch#))/20))
10100 PRINT" The FDM multichannel loading factor is";loadfac

      REM***ttonef is the variable for the 0-dBm test-tone rms frequency deviation

10110 ttonef = fpfdm#/(loadfac*3.16)

      REM***telchbw# is the variable for the telephone bandwidth.  This value is usu
ally
      REM***3.1 khz.
      REM***PWdb# is the improvement emphasis and psophometric weighting factor
      REM***in dB.  This value is usually 6.5 dB.

10120 INPUT " Input the telephone channel bandwidth in khz (3.1 khz).";telchbw#
10140 INPUT " Input the psophometric weighting factor in dB.";PWdb#
10145 IF optbb$ = "1c" OR optbb$ = "1C" GOTO 10250
10150 IF optbb$ = "1b" OR optbb$ = "1B" GOTO 10200

      REM***SNFFF# is the top channel signal-to-noise ratio
      REM***CNFFF is the FDM-FM-FDMA carrier-to-noise ratio

      REM***This section of the program calculates the carrier-to-noise ratio

10160 INPUT " Input the specified top channel signal to noise ratio in dB.";SNFFF#
10180 CNFFF = (SNFFF#) + 10/LOG(10)*LOG(telchbw#*1000/IFbw) +20/LOG(10)*LOG(
fmfdm#/ttonef) - PWdb#
10190 PRINT " The FDM-FM-FDMA Carrier to Noise ratio is ";CNFFF "dB."
10195 GOTO 11800

      REM***This section of the program calculates the signal-to-noise ratio

10200 INPUT " Input the specified top channel carrier to noise ratio in dB.";CNFFF#
10220 SNFFF = (CNFFF#) + 10/LOG(10)*LOG(IFbw/(telchbw#*1000)) +20/LOG(10)*LOG
(ttonef/fmfdm#) + PWdb#
10240 PRINT " The FDM-FM-FDMA Signal to Noise ratio is ";SNFFF "dB."
10245 GOTO 11800
```

```
       REM***This section of the program calculates the FDM multichannel rms freque
ncy deviation

10250 INPUT " Input the specified top channel signal to noise ratio in dB.";SNFFF#
10252 INPUT " Input the specified top channel carrier to noise ratio in dB.";CNFFF#
10253 INPUT " Input the maximum FDM baseband frequency in khz.";fmfdm#
10254 INPUT " Input the Intermediate frequency bandwidth in Mhz.";IFbwm
10255 frfdm = loadfac*fmfdm#*10^((SNFFF#-CNFFF#-10/LOG(10)*LOG(IFbwm*1000
telchbw#)  -PWdb#)/20)
10258 PRINT " The FDM multichannel rms frequency deviation is "; frfdm "khz."
10259 GOTO 11800

       REM***This section of the program is used to calculate the number of telephone
       REM***channels.  The maximum baseband frequency is equal to 4200*ntelch#.
       REM***This relationship is used to determine ntelch#

10260 INPUT " Input the specified top channel signal to noise ratio in dB.";SNFFF#
10262 INPUT " Input the specified top channel carrier to noise ratio in dB.";CNFFF#
10263 INPUT " Input the telephone channel bandwidth in khz.";telchbw#
10264 INPUT " Input the psophometric weighting factor in dB.";PWdb#
10265 INPUT " Input the Intermediate frequency bandwidth in Mhz.";IFbwm
10266 const= 10^((SNFFF#-CNFFF#-10/LOG(10)*LOG(IFbwm*1000/telchbw#)  -PWdb#
)/20)

      REM***arg1 is a dummy variable that is calculated from the Intermediate Frequ
ency
      REM***mindiff is the variable which represents the minimum difference
      REM***keep is a dummy variable which keeps track of the minimum difference

      REM***This portion of the program calculates the number of telephone channels
      REM***when the maximum is 240 channels

10268  arg1=IFbwm*1000000!/8400
10269 mindiff = arg1
10270 keep = 0
10271 FOR ntelch=1 TO 240
10272  arg= ntelch*((10^-.05)*3.16*const*10^(.2/LOG(10)*LOG(ntelch)) + 1)
10275 argdiff = arg-arg1
10276 diff(ntelch) = ABS(argdiff)
10277 IF diff(ntelch) > mindiff THEN GOTO 10281
10278  mindiff = diff(ntelch)
10279 keep = ntelch
10281 NEXT ntelch
10282 IF keep >= 240 GOTO 10286
10283 PRINT " The number of channels is ";keep"(Accuarcy is to within one channel)"
10284 GOTO 11800

       REM***This portion of the program calculates the number of telephone channels
       REM***when the total is greater than 240 channels.  The maximum number calc
ulated
       REM*** is 13.245 channels
```

```
10286 start = 240
10288 final = 495
10290 FOR count = 1 TO 50
10292 FOR ntelch=start TO final
10294  arg= ntelch*((10^-.75)*3.16*const*10^(.5/LOG(10)*LOG(ntelch)) + 1)
10296    ntelch1=ntelch-start
10298 argdiff = arg-arg1
10300 diff(ntelch1) = ABS(argdiff)
10302 IF diff(ntelch1) > mindiff THEN GOTO 10308
10304  mindiff = diff(ntelch1)
10306 keep = ntelch
10308 NEXT ntelch
10310 IF keep >= final GOTO 10316
10312 PRINT " The number of channels is ";keep"(+1/-0 channel)"
10314 GOTO 11800
10316 start = final
10318 final = final + 255
10320 NEXT count
10322 PRINT " The number of channels is greater than ";keep
10324 GOTO 11800

      REM***The following section determines the telephone performance specificati
ons
      REM***The noise power is converted between various units

10325 PRINT " Enter 1 to determine the S/N ratio from the noise power in pWp"
10326 PRINT " Enter 2 to determine the noise power in dBp from pwp"
10327 PRINT " Enter 3 to determine the noise power in dBm from dBp"
10328 INPUT " Enter 4 to determine the noise power in pWp from the weighted S/N rat
io ";telpf$
10329 IF telpf$ = "3" GOTO 10355
10330 IF telpf$ = "4" GOTO 10364

      REM***pWp# is the channel noise in picwatts (psophometrically weighted)
      REM***PdBpu is the unweighted noise power in dBp

10332 INPUT " Input the channel noise in picowatts psophometrically weighted (pWp) "
;pWp#
10333 IF telpf$ = "1" GOTO 10335

10334 PdBpu = (10/LOG(10))*LOG(pWp#) + 2.5
      PRINT " The unweighted noise power is ";PdBpu "dBp"
      GOTO 11800

      REM***SNu is the unweighted signal-to-noise ratio in dB.
      REM***SNw is the weighted signal-to-noise ratio in dB.

10335 SNu = 87.5 - (10/LOG(10))*LOG(pWp#)
10340 SNw = 90 - (10/LOG(10))*LOG(pWp#)
      PRINT " The unweighted signal-to-noise ratio is ":SNu "dB."
```

```
      PRINT " The weighted signal-to-noise ratio is ";SNw "dB"
      GOTO 11800

      REM***PdBp is the channel noise power in dB above a 1pwp reference
      REM***PdBmu is the unweighted noise power in dBm

10355 INPUT " Input the channel noise in dB above a 1 pWp reference (dBp) ";PdBp#
10360 PdBmu = PdBp# - 90
      PRINT " The unweighted noise power is ";PdBmu "dBm"
      GOTO 11800

10364 INPUT " Input the signal-to-noise ratio ";SNw
10365 pWp = 10^((90 - SNw)/10)
      PRINT " The noise power per channel for a S/N of ";SNw" dB is";pWp "(pWp)
      GOTO 11800

      REM***This section of the program is used to calculate the  SCPC-FM-FMDA
       REM***carrier-to-noise  ratio

11300 PRINT " Single channel per carrier (SCPC)-FM-FMDA carrier to noise calculation
s"
11310 PRINT " The IF bandwidth is calculated using Carson's rule"
11320 INPUT " Input the maximum FDM baseband frequency in khz.";fmfdm#
11330 INPUT " Input the test tone peak frequency deviation in khz.";ttonp#
11340  IFbw=2000*(fmfdm#+ttonp#)
11350 IFbwm = IFbw/1000!
11360 PRINT " The IF Bandwidth is";IFbwm "khz."
11365 IF optbb$ ="2b" OR optbb$ = "2B" GOTO 11440
11370 INPUT " Input the specific channel signal to noise ratio in dB.";SNscpc#
11380 CNscpc = 10*(1/LOG(10))*LOG(2/3) + 10*(1/LOG(10))*LOG(fmfdm#/IFbwm) +
20*(1/LOG(10))*LOG(fmfdm#/ttonp#) + SNscpc#
11390 PRINT " The SCPC-FM-FMDA carrier to noise ratio is ";CNscpc "db."
11400 GOTO 11800

      REM***This section of the program is used to calculate the  SCPC-FM-FMDA
       REM***signal-to-noise  ratio

11440 INPUT " Input the SCPC-FM-FDMA carrier to noise ratio";CNscpc#
11460 SNscpc = 10*(1/LOG(10))*LOG(3/2) + 10*(1/LOG(10))*LOG(IFbwm/fmfdm#) +
20*(1/LOG(10))*LOG(ttonp#/fmfdm#) + CNscpc#
11470 PRINT " The SCPC-FM-FMDA signal to noise ratio is ";SNscpc "db."
11480 GOTO 11800

      REM***This section of the program performs FM-FDMA television calculations

11500 PRINT " FM-FDMA television calculations"

       REM***delpf# is the variable for the peak frequency deviation
       REM***delf# is typically 13.8 for FM-FDMA ; 7.8 for DBS television channels
       REM***fv# is the variable for the maximum video modulating frequency
       REM***fv# is typically 4.2 Mhz
```

```
       REM***CNi# is the input carrier-to-noise ratio
       REM***Pre# is the preemphasis-deemphasis factor typically 12.8 dB
       REM***Q# is the noise weighting factor and is dependent upon the characterist
ics
       REM***of the system.  Typical values for P + Q range roughly from 18 to 26 dB

11510 PRINT " Input the peak deviation frequency in Mhz."
11512 PRINT " The deviation frequency is typically 13.8 Mhz for FM-FDMA television "
11514 INPUT " The deviation frequency is typically 7.8 Mhz for DBS television channels
 ";delpf#
11520 INPUT " Input the maximum video modulating frequency in Mhz (4.2 Mhz).";fv#
11530 INPUT " Input the incoming carrier to noise ratio in dB.";CNi#
11540 INPUT " Input the preemphasis-deemphasis factor in dB. ";Pre#
11550 INPUT " Input the noise weighting factor in dB (5.2 - 13.2).";Q#
11570 IFbwm=2*(delpf# + fv#)
11580 PRINT " The Carson's Intermediate Frequency bandwidth is";IFbwm"dB."

       REM***SNv is the variable for the output signal-to-noise ratio
       REM***SNpp is the peak to peak luminance signal-to-noise rato

11590 SNv= CNi# +1.76+10/LOG(10)*LOG(IFbwm#/fv#) +20/LOG(10)*LOG(delpf#/fv#
) + Pre# + Q#
11595 SNpp=SNv+6.0215
11600 PRINT " The output signal to noise ratio is ";SNv"dB."
11610 PRINT " The peak to peak luminance signal-to-noise ratio is ";SNpp "dB."

11800 INPUT "Do you desire to continue ? (Enter Y OR N) ";resp15$
11810 IF resp15$ = "Y" OR resp15$ = "y" GOTO 11830
11820 IF resp15$ ="N" OR resp15$ = "n" GOTO 14000

11830 PRINT "Do you desire to calculate additional Baseband Performane calculations
? "
11840 INPUT "Enter (Y or N)";resp16$
11850 IF resp16$ = "N" OR resp16$ = "n" GOTO 125
11860 IF resp16$ = "Y" OR resp16$ = "y" GOTO 10000

       REM***The next section determines the carrier-to-interference ratio from one
system
       REM***into another.  The separation angle is determined for two satellites from
 one earth
       REM***station.  The interference from one satellite (system A) into another (sy
stem B)
       REM***is found.  Then conversely the interference into one satellite (system A)
 from
       REM***another (system B) is determined

12000 PRINT " Carrier-to-Interference Calculation"
12002 PRINT " Enter 1 to determine the separation angle between two"
12004 PRINT " geostationary satellites "
12006 PRINT " Enter 2 to determine interference calculation into adjacent"
12008 PRINT " satellites (Satellite A into Satellite B) "
```

```
12010 PRINT " Enter 3 to determine interference calculation from adjacent"
12012 INPUT " satellites (Satellite A from Satellite B) ";optCI$

12018 IF optCI$ = "1" GOTO 12028
12020 IF optCI$ = "2" GOTO 12290
12022 IF optCI$ = "3" GOTO 12290

12028 PRINT " The angular separation distance between two geostationary "
12029 PRINT " satellites is determined."

12030 IF respptr$ ="N" OR respptr$="n" GOTO 12039
12032 LPRINT "  Subsatellite Point A    Subsatellite Point B   Earth Station A    Separa
tion  Angle"
12033 LPRINT "      Long                    Long          Lat  Long    "

12039 INPUT " Input the Subsatellite Point Longitude in Degrees for Satellite A ";lonsA
#
12040 INPUT " Input the Subsatellite Point Longitude Direction for Satellite A (E or W)
 ";lonsdA$
12050 INPUT " Input the Subsatellite Point Longitude in Degrees for Satellite B ";lonsB
#
12060 INPUT " Input the Subsatellite Point Longitude Direction for Satellite B (E or W)
 ";lonsdB$

12062 PRINT " Input the Site A Earth Station Coordinates "
12064 INPUT " Input the Site A Earth Station Longitude in Degrees"; loneA
12066 INPUT " Input the Site A Earth Station Longitude Direction ( E or W)";lonedA$
12068 INPUT " Input the Site A Earth Station Latitude in Degrees";lateA
12069 INPUT " Input the Site A Satellite Latitude in Direction( N or S)";latedA$

12070 IF lonsdA$ = lonsdB$  GOTO 12150
12080 IF lonsA#>180 GOTO 12100
12090 IF lonsB#>180 GOTO 12130

12100  lonsA#=360-lonsA#
12110 lonsdA$=lonsdB$
12120 GOTO 12150

12130 lonsB#= 360-lonsB#
12140 lonsdB$ = lonsdA$

      REM*** The absolute value of the longitude difference is calculated
      REM*** and converted to radians
      REM*** londif is the longitude difference between the subsatellite point and
      REM*** the Earth Station
      REM*** londifr is the longitude difference in radians

12150 londifl=ABS(lonsA#-lonsB#)
12160 londifrl  =  londifl*3.141592654#/180

12170 INPUT " Inout the slant oath distance to Satellite A from the Site A";dA#
```

```
12180 INPUT " Input the slant path distance to Satellite B from the Site A";db#

       REM***j is the cosine of the separation angle
       REM***csepa,csepa1,csepa2 are dummy variables which are used to determine j
       REM***separ is the separation angle in radians
       REM***sepa is the separation angle in degrees

12192  csepa=dA#^2 + db#^2
12194   csepa1=2*42164.2^2*(1-COS(londifrl))
12196   csepa2= 2*dA#*db#
12198  j = (csepa -csepa1)/csepa2
12200  separ = -ATN(j/SQR(-(j*j)+1))+1.5708
12202  sepa  =  separ*180/3.141592654#

12210 PRINT " The separation angle from Site A is ";sepa "degrees."

12212 IF respptr$ ="N" OR respptr$="n" GOTO 12220
12214 LPRINT "      ";lonsA#;lonsdA$"                        ";lonsB#;lonsdB$"              ";lateA;la
tedA$;loneA;lonedA$"          ";sepa

12220 PRINT " Do you wish to continue with Satellite and Earth Station "
12230 INPUT " Interference Calculations? (Enter Y or N) " ;optClc$
12240 IF optClc$ = "Y" OR optClc$ = "y" GOTO 12290
12250 IF optClc$ = "N" OR optClc$ = "n" GOTO 13000
12290 IF sepa <>0 GOTO 12300

       REM***The user inputs the parameters for satellite system A

12295 INPUT " Input the separation angle between the two geostationary satellites ";s
epa
12300 INPUT " Input the satellite A saturation transponder power flux density ";fluxA#
12310 INPUT " Input the satellite A saturation transponder EIRP ";EIRPA#
12320 INPUT " Input the satellite A transponder input backoff ";IBOA#
12330 INPUT " Input the satellite A output backoff ";OBOA#
12340 INPUT " Input the Satellite Differential Gain ";DifG#
12350 INPUT " Input Site A transmit antenna gain ";Gtxa#
12360 INPUT " Input Site A receive antenna gain ";Grxa#
12370 INPUT " Input the Satellite A number of carriers per transponder ";ncarA#
12375 INPUT " Input the Noise Bandwidth  for System A in Mhz.  ";NBA#
12380 fluxAc = fluxA#- (10/LOG(10))*LOG(ncarA#)
12390 EIRPAc = EIRPA#- (10/LOG(10))*LOG(ncarA#)

       REM***The user inputs the parameters for satellite system B

12400 INPUT " Input the satellite B saturation transponder power flux density ";fluxB#
12410 INPUT " Input the satellite B saturation transponder EIRP ";EIRPB#
12420 INPUT " Input the satellite B transponder input backoff ";IBOB#
12430 INPUT " Input the satellite B output backoff ";OBOB#
12440 INPUT " Input Site B transmit antenna gain ";GtxB#
12450 INPUT " Input Site B receive antenna gain ";GrxB#
12460 INPUT " Inout the Satellite B number of carriers oer transoonder ";ncarB#
```

```
12465 INPUT " Input the Noise Bandwidth  for System B in Mhz.  ";NBB#
12470 fluxBc =fluxB#- (10/LOG(10))*LOG(ncarB#)
12472 EIRPBc = EIRPB#- (10/LOG(10))*LOG(ncarB#)

      REM***This section determines the spectral interference due to multiple carrie
rs
      REM***The spectral interference is calculated for three types of carriers

      REM***The spectral interference is determined for the case where
      REM***the interference is into System A from System B
      REM***MIi is the maximum interfering power into A

12474 IF ncarA# < > 1 GOTO 12480
12476 MIi = 0
12478 GOTO 12640

12480 PRINT " The spectral interference is calculated for three types of carriers "
12490 PRINT " Enter Q for Satellite System A QPSK carriers"
12500 PRINT " Enter F for Satellite System A FDM-FM carriers "
12510 INPUT " Enter T for Satellite System A TV-FM carriers ";optcar$
12520 IF optcar$ = "Q" OR optcar$ = "q" GOTO 12600
12530 IF optcar$ = "F" OR optcar$ = "f" GOTO 12610
12540 IF optcar$ = "T" OR optcar$ = "t" GOTO 12630

      REM***The maximum interfering power for a QPSK carrier is determined
      REM***from the bandwidth of both satellite systems

12600 MIi = (10/LOG(10))*LOG(1.8/(NBB#*1000000!)) + (10/LOG(10))*LOG(NBA#*100
0000!)
12605 GOTO 12640

      REM***The maximum interfering power for a FDM-FM carrier is determined

12610 INPUT "Input the FDM multichannel rms frequency deviation for System B (khz)
"; frfdmB#
12615  MIi = (10/LOG(10))*LOG(1/(2*SQR(2*3.141592654#*(frfdmB#*1000)^2))) + (1
0/LOG(10))*LOG(NBA#*1000000!)
12620 GOTO 12640

      REM***The maximum interfering power for a  TV-FM carrier is determined

12630  MIi = -59 + (10/LOG(10))*LOG(NBA#*1000000!)
12635 GOTO 12640

      REM***The spectral interference is determined for the case where
      REM***the interference is from system A into system B
      REM***MIf is the maximum interference power from A into B

12640 IF ncarB# <> 1 GOTO 12650
12645 MIf = 0
12648 GOTO 12755
```

```
12650 PRINT " The spectral interference is calculated for three types of carriers "
12660 PRINT " Enter Q for Satellite System B QPSK carriers"
12670 PRINT " Enter F for Satellite System B FDM-FM carriers "
12680 INPUT " Enter T for Satellite System B TV-FM carriers ";optcar$
12690 IF optcar$ = "Q" OR optcar$ = "q" GOTO 12720
12700 IF optcar$ = "F" OR optcar$ = "f" GOTO 12730
12710 IF optcar$ = "T" OR optcar$ = "t" GOTO 12750

      REM***The maximum interfering power for a QPSK carrier is found

12720 MIf = (10/LOG(10))*LOG(1.8/(NBA#*1000000!)) + (10/LOG(10))*LOG(NBB#*100
0000!)
12725 GOTO 12755

      REM***The maximum interfering power for a FDM-FM carrier is found

12730 INPUT  "Input the FDM multichannel rms frequency deviation for System A  (khz)
 "; frfdmA#
12740  MIf = (10/LOG(10))*LOG(1/(2*SQR(2*3.141592654#*(frfdmA#*1000)^2))) + (1
0/LOG(10))*LOG(NBB#*1000000!)
12745 GOTO 12755

      REM***The maximum interfering power for a TV-FM carrier is found

12750  MIf = -59  + (10/LOG(10))*LOG(NBB#*1000000!)

      REM***The FCC regulations specifies a sidelobe envelope which is relative
      REM***to the normalized peak gain

12755 IF sepa >= 1 AND sepa <= 48 GOTO 12810
12800 Gsep = -13
12805 GOTO 12820
12810 Gsep = 29 - (25/LOG(10))*LOG(sepa)
12820 IF optCI$ = "3" GOTO 12900

      REM***CIui is the uplink Carrier-to-interference ratio for interference into A f
rom B
      REM***CIdi is the downlink Carrier-to-interference ratio for interference into
A from B
      REM***CIi is the total Carrier-to-interference ratio for interference into A fro
m B

12850 CIui = fluxAc  - IBOA# - (fluxB# - IBOB#)-MIi + GtxB# - Gsep + DifG#
12860 CIdi = EIRPAc- OBOA# -(EIRPB# - OBOB#)-MIi + Grxa# - Gsep
12862 CIi = (10/LOG(10))*LOG(1/(10^(-CIui/10)  + 10^(-CIdi/10)))

12870 PRINT " The Carrier-to-Interference ratio uplink is ";CIui"dB."
12880 PRINT " The Carrier-to-Interference ratio downlink is ";CIdi"dB."
12881 PRINT " The Total Carrier-to-Interference ratio of Satellite A into B is";CIi"dB.
"
```

```
12882 IF respptr$ ="N" OR respptr$="n" GOTO 12895
12883 LPRINT " Adjacent satellite system interference"
12884 LPRINT " The Carrier-to-Interference ratio uplink is ";Clui"dB."
12886 LPRINT " The Carrier-to-Interference ratio downlink is ";Cldi"dB."
12888 LPRINT " The Total Carrier-to-Interference ratio of Satellite A into B is";Cli"dB
."

12895 PRINT " Do you desire to calculate the interference of Satellite A from B
12896 INPUT  " for this system? (Enter Y or N)";optCIn$
12898 IF optCIn$ = "N" OR optCIn$ ="n" GOTO 13000

      REM***Cluf is the uplink Carrier-to-interference ratio for interference from A
 into B
      REM***Cldf is the downlink Carrier-to-interference ratio for interference from
 A into B
      REM***Clf is the total carrier-to-interference ratio for interference from A in
to B

12900 Cluf = fluxBc-IBOB# - (fluxA# -IBOA#) -MIf +Gtxa# -Gsep + DifG#
12910 Cldf = EIRPBc - OBOB#-(EIRPA# - OBOA#)-MIf +GrxB# -Gsep
12920  Clf = (10/LOG(10))*LOG(1/(10^(-Cluf/10)  +  10^(-Cldf/10)))

12930 PRINT " The Carrier-to-Interference ratio uplink is ";Cluf"dB."
12932 PRINT " The Carrier-to-Interference ratio downlink is ";Cldf"dB."
12934 PRINT " The Total Carrier-to-Interference ratio of Satellite A from B is";Clf"dB
."

12936 IF respptr$ ="N" OR respptr$="n" GOTO 12952
12937 LPRINT " Adjacent satellite system interference"
12944 LPRINT " The Carrier-to-Interference ratio uplink is ";Cluf"dB."
12946 LPRINT " The Carrier-to-Interference ratio downlink is ";Cldf"dB."
12948 LPRINT " The Total Carrier-to-Interference ratio of Satellite A from B is";Clf"d
B."

12952 PRINT " Do you desire to calculate the interference of Satellite A into B
12954 INPUT  " for this system? (Enter Y or N)";optCIn$
12956 IF optCIn$ = "Y" OR optCIn$ ="y" GOTO 12850

13000  INPUT "Do you desire to continue ? (Enter Y OR N) ";resp16$
13010  IF resp16$ = "Y" OR resp16$ = "y" GOTO 13030
13020  IF resp16$ ="N" OR resp16$ = "n" GOTO 14000

13030 PRINT "Do you desire to calculate additional adjacent satellite interference "
13040 INPUT "Enter (Y or N)";resp17$
13045 sepa = 0
13050 IF resp17$ = "N" OR resp17$ = "n" GOTO 125
13060 IF resp17$ = "Y" OR resp17$ = "y" GOTO 12000

      REM***The system availablility is determined for a communications system
```

```
13500 PRINT " System Availability"
13501 PRINT " Enter 1 for Direct Availabilty Calculations."
13502 PRINT " Enter 2 for Lambda Availability Calculations."
13504 INPUT " Enter 3 for Redundancy Calculations ";optAV$

13506 IF optAV$ = "3" GOTO 13700

      REM***MTBFxxxx is the mean time before failure for the indicated unit
      REM***MTTRxxxx is the mean time to repair for the indicated unit

13507 INPUT " Enter the Mean Time Before Failure for the  Transmit Antenna";MTBFat
13510 INPUT " Enter the Mean Time To Repair for the Transmit Antenna";MTTRat

13515 INPUT " Enter the Mean Time Before Failure for the Transmit Outdoor Unit";MTBF
ot
13520 INPUT " Enter the Mean Time To Repair for the Transmit Outdoor Unit";MTTRot

13525 INPUT " Enter the Mean Time Before Failure for the Transmit Indoor Unit";MTBFi
t
13530 INPUT " Enter the Mean Time To Repair for the Transmit Indoor Unit";MTTRit

13535 INPUT " Enter the Mean Time Before Failure for the Transmit Connectors";MTBFc
t
13540 INPUT " Enter the Mean Time To Repair for the Transmit Connectors";MTTRct

13545 INPUT " Enter the Mean Time Before Failure for the  Receive Antenna";MTBFar
13550 INPUT " Enter the Mean Time To Repair for the Receive Antenna";MTTRar

13555 INPUT " Enter the Mean Time Before Failure for the Receive Outdoor Unit";MTBFo
r
13560 INPUT " Enter the Mean Time To Repair for the Receive Outdoor Unit";MTTRor

13562 INPUT " Enter the Mean Time Before Failure for the Receive Indoor Unit";MTBFir
13564 INPUT " Enter the Mean Time To Repair for the Receive Indoor Unit";MTTRir

13566 INPUT " Enter the Mean Time Before Failure for the Receive Connectors";MTBFcr
13568 INPUT " Enter the Mean Time To Repair for the Receive Connectors";MTTRcr

      REM***Asat is the satellite availability
      REM***prrbt# is the percent of year link outage exceeds threshold

13570 INPUT " Enter the satellite availability";Asat
13571 INPUT " Input the percent of year link outage exceeds threshold ";prrbt#

      REM***Axx is the Availability calculated from the MTBF and MTTR

13572 IF optAV$ = "2" GOTO 13605
13575  Aat = MTBFat/(MTBFat + MTTRat)
13580  Aot = MTBFot/(MTBFot + MTTRot)
13585  Ait = MTBFit/(MTBFit + MTTRit)
13590  Act = MTBFct/(MTBFct + MTTRct)
```

```
       REM***Atermt is the transmit terminal Availability determined from the product of the component
       REM***availabilities
       REM***Atermtp is the transmit terminal availability in percent

13591  Atermt  =  Aat*Aot*Ait*Act
13592 Atermtp  =  Atermt*100
13593 PRINT " Transmit terminal availability is ";Atermtp"%."

13594  Aar = MTBFar/(MTBFar + MTTRar)
13596  Aor = MTBFor/(MTBFor + MTTRor)
13598  Air = MTBFir/(MTBFir + MTTRir)
13600  Acr = MTBFcr/(MTBFcr + MTTRcr)

       REM***Atermr is the receive terminal Availability determined from the product
       REM***of its component availabilities
       REM***Atermrp is the receive terminal availability in percent

13601   Atermr  =  Aar*Aor*Air*Acr
13602   Atermrp  =  Atermr*100
13603 PRINT " Receive terminal availability is ";Atermrp"%."
13604 GOTO 13686

       REM***lamdaxx is the failure rate which is determined from the inverse of the MTBF
       REM***lamdaxxt is the transmit failure rate
       REM***lamdatt is the total transmit terminal failure rate

13605 lamdaat  =  1/MTBFat
13606 lamdaot  =  1/MTBFot
13608 lamdait  =  1/MTBFit
13610 lamdact  =  1/MTBFct
13625 lamdatt  =  lamdaat +lamdaot +lamdait +lamdact

       REM***lamdaxxr is the receive failure rate
       REM***lamdatr is the total receive terminal failure rate

13628 lamdaar  =  1/MTBFar
13630 lamdaor  =  1/MTBFor
13632 lamdair  =  1/MTBFir
13634 lamdacr  =  1/MTBFcr
13635 lamdatr  =  lamdaar +lamdaor +lamdair +lamdacr

       REM***Failyt is the expected number of failures per year for the transmit terminal
       REM***Failyr is the expected number of failures per year for the receiver terminal

13636 Failyt  =  lamdatt * 24*365
13637 Failvr  =  lamdatr * 24*365
```

```
13638 PRINT " The expected number of failures per year for the transmit terminal is ";Failyt
13639 PRINT " The expected number of failures per year for the receive terminal is ";Failyr

      REM***The terminal availability is determined from the failure rate

13640 IF MTTRat=MTTRot=MTTRit=MTTRct THEN GOTO 13656
13642  Aat = 1/(1+lamdaat*MTTRat)
13644  Aot = 1/(1+lamdaot*MTTRot)
13646   Ait = 1/(1+lamdait*MTTRit)
13648   Act = 1/(1+lamdact*MTTRct)
13650    Atermt = Aat*Aot*Ait*Act
13651   Atermtp = Atermt*100
13652  PRINT " Transmit terminal availability is ";Atermtp"%."
13654 GOTO 13664

       REM***The transmit terminal availablility is determined from the total failure rate

13656 MTTRt =MTTRat
13658  Atermt = 1/(1+lamdatt*MTTRt)
13659  Atermtp = Atermt*100
13660  PRINT " Transmit terminal availability is ";Atermtp"%."

       REM***The receiver terminal availability is determined

13664 IF MTTRar=MTTRor=MTTRir=MTTRcr THEN GOTO 13680
13666  Aar = 1/(1+lamdaar*MTTRar)
13668  Aor = 1/(1+lamdaor*MTTRor)
13670   Air = 1/(1+lamdair*MTTRir)
13672   Acr = 1/(1+lamdacr*MTTRcr)
13674    Atermr = Aar*Aor*Air*Acr
13675   Atermrp = Atermr*100
13676  PRINT " Receiver terminal availability is ";Atermrp"%."
13678 GOTO 13686

13680 MTTRr=MTTRar
13682 Atermr = 1/(1+lamdatr*MTTRr)
13683 Atermrp = Atermr*100
13684 PRINT " Receiver terminal availability is ";Atermrp"%."

      REM***The link availability is determined from the percent of year link
      REM***outage exceeds a threshold
      REM***Asys is the system availability
      REM***Asysp is the system availability in percent

13686 Alink = (1 - (prrbt#/100))
13655 Asys = Atermt * Atermr * Alink * Asat
13656 Alinkp = Alink*100
```

```
13658 Asysp = Asys *100
13660  PRINT " The Link availability is ";Alinkp"%."
13665  PRINT " The System availability is ";Asysp"%."

       REM***HOpyt is the transmit terminal hours outage per year
       REM***HOpyr is the receive terminal hours outage per year
       REM***HOpys is the communications system hours outage per year

13670  HOpyt  =  24*365*(1-Atermt)/100
13675  HOpyr  =  24*365*(1-Atermr)/100
13680  HOpys  =  24*365*(1-Asys)/100

13685 PRINT " The Transmit Terminal hours outage per year is ";HOpyt
13690 PRINT " The Receive Terminal hours outage per year is ";HOpyr
13695 PRINT " The Communications system hours outage per year is ";HOpys
13696 GOTO 13770

       REM***The availability of a redundant system unit is determined

13700 PRINT " The Availability of a Redundant System"
13701 INPUT " Enter the name of the redundant unit to be analyzed ";RUnit$
13702 PRINT " Do you desire to calculate the availablity of ";RUnit$" ?"
13703 INPUT " Enter Y or N ";optRAa$
13704 IF optRAa$ ="N" OR optRAa$="n" GOTO 13712

13705 PRINT " The Mean Time Before Failure for the ";RUnit$" must be input."
13706 INPUT " Enter the Mean Time Before Failure ";MTBFu
13707 PRINT " The Mean Time To Repair for the ";RUnit$" must be input."
13708 INPUT " Enter the Mean Time to Repair ";MTTRu
13709  Aunit# = MTBFu/(MTBFu + MTTRu)
13710  PRINT " The availability of ";RUnit$" is";Aunit#
13711  GOTO 13714

13712 INPUT "  Input the availability of the unit in question";Aunit#
13714  HOpyu  =  24*365*(1-Aunit#)/100
13715  Ars#  =  100*Aunit#*(2 - Aunit#)

13720 PRINT " The ";RUnit$" hours outage per year is ";HOpyu
13725 PRINT " The Redundant availability of ";RUnit$" is";Ars#" %."

13730 PRINT " Do you want to analyze the redundancy of another unit "
13735 INPUT " Enter Y or N ";optRA$
13740 IF optRA$ = "Y" OR optRA$ = "y" GOTO 13700

13770  INPUT "Do you desire to continue ? (Enter Y OR N) ";resp18$
13775  IF resp18$ = "Y" OR resp18$ = "y" GOTO 13785
13780  IF resp18$ ="N" OR resp18$ = "n" GOTO 14000

13785 PRINT "Do you desire to continue with additional availability calculations ?"
13790 INPUT "Enter (Y or N)";resp19$
```

```
13795 IF resp19$ = "N" OR resp19$ = "n" GOTO 125
13800 IF resp19$ = "Y" OR resp19$ = "y" GOTO 13500

14000 END
```