Applied Technology Institute (ATIcourses.com)

Stay Current In Your Field • Broaden Your Knowledge • Increase Productivity

349 Berkshire Drive • Riva, Maryland 21140
888-501-2100 • 410-956-8805
Website: www.ATIcourses.com • Email: ATI@ATIcourses.com

Boost Your Skills With ATIcourses.com!

ATI Provides Training In:

- Acoustic, Noise & Sonar Engineering
- Communications and Networking
- Engineering & Data Analysis
- Information Technology
- Radar, Missiles & Combat Systems
- Remote Sensing
- Signal Processing
- Space, Satellite & Aerospace Engineering
- Systems Engineering & Professional Development

Check Our Schedule & Register Today!

The Applied Technology Institute (ATIcourses.com) specializes in training programs for technical professionals. Our courses keep you current in state-of-the-art technology that is essential to keep your company on the cutting edge in today's highly competitive marketplace. Since 1984, ATI has earned the trust of training departments nationwide, and has presented On-site training at the major Navy, Air Force and NASA centers, and for a large number of contractors. Our training increases effectiveness and productivity.

Learn From The Proven Best!

Via Satellite, May 2000

Rain

How It Affects the Communications Link

by Robert A. Nelson

Rain affects the transmission of an electromagnetic signal in three ways: (1) It attenuates the signal; (2) it increases the system noise temperature; and (3) it changes the polarization. All three of these mechanisms cause a degradation in the received signal quality and become increasingly significant as the carrier frequency increases.

At C-band the effects are minor and at Ku-band, while they are noticable, can be accommodated. But at higher frequencies, such as Ka-band or V-band, the degradation can be so great that it simply cannot be be compensated at the level of availability usually expected for lower frequencies. This article will explore the physical mechanisms of rain degradation and will compare the relative effects in various frequency bands used for satellite communication.

ATTENUATION

The first, and most well known, effect of rain is that it attenuates the signal. The attenuation is caused by the scattering and absorption of electromagnetic waves by drops of liquid water. The scattering diffuses the signal, while absorption involves the resonance of the waves with individual molecules of water. Absorption increases the molecular energy, corresponding to a slight increase in temperature, and results in an equivalent loss of signal energy. Attenuation is neglible for snow or ice crystals, in which the molecules are tightly bound and do not interact with the waves.

The attenuation increases as the wavelength approaches the size of a typical raindrop, which is about 1.5 millimeters. Wavelength and frequency are related by the equation $c = \lambda f$, where λ is the wavelength, f is the frequency, and c is the speed of light (approximately 3×10^8 m/s). For example, at the C-band downlink frequency of 4 GHz, the wavelength is 75 millimeters. The wavelength is thus 50 times larger than a raindrop and the signal passes through the rain with relatively small attenuation. At the Ku-band downlink frequency of 12 GHz, the wavelength is 25 millimeters. Again, the wavelength is much greater than the size of a raindrop, although not as much as at C-band. At Ka-band, with a downlink frequency of 20 GHz, the wavelength is 15 millimeters and at V-band, at a downlink frequency of 40 GHz, it is only 7.5 millimeters. At these frequencies, the wavelength and raindrop size are comparable and the attenuation is quite large.

Considerable research has been carried out to model rain attenuation mathematically and to characterize rainfall throughout the world. For example, experimental measurements and methods of analysis are discussed in the book *Radiowave Propagation in Satellite Communications* by Louis J. Ippolito (Van Nostrand, 1986). The standard method of representing rain attenuation is through an equation of the form

$$L_r = \alpha R^\beta L = \gamma L$$

where L_r is the rain attenation in decibels (dB), R is the rain rate in millimeters per hour, L is an equivalent path length (km), and α and β are empirical coefficients that depend on frequency and to some extent on the polarization. The factor γ is called the specific rain attenuation, which is expressed in dB/km. The equivalent path length depends on the angle of elevation to the satellite, the height of the rain layer, and the latitude of the earth station.

The rain rate enters into this equation because it is a measure of the average size of the raindrops. When the rain rate increases, *i.e.* it rains harder, the rain drops are larger and thus there is more attenuation. Rain models differ principally in the way the effective path length L is calculated. Two authoritative rain models that are widely used are the Crane model and the ITU-R (CCIR) model.

The original Crane model is the global model. A revision of this model that accounts for both the dense center and fringe area of a rain cell is the so-called two component model. These models are discussed in detail in the book *Electromagnetic Wave Propagation Through Rain* by Robert K. Crane (Wiley, 1996), which is accompanied by spreadsheet add-in software.

In the design of any engineering system, it is impossible to guarantee the perfomance under every conceivable condition. One sets reasonable limits based on the conditions that are expected to occur at a given level of probability. For example, a bridge is designed to withstand loads and stresses that are expected to occur in normal operation and to withstand the forces of wind and ground movement that are most likely to be encountered. But even the best bridge design cannot compensate for a tornado or an earthquake of unusual strength.

Similarly, in the design of a satellite communications link one includes margin to compensate for the effects of rain at a given level of availability. The statistical characterization of rain begins by dividing the world into rain climate zones. Within each zone, the maximum rain rate for a given probability is determined from actual meteorological data accumulated over many years.

Referring to a chart of rain climate zones throught the United States, it might seem inconsistent at first glance that Seattle and San Francisco are in the same rain climate region. Seattle is well known for its rainy climate, whereas San Francisco can justifiably boast of fair weather. However, it is not the annual rainfall that matters, but rather the probability of a given rain rate, since it is the rain rate that determines the average size of a raindrop. Thus in Seattle it rains often but it rarely rains hard. The probability of a cloudburst in Seattle is about the same as that in San Francisco. It is more likely for a heavy rain shower to occur in Washington, DC.

Washington, DC is in rain climate ragion D2. With a probability of 99.95 percent, the maximum rain rate is 22.3 mm/h. Thus if a total rain degradation for this rain rate is compensated by adding sufficient margin to the link budget, there will be a 99.95 percent probability that the signal can be received with the specified system performance objective. That is, there is a probability of only 0.05 percent that the anticipated degradation will be exceeded. This probability translates to a possible total unavailability of 4.38 hours in increments distributed randomly over the entire year.

For a digital signal, the required signal power is determined by the bit rate, the bit error rate, the method of coding, and the method of modulation. The performance objective is specified by the bit error rate. If the maximum allowed rain rate is exceeded, the bit error rate would increase at the nominal bit rate, or else the bit rate would have to decrease to maintain the required bit error rate.

At C-band, the rain attenuation for an elevation angle of 40° and a maximum rain rate of 22.3 mm/h in Washington, DC is 0.1 dB. This is practically a negligible effect. At Ku-band, under the same conditions, the attenuation is 4.5 dB. This is a large but manageable contribution to the link budget. However, at the Ka-band downlink frequency of 20 GHz, the attenuation is 12.2 dB. This would be a significant effect, requiring over 16 times the power as in clear sky conditions. At the uplink frequency of 30 GHz, the attenuation would be 23.5 dB, requiring over 200 times the power. At the V-band downlink frequency of 40 GHz, the attenuation would be 34.6 dB and at the uplink frequency of 50 GHz the attenuation would be 43.7 GHz. These losses simply cannot be accommodated and thus the availability would be much less.

In practice, these high rain attenuations are sometimes avoided by using site diversity, in which two widely separated earth stations are used. The probability that both earth stations are within the same area of rain concentration is small. Alternatively, a portion of spectrum in a lower frequency band may be used where needed. For example, a hybrid Ka-band/Ku-band system might be designed in which Ka-band provides plentiful spectrum in regions of clear weather, but Ku-band is allocated to regions in which the rain margin at Ka-band is exceeded.

SYSTEM TEMPERATURE

In addition to causing attenuation, rain increases the downlink system noise temperature. The figure of merit of the earth station receive antenna is the ratio of the antenna gain to the system temperature G/T. The effect of rain is to increase the system temperature and thus reduce the figure of merit.

The clear sky system temperature is

$$T = T_a + T_e$$

where T_a is the clear sky antenna noise temperature and T_e is the equivalent temperature of the receiver. The antenna temperature is the integrated sky temperature weighted by the antenna gain. At a high angle of elevation, the clear sky temperature is typically about 25 K since the antenna looks at cold space. However, the temperature of liquid water is about 300 K. Thus the rain increases the sky temperature by an order of magnitude. Therefore, the noise admitted to the earth station receive antenna increases and causes further signal degradation. However, rain does not affect the system noise temperature of the satellite because its antenna looks at the warm earth.

The rain layer acts very much like a lossy waveguide. The equivalent temperature of the rain is

$$T_r = (L_r - 1)\, T_0$$

where L_r is the rain loss and T_0 is the physical temperature of the rain. The antenna noise temperature in the presence of rain is given by

$$T'_{\mathrm{a}} = (T_{\mathrm{a}} + T_{\mathrm{r}}) / L_r$$

where T_{a} is the clear sky antenna noise temperature. The system temperature in this case is thus

$$T' = T'_{\mathrm{a}} + T_{\mathrm{e}}$$

where T_e is the equivalent temperature of the receiver, which is the same as before. The increase in system temperature may thus be expressed

$$\Delta T = T' - T = (T_0 - T_{\mathrm{a}})\, (L_r - 1)/L_r$$

The coefficient of the term on the right is about 275 K. The rain causes an increase in system temperature and produces a degradation effect that can be comparable to the attenuation itself. For large attenuation, the limiting ratio of system temperatures is

$$T' / T = (T_0 + T_e) / (T_a + T_e)$$

Thus the antenna temperature approaches the temperature of the rain.

DNPOLARIZATION

Rain also changes the polarization of the signal somewhat. Due to the resistance of the air, a falling raindrop assumes the shape of an oblate spheroid. Wind and other dynamic forces cause the raindrop to be rotated at a statistical distribution of angles. Consequently, the transmission path length through the raindrop is different for different signal polarizations and the polarization of the received signal is altered.

For a satellite communication system with dual linear polarizations, the change in polarization has two effects. First, there is a loss in the signal strength because of misalignment of the antenna relative to the clear sky orientation given by

$$L = 20 \log(\cos \tau)$$

where τ is the tilt angle relative to the polarization direction induced by the rain. Second, there is additional interference noise due to the admission of a portion of the signal in the opposite polarization. The average canting angle with respect to the local horizon can be taken to be 25°.

It is an interesting property of earth-satellite geometry that a linearly polarized signal is not oriented with the local horizontal and vertical directions, even though a horizontally polarized signal is parallel to the equatorial plane and a vertically polarized signal is perpendicular to the equatorial plane when transmitted from the satellite. Thus the optics of the earth station antenna must be correctly rotated in order to attain the appropriate polarization alignment with the satellite. The earth station feed rotation angle θ is given by

$$\tan \theta = G \sin \Delta\lambda / \tan \phi$$

where ϕ is the latitude of the earth station, $\Delta\lambda$ is the difference in longitude, and G is a geometrical factor that for a geostationary satellite is nearly unity. For example, in Washington, DC, at a latitude of 39°, the antenna polarization must be rotated by about 12° if the difference in longitude between the earth station and satellite is 10°. Thus the average effective rain canting angle relative to the polarization direction is about 25° − 12° = 13°. The corresponding polarization loss is 0.2 dB.

CONCLUSION

A variety of new satellite services are being developed in frequency regimes higher than the usual C and Ku bands due to the availability of spectrum. These systems include the broadband services planned for Ka-band. Rain will have a significant impact on the availability. Mitigating techniques such as site diversity or the allocation of spectrum sparingly at lower frequencies where needed will be necessary to ensure uninterrupted service. Alternatively, data rates and bandwidth capacity must be adjusted to maintain the specifed bit error rates.

The mobile satellite service has failed to meet market expectations primarily because of the availability of terrestrial services that are cheaper, have greater signal strength, and require simpler equipment to operate. This paradigm must be avoided if broadband satellite services are to succeed. The competion with fiber and cable will be critically affected by the level of access, the data rates, the complexity of the user equipment, and the availability. The effects of rain will have an important influence on these factors.

Dr. Robert A. Nelson, P.E. is president of Satellite Engineering Research Corporation, a satellite engineering consulting firm in Bethesda, Maryland. He is *Via Satellite*'s Technical Editor.

Effects of Rain Degradation on the Satellite Communications Link

Assumptions

Rain region	D2
Elevation angle	40°
Earth station latitude	39°
Earth station altitude	0 km
Clear sky temperature	25 K
Receiver equivalent temperature	120 K
Rain temperature	300 K
Polarization	vertical

Availability (percent)		99.99	99.95	99.90	99.50	99.00	98.00	97.00
Unavailability (percent)		0.01	0.05	0.10	0.50	1.00	2.00	3.00
Maximum rain rate (mm/h)		47.1	22.3	15.2	5.3	3.0	1.5	0.9
Attenuation (dB)								
C-band downlink	4 GHz	0.2	0.1	0.1	0.0	0.0	0.0	0.0
C-band uplink	6 GHz	1.3	0.5	0.3	0.1	0.0	0.0	0.0
Ku-band downlink	12 GHz	10.5	4.5	2.9	0.8	0.4	0.2	0.1
Ku-band uplink	14 GHz	13.7	6.1	4.0	1.2	0.6	0.2	0.1
Ka-band downlink	20 GHz	26.4	12.2	8.1	2.5	1.3	0.6	0.3
Ka-band uplink	30 GHz	48.8	23.5	16.1	5.4	2.9	1.4	0.8
V-band downlink	40 GHz	68.8	34.6	24.2	8.6	4.9	2.4	1.5
V-band uplink	50 GHz	83.8	43.7	31.2	11.8	6.9	3.5	1.9
Decrease in G/T (dB)								
C-band downlink	4 GHz	0.4	0.2	0.1	0.0	0.0	0.0	0.0
Ku-band downlink	12 GHz	4.4	3.5	2.8	1.2	0.7	0.3	0.2
Ka-band downlink	20 GHz	4.6	4.4	4.2	2.6	1.8	0.9	0.6
V-band downlink	40 GHz	4.6	4.6	4.6	4.2	3.6	2.6	1.9