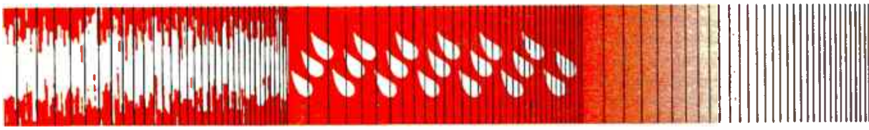
The Lenkurt DEMODULATOR

OCTOBER 1969

the reach for higher frequencies

PART 1



The trend toward higher radio frequencies creates new problems in system design.

Congestion of the radio-frequency spectrum has been foreseen almost from the beginning of commercial radio transmission. As radio technology has advanced, increasing demands for radio services have outpaced improvements in the efficiency of spectrum usage.

The result has been a continuing trend toward the use of higher and higher frequencies. There is no end in sight, with the upsurge in data transmission and other services that require the bandwidth of hundreds of voice channels.

Not too many years ago, "higher frequencies" referred to the VHF and UHF bands, with the then-new concept of line-of-sight propagation. Then came the microwave frequencies – 2, 4, and 6 GHz – where the signal behaved even more like a light beam. Each frequency "plateau" required new approaches to systems as well as hardware design.

Today, the 4 and 6 GHz bands form the heart of many communications systems. But new allocations in these bands are often difficult to get (impossible for some kinds of service). And in some major metropolitan areas, where the demand for service is the heaviest, no allocations are available at all. There is literally no place to go but up. For most types of service, the next available frequency bands are above 10.7 GHz.

The problems involved in building equipment for these higher frequencies were solved several years ago (Lenkurt introduced the highly reliable 76D Microwave Radio System in 1964). But the most reliable equipment is worth little if the system "goes down" because of propagation failure.

Path Considerations

In many ways, the higher microwave frequencies behave just like the lower ones. The path-attenuation calculations, for example, are identical. For a given path, they show that a 12 GHz signal has 6 dB more path attenuation than a 6 GHz signal. On the other hand, the gain of a parabolic antenna of given size is 6 dB higher at

12 GHz. Since both the transmitting and receiving antennas are involved, the 12 GHz signal would appear to have a 6 dB advantage. In practice, however, this advantage is essentially cancelled by higher receiver noise figures and higher waveguide losses at 12 GHz.

Selective fading at the higher frequencies can be effectively combatted by methods used at lower frequencies. Space diversity, for example, with its redundant transmission paths, substantially increases path reliability. The chance of both paths fading simultaneously is remote. In the types of service for which the allocations are available, in-band frequency diversity is an excellent defense against selective fading. Its chief disadvantage is the total amount of frequency spectrum it uses.

The effect of selective fading varies only slightly with frequency. For any given path reliability, the required fade margin in the 11 GHz band is at most a few dB greater than that needed at the lower frequencies.

Slightly less path clearance is required at the higher frequencies because the Fresnel-zone radii are smaller. Except in critical cases or on short hops, however, the difference is not likely to be very significant. For instance, on a 20 mile, 6.175 GHz hop, the first Fresnel-zone radius at 10 miles is 64.9 feet. If the frequency on the same hop is increased to 11.2 GHz, the radius decreases by only 16.8 feet.

Effects of Precipitation

In the design of most microwave systems, the path attenuation is assumed to be the same as that encountered in free space. This is a good approximation for frequencies up through the 6 GHz band. But as frequency increases, the signal becomes progressively more sensitive to precipitation.

Rain attenuates a microwave signal in two ways: the water absorbs energy, and the droplets scatter it. The severity of the attenuation is a function of the drop size, the temperature, the volume of water involved, and the signal frequency. The most significant part of this complex relationship can be summed up this way: the harder it rains, the bigger the drops, and the higher the frequency, the more severe the attenuation will be.

Of course, other forms of atmospheric moisture also affect signal attenuation, but rain is usually the dominant factor. Fog and mist are essentially light rain. Attenuation due to hail is only a small fraction of that caused by rain. The effect of snow varies widely, depending on the moisture content, the flake size, and the temperature; but snow generally carries a much lower volume of water than rain does.

At the higher frequencies, heavy rain can be a real problem. The theoretical curves of Figures 1 and 2 show how frequency would increase excess path loss if the rainfall rate were constant along the path. While actual rainfall rates are never uniform along the entire path, a hypothetical example based on Figure 1 gives some feel for the effect of extremely heavy rain (4 inches per hour) on signals of different frequencies.

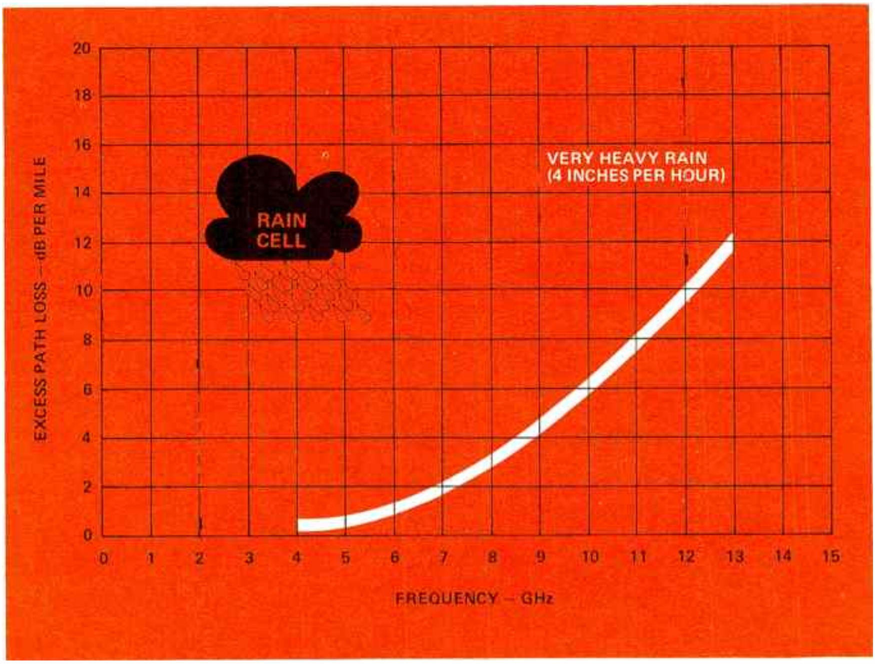


Figure 1. Excess path loss caused by heavy rain increases rapidly with increasing frequency.

A 6 GHz signal, with an excess path loss due to rain of only about 1.2 dB per mile, would be attenuated by about 24 dB over a 20 mile hop. That is centainly significant, but it is within the operating capability of a system engineered with, say, a 40 dB fade margin.

A 13 GHz signal, on the other hand, would suffer rainfall attenuation of about 240 dB.

As shown in Figure 2, a "heavy" rainfall of 0.6 inch per hour would cause excess path loss of only about 1.1 dB per mile at 13 GHz – roughly the same as the 6 GHz signal would suffer at the much higher rainfall rate.

The trouble with curves such as these is that they fail to take into account the changing nature of heavy rain.

Local Rainfall Distribution

It is relatively easy to measure the effect of rain on a microwave path. The difficulty arises in trying to measure the rainfall rates along the path for accurate correlation with the attenuation measurements. The harder it rains, the more likely it is that the rainfall rate will show wide and almost instantaneous variations. Furthermore, there may be very heavy rain at one point, and almost none a short dis-

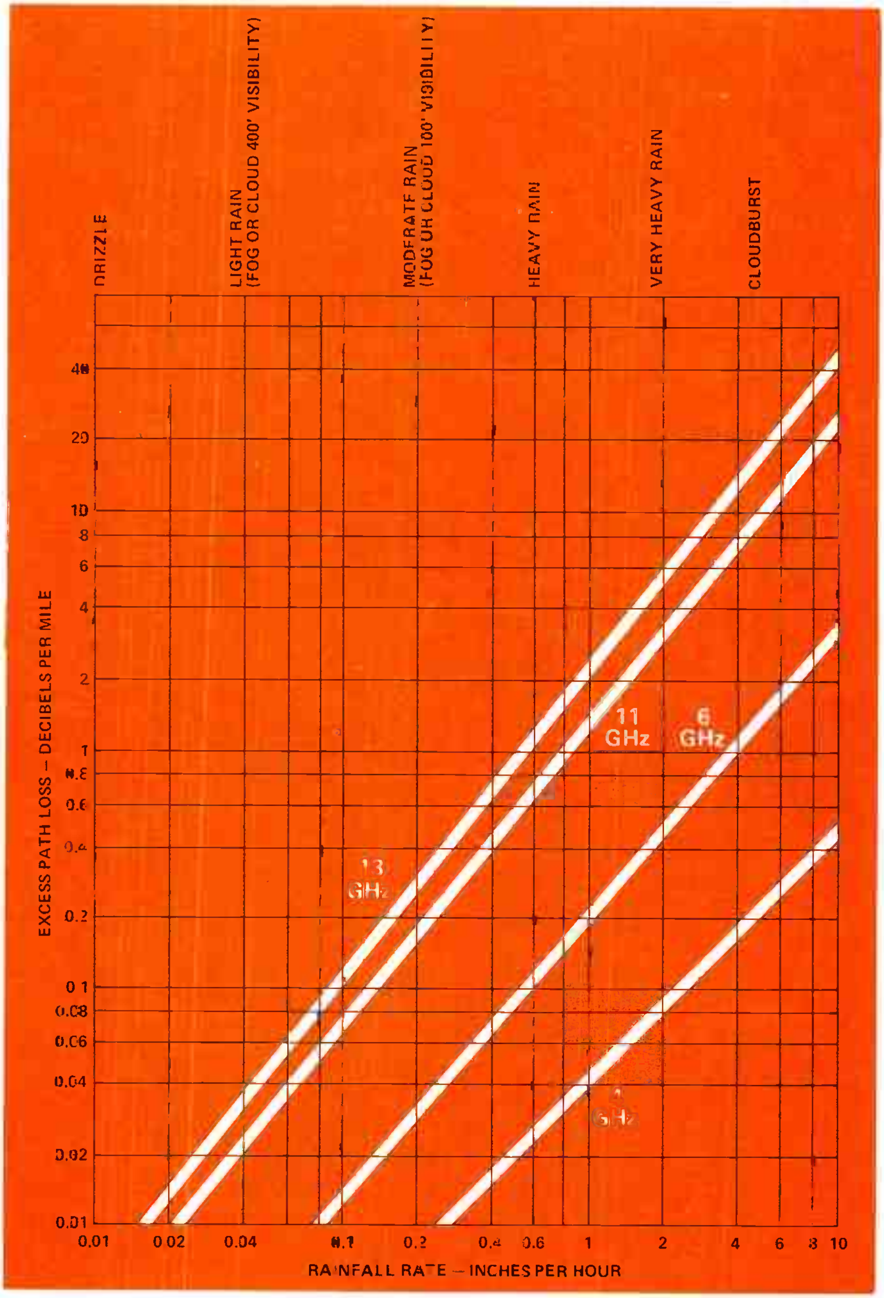


Figure 2. Theoretical curves show how attenuation increases with rainfall rate (based on calculations by Ryde and Ryde).

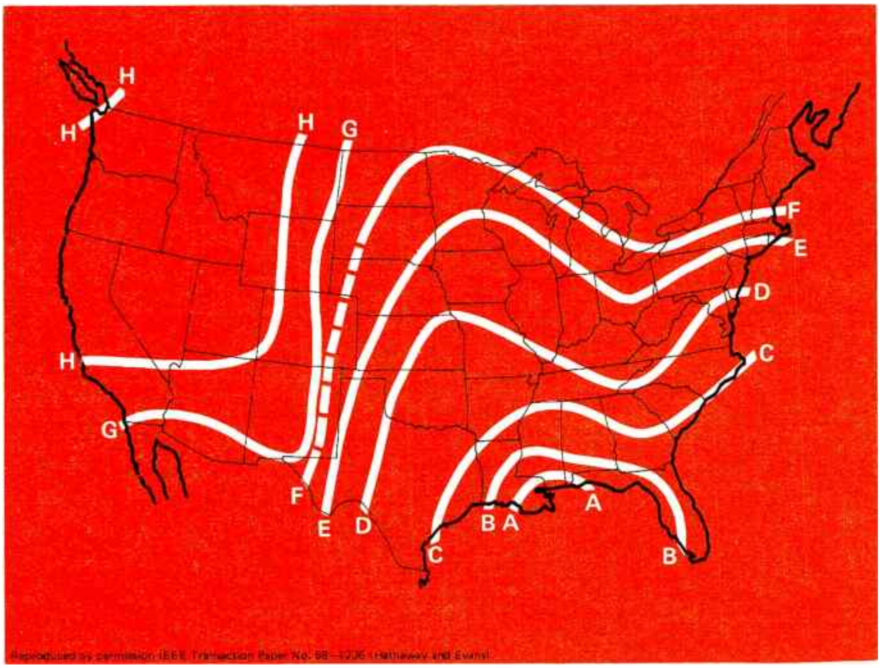


Figure 3. The contours of this map are for fixed transmission outage time and can generally be used in conjuction with the curves of Figure 4, to predict the effect of rainfall on outage time.

tance away. The cumulative figures for the total length of a microwave path are often irrelevant.

Much work has been done in recent years on the nature of rainfall patterns. The results are not conclusive, but they indicate that the most intense rain, the rain that significantly affects microwave propagation, occurs in relatively small cells. Available evidence indicates that these cells rarely exceed a few miles in diameter, and the rainfall rate varies even within the cell.

This variation means that even an intense cell may not block a microwave path for the entire time it takes to cross the path. A five mile wide cell, moving at 20 miles per hour, takes 15 minutes to cross a particular path at right angles. But regardless of its intensity, it may only cause some short outages. It is unlikely to block the path completely for 15 minutes.

Rainfall Distribution

Paradoxically, some geographical regions known for their large annual rainfall (such as the rain forests of Oregon and Washington) do not present as difficult a transmission problem as do other "drier" areas. The reason is, of course, that the total annual

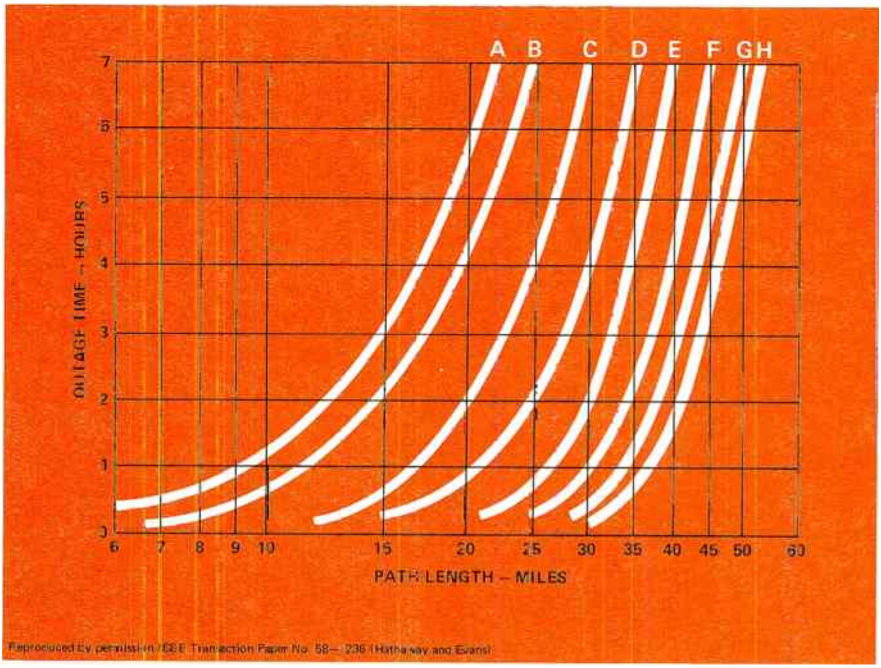


Figure 4. Expected outage time varies greatly with changing geographical rainfall distribution. These curves, for use with the contour map of Figure 3, are based on 11 GHz paths with 40 dB fade margins.

rainfall is of little consequence. *Concentrated* rain causes the trouble. The significant questions are: How heavy are the rainfall rates that can be expected? How often can such rates be expected?

The problem in any area is complicated by the fact that although much information is available on *annual* rainfall, very little is known about *instantaneous* rates. Gradually, however, the body of knowledge has built up so that it is now possible to generalize about many geographical areas.

The key factor, of course, is the amount of outage time a particular system is likely to suffer. Some types of service can tolerate substantial outages, while others cannot. Figures 3 and 4, the results of empirical studies, indicate generally how expected outage time varies with geography in the United States. For example, an 11 GHz path, 30 miles long and engineered for a 40 dB fade margin, would have an expected outage time of about 0.2 hour per year on Washington's Olympic Peninsula (contour H). This translates to a reliability of 99.998 percent.

If the same path were located on the coast of the Carolinas (contour C),

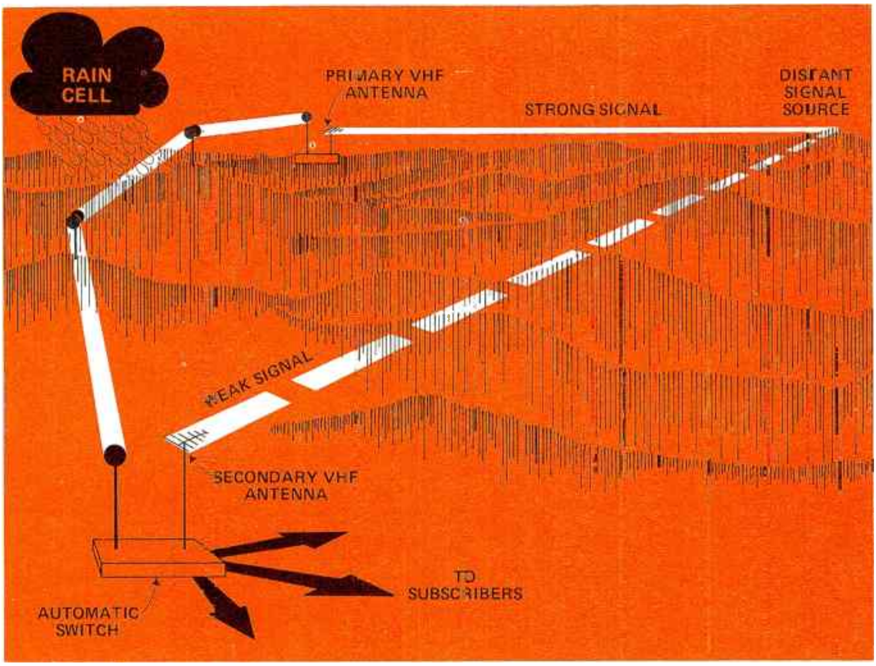


Figure 5. Many CATV systems can use a secondary off-the-air antenna as a back-up for a microwave link.

the predicted reliability would drop to 99.92 percent because the expected outage time would increase to 7 hours per year.

Now consider the same path on the Gulf Coast of Mississippi (contour A) and assume that the expected annual outage time must be held to the same 7 hours. The path would have to be shortened from 30 miles to 22 miles, or the fade margin would have to be increased substantially.

It must be remembered that these calculations are for a single hop. The outage time for the entire system can be expected to equal the sum of the single-hop outages. In terms of reliability, 10 hops with 99.99 percent reliability form a system that is only 99.9 percent reliable.

Living With the Problem

It may appear from what has been said that the frequencies about 10.7 GHz are a poor second choice, to be considered only when allocations at lower frequencies are not available. But this is only partly true. When the limitations of the higher bands are recognized, they give very good service. This really means learning to live with the rainfall problem.

First, of course, rainfall attenuation may not even be a problem. If the system is located in an area where rain rarely falls in cloudburst proportions, it can probably be engineered like any other system, with little worry about excess outage time.

Second, the type of service may be able to tolerate occasional outages of a few seconds to a few minutes. Some services, such as telephone common carrier, demand very high reliability. Others may be able to live with a few short outages.

A case in point is a CATV relay. Typically, the system operates only 18 hours a day. Thus, 25 percent of the heavy rains would be expected to occur during off-the-air hours. In some areas, heavy rainfall is consistently concentrated in these early morning hours.

Furthermore, many CATV systems can use a kind of "microwave/VHF diversity". If there is an outage in the microwave link, the signal is simply taken from the secondary antenna as shown in Figure 5. This provides an inferior signal, but it is usually watchable for the short periods of rain-induced outages.

The third factor in living with the rainfall problem is the length of the proposed system. Outages are cumulative. So a very long microwave system may have comparatively low reliability, even though the reliability of every hop is high. The longer the system, the greater the chance of a severe rain cell moving across the path somewhere. An obvious solution is to use the higher frequencies for short systems, and to reserve the lower frequencies for long, cross-country systems.

Diversity Arrangements

Heavy rain is not the only thing that will put a microwave system temporarily out of business. The mechanisms of selective fading are completely separate from those of rainfall attenuation. When the effects of rainfall attenuation cannot be completely controlled, one way to keep annual outage time down is to pay special attention to selective fading. This implies some sort of diversity arrangement. All diversity arrangements combat selective fading, and some provide protection against rainfall attenuation, as well.

Space diversity is no defense against rainfall attenuation because the two transmission paths are quite close, and subject to essentially the same rainfall pattern. In the typical case, where one path is directly above the other, the same rain will block both paths simultaneously.

While in-band frequency diversity also offers good protection against selective fading, it still provides no defense against rainfall attenuation. The two frequencies are so close together (typically separated by only two percent of the frequency) that the effect of rain is essentially the same on both.

On the other hand, if frequency diversity is extended to include both the 6 GHz and the 11 GHz bands (cross-band diversity), it can provide excellent protection against both selective fading and rain. It is true that when the 11 GHz path fails because of rain the entire load falls on the 6 GHz path. Fortunately, however, severe selective fading rarely occurs during per-

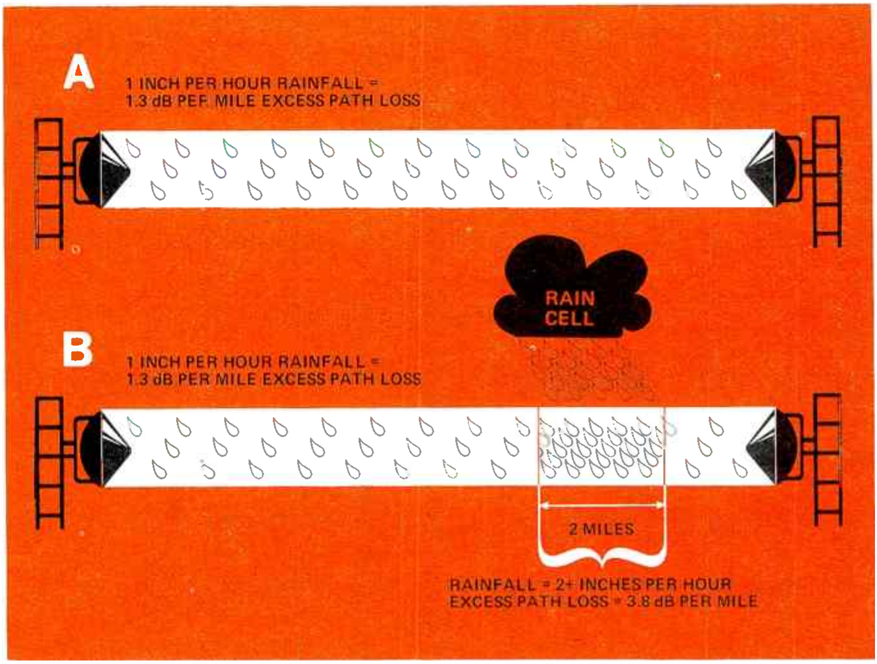


Figure 6. Raising the fade margin by 5 dB, (as in B above) can permit transmission through a rain cell of substantially greater intensity.

iods of heavy rain. This makes the 6 GHz path exceptionally reliable during such periods. Thus, cross-band diversity is probably the best solution – provided, of course, that frequency allocations and regulatory approval are available.

Perhaps the ideal solution would be route diversity – an extreme form of space diversity. The same signal would be sent over two paths separated by several miles. This would all but eliminate the possibility that rain would block both paths simultaneously. In practice, however, route diversity is not often used in present-day systems. The main reason is simple economics. Equipment and installation costs are quite high. Furthermore, the process of dropping and inserting channels is complicated – not to mention the difficulty encountered at the receiving end in trying to combine the signals from two paths of substantially different length.

Conservative Engineering

It is apparent that there is no easy, clear-cut way to avoid problems with rain. The most effective defense is a combination of techniques. And conservative engineering is the first one. A marginally engineered system is an invitation to excess outage time.

One thing that can be done, for example, is to increase the fade margin. This does not guarantee transmission through the heaviest rain, but it does effectively lower the expected outage time.

Because of variations in the instantaneous rainfall rate, it is not always possible to specify exactly how much effect a higher fade margin will have on rainfall attenuation. But some idea can be gained from a hypothetical example like this: Suppose a particular 11 GHz microwave hop can withstand an average rainfall along the path of 1 inch per hour – an excess path loss of about 1.3 dB per mile. If the fade margin is then raised by 5 dB, the hop can still withstand the 1 inch per hour rain along the path, except for a two mile segment where it passes through a rain cell. In that segment, it can withstand excess path loss of 3.8 dB per mile – equivalent to a rainfall rate of over 2 inches per hour (see Figure 6). In many areas, that much improvement will not eliminate rainfall outages. But it will reduce them.

Of course, increasing the fade margin may not always be desirable. If it means an increase in the number of hops, for instance, any gains in path reliability may be more than offset by the decrease in equipment reliability as more transmitters and receivers are added.

Equipment reliability is equally as important as path reliability. So is the reliability of the power source. And good maintenance is important, too. Improving the reliability of any one of these naturally improves the end product – total system reliability. Thus, economics is the common denominator in improving system reliability.

Where to Next?

The move to the 11 GHz microwave band is not the final rung on the ladder of ascending frequencies. This band will eventually become congested like all the others below it. What then? Still higher frequencies, with even more severe attenuation problems? Coaxial cable? Millimeter waveguides? Laser transmission?

The second part of this two-part article, to appear in next month's *Demodulator*, will discuss the future of transmission technology.

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