ATS-5 MILLIMETER WAVE PROPAGATION MEASUREMENTS

Louis J. Ippolito

I'd like to describe the problems that would occur as we move up into the frequency bands where the wavelength is on the order of magnitude of raindrop diameter, and the rain therefore becomes a problem. The communication designer has to go to these higher frequency bands as more and more users require more and more bandwidth. Virtually all of our present communication links are at frequencies below 10 gigahertz, but systems are being designed to go to the bands above 10 GHz; it is necessary to define these bands, to determine the propagation problems, and to look at ways to overcome them.

The first flight experiment available to evaluate frequencies above 10 gigahertz was the ATS-5 propagation experiment, launched in August 1969. Figure 1 shows the basic configuration of the ATS-5 experiment. A downlink was available at 15.3 gigahertz with a full earth coverage horn to provide participants throughout the U.S. and Canada the opportunity to observe the signal over long periods of time. They had a chance to determine attenuation and fading characteristics as a function of rainfall rate and other meteorological parameters.

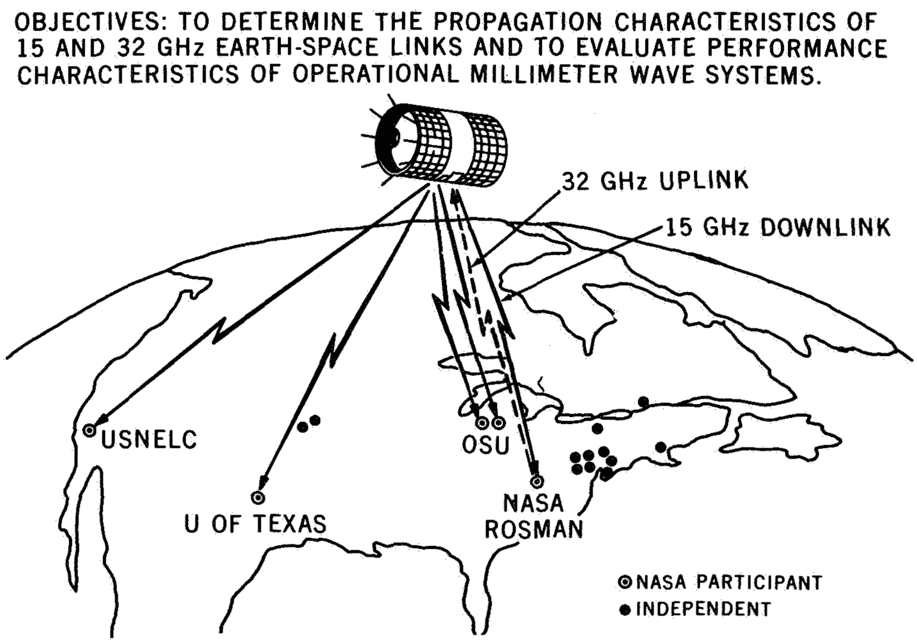

Figure 1. The ATS-5 Millimeter Wave Experiment, launched in August, 1969, provided the first operational earth-space link at frequencies above 10 GHz. Fourteen ground stations participated, with nearly two years of experimental measurements.

In addition, an uplink at 32 gigahertz was implemented at Rosman, North Carolina, to evaluate similar characteristics at the higher frequency band. Fourteen stations participated in the experiment during two years of satellite operations. Besides measuring the basic parameters, we studied the correlation of the attenuation with radiometric data, radar data, rain gauge data, and standard meteorological data.

I'd now like to discuss two of the major results of the ATS-5 experiment. First, the level of the attenuation that was experienced throughout the U.S. will be summarized; and second, a method to overcome the attenuation problem will be described.

Figure 2 gives an indication of the magnitude of the attenuation problem at 15.3 gigahertz. Here we see five locations where sufficient data were available to give a yearly statistic and the values in dB are the values required at those sites to maintain a 99.99 percent reliability. That is roughly a one hour a year outage time.

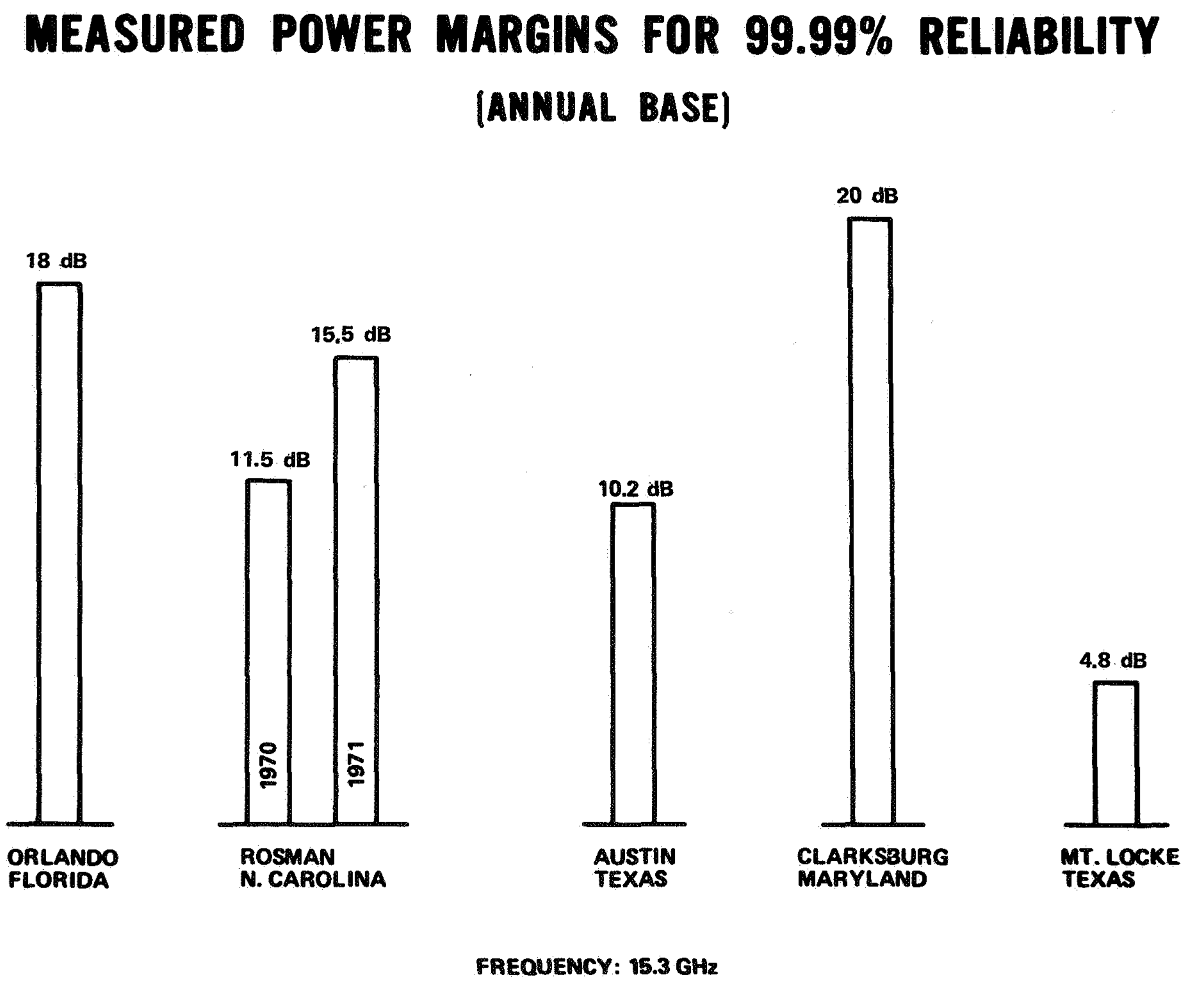

Figure 2. Measured attenuation at five locations showed large variations which did not coincide with the general weather profiles of each location. Also, annual measurements taken at one location (Rosman) for two consecutive years showed a 4-dB difference in maximum levels.

You can see, for example, at Orlando, Florida, which has a fairly high rainfall, an 18 dB margin was required to maintain a 99.99 percent reliability. The values range as high as 20 dB at Clarksburg, Maryland, down to fairly low margins in the desert area at Mt. Locke, Texas.

I'd like to make two points about this type of result. First, you can see that at Rosman, where we had two years of data available, the yearly margins differed by 4 dB. Therefore, looking at only one year of data can be sometimes misleading in determining site margins. The second point is that the sites are listed in order of decreasing rainfall towards the right; however, the attenuation statistics did not generally follow that trend. Note that Clarksburg, Maryland has lower average rainfall than three other sites, yet is showed the highest attenuation.

So, in summary we see that the margins can vary quite a bit, they can be quite severe, and they don't necessarily follow the expected results from rain gauge data.

There are ways to overcome attenuations of this type. We investigated the most promising technique–site diversity. In this technique, two ground stations separated by a few kilometers are utilized. Intense rain cells are usually quite small in size, and if the stations are separated by an adequate distance, there will be a high probability that only one site will be undergoing attenuation from the rain cell at a given time.

Figure 3 summarizes the measurements at Columbus, Ohio, where two sites were located, roughly four kilometers apart. The dashed arrows show the direction toward the satellite. Here we see the enhancement that diversity can produce. On the left are time plots of received signal power for a storm which passed over the two sites. The upper graph shows the attenuation experienced at site 1. A fade of about 10 dB occurred at site 1, but very little attenuation was noted at the second site. The attenuation moved to site 2 about ten minutes later.

We can look at this type of measurement over a long period of time, look at the enhancement we get, and the result is summarized in the plots on the right of Figure 3. The two upper curves show the attenuation characteristics of each site individually, for example, the attenuation exceeded 12 dB about 2 percent of the time at either site.

However, if we go to diversity switching, and select the site with the lowest attenuation, we get a tremendous improvement, e.g. for a 9 dB fade, we have about a 100 to 1 improvement or reduction in time outage. For a given percentage, we can reduce our margin by as much as 4 to 5 dB. We see here a very powerful technique to overcome the heavy attenuation problem when percent reliabilities of 99.9 percent or better are required. In applications where reliabilities of this level are required, but you can't place the site in a low rain area, site diversity is a very powerful technique to overcome the attenuation.

SITE DIVERSITY MEASUREMENTS AT COLUMBUS, OHIO UTILIZING THE ATS-5 SATELLITE

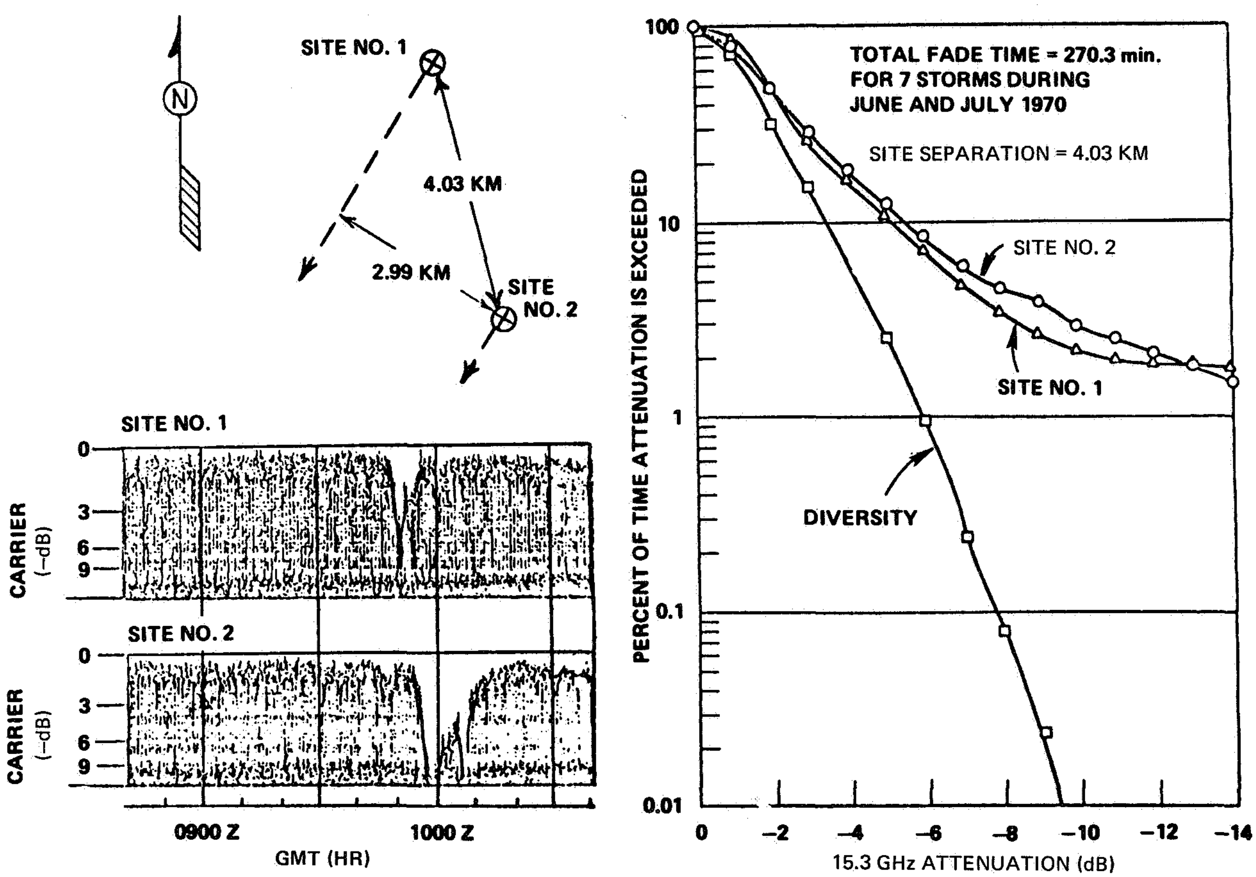

Figure 3. Dual site diversity with a 4-km separation showed improvements of 100-to-1 in outage time and 6-dB improvements in margin requirements over a single station.