Low Power, Great Signals

Every communication setup can be analyzed in advance to determine a range of expected signal strength. This is true regardless of the frequency or propagation mode. On the higher bands we don't have any chance of using the ionosphere and paths are considerably shorter than on HF or even VHF, so propagation is a little more predictable.

I will not describe or try to analyze the greatest DX modes for microwaves, which include atmospheric ducting and other weather phenomena. Instead, I will concentrate on the more common line of sight, and simple diffraction paths that people use regardless of the weather. By taking the simple cases, you can see how strong signals can be heard with the relatively low power we use on the upper bands. The equations are intuitive and except for conversion of some values into logarithms, involve only adding and subtracting to sufficiently analyze a communications channel.

Gain

Although larger aperture antennas are harder to point because they concentrate the RF into a narrow beam, they also provide more gain, putting more of the transmitted power into the receiver antenna. The larger receiver antenna likewise intercepts more of the transmitted field, and so presents more signal level to the receiver than a smaller antenna would. As described in more detail in the antenna issue of *QST*, July 2002, these larger aperture, and therefore higher gain antennas are what make microwave communications possible. But, just how large an antenna is needed?

Radio communication is a system. To understand how well one station will hear the other, one has to think of the entire system. This includes the transmitter, transmitter antenna, losses due to spreading of the signal and other blockage, receiving antenna, receiver sensitivity and bandwidth. The frequency of operation comes into the picture in two ways.

Path Loss

If the antennas are described in terms of their aperture, then spreading loss simply follows the reciprocal squared law, and so path loss would be due only to the spreading of the energy. This spreading does not depend on frequency. If the antennas are described in terms of gain, then we are comparing the antennas to isotropic radiators (gain is expressed in dBi, or decibels referenced to isotropic). Because isotropic radiators at higher frequencies (smaller wavelengths) have smaller effective apertures, then "path loss" based on antenna gain (rather than aperture) accounts for this small aperture as well as energy spreading. Most published tables for path loss are based on isotropic radiators so that antenna gain values can be used instead of aperture. Remember, however, that the basic spreading of energy does not change with frequency.

Propagation

The other way that frequency enters the communications performance picture is through losses from the atmosphere and intervening obstructions. At microwave frequencies the atmosphere begins to absorb RF. As frequency goes up, it absorbs more. There are also some spikes in the absorption curve due to resonances of the water and the oxygen molecule. These effects all add up to a pattern of curves that change depending on water vapor content. Fog, rain and snow also can attenuate signals. Except on long paths and bands above 10 GHz, these effects are small. Record breaking QSOs at 24, 47, 81, 120, 145 and 241 GHz are usually accompanied with reports of dew points or humidity and temperature because of the sensitivity at these frequencies to water vapor.

Some obstructions, such as a mountain, can actually provide a means for scattering the RF allowing the signals to fill in areas on the other side of the obstruction. This is called "knife edge effect," and under ideal conditions is well understood. Actual conditions, however, are rarely ideal, and so amateurs often experience signal levels different from those calculated when applying expected values for scatterers such as mountaintops. The author has often made QSOs with amateurs on the other side of mountains when common intuition would lead one to not try it at all. Specifics for different types of absorption and propagation in general can be found in several publications. A particularly clear treatment, with helpful charts and examples, is found in the *ARRL UHF/Microwave Experimenter's Manual*.

Bandwidth

The bandwidth of a signal strongly affects our ability to receive it. Why is this so? It is because all receivers have noise. Our standardized representation for noise is a random process that has the same amount of power for every unit of frequency. This understanding is based on noise as having a thermal origin, and leads to simple statistical models. Often noise is expressed in dBm/Hz (decibels referenced to a mW per Hz). A 1 kHz bandwidth will contain 1000 times the noise power of a 1 Hz bandwidth, and a 2.5 kHz (typical SSB) bandwidth will have five times the noise power of a 500 Hz (typical CW) bandwidth. So, if we try to hear a CW signal through an SSB filter, it will carry along with it five times the noise than we would hear if we were listening through a CW filter. The effect is not quite as dramatic as all this would lead us to believe, because the human ear is capable of providing its own adaptive bandwidth to CW signals. The effect is true in general, however, and is easy to demonstrate when comparing wide band FM to SSB, for instance.

The Equation

To simplify the computation that will tell us how strong a signal will be at the receiver end of a communication system, we use decibels and addition and subtraction. Recall that addition of logarithms is the same as multiplying the underlying linear values, and subtraction the same as division. It is common to express noise figure, power, and gain in decibel forms. Path loss from charts (or from the equation below) is also expressed in dB. We do not normally express bandwidth as a logarithm, however, so the formula for that is given as well. I may use slightly different names for terms than some of the publications. It should be clear from these descriptions just what each term is.

Received signal power:

$$P_R = P_T + G_T - L_P - L_A + G_R$$

Received noise power:

$$P_N = B_R - 174 + N_F$$

P_R is the power of the received signal in the passband. P_N is the power of the noise in the receiver passband. The ratio between P_R and P_N is the signal-to-noise ratio (SNR). Because we are using logarithms, the ratio is simply $P_R - P_N$

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expressed in decibels. Usually, a SNR of between 0 dB and 3 dB is necessary for a CW message. Usually a 6 dB SNR is barely adequate for a SSB and an FM conversation, and 10 dB is considered enough for solid copy.

The equation for received power is simply the transmitted power plus the transmitter antenna gain, resulting in effective radiated power, minus the path losses, plus the receiver antenna gain. This tells us how much signal power appears at the antenna terminals of the receiver.

P_T is the power of the transmitter expressed in dB referenced to some standard power. One can use watts or mW. For this treatment, I will use mW, so power is expressed as dBm. A 1-W transmitter has 30 dBm of power; a 100-W transmitter has 50 dBm.

G_T is the transmitter antenna gain, in dB. Microwave antennas often have 20 dB or more of gain. Some larger antennas, at higher frequencies can have over 40 dB. As we will see in the examples, microwave operators depend on lots of gain to make contacts.

L_P is the path loss. This is the path loss due to spreading function and related to isotropic radiators so that we can use gain instead of aperture in the calculations. A simple function for calculating this is L_P =32.5 + 20*log(MHz) + 20*log (km). This equation is also represented in tables and charts in some publications.

L_A is the second component of path loss; loss due to absorption. L_A is due to absorption by the propagation medium and absorption and scattering by obstructions.

G_R is the gain of the receive antenna.

The equation for the received noise power adds the receiver noise (noise figure) to the background noise, resulting in dBm/Hz and then adds the increase due to the bandwidth (effectively multiplying by the number of Hz in the bandwidth). This tells us how much noise power exists in the passband.

B_R is the bandwidth factor, expressed as a logarithm, B_R = 10*log(Hz). For example, 500 Hz is 27, and 2000 Hz is 33.

–174 is the noise level presented by 290 kelvins expressed in dBm/Hz. The kelvin scale is the Celsius scale moved so that absolute zero is 0 K. 290 K is about 68 degrees Fahrenheit, and is used as a reference because it is a standard temperature. This is the noise floor that will be heard from a noiseless receiver with its antenna pointed at earth, or objects at normal room temperature. For space communications a lower figure is used for the background noise. All noise figures of low noise amplifiers and for that matter noise figures of all amplifiers and other components are referenced to 290 K or –174 dBm/Hz.

N_F is the noise figure of the receiver. It basically expresses how much noise is present referenced to –174 dBm/Hz. A noise figure of 3 dB means that the electronics in the receiver generate a noise power equal to that of the warm earth.

Examples

Let's look at two attempted QSOs at 10 GHz. In the first case, both stations are using medium size horns with 17 dBi gain. The radios are using Gunnplexer oscillators and mixers. The output power is 10 mW (which is 10 dBm), the bandwidth is 200 kHz (this is a wide-band FM system) and the receiver noise figure is 10 dB. The two stations are 100 km apart.

The path loss due to spreading and isotropic reference is

32.5 + 20*log(10,000) + 20*log(100) or 32.5 + 80 + 40 = 152.5 dB.

The received power is

P_R = 10 + 17 – 152.5 + 17 = –108.5 dBm

This assumes that there is no significant atmospheric loss and that the path is line of sight.

The receive bandwidth factor in dB is 10*log(200,000) or 53. The noise power is:

P_R= 53 – 174 + 10 = –111 dBm

Signal to noise = –108.5 –(–111) = 2.5 dB SNR. This is insufficient for a good QSO. A slightly higher power, or slightly larger antennas will make communication easier. If there is any additional loss due to humidity or obstructions, this path would be unworkable.

In another example, still at 10 GHz, we have a 100 mW transmitter (20 dBm), again a 17 dBi horn at each end, a low noise amplifier with a noise figure of 1.5 dB, a path length of 100 km, and are using SSB in a 2 kHz bandwidth.

The path loss is exactly the same as the previous example at –152.5 dB. The received power is P_R = 20 + 17 – 152.5 + 17 = –98.5 dBm received signal power, again with the same assumptions.

The receive bandwidth factor in dB is 10*log(2000) or 33. The receive noise power is

P_N = 33 – 174 + 1.5 = –139.5 dBm.

Signal to noise = –98.5 –(–139.5) = 41 dB. Wow, the same antennas, and we end up with super strong 5×9 SSB signals. Why the big difference in what looks like very similar stations? The contributing factors are 10 dB more power, an 8.5 dB better noise figure and a whopping 20 dB improvement from using a narrow bandwidth.

Atmospheric losses at 10 GHz typically run less than 0.01 dB/km, so a 100-km path would only experience 1 dB of loss in addition to energy spreading loss. At 24 GHz, losses due to humidity can become significant, where on a warm and humid day (at about 70% humidity at 70 degrees F), losses of as much as 0.3 dB/km can equal 30 dB over a 100 km path. Note that spreading losses only increase by 6 dB for every doubling of distance, whereas humidity losses increase linearly with distance. When trying to increase DX from 100 km to 200 km in this 24 GHz example we will add 6 dB of energy spreading loss, while adding an additional 30 dB of loss to humidity. Because of a water vapor resonance at 22 GHz, the losses of this type at 24 GHz are about twice as great as those at 47 GHz. Unfortunately, at 60 GHz there is very significant and broad absorption by oxygen, and this affects 47 GHz as much as 0.3 dB/km. This results in similar atmospheric losses at the 24 and 47 GHz bands except during low humidity conditions, when 24 GHz performs better.

Another factor not included in the above analysis is feed line loss. Feed line losses between the transmitter and antenna, and between the receive antenna and receiver (LNA) can simply be subtracted from P_R. Usually, these are kept to under 2 dB each in well designed portable systems, resulting in a system performance degradation of 4 dB or less.

Can I do Better than these Equations Suggest?

During the recent 10 GHz and up cumulative contest, I made a 200-km contact using about 10 mW and a 10 dB noise figure receiver and a 1-foot dish at 24 GHz. The other station was better equipped with about ½ W of power and a better noise figure receiver. It is quite amazing how far one can reach between two well-equipped 10 GHz stations, each with 1 W, a 1.5 dB noise figure, and a 2-foot dish. QSOs of over 300 km are challenging, but are accomplished often.

Over the horizon contacts are commonly made, using propagation modes that are beyond the scope of this column. Opportunities for DX of over 1000 km exist, usually supported by atmospheric conditions, and covering frequencies from VHF to the 1296 MHz band, and sometimes higher. System analysis is not easily applied to these situations because the propagation and therefore the path loss are not easily described. The challenge is to get on the air with the best radios we have and try to catch those conditions that extend our capabilities. A new personal DX record can be just as thrilling as that first contact, and when we continue to improve our stations and learn the tricks of good operating and predicting good conditions, we keep on pushing the frontiers. QST