Microwave Antennas

Microwavers are faced with low power, high losses and poor noise figures (at least until recently), so how do they make contacts? The answer is simple—high-gain antennas. The principles of antennas apply to all frequencies, but most common HF designs, such as long-wires, dipoles, rhombics and 3-element Yagis, provide insufficient gain for serious microwave communications, and some antenna approaches used on microwaves are not practical for lower frequencies. A typical 2-foot diameter dish on 10 GHz would scale to over 2000 feet for use on the 40-meter band!

To understand antenna gain, let's visualize the pattern of power in the radiated RF wave. Imagine that we have a magic balloon. It is quite easy to expand this balloon, and its magical property is that instead of being expanded by air pressure, its expansion (out from the center) is based on the amount of RF power that is hitting its surface. We place this balloon on an antenna and feed it with some power. If we had a perfectly *isotropic* radiator, it would radiate equal energy in all directions (by definition), and the balloon would form a sphere. The power balloon for a dipole would look like a doughnut. In both of these low gain antennas, most of the energy is spread across a large percentage of the volume. Far away from such an antenna the amount of energy that crosses one unit of area is fairly small. This is because the total transmitted energy is distributed over very many such units of area.

By comparison, a high-gain antenna will radiate most of its power over a narrow angle, mostly in one direction. Our balloon will have a long sausage shape. Unlike the low gain antenna, the majority of the radiated power is heading in one direction, so that when intercepted at some far away distance, much more of the original power will cross a unit of area than with the dipole radiator. The formal name for our power balloon is "antenna radiation pattern" and it is often sliced and presented as a two-dimensional diagram.

An exact reciprocal situation exists on receive. A high gain antenna will receive more of its energy from one direction than others. This means that it is more directive than a lower gain antenna. It is also physically larger than a lower gain antenna and thereby intercepts a larger area of the incident wavefront, delivering more power to the receive terminals than a lower gain antenna would.

To get greater gain we need larger apertures, similar to camera lenses, where greater apertures increase exposure. This can be accomplished by creating a flat grid of phased antennas (dipoles, patches, Yagis) or by constructing a horn with a large opening, or by using a parabolic dish and a proper feed.

Q: What is gain and what units are used?

A: Gain is the measure of how much more energy is delivered at the peak of the antenna pattern in relation to the energy that would be delivered (at the same distance and power level) from an isotropic radiator. It is expressed in units of dBi, or *d*ecibels relative to *i*sotropic. Another unit used is dBd, which relates to a dipole rather than an isotropic radiator.

Decibels are a logarithmic expression of the relationship between two amounts of power. It is not a measure of power, but rather is a measure of relative power. The decibel is one tenth of a bel. Saying that X is one bel stronger than Y means that X is 10 raised to the one power ($10^1 = 10$) times the watts of Y. Saying that X is 2 bels stronger than Y means that X is 10^2 (which is 100) times the watts of Y. For example, if Y was 5 W and X is 2 bels stronger, then X would be 500 W. If we want to express that X is only twice as much power as Y (eg, X is 10 W when Y is 5 W) then it would be 0.302 bels because $10^{0.302}$ equals 2 (twice the power). To make units more convenient, we use tenths of bels, or "decibels." So 10 dB (1 bel) is a factor of 10, 20 dB is a factor of 100 and 3 dB (rounded from 3.02) is a factor of 2.

To determine that an antenna has a gain of 20 dBi we could set up an experiment. At some reasonable distance from a mast we place a receiving antenna. We would place an isotropic antenna on the mast, put a known unit of power into the isotropic antenna and measure the power delivered to the receiving antenna. Then, we would replace the isotropic antenna on the mast with the high gain antenna and put the same power into it. After peaking the setup for greatest gain, we measure the received power and should see that the high gain antenna delivers 20 dB more power (100 times more) than we received from the isotropic antenna. Unfortunately, an isotropic antenna is very difficult to construct, so in real antenna measurements, antennas with well-known gains are used instead as the standard, and the standard's gain is subtracted to achieve a measurement of dBi.

Q: How is gain related to aperture?

A: In general, larger apertures (bigger antennas) have higher gain, but only if the antenna is designed well and efficient. The gain increases with the square of the diameter, and inversely with the square of the wavelength. Twice the effective aperture diameter results in 4 times the gain, or a 6-dB increase.

Horns and dishes have physical areas that are simple and obvious. They can be measured directly. Yagis are not physically flat, and so it is not obvious that they have apertures that grow in diameter, as they get longer—but they do. Longer Yagis affect larger and larger areas around them and radiate and receive more directive patterns. Aperture efficiencies typically run from 50% to 70% in well-designed and constructed antennas.

Q: What is beamwidth and how is it related to gain?

A: Beamwidth is the angle over which most of the energy is transmitted, or the width of the primary protrusion in the power balloon. The technical term used is HPBW or half power beamwidth. It is the angle between the directions where the power drops to half of the peak. Higher gain antennas have narrower beamwidths (as shown in Table 1) making them tricky to point. Pointing an antenna often requires that it is within the 1-dB beamwidth, which is about $^1/_4$ of the HPBW in the table. When the pointing beamwidth is smaller than one

Table 1
Approximate Relation between Gain and Beamwidth for Typical Amateur Microwave Antennas

Gain (dBi)	*Beamwidth (degrees)*
10	50
15	30
20	16
25	9
30	5
35	3
40	1.3

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Table 2
Some Example Sizes and Typical Gains of Amateur Antennas for Microwave Bands

Band (MHz)	*Loop Yagi (feet)*	*Gain (dBi)*	*Dish Diameter (feet)*	*Gain (dBi)*	*Horn Height (inches)*	*Gain (dBi)*
903	18	20	12	25	—	
1296	15	21	10	29	—	
2304	12	23	4	27	18	17
3456	8	23	4	30	12	15
5760	Not practical	—	3	32	10	20
10,368	Not practical	—	2	35	6	22
24,192	Not practical	—	1	35	4	26

or two degrees, pointing is very difficult at best. When starting in microwaves, it is advisable to use a moderate gain antenna and spend effort on making electronics that are stable rather than adding to frustration with a difficult narrow beamwidth antenna.

Q: Why are some types of antennas more widely used on certain bands?

A: Yagis are the antennas of choice at 903 and 1296 MHz, unless a very large dish (10 feet or larger) is available. At 2 and 3 GHz with wavelengths of 5 inches and less, the requirements for precision and stability put demands on the mechanical structure of a Yagi. Nonetheless, there are a number of successful designs in regular use, in particular the "Loop Yagi" for these bands that can achieve 20-dBi gain or more. Often, amateurs will try using parabolic dishes on 2 and 3 GHz, where a 4 ft dish is sufficiently large to yield good results. On the 5 GHz band and higher, Yagi type antennas are not practical. Even a dish as small at 2 feet diameter or a horn with an aperture of one square foot will give very good results on these and higher frequencies. A good rule of thumb is that a dish should be at least 10 wavelengths in diameter. Table 2 shows some approximate gain values for different sizes and types of microwave antennas.

The horn antenna is a very simple device, reasonably easy to construct with some metalworking skills, and can provide sufficient gain for microwave contacts under all but the most demanding situations. The gain of a horn is directly related to its size when reasonably narrow flare angles are used. Horn antennas become impractical at high gains, as the length needed for proper operation becomes excessive. Because their gain is less than a typical dish, they are easier to point (not quite as narrow a beamwidth), and they do not require the difficult adjustments that a dish and feed do for good performance.

Q: Can I purchase an antenna?

A: Several sources can supply microwave antennas, ready-built and kit form. Often there are good microwave antennas at ham fests, either surplus from commercial or government or used amateur home-brew. Unless you are experienced and can get some help, it is unwise to expect immediate good results from a dish and feed. However, horns and Yagis are very likely to perform well if they appear to be in good physical shape.

Q: Can I build my own antenna?

A: Many amateurs build their own antennas. There are articles in various publications over the years that get into details of all types of microwave antennas. The resources listed are good starting places to learn more, and give theory and practical advice.

Q: What about transmission line?

A: The transmission line is always a very important part of a microwave system. Because transmission line losses grow significantly with frequency, microwavers put a lot of thought into making them very short, or overcoming the loss with additional gain (amplifiers) as close as possible to the antenna. At 5 GHz for example, 1/2-inch Hardline coax can lose over 1/2 dB every 10 feet. A 100-foot run could lose 6 dB, delivering only 1/4 of the original power to the antenna. The best advice is to plan out the power levels and losses well in advance of designing and building a system, and talk to others who have constructed systems similar to the one you are working toward. They will know what to do and what not to do, and probably know where to get some good transmission line, too!

Q: What is waveguide?

A: Waveguide is rectangular (or circular) empty metal tube, used as transmission line. RF will propagate inside the tube with fairly low loss compared to coaxial cable. Any particular waveguide size has a limited frequency range, usually less than one octave (less than a factor of two from the lowest to highest frequency recommended). It can be directly connected to a horn or a horn type of dish feed, or an adapter can be used to convert back to coaxial cable. Waveguide is quite large for lower frequencies, such as 1296 or 2304 MHz, but is manageable at 5, 10, 24, 47 GHz and higher. At 5 GHz and below, most amateurs use coaxial cable for transmission line functions. Some amateurs use waveguide at 10 GHz. Coaxial cable becomes very lossy, to the point of being almost useless in most amateur applications at 47 GHz and above. Some amateurs have used copper water pipe as waveguide on 10 GHz with success.[1]

Long runs of waveguide will condense moisture inside causing significant losses and corrosion. To overcome this, commercial users pump dried air or bottled nitrogen into the waveguide at low pressure, allowing it to leak out toward the end of the run. The cost of the waveguide and continuous maintenance are high enough hurdles to force most to find other ways of getting the signal to the tower. One interesting way is to use no transmission line at all. Instead, a reflector can be put on the tower and a high gain antenna pointed toward it from the ground.[2]

Next time we will discuss just how amateurs get on microwaves and give some advice on how to do it.

I wish to thank Paul Wade, W1GHZ, for his help in reviewing the column. Paul has contributed to amateur microwaves—publishing, giving talks, building and operating for decades. His on-line antenna book[3] is an excellent treatment of the subject of Amateur Radio microwave antennas. I highly advise that you download and keep this on hand whenever you want to learn about and build a microwave antenna.

Resources

- Directive Systems
  RR 1, Box 282, Lebanon, ME 04027
  www.directivesystems.com
- Down East Microwave
  954 Rte 519, Frenchtown, NJ 08825
  tel 908-996-3584
  www.downeastmicrowave.com
- SSB Electronic USA
  124 Cherrywood Dr
  Mountaintop, PA 18707
  tel 570-868-5643
  www.ssbusa.com/
- Various publications in the Microwave section of *ARRLWeb* at **www.arrl.org**

Notes

[1]Paul Wade, W1GHZ , "Understanding Circular Waveguide—Experimentally," *QEX*, January 2001.
[2]Paul Wade, W1GHZ, "Periscopes for Microwaves: 10 GHz without Feed-Line Loss," *QEX*, May/June 2002.
[3]Paul Wade W1GHZ, *The On-line Antenna Book*, **www.w1ghz.com**.