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An in-depth look at a radio-related topic

How a Yagi antenna works

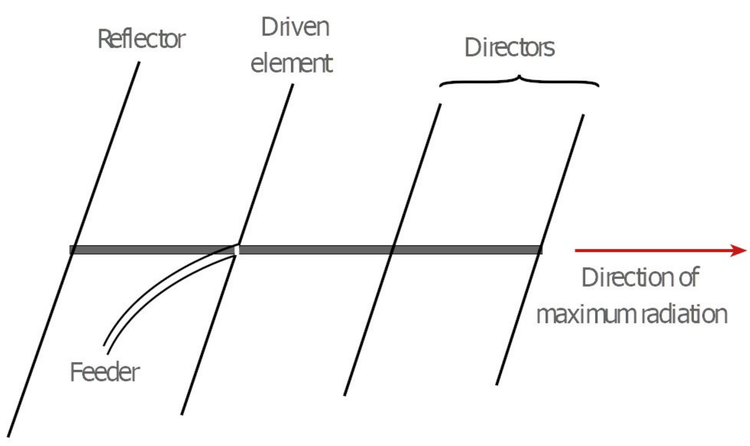
If there's any one image that's aptly symbolic of ham radio, it might be that of a *Yagi antenna*. It's perhaps the most sought-after high-performing amateur radio antenna, and for good reason.

Background

The actual name of this antenna is the Yagi-Uda antenna, after the two who were given the most credit for its design. In fact, it's fairly well understood that in 1926, Shintaro Uda of Japan was the principal engineer of the antenna, with his colleague Hidetsugu Yagi playing a lesser role in the design. Later, Yagi filed a patent on the antenna in Japan, inadvertently omitting Uda's name from the filing. Once the patent was transferred to the Marconi Company in the UK, the Yagi name stuck.

The Yagi antenna is known for its *high gain* and *high noise rejection*. Similar to narrowing a flashlight beam, to concentrate its light to a smaller area, a Yagi antenna can be made with high *directivity*, providing more focus of the signal "beam" in a particular direction, and leading us to refer to such a Yagi antenna by the nickname *beam antenna*.

Construction



The Yagi antenna consists of two or more parallel conductors in the shape of rods, wires, or tubes that we call *elements*. Among these elements are a single *half-wave dipole*, a single rear conductor, and zero or more forward conductors. The feed line (coax or other type) electrically connects to the dipole, which is called the *driven element*, made from two collinear, quarter-wavelength conductors.

The other elements are not electrically connected to the feed line, but operate by feeding off the energy radiated by the driven element, and so are called *parasitic elements*. As will be explained, because of the way each of the parasitic elements reacts to the driven element radiation, the longer rear element is called the *reflector*, and the shorter forward elements are called *directors*. All the conductive elements are then spaced apart, and placed parallel to each

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other, installed on a rigid *boom*. A Yagi antenna constructed this way radiates in all directions, with the direction of the strongest radiation from the driven element outward, in the direction opposite that of the reflector. Because this antenna can focus more of its radiation energy in one direction than in others, we say that it has ***directivity***, making it a *directional antenna*.

Folded dipole variation

An adaptation of the driven element is the use of a *folded half-wave dipole*, instead of a standard half-wave dipole, to offer nearly four times the *radiation resistance* of a standard dipole, with the same radiation pattern, but with improved radiation efficiency. This results in a greater ratio of the signal sent by the transmitter being converted to electromagnetic radiation, compared with that consumed by the antenna ("ohmic" resistance) and given off as heat.

Furthermore, in a standard half-wave dipole Yagi, the parasitic elements tend to lower the feed-point impedance to nearly 20 ohms, often requiring a gamma (or similar) match to bring the impedance up to nearly 50 ohms. In a folded half-wave dipole Yagi, the parasitic elements tend to lower the feed-point impedance to around 100 ohms, which is within the range of most tuners, avoiding the need to install a match on the antenna, if the target feed line is 50-ohm coaxial cable.

In place of the two-conductor dipole, a folded Yagi uses a folded dipole, which is a single full-wavelength conductor that's folded in half, the two half-sides parallel to each other, but a fraction of the wavelength apart from each other. You might more often see this type of Yagi antenna used for VHF television and FM broadcast radio reception.

Cubical quad antenna

Other shapes of the Yagi antenna elements characterize different models of the same antenna, and result in some advantages over the conventional straight-element Yagi. One formerly popular version is the cubical quad (or simply, "quad"), and its little brother, the quagi antenna, both of which use driven and parasitic elements formed into squares, to allow for greater signal capture (good receiving antenna) and higher gain (good transmitting antenna). In the case of these quads, the elements are typically wires strung tightly around non-conducting rods, such that each side of the driven element is a quarter-wavelength long. In this configuration, a two-element

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quad antenna exhibits about the same forward gain as a three-element Yagi antenna for the same frequency. To construct a multi-band quad, you would merely install more squares of wires on the same rods, inside the existing wire squares.

Cubical quad antennas do have their disadvantages, however, when compared with the conventional Yagi antenna. Quads tend to be quite large, some 40-meter boxes taller and wider than your house. Cubical quads are also very difficult to build and maintain. Birds love them as a perch, and the tightly stretched wire elements often give way to their weight when they flock on them. Ice buildup can also place excessive weight on the wires. So, even though a cubical quad can outperform a Yagi of the same band, and might even cost a lot less, you'll rarely see one of these gems anywhere today, simply because of its size and required maintenance.

What makes it tick

Our understanding of how a Yagi antenna functions begins with the driven element, a half-wave dipole. Most of us are familiar with the workings of a dipole antenna, so let's refresh our memory on that, and go from there. The half-wave dipole antenna works essentially by reactance, connecting the two sides by capacitance. When an alternating current from the transmitter is fed through the feed line into the dipole, the oscillating charges in the two dipole elements produce time-varying electric and magnetic fields. The resulting *electromagnetic wave*, which increases and decreases in magnitude, then reverses in polarity, alternates at the frequency of the RF (radio frequency) current. Keep in mind that the time-varying electric field follows the *current* in the element, not the voltage.

The electromagnetic wave from the dipole then emanates in all directions equally and perpendicular to the axis of the dipole. The Yagi antenna reflector element is typically about 5% longer than the total length of the driven element. When the electromagnetic wave from the driven element strikes the reflector, a current is induced in the reflector that is 180˚ out of phase with the original wave, because the reflector acts like a "shorted" dipole.

But because the reflector is a bit longer than the received wavelength, it presents an inductive reactance. That way, because the induced current subsequently causes the reflector to radiate, a new electromagnetic wave is given off by the reflector, the result of a current whose phase lags that of its voltage. The reflector is spaced a fraction of a wavelength from the driven element, allowing the new wave to return to the driven element in phase with the wave given off by the driven element.

A Yagi antenna director is typically about 5% shorter than the driven element. When the combined electromagnetic wave from the driven element and the reflector strikes the director, a current is induced in the director that is 180˚ out of phase with the original wave, because it also acts like a "shorted" dipole. Because the director is a bit shorter than the received wavelength, it presents a capacitive reactance.

And because the induced current causes the director to radiate, another new electromagnetic wave is given off by the director, the result of a current whose phase leads that of its voltage. The director is spaced a fraction of a wavelength from the driven element, allowing the additional wave to leave the director in phase with the first two combined waves.

Finally, the waves traveling in the reverse direction partially cancel each other out, by virtue of

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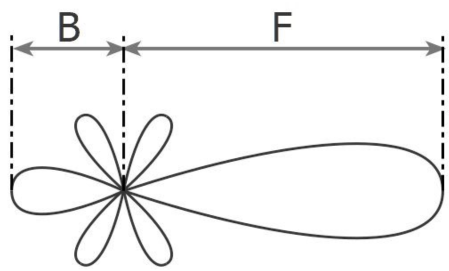
destructive interference, rendering the wave amplitude in the forward direction relatively large, compared with the wave amplitude in the reverse direction, known as the *front-to-back ratio*. The larger the front-to-back ratio, the greater the transmitted signal strength toward the front direction, and the greater the antenna ***gain*** (focus of signal), making the Yagi antenna one of the most effective directional antennas in use today.

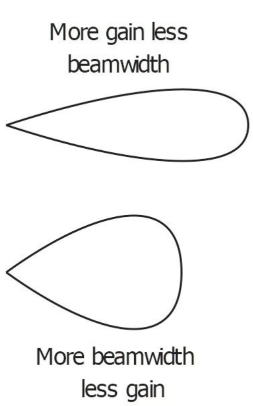


By the physical principle of reciprocity, a Yagi is also an effective receiving antenna, *because* it's an effective transmitting antenna. This is an important concept, because it means that it's able to receive much better from one direction than from others. If an antenna can receive better from one direction, it also means that it can receive less unwanted signals from other directions. For this reason, we say that a Yagi antenna is ***less susceptible to noise*** than less-directional antennas; it simply picks up less noise from other than the forward direction.

APPROXIMATE YAGI-UDA ANTENNA GAIN LEVELS

NUMBER OF ELEMENTS	APPROX ANTICIPATED GAIN DB OVER DIPOLE
2	5
3	7.5
4	8.5
5	9.5
6	10.5
7	11.5

It's known that the more directors are installed on a Yagi antenna, the greater its gain, at about 1 dB of gain increase for each director installed. But with an increase of gain, comes a decrease in ***beamwidth***, which is an angle (planar or spatial) measured by the area projected by –3 dB (half) of the maximum signal strength or greater. A higher-gain antenna, therefore, requires the operator to adjust the antenna direction more often, to effectively contact the same given set of stations, for example.



Also, a Yagi antenna can be oriented vertically, horizontally, or circularly (in the case of a satellite antenna), to produce a signal with the corresponding ***polarization***. Vertical and horizontal orientation can be achieved by simply installing the antenna with the elements aligned in the desired direction of polarization, in relation to the direction of gravitational pull (not that gravity has much to do with it.)

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Keeping it all together

The Yagi boom is the rigid bar, rod, beam, or pole that holds all the elements in place, including their parallel orientation and their planar spacing. The question that seems to surface most is whether it's acceptable to use a metal conductor for the boom. And the frequent follow-up question is whether the elements should be insulated from such a metal boom. The answer is, ***if the Yagi antenna is constructed properly***, you can use a metal boom, and the parasitic (not driven) elements do not need to be insulated from the boom because the points of contact are all at current nulls (zero amps) at the resonant frequency.

That being said, most competent Yagi antenna designers calculate the minor effects contributed by a metallic boom, using a *boom correction factor*, which in most cases is an approximate *fudge* number. Furthermore, never allow any part of the driven element to come in contact with the metal boom.

Configuration alternatives

Due to their directivity and high gain, Yagi antennas have been utilized in a variety of forms and configurations, as was touched on previously with the folded dipole and cubical quad versions. Here are a few more practical ways they've been used:

- An *NVIS* (near-vertical incidence skywave) antenna is merely a Yagi antenna that is pointed straight upward. The resulting beamwidth striking, and then refracting off, the ionosphere, produces the relatively local zone of contact through skywave propagation. NVIS antennas typically do not include directors, only the driven element and reflector.
- A *satellite antenna* typically consists of two Yagi antennas of two different frequency bands built together to communicate with a satellite uplink and downlink. They can be constructed in parallel with each other or at right angles to each other.
- A *stacked antenna array* is often constructed from two or more Yagi antennas that are electrically connected in-phase by a phasing harness, with all antennas pointed in the same direction, but separated vertically by a half-wavelength.

Antenna height

Finally, be sure to install your Yagi antenna at least a half-wavelength above ground, for optimum effectiveness. Because of the size of your antenna, this might not always be possible. At 40 meters, for example, a height of a half-wavelength means 20 meters, or 66 feet up. Yikes.

Summary

A Yagi antenna is probably the signature antenna of ham radio. It's characterized by multiple parallel elements that work in concert with principles of electrodynamics to produce high gain and low noise reception. Its directivity and gain can be increased by adding directors on the boom, but comes at the cost of reduced beamwidth, requiring frequent direction changing for effective communication. To provide for maximum benefit, you should install your Yagi antenna at least a half-wavelength over ground, which might prove difficult for some.

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