Skill Builder

Antennas in the Wild

Tim Deagan, KJ8U

Get the skinny on radio antennas with this primer and field guide

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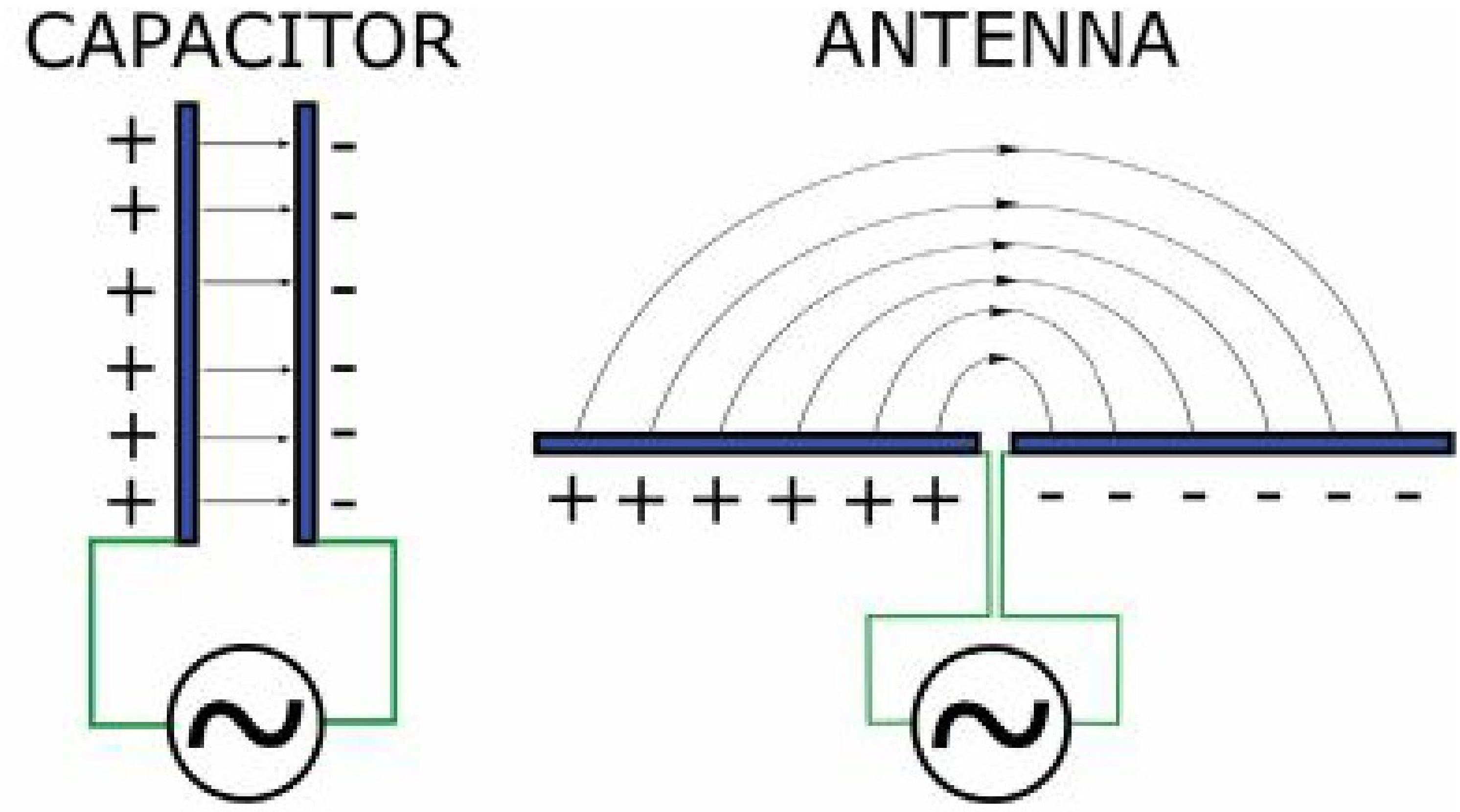
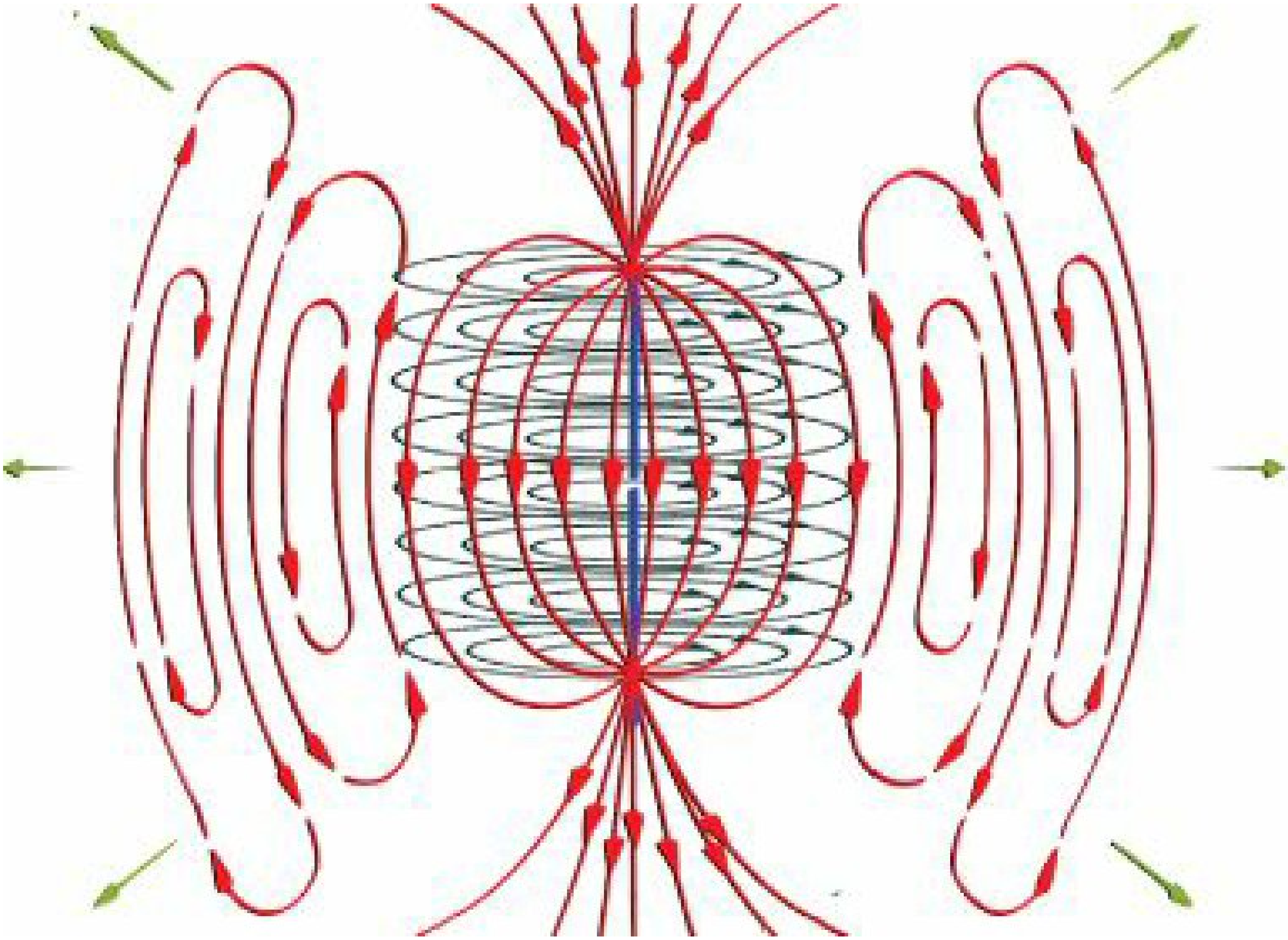
There are easily thousands of different types of antennas serving different purposes. Some are simple lengths of wire, others exotic assemblages of high math and science. Most of the antennas around us are pretty straightforward and have a set of identifiable characteristics. With a few patterns in mind and some rules of thumb, you can usually make a pretty good guess at what most antennas are being used for, or at least the parts of the EM spectrum on which they're operating.

MAKING ELECTROMAGNETIC WAVES



A »



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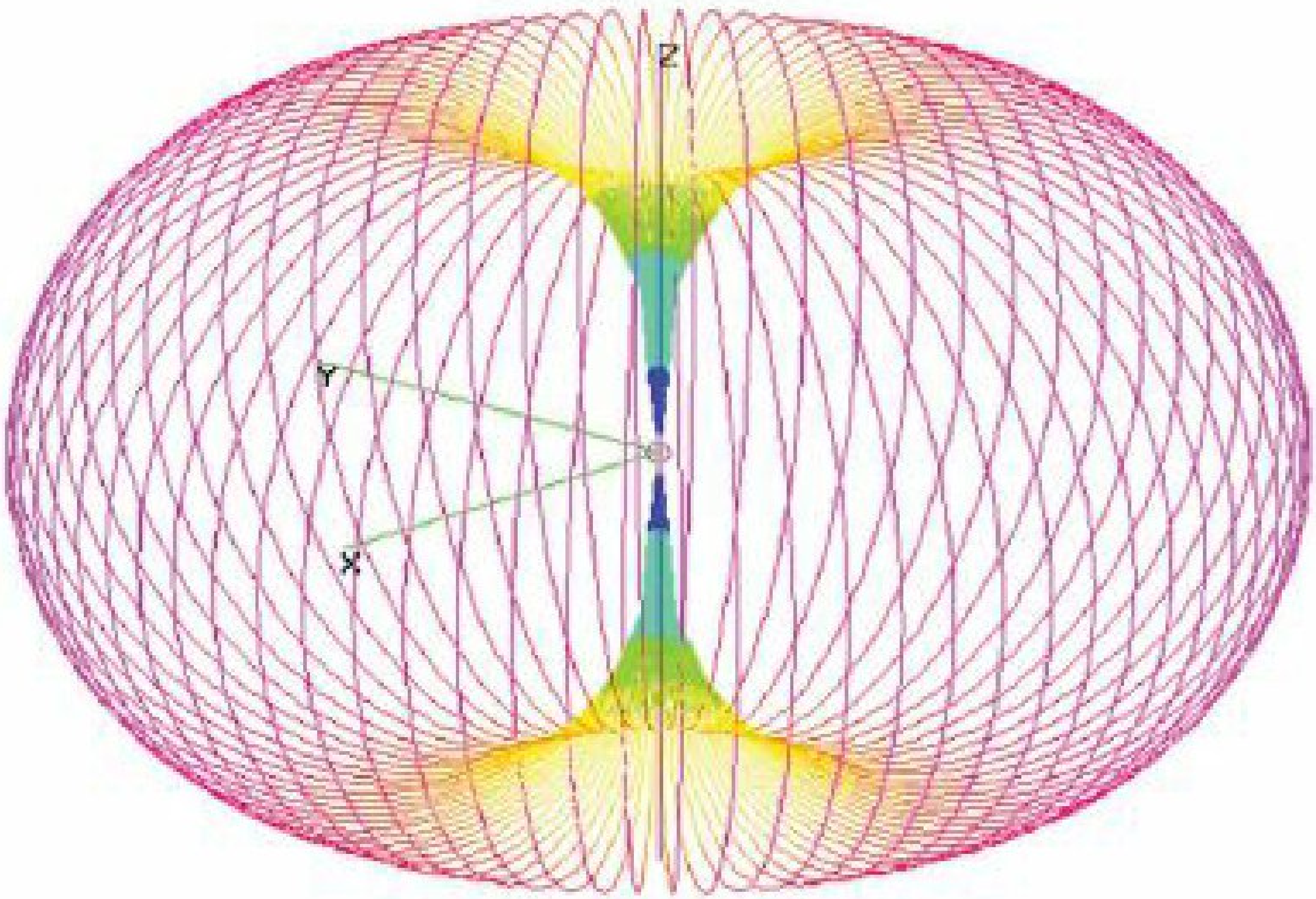
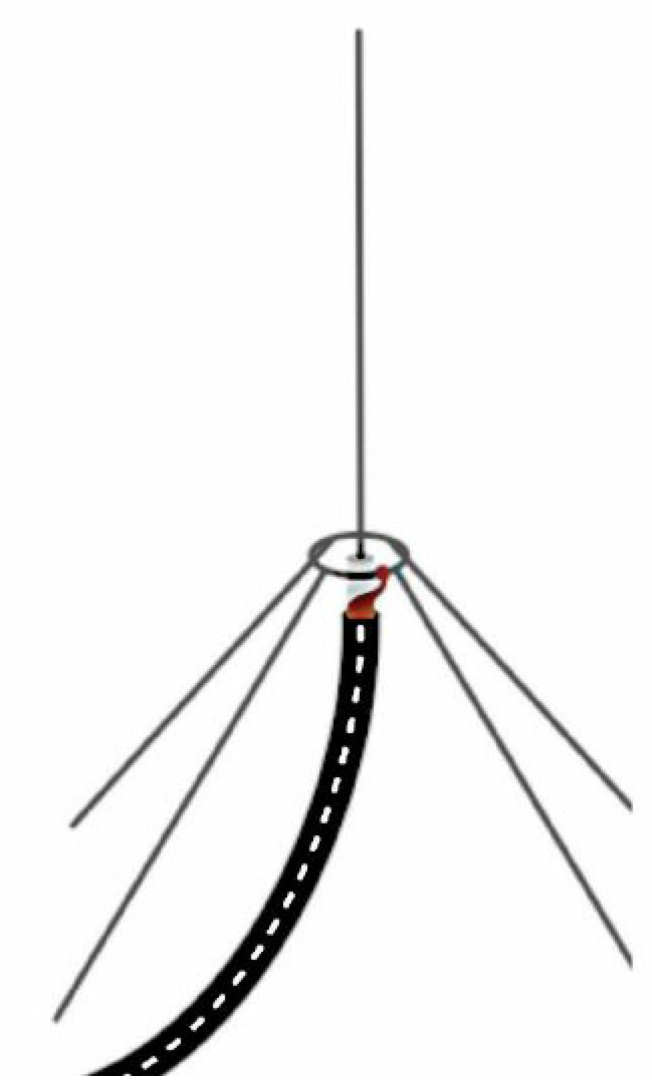


C »

Antennas are driven from radios by feedlines consisting of two conductors (often bundled in a coax cable with a center conductor and a shield) which carry the two sides of the alternating current signal the radio produces. The simplest antenna, a **dipole,** takes the two conductors from the feedline and spreads them out away from each other. The antenna might appear to be a break in the circuit since the two arms of the antennas are separated instead of connected. What's actually happening is that the two wires are acting like a big air-gap capacitor. Instead of the current being contained within the dielectric gap of a capacitor, the current is flowing in space as an electric field arc between the two arms of the dipole (Figure **A**).

As the oscillating AC signal moves electric charges back and forth across the antenna arms, the accelerating charges create a magnetic field around the antenna, just like an electromagnet. Without trying to go too deep into Maxwell's equations, rest assured that changing magnetic fields create electric fields, and changing electric fields create magnetic fields. The electrical energy applied to the antenna is thus converted into electromagnetic waves that self-sustain (magnetic and electric fields each relentlessly creating the other) and radiate away from the antenna (Figures **B** and **C**). Radio!

This only works efficiently if the antenna has the appropriate length for the frequency of signal it's trying to radiate. An antenna that is perfectly matched to a frequency is called **resonant.** When you change the free length of a guitar string by pressing on frets, you change the note (frequency) the string resonates at. When you change the length of an antenna, you change the frequency that it resonates at (though *resonance* has a number of additional technical meanings when used in electronics and radio).



D »

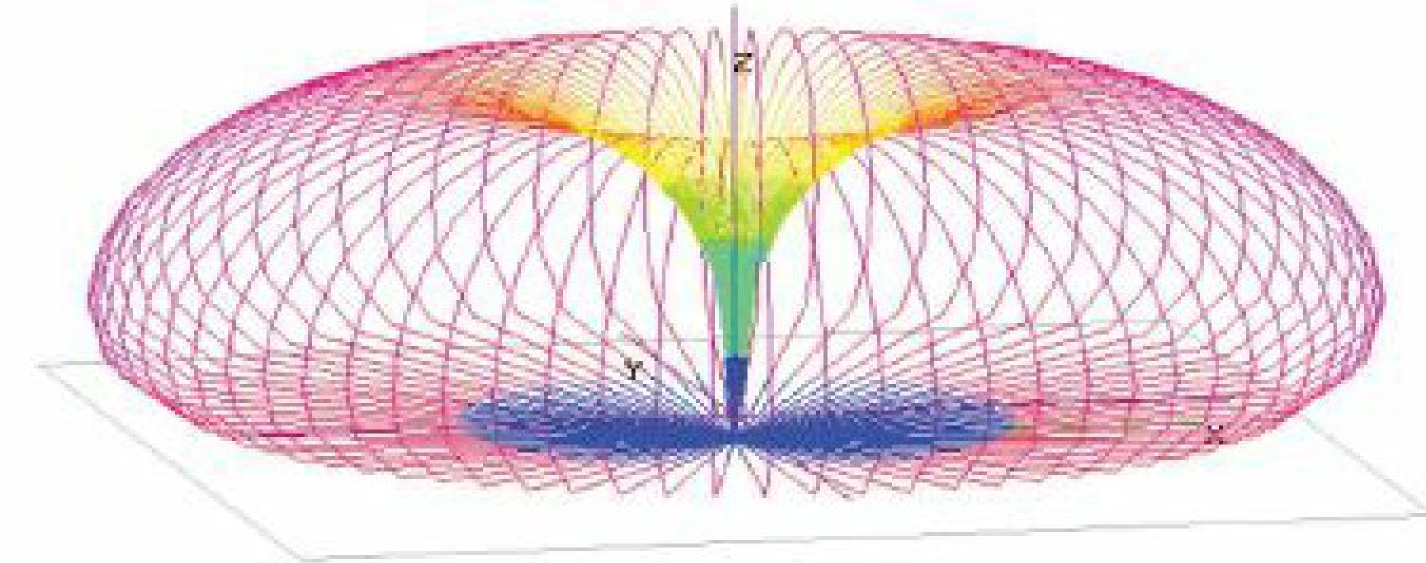
ANTENNA SIZE AND SHAPE

Antenna lengths are generally whole-number multiples or fractions of a target wavelength (½λ, ¼λ, ⅛λ, 1λ, 2λ, 4λ, etc.), so they often provides clues about the intended frequency of operation. Long wavelengths/low frequencies tend to use long antennas and short wavelengths/ high frequencies tend to use short antennas. Engineers have created a wealth of tricks to allow antennas to operate on multiple bands, but there are almost always limits. Shortwave antennas designed for wavelengths of tens of meters aren't very useful for PCS cell wavelengths in the tens of centimeters, and vice versa.

If your initial image of an antenna is the wire sticking out of your car, don't worry! That single wire (a **monopole** instead of a dipole) is doing the same thing as one arm of the dipole (Figure **D**). As a substitute for the other arm, monopole antennas connect that side of the feedline to a reference source, or **ground plane,** that's usually perpendicular to the monopole (shown below the radiation pattern in Figure **E**). The ground plane could be your car, a set of wires, the earth, or in the case of cell phones, our bodies.

SHAPING ELECTROMAGNETIC RADIATION

Monopoles and dipoles send their signals out in a donut-shaped 360° ring around the length of the wire. This is referred to as an *omni-directional* signal. However, electromagnetic (EM) waves interact with matter in different ways. In some cases it's absorbed, in some reflected, and others refracted. Conductive items that respond to EM waves may, in turn, re-radiate them out again. If the secondary radiation interacts with the initial waves, the two signals may reinforce or cancel each other out depending on their phase relationship. This is referred to as *constructive and destructive interference* (Figure **F**).



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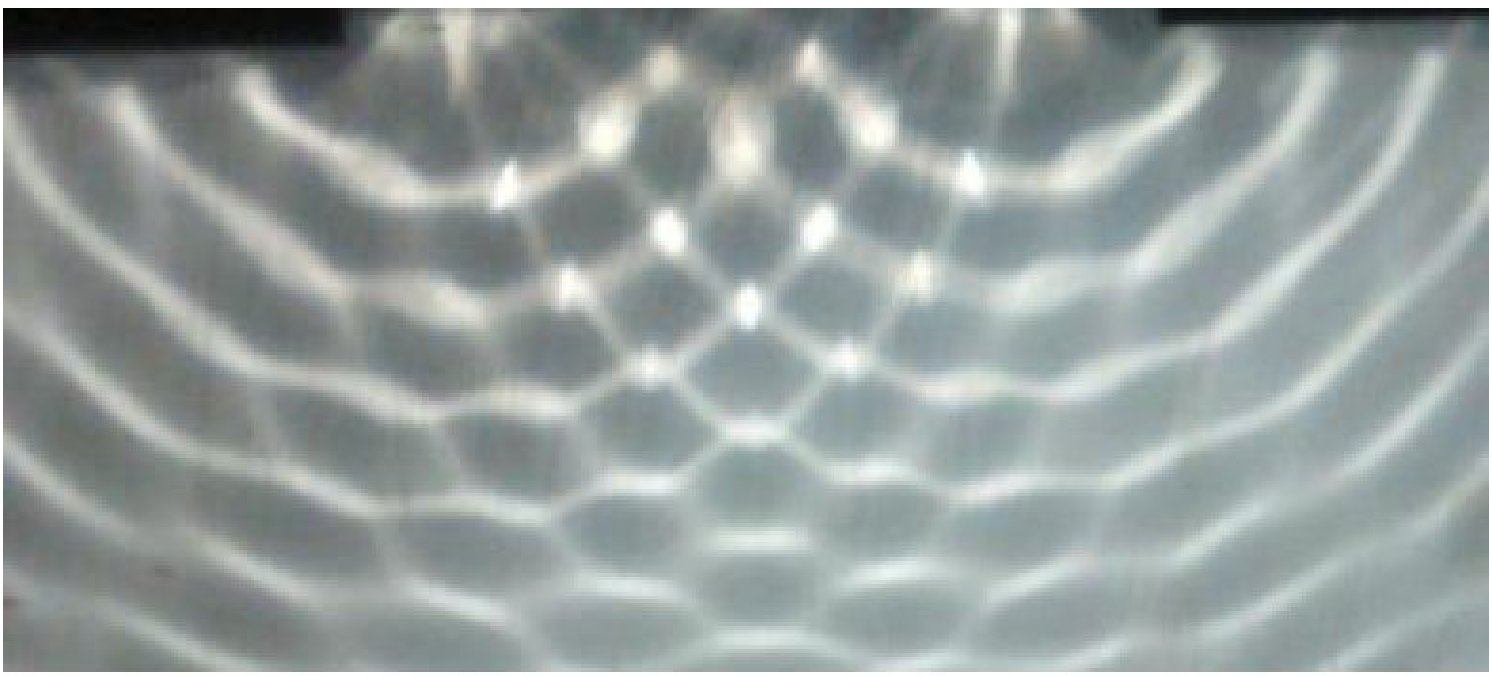

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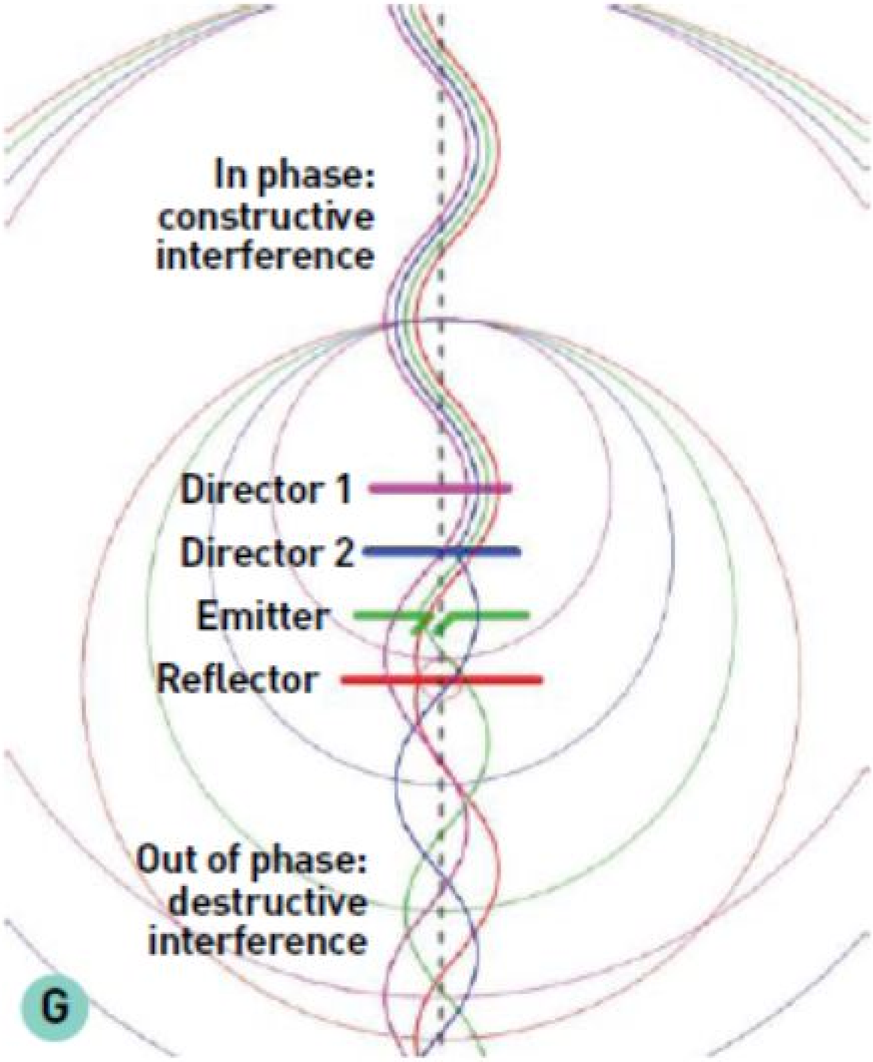
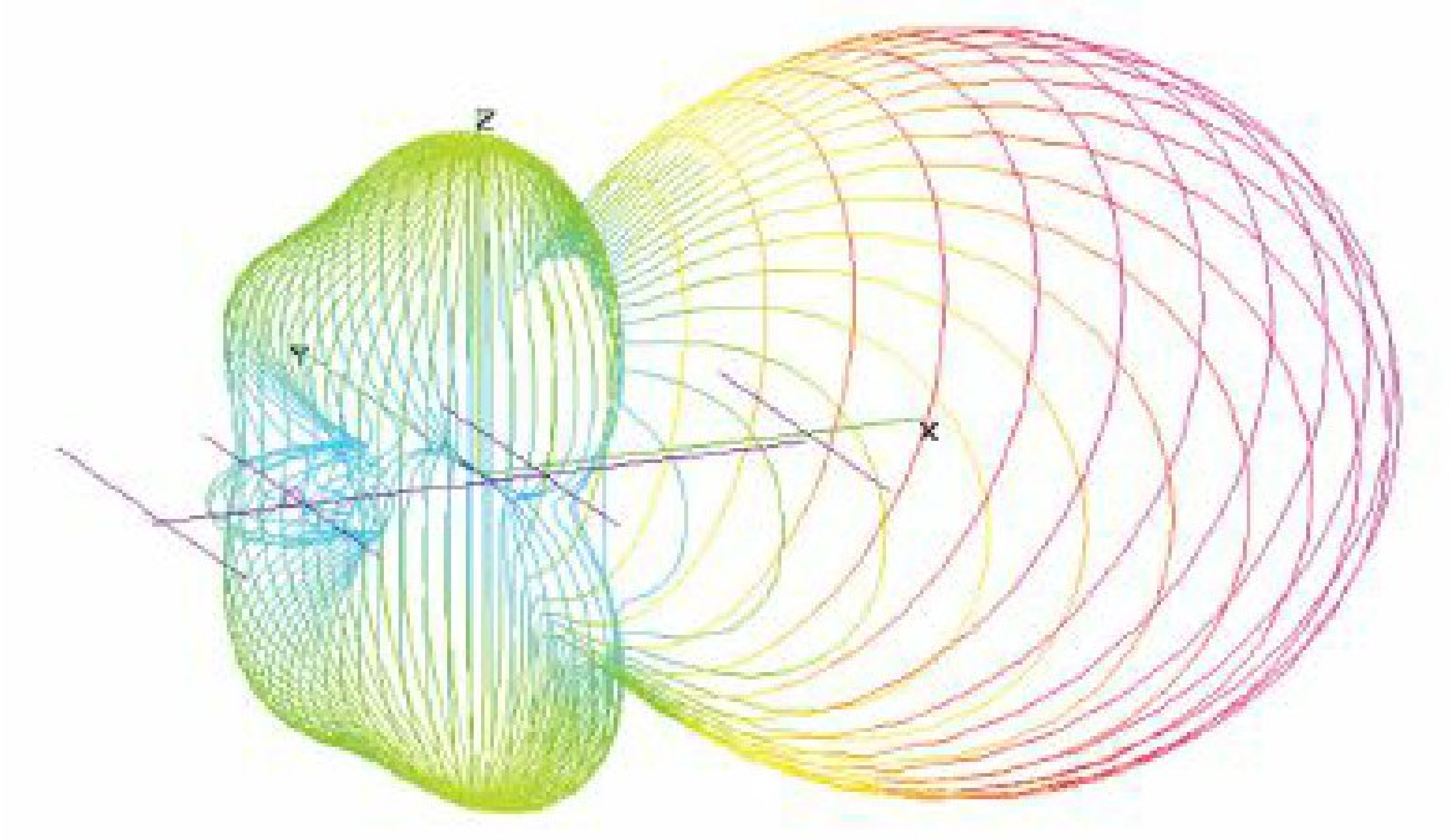
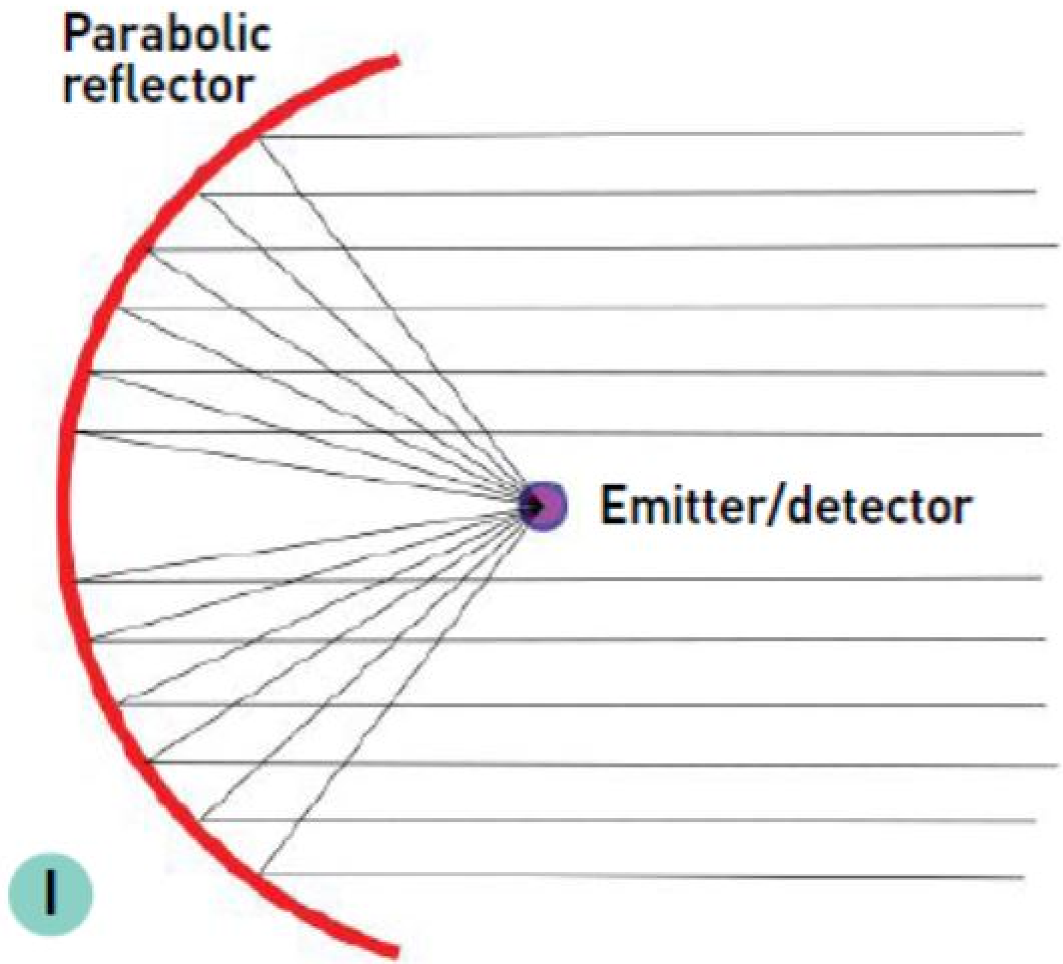

In phase:
constructive
interference
Director 1
Director 2
Emitter
Reflector
Out of phase:
destructive
interference
G

G »

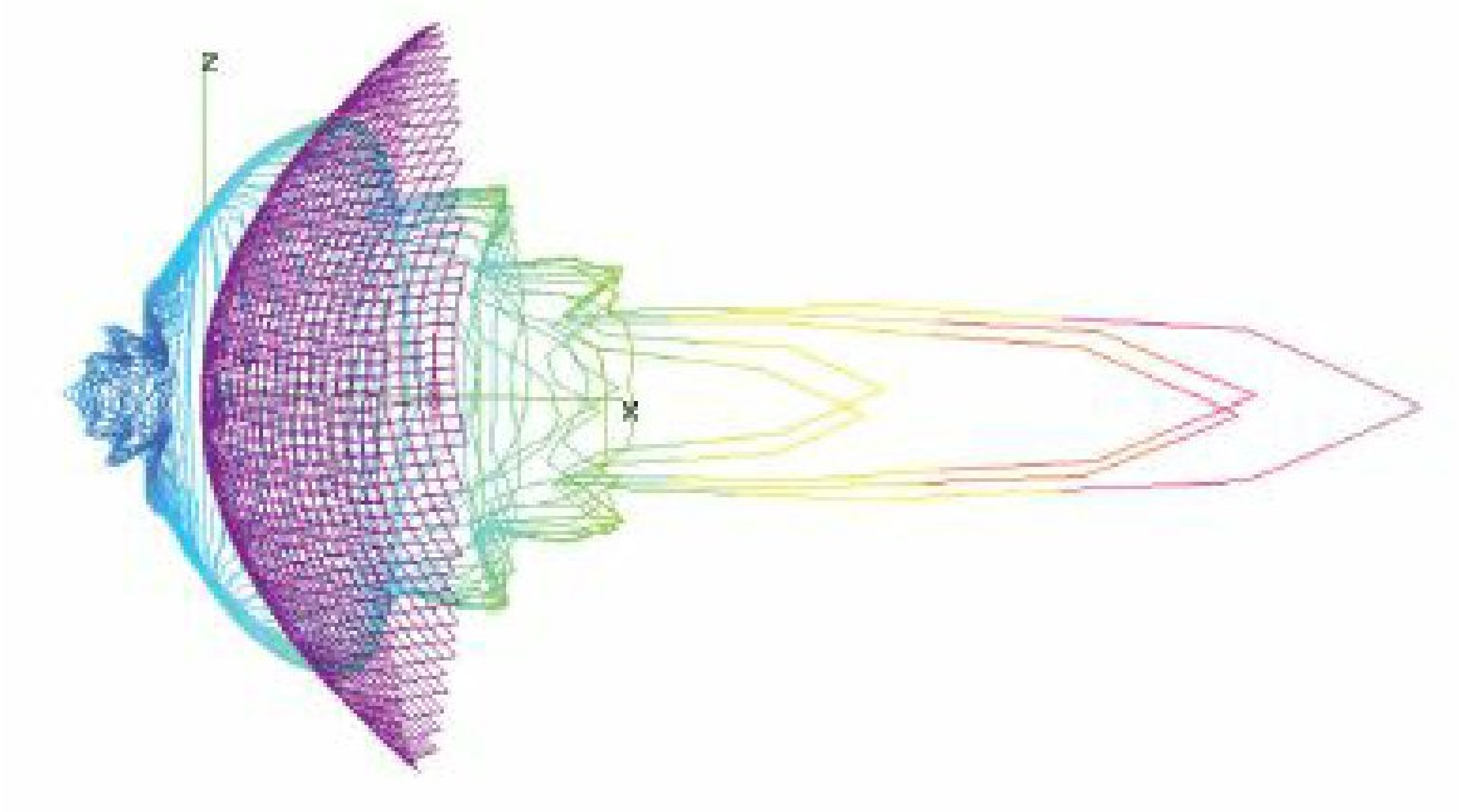


H »

When carefully managed, this effect can be used to shape and direct the output of an antenna. Many antenna designs have a driven element called an **emitter** (frequently a dipole) and one or more additional elements (**reflectors** and **directors**) that shape the resulting combined field. While no antenna can add power to the initial signal, by using additional elements a power gain can be created in one or more specific directions by reducing power in other directions. The result is often called a *uni-directional* signal (Figure **G**). These are described as **beam** or **directional** antennas and are either fixed at a specific target to improve transmission and reception or rotated to change targets (Figure **H**).


Parabolic
reflector
Emitter/detector
I

/ »



J »

EM waves’ ability to reflect can be leveraged to great effect when they are aimed at a **parabolic dish.** Satellite dishes and space telescopes both use the same principle of concentrating a tight capture area into a small point for reception and focusing the output of a small point into a directional beam for transmission. The dish is a passive reflector element and the driven element is positioned at the focal point of its parabola (Figures **I** and **J**).

Reflection also allows EM waves to be routed through shaped hollow pipes called **waveguides.** Though there are examples of waveguides for all kinds of waves, these tools are a common feature used in antennas used for extremely highfrequency waves, commonly called *microwaves* when above 1GHz (though other definitions start microwaves at 300MHz). Waveguides allow a lowloss way to direct EM waves while also serving as a *high-pass filter,* rejecting waves below a certain frequency (Figure **K** on the following page).

K »

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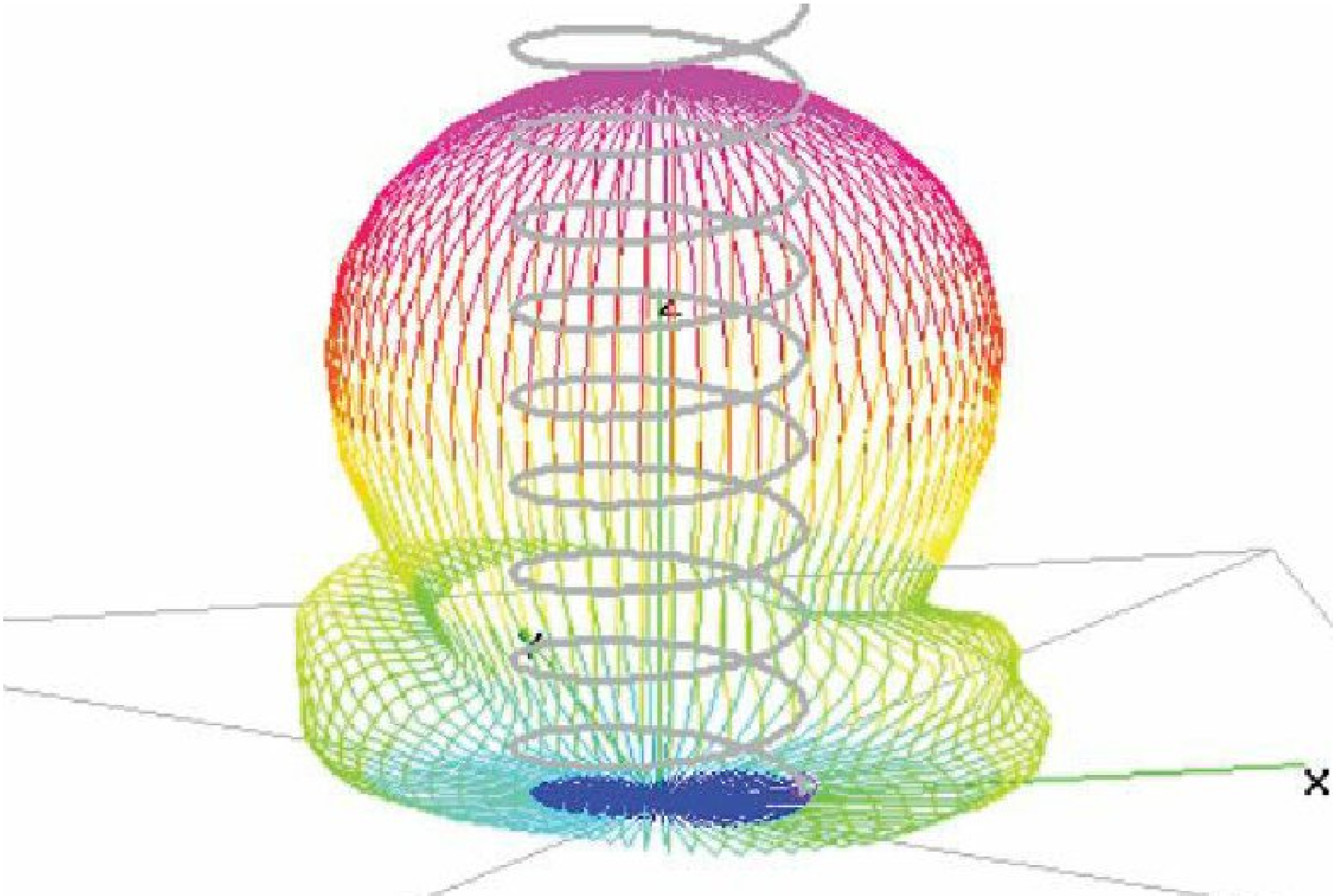


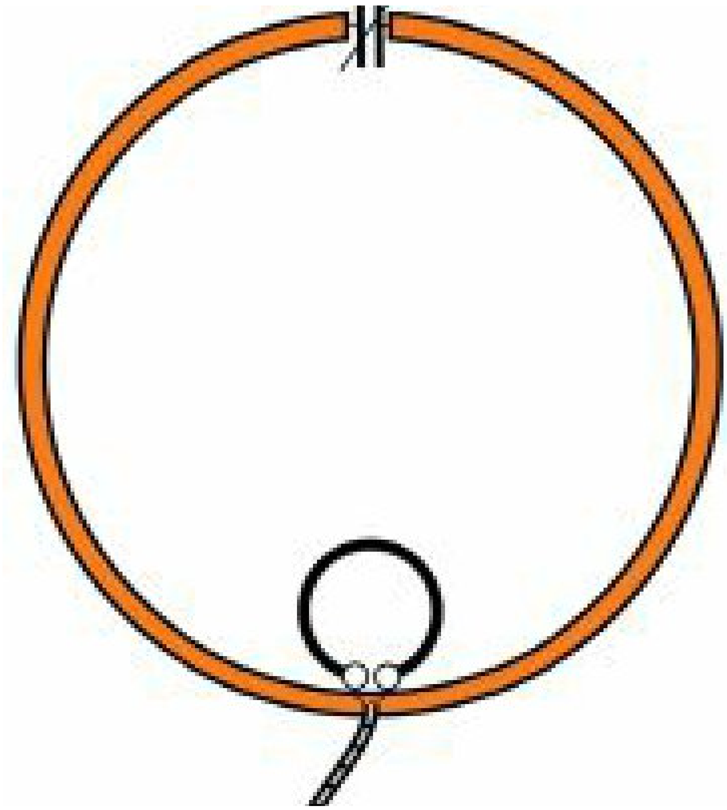
M »

Figure A's diagram illustrating the electrical wave arching from one end of a dipole to the other implies an orientation that antennas create for the waves they generate. This effect is called **polarization** and it is an important aspect of antenna design. Antennas have different polarizations if they are mounted vertically or horizontally. A receiving antenna operates best if it has the same orientation as the transmitted signal it's picking up. Other polarization schemes are used as well. **Helical antennas** are an example of a circular polarization design that can receive both horizontal and vertically polarized waves. This is especially useful for receiving signals from satellites (Figure **L**) that are changing orientation (and therefore polarization) as they orbit or experiencing an effect called *Faraday rotation* as their signal traverses the ionosphere (Figure **M**).

Most antennas operate by interacting with the electrical field of an EM wave. But the magnetic field is always there too, and that's the aspect used to transmit and receive with most **loop antennas.** These antennas can be circular, hexagonal, square, or any closed geometry. There may be more than one loop serving the same purpose as the additional elements on a beam antenna. Small loop antennas (Figure **N**) can have especially sharp *nulls* where they can't receive. This makes them especially useful for radio direction finding. By turning the loop until a signal disappears, you can determine the direction from which it is coming (Figure **O**).

HOW ELECTROMAGNETIC WAVES TRAVEL

EM waves can travel, or **propagate,** in a variety of ways, though different frequencies have different abilities in this regard. These propagation types are: **ground waves, direct waves,** and **sky waves** (Figure **P**). Extremely low-frequency (used for communication with submarines around the world) to medium-frequency signals (3Hz–3MHz, such as AM radio) hug the Earth as they travel and are called *ground waves.* High-frequency (HF) waves in the 3MHz–30MHz range (and mediumfrequency waves) have the ability to refract off the layers of the ionosphere as *sky waves,* if they're at a shallow enough angle (otherwise they head into space), often multiple times, and reach around the world. Very high-frequency (VHF) and above waves (30MHz and up) rely on *direct,* or *line-of-sight,* transmission. These waves are obstructed by the curvature of the Earth or other obstacles and tend to have limited range compared to lower frequencies. Of course, that depends on where you point them. Aim them at a satellite and even a handheld radio can contact low Earth orbit!



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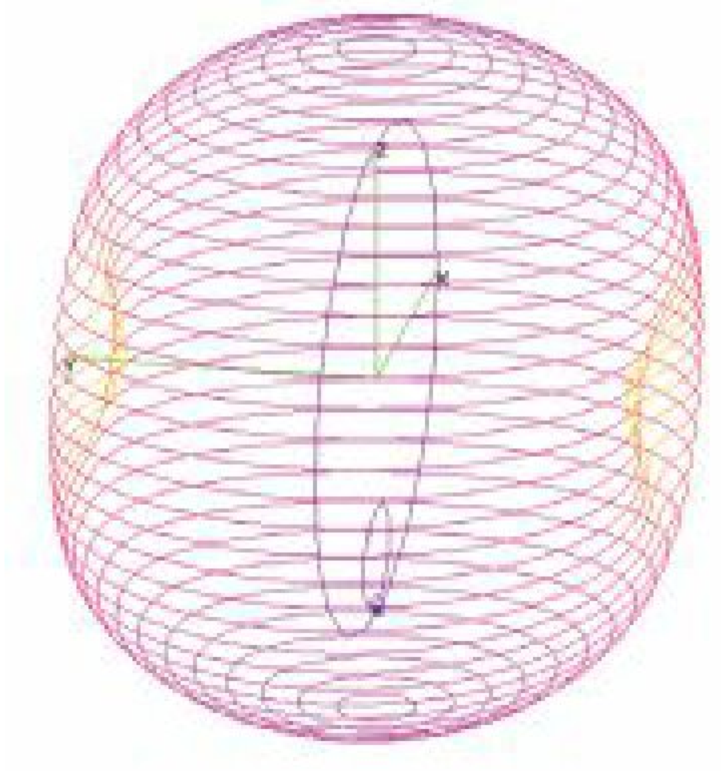

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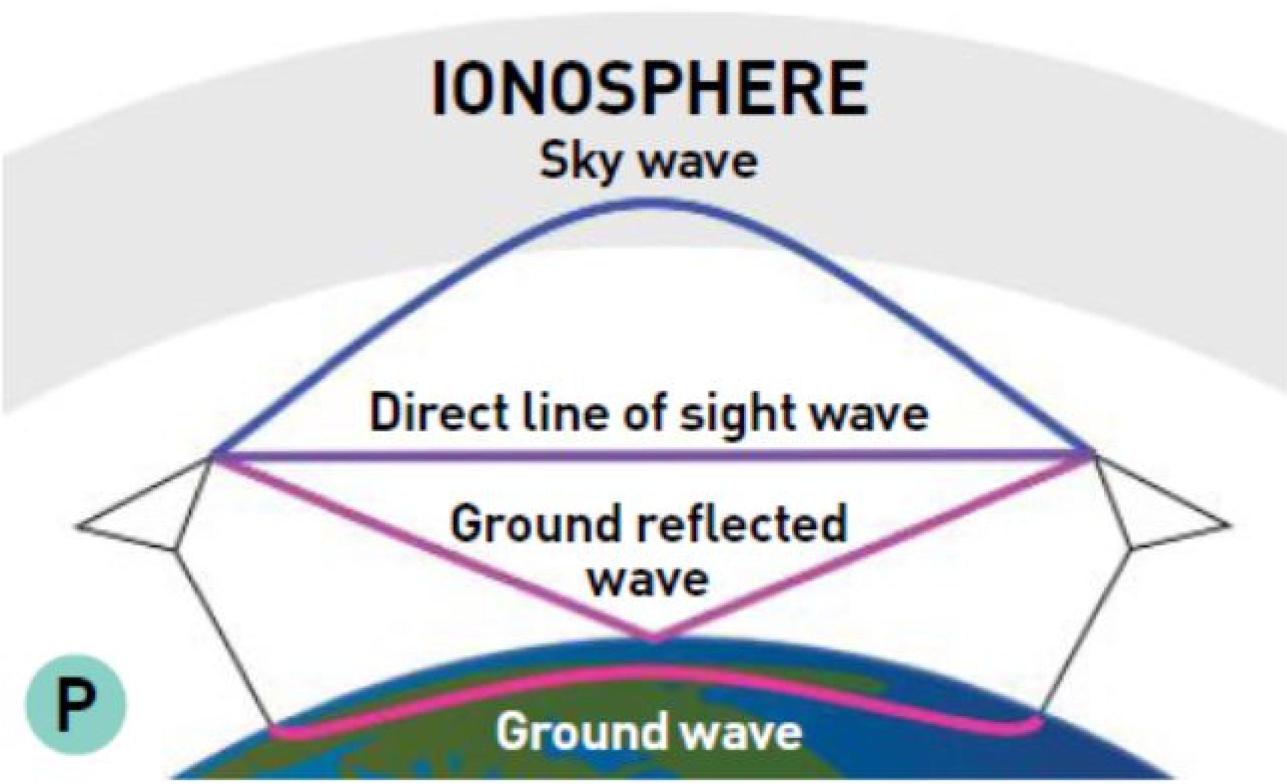
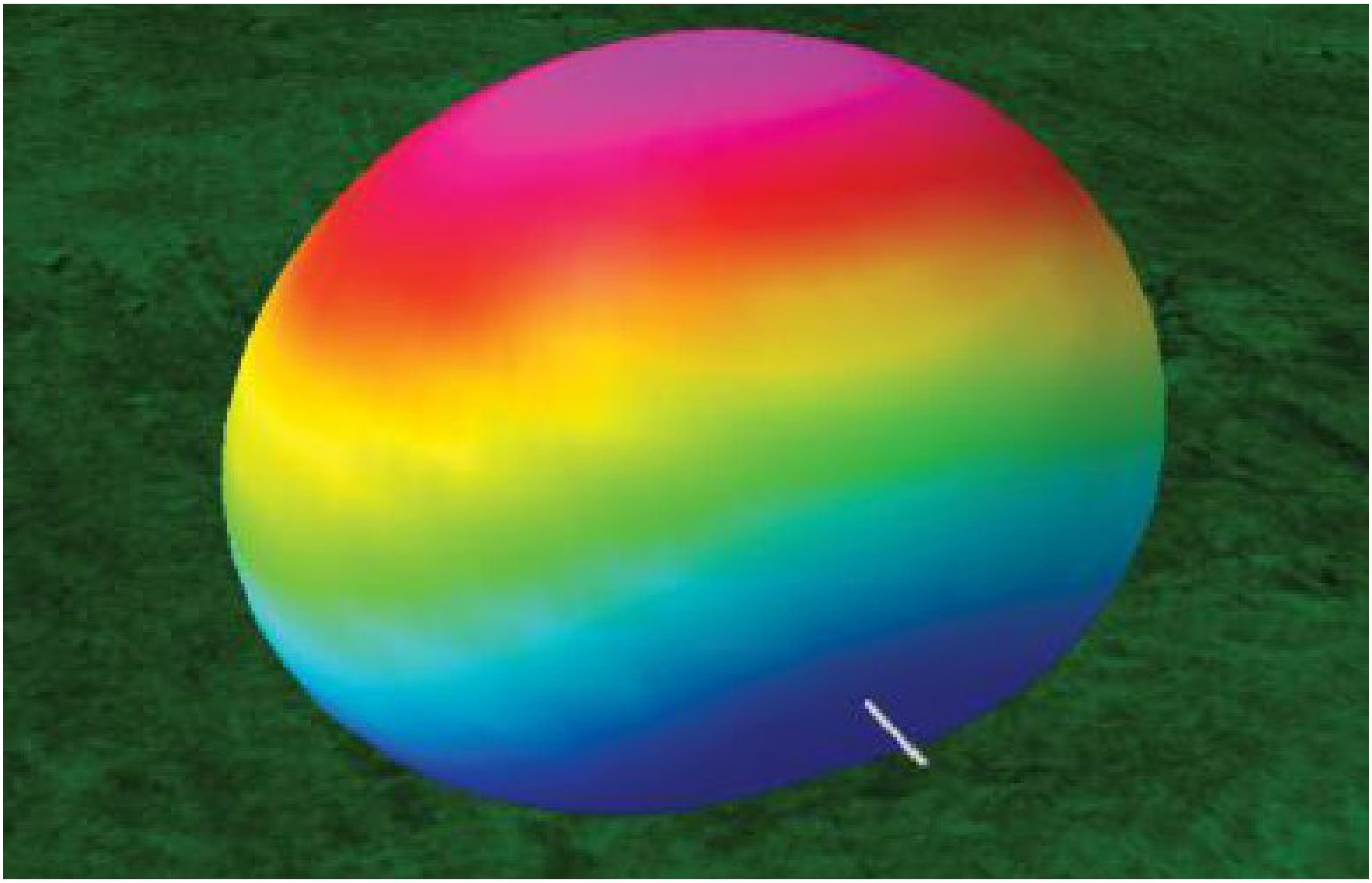

IONOSPHERE
Sky wave
Direct line of sight wave
Ground reflected wave
P
Ground wave

P »



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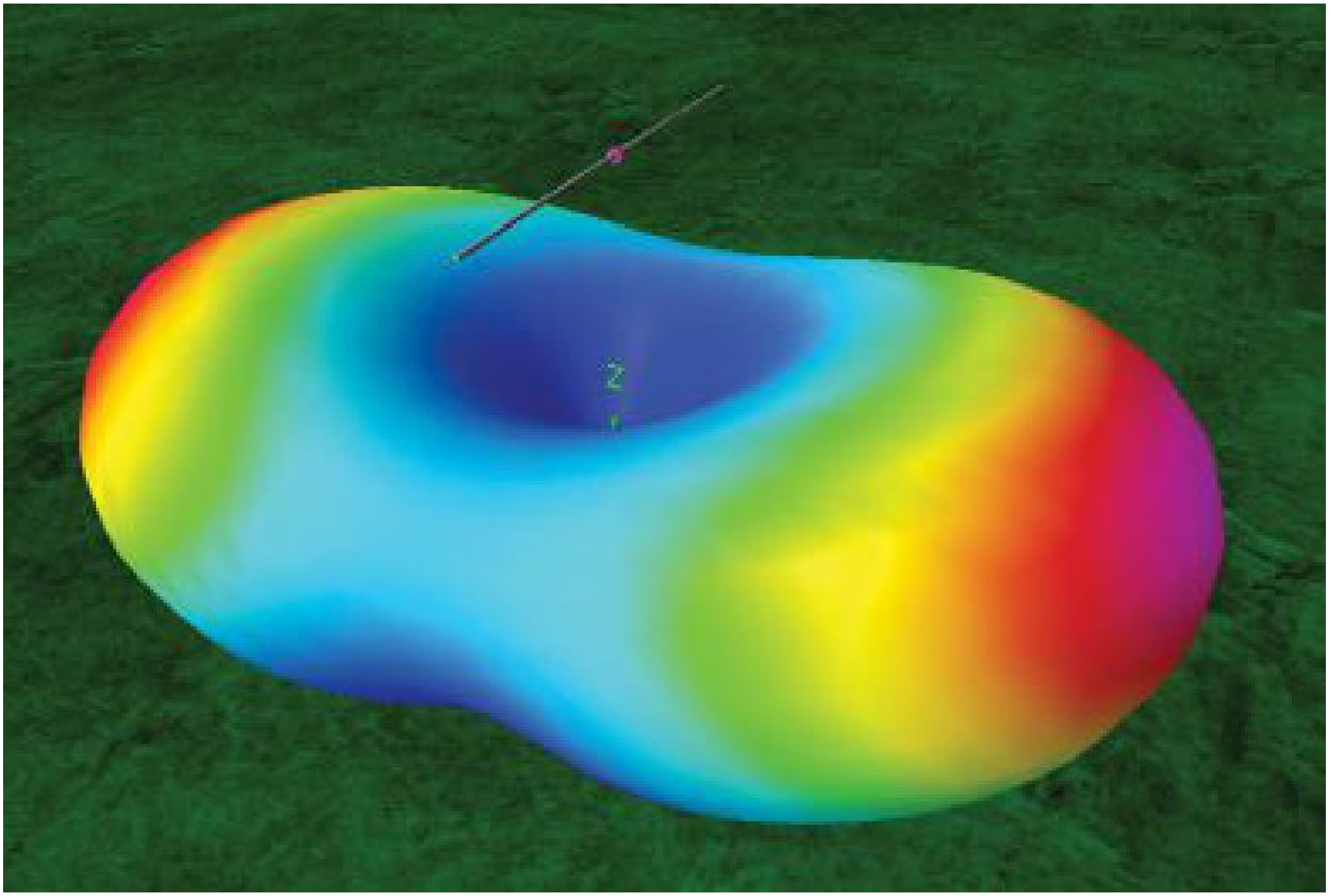


R »

The higher an antenna is mounted, the farther its line-of-sight radius is. Tall antenna towers provide broad coverage for antennas relying on direct propagation. Cellphone towers, commercial radio, amateur radio repeaters, microwave data transmission, emergency services, and other UHF/VHF/microwave antennas all tend to be mounted as high as feasible to increase their range.

Even HF antennas attempting to bounce signals off the ionosphere benefit from height. Some part of the signals they output bounce off the Earth below them. When they are less than half a wavelength above the ground, these reflected waves interfere with the transmitted wave and tend to make most of the signal go upward at an angle so steep that it either passes through the ionosphere or bounces straight back down. This means that an antenna operating on the 40-meter amateur band would ideally be at least 20 meters (65 feet) above the ground to achieve long distance propagation. Figures **Q** and **R** show the comparison of this band being broadcast at 5 meters high and 20 meters high. In some cases, if you want to communicate locally, aiming up and bouncing down is desirable. This is referred to as **near-vertical-incidence skywave (NVIS)** operation.

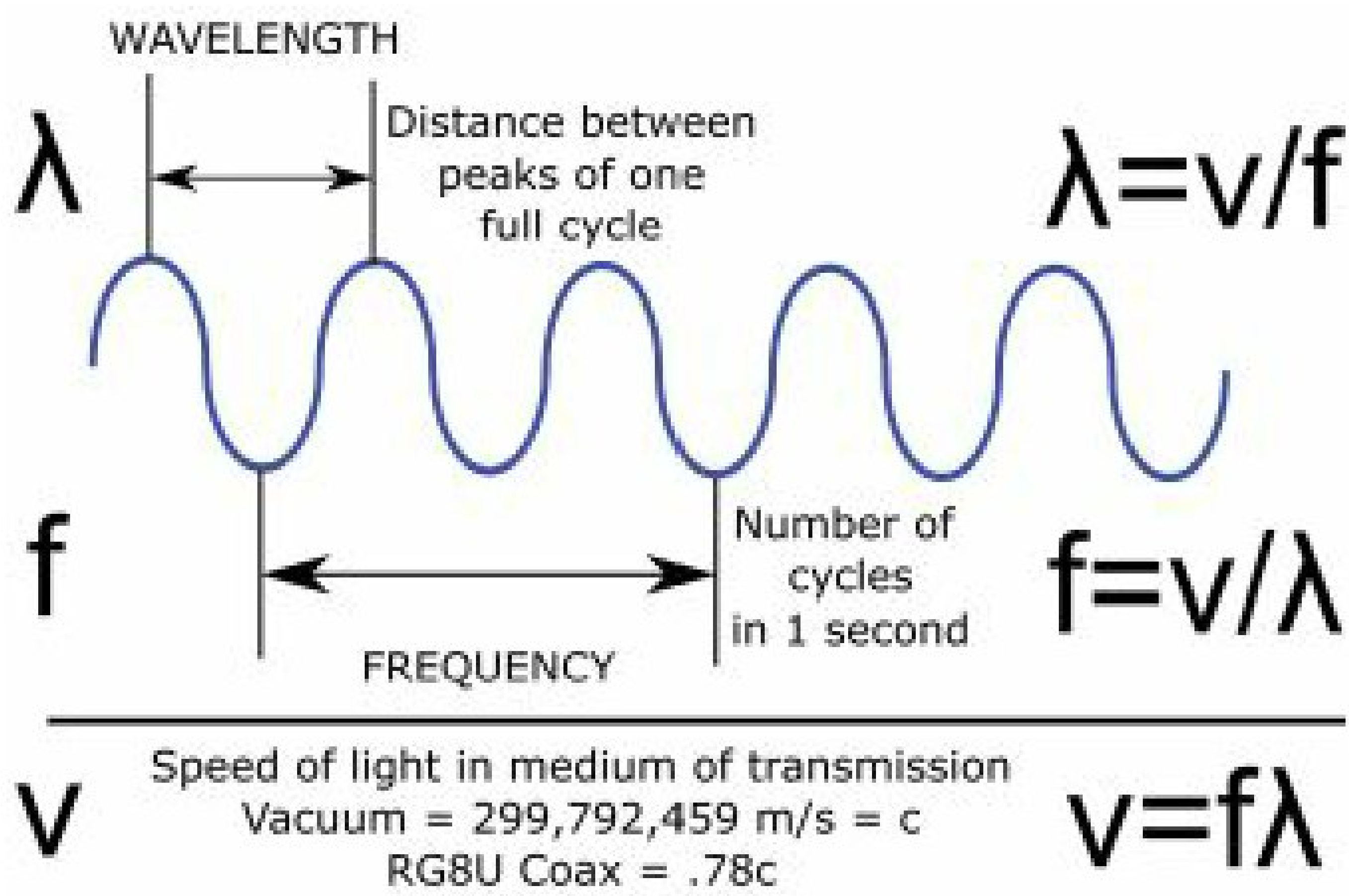
All these characteristics provide clues when spotting an antenna in the wild. The length of the elements relates to the frequency of operation. The height offers clues to the coverage area. Odd shapes like horns suggest waveguides which are most likely used for high-bandwidth microwave transmissions. Directional antennas are usually pointed at a target such as a receiver at a given compass bearing. If they're pointed at the sky, that target is probably a satellite.

We spend our lives constantly bathed in the radio waves propagating around us. Much of our daily activity relies on radio-enabled cellphones, tablets, GPS, and Wi-Fi. Recognizing the amazing proliferation of antennas can be an exciting way to gain awareness of these tools for manipulation of the invisible forces underlying our modern world. And with that, let's take a look at some of the more common antennas you'll see in the wild ...

FREQUENCY AND WAVELENGTH

Frequency is the number of times the wave completes a cycle in a given amount of time. The common unit of measure is the Hertz (Hz), or cycles per second. Since waves travel through space at the speed of light, the distance between peaks, called the **wavelength** (λ), is directly related to the frequency. This is generally measured in meters and derived by dividing the speed of light by the frequency. A signal with a frequency of 14.074MHz has a wavelength of 21.03m.

Ranges of frequencies are usually referred to as **bands,** such as the US 40m amateur radio band (7.000MHz–7.300MHz) or the US AM radio band (525kHz–1705kHz).



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TIM DEAGAN likes to transform things from the digital world into real life in Austin, Texas.

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