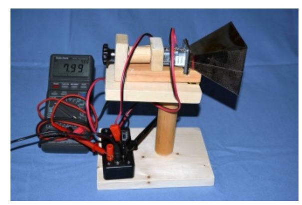
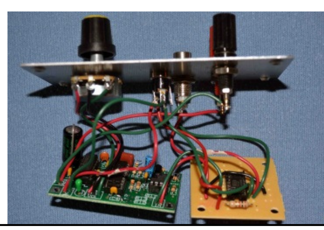
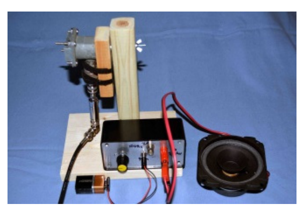
Microwave Antenna Demonstrations Based on the IEEE Presentation by John Kraus – Jon Wallace

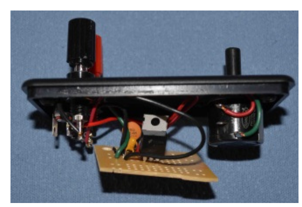
Abstract: The presenter has had a fascination with non-visual astronomy for over 25 years and has developed and built devices to share this with students and other teachers. After seeing a video of John Kraus giving a demonstration on radio antennas many years ago to the IEEE, the presenter was so inspired that he sought to reproduce as much of it as he could. Many of the ideas were unknown to the presenter and a couple were thought provoking and required exploration. It is hoped that these demonstrations will educate and inspire others to explore as well. The equipment consists of a Gunn diode source with horn antenna and a horn antenna with crystal detector, instrumentation amplifier, and VCO so that changes in intensity will be heard as pitch changes. The demonstrations cover topics which include: beam width, inverse square law, polarization, reflection, refraction, interference, diffraction, absorption, gain, wave guides, and more.

The Equipment: The equipment consists of a transmitter (a Gunn diode device) with a larger horn antenna and regulated 8V power supply; a receiver with a small horn antenna, crystal detector, instrumentation amplifier, voltage controlled oscillator, powerful speaker, and powered by a 9V battery. The transmitter and receiver are mounted in such a way as to allow them to be rotated 90^{o} to allow polarization to be explored. The various demonstration devices will be described in each section.









Pictures clockwise from top: the transmitter and receiver; the transmitter with power supply and meter; the power supply opened up; the receiver with instrumentation amplifier, VCO, speaker and 9V battery; the receiver electronics opened up; the horn antenna and crystal detector.

The Demonstration: For most of these demonstrations we will be at far-field. If the maximum linear dimension of an antenna is d and you are $2d^2/\lambda$ or farther from an antenna, you are in the far-field. For us, the maximum dimension is 9.42 cm (transmitter horn) yielding a far field of about 59 cm.

Beamwidth: There are many “beamwidths” defined for various reasons. In our case, using the receiver as a power detector we will use the measure of an angle from the first null on one side of the beam to the first null on the other side of the beam. We will explore the relationship between the small horn on the receiver and a large horn placed over it and show that the beamwidth for a larger horn is narrower. For a more mathematical expression we can use the approximation for half power beam width (HPBW - the beam width at 0.5 peak power or 0.707 peak voltage) also known as the -3dB beamwidth:

(HPBW) Beamwidth = $70\lambda / D$ where,

λ = Wavelength

D = Diameter

$\lambda = 0.3$ / frequency = 0.03 (for 10GHz)

For the small horn (maximum d = 3.6 cm); the HPBW = 58.3^o.

For the larger horn (maximum d = 9.42 cm); the HPBW = 22.3^o.

Small horn and large horn

Gain: Gain is a measure of the antenna's directivity and electrical efficiency. Gain is related directly to antenna area and therefore a larger horn not only has a smaller beamwidth but a larger gain which we can hear in our demonstration. Gain can be expressed as:

$G = [(4\pi A)/\lambda^2]e_A$ where,

A is the area of the aperture,

λ is the wavelength,

e_A is called the aperture efficiency and ranges from 0 and 1. For a pyramidal horn antenna it is generally around 0.5.

For our small horn (A=6.84) G=4.8.

For our large horn (A=64.8) G=45.2.

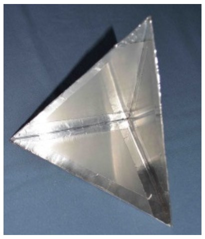
Antenna gain is usually expressed as dB = 10 log(G); so our values become: 6.8dB and 16.6dB respectively.

Inverse Square Law: We are detecting the power transmitted and received by our horn antennas and this is then governed by the inverse square law which states that the power received is directly proportional to the inverse of the square of the distance. This can be heard with our demonstration.

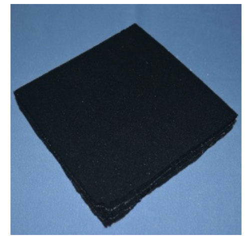
Linear polarization: This generally refers to the orientation of the electric field along a single plane – in our case vertical. Rotating the receiver horn shows maximum signal at vertical orientation while no signal at 90 degrees (horizontal) and decreasing signal from 0 to 90 degrees. Placing a grid between the transmitter and receiver shows the effect as well. With the grid vertical you get no signal through (the electric field is vertical, it comes to the grid which is parallel and the electric charge runs along the grid and doesn't pass through). With the grid horizontal you get maximum signal through (the electric field can't move much in the thin grid wires so most of the signal passes through). If you rotate the grid to 45 degrees, then part of the signal passes and it basically rotates the polarization so that the horn can detect the signal at 90 degrees. The grid must have a separation distance of around $\lambda/2$, which in our case is 1.5 cm and the metal grid must be a small fraction of the λ. (see cut-off frequency below).

Copper clad grid

Reflection: Remember that the angle of Incidence equals the angle of Reflection. Many things will reflect the 10 GHz radiation including a hand and a metal sheet. By placing three metal plates mutually perpendicular to each other a three-corner reflector is made and this device has the effect of reflecting any signal which enters back in the direction it came from. An absorber will also be shown and the effect is quite dramatic, no signal is reflected.



Three-corner reflector and absorber

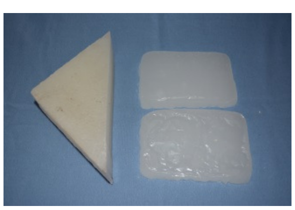


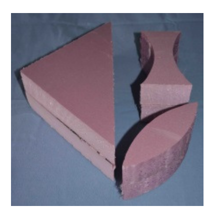
Interference/Standing Waves: By placing the receiving horn where it can detect the transmitter signal directly as well as from a reflected source creates an interference pattern. In this demonstration a flat metal sheet is moved toward the transmitter and aimed toward the receiver. In some instances the signals arrive in phase (for example both at peak – they both add together) and a maximum signal is heard while when the two signals are out of phase (for example one at peak and one a trough – they both cancel) and no signal is heard. As the flat metal plate is moved, a pattern is seen such that every λ/2 (1.5 cm) a peak is heard. This is called a standing wave pattern.

Refraction: Radio waves can bend as well and lenses can be made to take advantage of this property. A polyrod antenna (in this case a 3/8" acrylic rod) will be demonstrated and the effect is obvious! Polyrods are used in the human eye, where over 100 million polyrods in the retina are used to gather light and form images but are millions of times smaller than our 10 GHz version. The polyrod has a narrow beamwidth and behaves as if the effective aperture is much greater.

Acrylic polyrod antenna

A good lens material is paraffin wax and convex and concave lenses and prism of paraffin will be demonstrated. Polystyrene can also be used to form lenses and prisms of various types and these will be explored. The forms demonstrated include: a polystyrene half sphere, polystyrene lenses (convex/concave), and a polystyrene prism.





Wax prism, convex and concave lenses; wax prism on stand; polystyrene half sphere; polystyrene lenses and prism

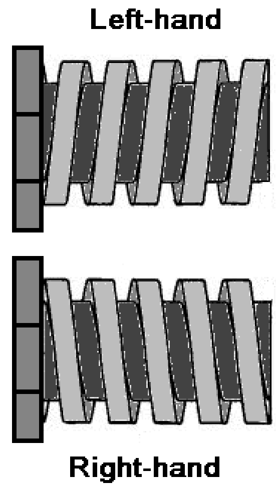
Waveguides: A waveguide is a device that 'guides' the electromagnetic radiation. In this demonstration, pipes will be used. Starting with a large diameter pipe and noticing that the signal is passed through the pipe we continue to decrease the size of the pipe opening until we see no signal. This is known as the cut-off frequency and is calculated with the following formula:

Waveguides – metal pipes

Cut-off frequency = c/2a where,
c = speed of light (300,000,000 m/s)
a = largest side length (2.2cm = 0.022m)

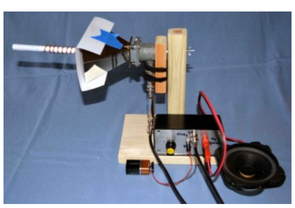
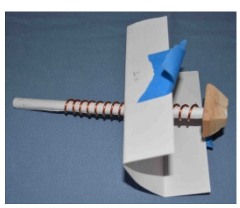
For the receiver waveguide, the cut-off frequency is about 6.8 GHz. The rule of thumb for rectangular waveguides is that they operate at between 125% and 189% of the cutoff frequency. Thus for our WR-90, the cut-off is about 6.8 GHz, and the band of operation is about 8.2 to 12.4 GHz. For the pipes used, the smallest has an inside diameter of 1/2 inch which is equal to about 1.25 cm = 0.0125m. Thus our cutoff frequency for this pipe is about 12GHz so our 10GHz signal will not be passed through. Inserting a polyrod antenna will allow the signal through because the polyrod increases the effective aperture as mentioned above.

<u>Circular Polarization</u>: In this case the orientation of the electric field is rotated in a circular motion by a helical (spiral) antenna. There are left-handed and right-handed helices. The demonstration uses left-handed helices since they were easier to make but have no bearing on the performance of the demonstrations.
With the polyrod antenna in place a helix is pulled over the rod and the receiving horn is now circularly polarized and the signal can be detected in all orientations as the horn is rotated.



forum.flitetest.com/showthread.php?2169-How-to-build-a-5-8GHz-Helical-Antenna/page2

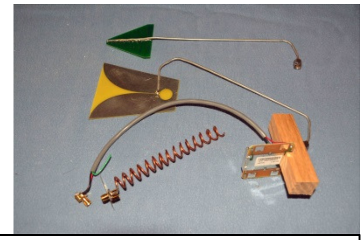
<u>Aluminum Ground Plane</u>: Placing a sheet of aluminum foil over the table we create a ground plane and radiation can be reflected as in the interference demonstration done earlier. This simulates the real-world antenna situation with a transmitter tower a long way off and the radiation not only comes directly to your receiver but the signal is reflected off the ground and interferes with the incoming direct signal creating the standing wave pattern again. As the receiving horn is raised the standing wave pattern can be heard. By placing a helical antenna on both the transmitter and receiver a circularly polarized signal is created and the standing wave pattern is theoretically eliminated. This is due to the fact that the reflected circularly polarized signal is oppositely polarized from the incoming signal and can't be detected by the left-handed helix being used for this demonstration. Only the direct signal is detected. This of course is theoretical. In our case there is some mismatch of the impedances, the placement in the horn is not a very good method for coupling, and the helices aren't made very accurately. With this in mind the demonstration shows the ideas mentioned here reasonably well.

Helical coil placed in horn

<u>Parabolic Reflectors</u>: Using a parabolic shape to focus the signal more tightly greatly increases the gain and narrows the beamwidth. The effect is so great that the demonstration has to be done at some distance from the transmitter.

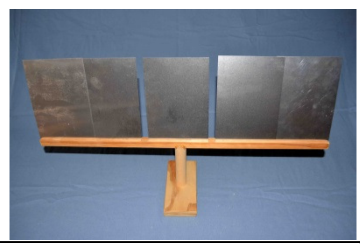
Other Antennas Demonstrated: A true helical antenna, log-periodic, and Vivaldi antenna are shown and compared to the horn used in this demonstration. The helical was wound by me so doesn't quite live up to its 13dB calculation. Two other antennas built by Kent Britain are the log-periodic which has a gain of about 6 dB and the Vivaldi which has a gain of about 8-10 dB. The last antenna is a patch antenna from a microwave DRO (Dielectric Resonant Oscillator) with a gain about 5dB.



Antennas from top: log-periodic; Vivaldi; patch; helical

Diffraction: Tilting the transmitter and receiver so that the electrical field is oriented horizontally, we can set-up three diffraction demonstrations. First is the knife edge effect where the microwaves are diffracted around an obstruction. This is observed when radio waves encounter a building or mountain. Signal will be detected in an interference pattern by the receiver. Second is the single slit experiment where the signal is diffracted through a single slit and produces an interference pattern. The slit should be on the order of the wavelength of radiation. In our case a 1.5 cm wide slit is used and the interference pattern will be detected. Third is the double slit experiment. By placing metal sheets about 13cm wide in the center with a 1.5 cm gap on both sides followed by metal sheets on the ends. These sheets are placed about half way between the two units and the receiver is moved back and forth in front of the sheets. A diffraction pattern with a large peak in the center and lower intensity peaks every 10-15 degrees on either side of the central peak. This satisfies the equation for diffraction: $\theta = \sin^{-1}(n\lambda/d)$, where θ is the angle, n is an integer, λ is the wavelength (about 3cm), and d is the width between openings (in our case above about 14.5 cm). Plugging in for the first peak we get about 12 degrees, second at about 24 degrees and so on.

Knife-edge diffraction set-up



Double slit diffraction set-up

Acknowledgements: The following people provided invaluable help in making this project: Paul Wade (ARRL); Alan Rutz (SHF Microwave); Kent Britain (PCB Antennas); Richard Bitzer (SARA –Society of Amateur Radio Astronomers); Peter Kandefer and Shef Robotham (Litchfield Hill Amateur Astronomy Club); Vacek Miglus (Wesleyan University).