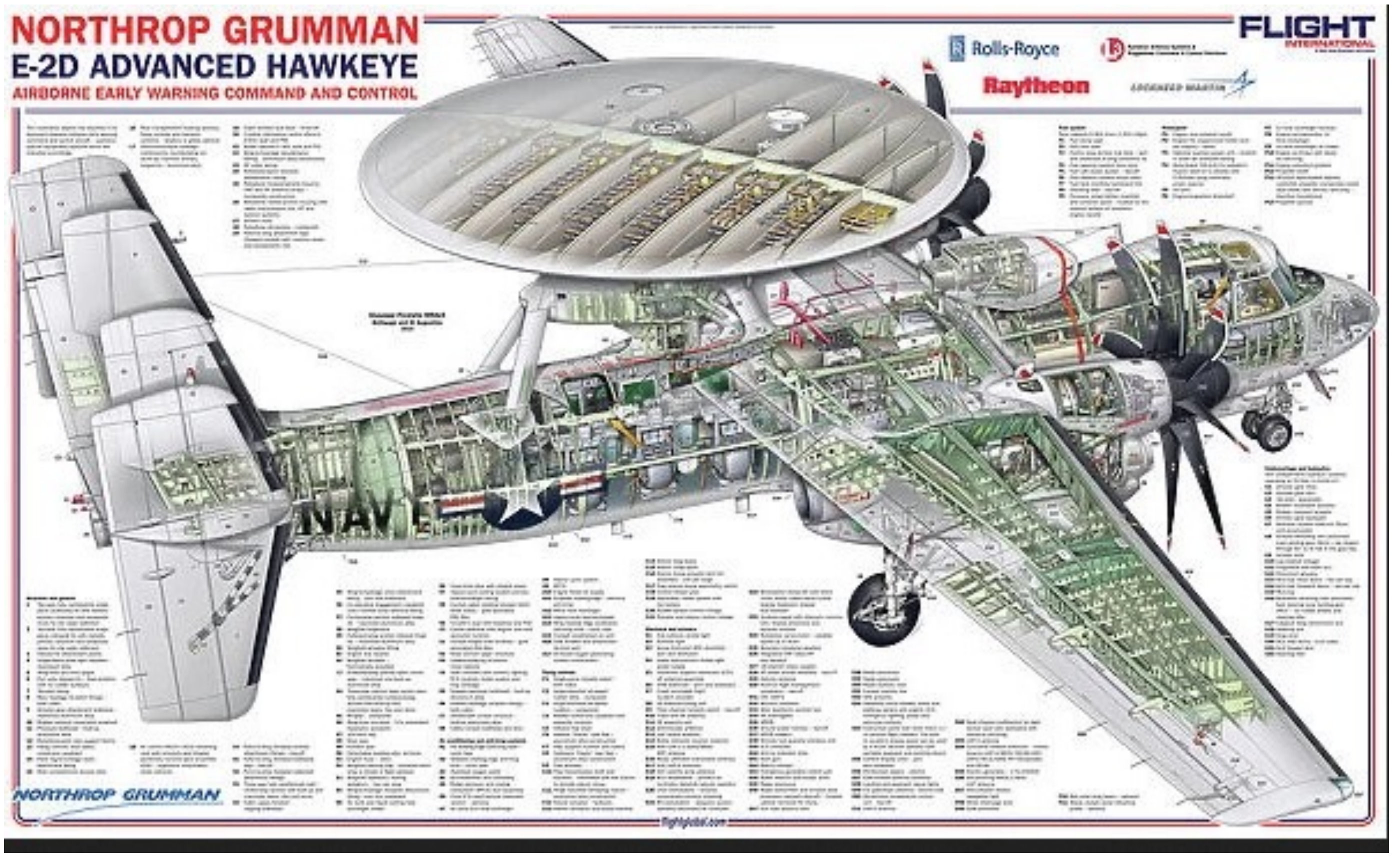
Fascinating Antennas … for Complex Systems



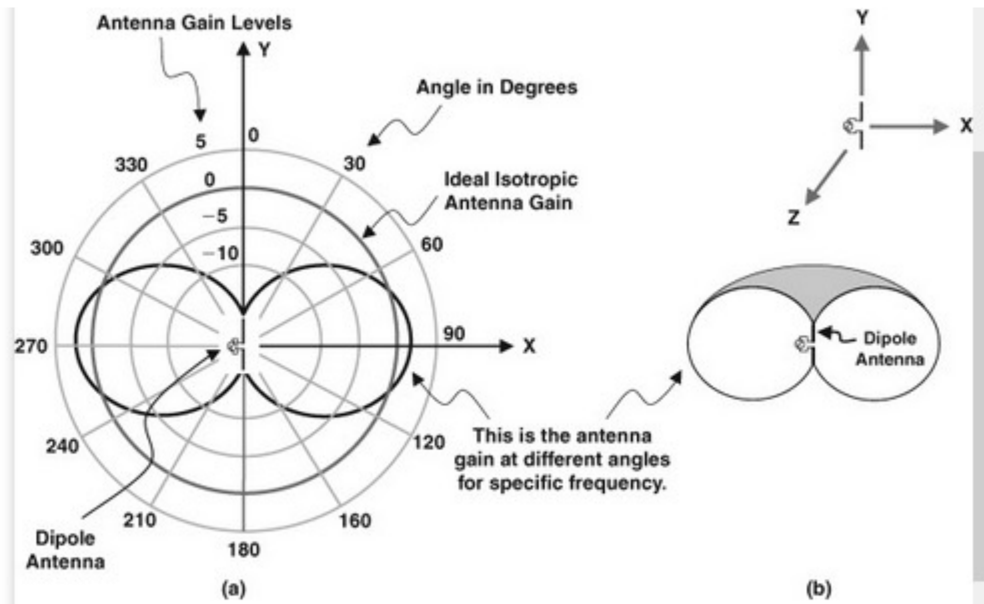
Ed Gellender

December 7, 2023

“You can tell the men from the boys by the price of their toys”

- All of the examples presented here have been funded, one way or another, by the US Government
- While I haven’t personally worked on all of them, I have been heavily involved in most.
- I certainly couldn’t remotely afford any of them
- So, It has been great playing with some of the most complicated and expensive toys ever.

INTRODUCTION - BASICS



Lets go to the VERY beginning

- Fourteen billion years ago the Big Bang created light
- A few thousand years ago someone tried to explain it: "…and darkness was over the surface of the deep….. And God said, let there be light"
- In 1865 James Clerk Maxwell edited it to "And God Said…

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{j} + \frac{1}{c^2}\frac{\partial \mathbf{E}}{\partial t}$$

- ….And there was light"

Electromagnetic Spectrum

- After Maxwell's breakthrough, it was soon found that the electromagnetic spectrum extends beyond light to, say, radio
- Much of what our society runs on has one thing in common: We are always coupling signals to or from the electromagnetic spectrum
- Anything that does that coupling is called an antenna. However, the term covers an incredibly diverse selection, from under an inch of wire, up to huge deep-space networks
- But when reduced to basics, they all use simple antennas; sometimes one or two ; sometimes hundreds

Basics1: The dipole

- The most basic, fundamental antenna is the dipole.
- A dipole is half a wavelength long at the desired frequency
- FUN FACT: The wavelength of a signal is the speed of light (300,000,000 meters/sec) divided by the frequency.
- Examples:

frequency	band	wavelength	dipole length
120 MHz	VHF	2-1/2m	1-1/4m (50”)
450 MHz	UHF	2/3m	1/3m (13”)
1200 MHz	L-band	1/4m	1/8m (5”)
5000 MHz	C-band	0.06m	0.03m (1.2”)
10,000 MHz	X-band	0.03m	0.015m (0.6”)
15,000 MHz	Ku band	0.02m	0.01m (0.4”)

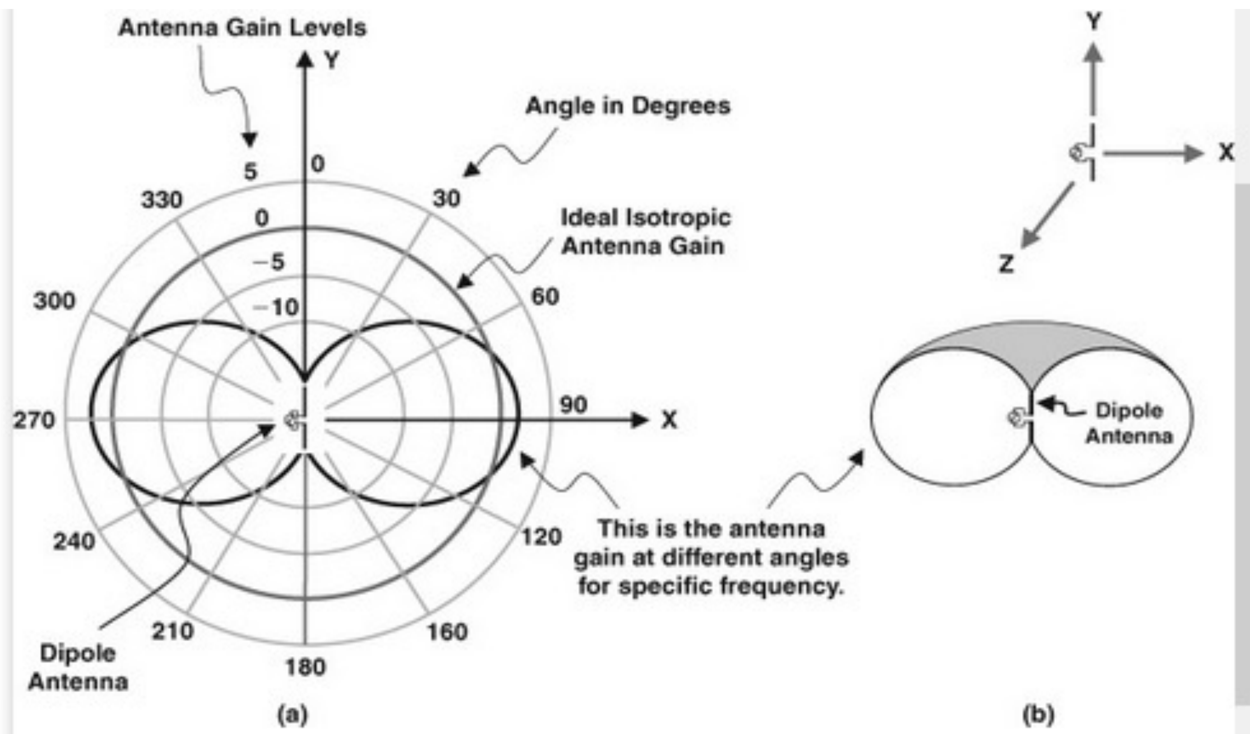
Basics2: Antenna Patterns

- Every antenna of any type has a 3-dimensional pattern where the signal is radiated or received
- An isotropic antenna radiates or received equally in all directions (a sphere). It is an ideal, a concept, that cannot actually be built. Yet it is used as the reference for the performance of all real antennas. (dBi gain)
- Since three-dimensional drawings are problematic, real-world antennas usually are shown in two drawings (horizontal and vertical).
- Typically a real-world antenna focuses the energy in a desired direction at the expense of other less important directions
- An antenna is kind of like a beanbag that as you squeeze it, it bulges out in one or more directions, but the volume of the beanbag represents the energy, which is set by the transmitter power output

Dipole Pattern

A dipole antenna has a radiation pattern like sliding a donut over the wire. It radiates best perpendicular to the wire and worst off the wire ends. The sketch is for a vertical dipole

The left sketch shows the pattern, while the shading on the right shows the symmetry

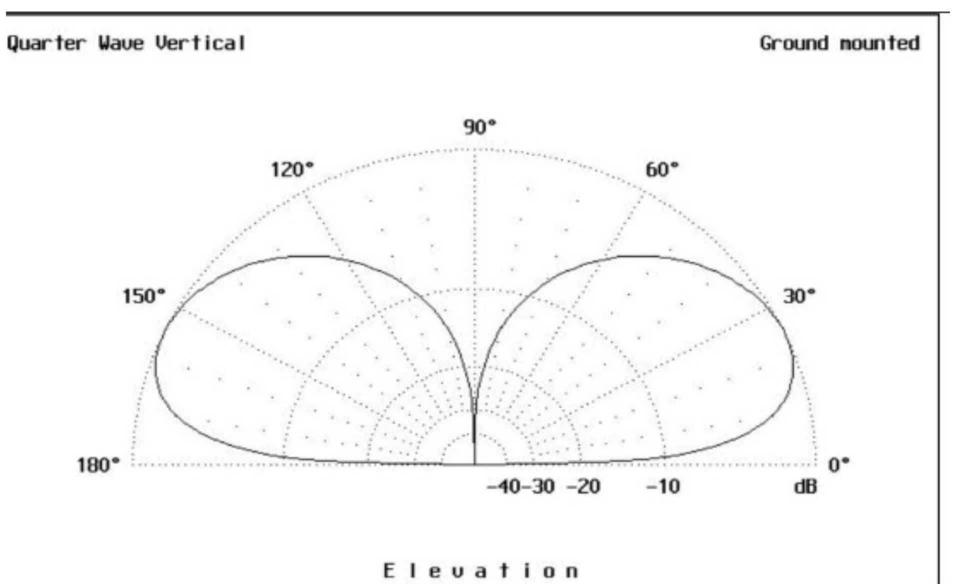


Quarter-Wave Monopole

- One of the simplest antennas, despite the fancy name
- It is simply half of a dipole with the other half replaced by a large flat metal surface (a “ground plane”).
- The flat metal surface is very forgiving in frequency, so long as it is at least as long as the monopole
- Most commonly it is mounted on the roof of a car or airplane, sticking up above the metal body
- The antenna pattern of such an antenna is totally above the metal plate, where reflections cause the pattern to elevate above the ground plane

Quarter wave monopole pattern

- A quarter wave vertical antenna mounted on a ground plane has a pattern that shows some reflections from the ground.
- Note that the peak gain is at an elevation of about 20 degrees above the horizon, equal in all horizontal directions.
- In theory, no energy goes out horizontally



Improving gain of vertical antennas

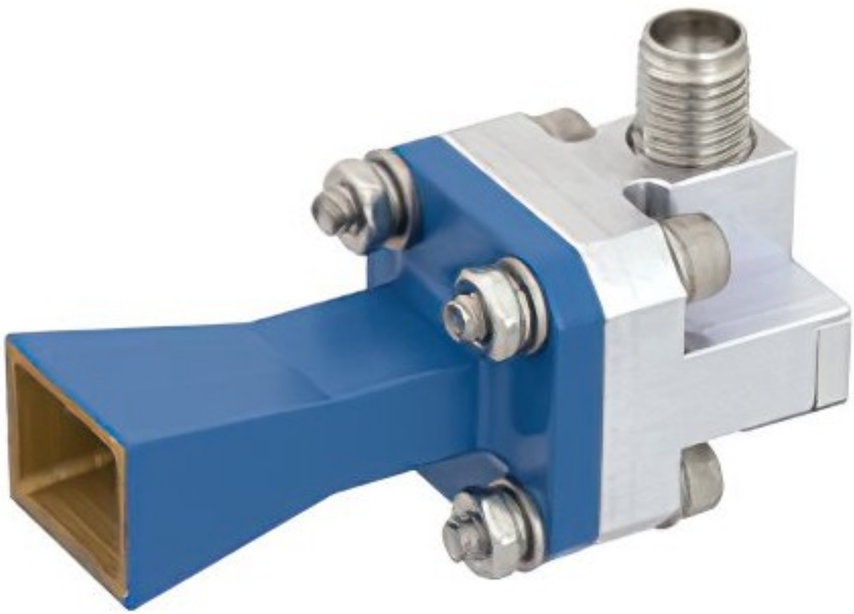
- By increasing the length of a quarter-wave vertical antenna to 5/8 wave, the main lobe drops, and puts more signal near the horizon. (note it needs an impedance match, but that is no big deal)
- To get higher gains towards the horizon, if a half-wave section is placed above the quarter-wave, the distances and cable runs can be tweaked for proper phasing, and thus a pattern nearer to the horizon increases signal levels.
- If height is not a limitation, like on top of a tower or large building, more elements can be piled on and delicately phased in, to get even narrower beams out to the horizon

Waveguide Launcher

- At relatively low frequencies (below 2000 MHz), a pair of wires usually connects the antenna to the radio
- These wires can be in parallel, or an insulated wire surrounded by a braid (coaxial cable)
- At frequencies above 2000 MHz waveguides become more practical
- A waveguide is a machined “pipe” – usually a square but can be round – with precise dimensions such that two sides are precisely a multiple of half-wavelengths apart. The signal actually travels through the waveguide the same way it propagates through open space
- A quarter wave vertical monopole is often placed inside the waveguide to “launch” the signal
- If the waveguide is then carefully flared out to an open end, the signal can be launched into space in the proper direction

WAVEGUIDE LAUNCHER

- A radar signal enters the coaxial connector.
- A monopole internal to the waveguide launches the signal down the waveguide
- The flared opening couples the signal to the environment
- Receives as well as transmits



Mirror, mirror on the wall

- Metal acts like a mirror to radio waves. Putting a piece of metal near an antenna will distort the radiation pattern. Complex antennas use this to create some useful antenna patterns
- Putting a piece of metal on one side of an antenna can block the pattern in that direction while the reflected signal ideally adds to the original signal and increases the gain in that direction.
- I once worked on an aircraft receiving antenna pointing forward at 5GHz C-band. It had a 1.2 inch quarter wave monopole in front of a triangular piece of metal attached to the fuselage. The metal behind the radiator caused reflections to double the received signal energy from the front at the expense of signals from the rear

Definitely not complex, but I love it anyway

Note the triangle on top of the fuselage in the center of the photo. The 5GHz C-band monopole is in front of the right angle triangle reflector. The pattern is distorted to favor signals from the front, at the expense of signals from the rear

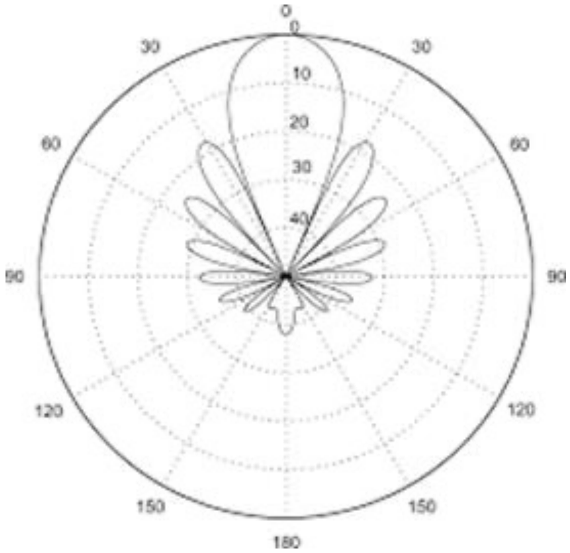
If you are really sharp you can also see the 15GHz Ku-band version in front of it

Yagi vs Uda, Tokyo 1925

- University of Tokyo, 1925: Dr. Uda publishes a paper on a new antenna. Nobody notices it. Ditto the second paper. Third time he lets his grad student Yagi do it …. And it goes worldwide. Everybody forgets poor Dr. Uda.
- In the simplest form, a reflecting rod is mounted at the optimum distance behind a dipole. All the dimensions are critical and must be perfect for it to work
- The antenna provides significant focusing of the dipole pattern away from the reflector
- Later it was discovered that placing additional precisely measured rods in front of the dipole (“directors”) the forward gain could be further increased

9 element Yagi

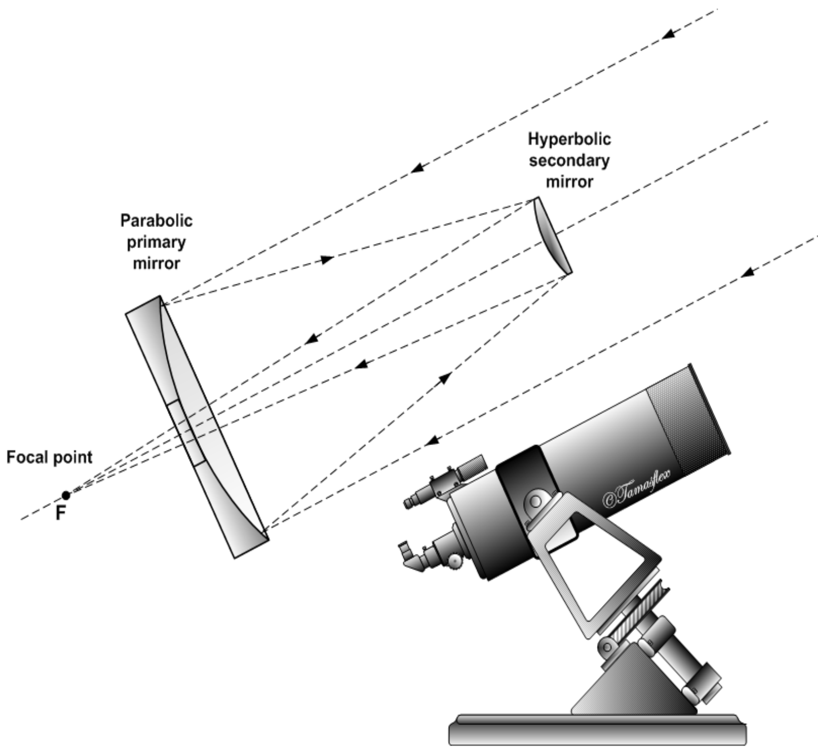
- The dipole is the second from the right (note the coaxial cable) and the reflector is at the far right
- There are 7 directors in front of it for additional gain (to the left)
- Note that the signal is narrowed in the horizontal plane and wide in the vertical plane. The off-peak-blobs are called sidelobes and backlobe
- Note the gear-motor on the mount used to mechanically point the antenna in the desired direction and allow remote control



Some other ways to get antenna directionality

- Putting a dipole the proper distance in front of a reflecting screen will focus the energy in one direction, albeit with a broad pattern
- A curved or bent screen can narrow the pattern.
- A number of dipoles arrayed properly in front of the screen can also narrow the pattern. Two dipoles arranged vertically work together to focus the vertical coverage closer to the horizon
- Similarly two dipoles arranged horizontally will narrow the beam’s horizontal coverage
- The upcoming antenna arrays are all examples of this

Cassegrain feed



chining and techniques.

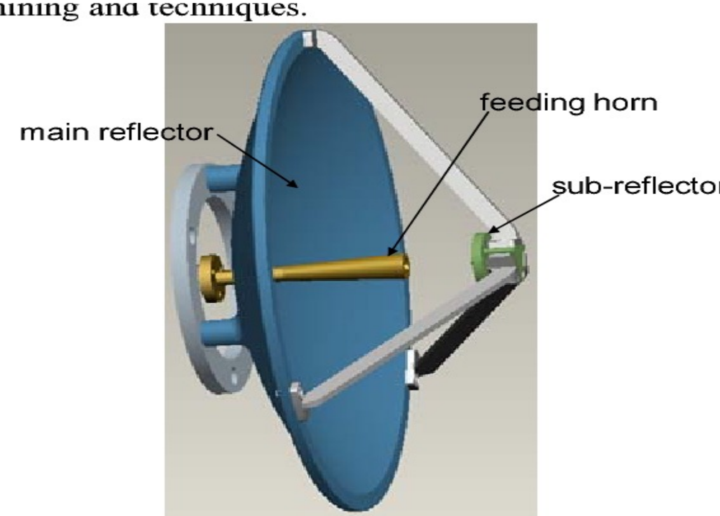


Figure 1. Configuration of the terahertz Cassegrain reflector antenna.

Cassegrain feed

- In a reflecting telescope, the eyepiece is up at the front
- Often, the preferred position for the eyepiece is the rear
- The solution is often a second, much smaller, reflector up front to bounce the beam back to the eyepiece, with minimal blockage.
- Of course the two mirrors much be precisely matched to focus the beam precisely
- The same idea is used for dish antennas.
- Some dish antennas have the feed up front, while others have the feed at the dish, with a front small reflector
- Cassegrain antennas are popular with deep space antennas, due to the need to minimize the length of cable or waveguide to the receiver

PART 1 – Mechanically scanned and commutated arrays

Sneak Preview – the Doppler Effect

- The classic case of Doppler effect takes place at railroad crossings as a train approaches while blowing the horn
- As the train passes, you hear the pitch of the horn drop
- This is because the train velocity compresses the sound waves as it approaches and expands the sound waves as it leaves. The pitch noticeably drops with a change proportional to speed
- This effect is often very important with radio signals, although much more subtle, as the speed of light is so large it takes an incredible velocity to make much of a difference
- This is a necessary prerequisite to the next topic

Example 1 - Doppler-scan Radio Direction Finder

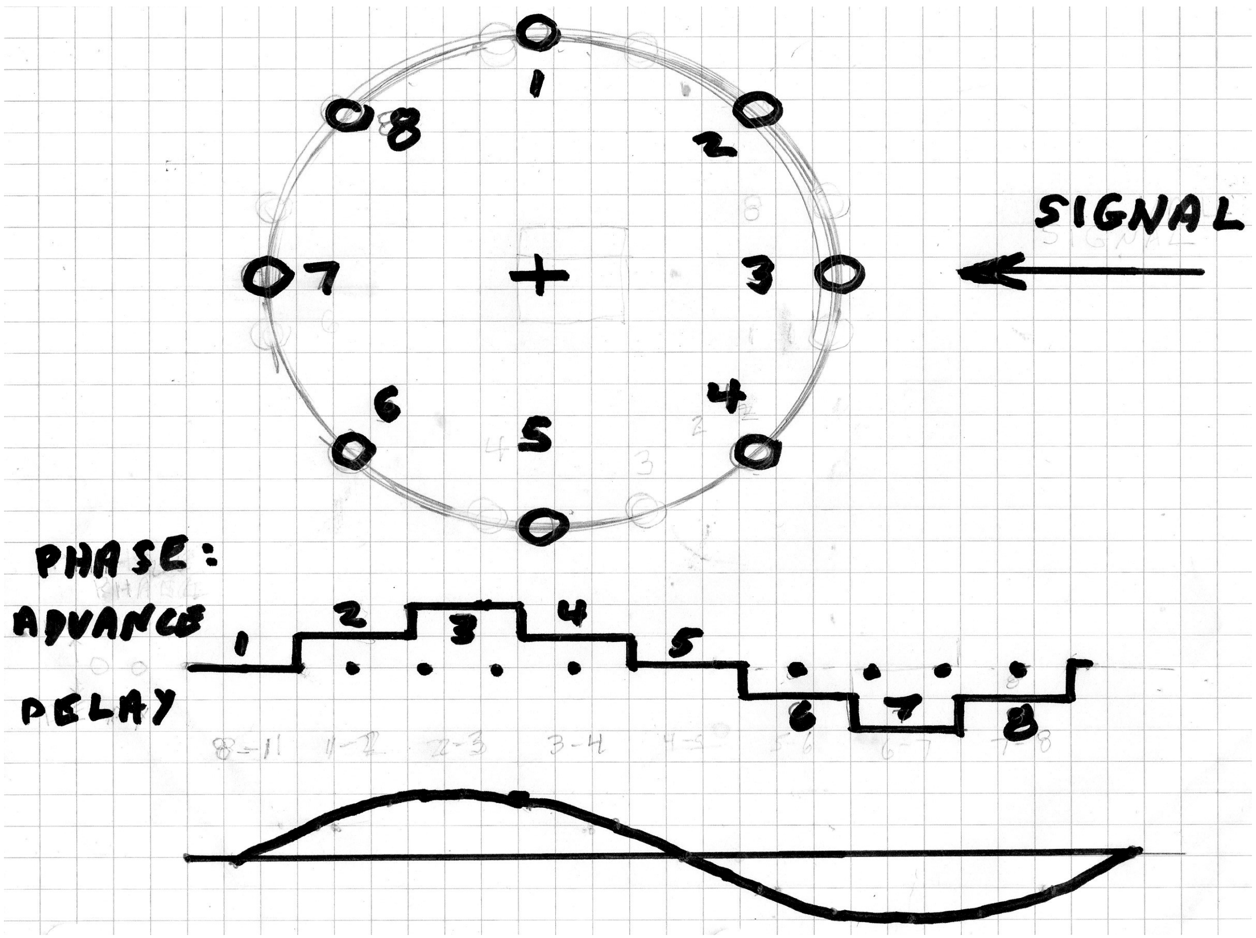
Doppler Scan Radio Direction Finding

- Imagine an airport control tower receives a radio call from a pilot of a small plane who is lost.
- If they can find out what direction the signal is coming from they can provide directions to the plane towards the airport
- Then, by having the plane make a right turn, they can estimate distance by the rate of change of direction angle
- There are several approaches to this, but the standard is the doppler-scan
- Such units use from 4 to32 vertically oriented dipoles at the usual radio frequency arranged in a circle
- In the aircraft radio band such dipoles are 50 inches high
- In general, the more dipoles in the array, the larger it is, but the more accurate.

How it works -1

- Imagine an array of 8 dipoles in a circle. (or go back 2 slides)
- Let us arbitrarily label the dipoles 1- 8 (like the face of a clock), but with 1 at the top. Imagine a signal coming from the right (dipole 3 or 3 o'clock).
- At first, dipole 1 is connected to the receiver
- Then dipole 1 shuts off and dipole 2 is connected
- Note that switching dipoles off also detunes them, so there is only one on-frequency antenna at a time and no interaction.
- As the switched dipoles go around the circle, it is like a single mechanically rotating dipole.
- The receiver input phase is advanced or delayed by the fraction of a wavelength in increased or decreased travel distance from the origin of the signal
- As the dipoles go around the circle the phase represents a sinewave at the rotation frequency

Doppler Scanning



How it works -2

- As the simulated spinning antenna goes around the circle, the resulting phase pattern creates a sinewave at the rotation frequency.
- The phase of the sinewave is directly related to the angle of arrival of the signal relative to a selected reference point (usually set so that 0 degrees is true north, to follow standard aviation direction terminology)

How it works - 3

- The more dipoles in the circle, the larger the array, but the closer the output waveform is to a sinewave
- Note that there is 360 degree reception, which includes reflected signals off of any metallic objects (multipath). Such reflections cause distortion of the waveforms and angular errors
- The larger arrays are less susceptible to multipath, so whenever possible a 16 dipole antenna is used (FAA), and there is a (positively huge) 32 dipole array available
- Note that on a car roof (see "Lojac") you can cheat with only a 4 element array. As the car moves, the reflection errors move around and you can "eyeball average" the bouncing display to get the average angle
- Notice I said "as the car moves." Very important. Kids don't try this at home.

Example 2 - VOR beacon

VOR – VHF Omnidirectional Range

- To fly in your airplane, you need to know where you are. For a pleasant flight on a nice day you follow lakes, rivers, bridges, and the like
- When you cannot see any landmarks, you need to have something instead, but what?
- One of the earliest – and still used (although less so now with GPS navigation) is the radio beacon. It is a ground station that continuously transmits signals that can be decoded on an airplane to show you what heading you have to fly to get to it
- It is basically a direction finding system run backwards
- As with all avionics, the idea is to have the airborne equipment as inexpensive and light as possible, while sparing no expense on the ground to support it.

VOR - 2

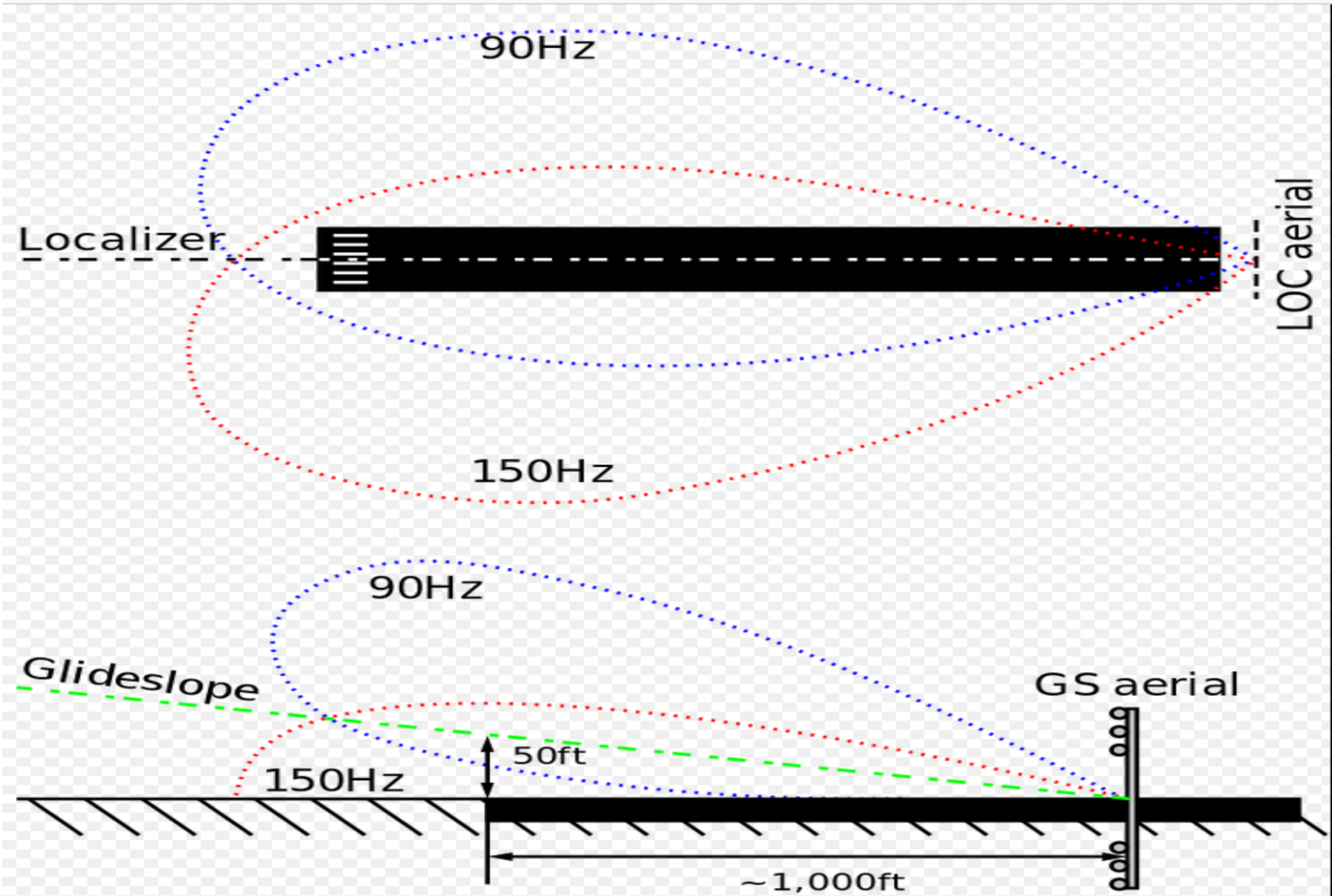
- The VOR transmitter provides two outputs close enough in frequency that the receiver can decode both on one channel (sort of like upper and lower sidebands on an AM signal)
- One is a constant signal modulated with a 30Hz sinewave
- The other is a dead carrier, switched around a circle of 48 antennas, just like the direction finder antenna is switched, such that a complete circle occurs 30 times a second
- When an antenna switches to the next one, the phaseshift is increased if the new position is closer, and decreased if further, etc.
- A 30 Hz sinewave is generated in the receiver
- The first channel matches the 30Hz sinewave that results if the aircraft is north of the VOR
- The receiver processor measures the phase difference to produce a heading indication on the panel

Example 3 – Instrument Landing System (ILS)

Instrument Landing System (ILS)

- ILS uses 2 systems. The localizer, used to keep an airplane lined up with the runway centerline, operates at frequencies between 108 and 112 Mhz.
- The glideslope sets up a 3 degree vertical path (glideslope) that the plane follows down to the runway. It operates between 329 and 335 MHz
- Two separate antennas each send out a narrow beam. One is focused to be just to the left of the runway (above the glide slope), and the other to the right (below)
- At centerline (glideslope) The antennas have the exact same signal level, and become mismatched off center. See the figure on the next slide

Instrument Landing System (ILS) - 2



Instrument Landing System (ILS) - 3

- For the localizer, a signal at the proper frequency is generated and split to two multipliers (double balanced mixers).
- Lets take localizer 150Hz. Normally, when 150Hz and the channel frequency of, say, 110 MHz, are multiplied, two signals are produced at 150 Hz above and below 110MHz.
- By adding 90 degrees of phaseshift to both inputs, one of the multiplier products cancels and a single output of 110MHz plus 150 Hz is amplified and transmitted
- Similarly, another signal of 110 MHz plus 90Hz is transmitted
- Both signals are sourced from the same signals and can be simultaneously received without distortion.
- They are split back apart to create the 90 and 150 Hz signals with amplitudes that vary with position and are matched on centerline.

Instrument Landing System (ILS) - 4

- The relative amplitudes of the 90 and 150Hz signals are compared and an error function generated to drive a vertical bar on an indicator that is centered on centerline.
- As 90 or 150 Hz signal amplitude mismatch increases, the bar moves left or right as appropriate to indicate what corrections are needed
- The same thing occurs for glideslope
- A horizontal bar similarly indicates on-glideslope when vertically centered and moved up and down to indicate the necessary correction
- Note that eventually the bars reach full displacement, but maintain the relationship over a wide range of approaches

Typical crosspoint indicator, shown centered
Used for both VOR and ILS

Example 4 - The King of Doppler – Microwave Landing System

- A few decades ago I blundered into a once-in-a- lifetime chance to play with some truly awesome toys
- The FAA was investigating upgrading the standard VHF-based Instrument Landing System (ILS) that brings aircraft down to the runway in poor visibility. It allows pilots to line up with the runway and a 3 degree glide-slope, well before they can actually see the runway
- The new landing system used a wide-open 5GHz beam to allow an entire assortment of ways to approach the runway.
- Spoiler alert: The prototype system I worked on performed perfectly, but in the end it never was implemented

MLS -1 Basics

- Imagine an antenna pointing down the runway with a beam that is about 30 degrees on either side of the centerline and from 1 to 10 degrees vertically
- Now put this transmitter and antenna on a cart and place the cart at the end of the runway, off to one side.
- Then drag the cart across the width of the runway REALLY fast.
- Once you reach the other side. The cart and all the equipment on it disappear and reappear back at the starting point
- Ignoring the mechanical absurdity, let's say the cart travels 100m at 2400m/s (0.0417sec; 5250mph) as an airplane approaches perpendicular to the runway. There is a doppler shift of (speed)/(speed of light)X(frequency) or 2400/3E8X5E9 = 40kHz

MLS -2 Details

- Now, consider the 8-dipoles in a circle of the direction finder discussed recently
- Let's cut the circle and spread it out in a line. Since it is significantly longer, we will need, say, 50 antenna elements
- Now we can see that if we commutate (switch) across a linear array of antenna elements, with each one radiating for 800uS, the signal sweeps left to right at 5000 mph and then jumps back to the starting point
- The 5GHz receiver mixes the signal with 499.9GHz to produce a nominal 100 kHz output
- Since we only need to operate within 30 degrees of the centerline, the Doppler component is reduced to a range of 80 to 120 kHz.

MLS -3   more details

- If a plane is approaching on runway centerline, it is perpendicular to the scan and there is no received doppler content, so the output is 100kHz.
- If the plane is approaching runway 10 (heading 100 degrees) at a heading of 70 degrees the output is 120kHz, and at a heading of 130 degrees the output is 80 kHz
- Note that elevation is the same idea; just turned on its side - but over a range of 0-10 degrees with the base angle (100kHz) at a 3 degree glideslope

MLS Glide Path Antenna

-Note the small vertical array of commutated antenna elements
-The signal goes to the large reflector and then then goes (off to the left) to cover +/- 30 degrees in azimuth as it scans 0-10 degrees elevation

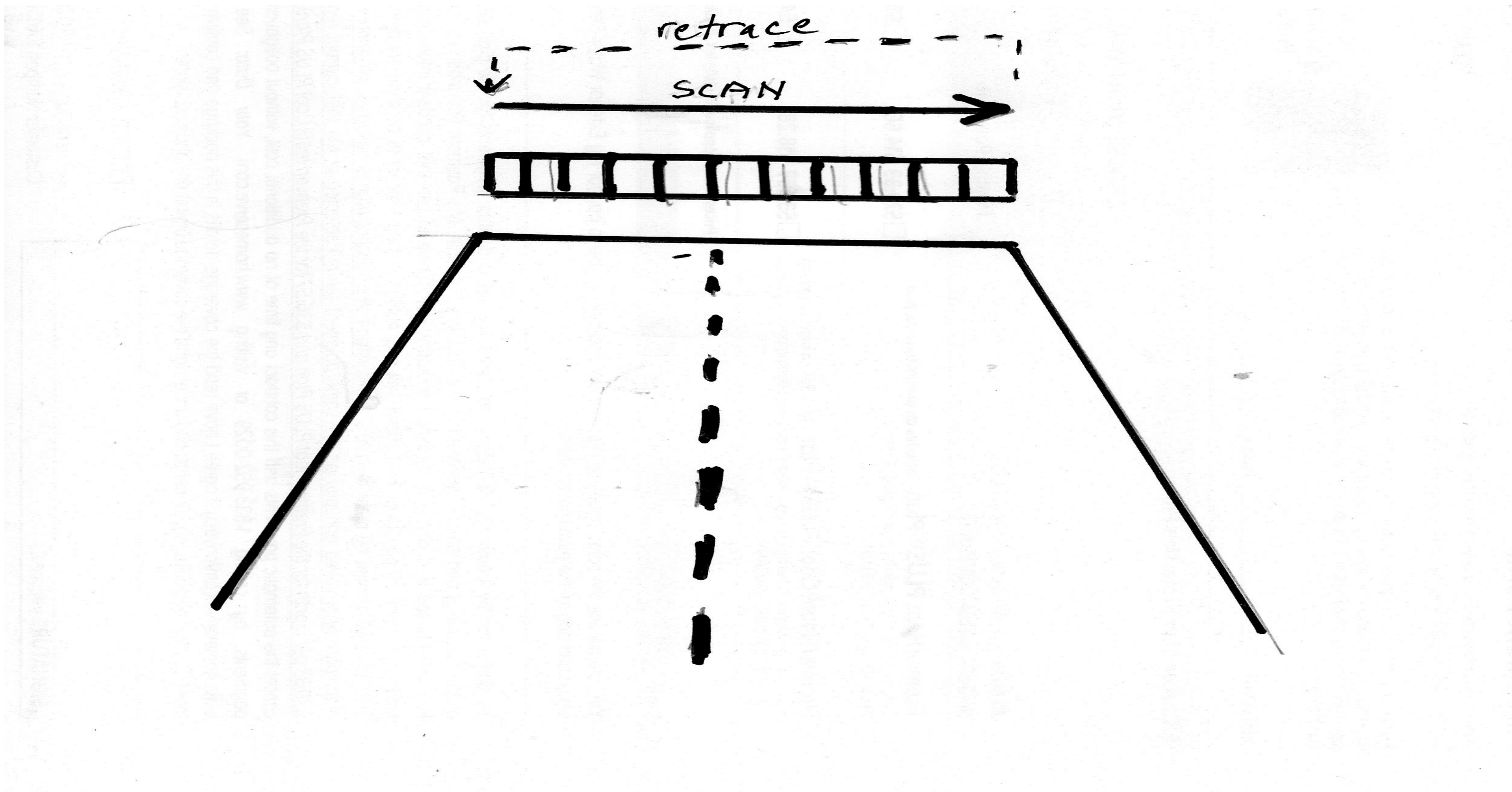
Longer view

- The left hand unit is the glidepath antenna
-The smaller right hand unit is the Ku-band flare guidance antenna that would normally be a few hundred feet further up the runway at the touchdown point
-Just starting to flare here

Pilot View

Azimuth operation

- Best I can do here is this sketch



The MLS System

- Just past the end of one runway the azimuth array radiated a beam that could be received over a range of at least 30 degrees on either side of runway centerline
- The beam vertically covered from the horizon up to 10 degrees, as planes normally land at a 3 degree glideslope , but occasionally up to 6, and possibly more in an emergency
- FUN FACT: Private pilots often practice landing at a 6 degree glideslope. Why? Because if the engine dies that is how they glide.
- The glideslope array was located at a nominal point down the runway, with the same coverage area
- The “flare guidance” was supposed to be for the last-moment levelling off for touchdown, but it was never tested that way

MLS Flight Test

- The FAA set up a flight test at the Wallops Island airport – a former navy base on the Atlantic coast by the Maryland / Virginia state line, used primarily to support NASA missile launches from nearby Wallops Island.
- During missile launches the place is crazy; not so much otherwise
- Our flight equipment was installed on NASA438, a WW2 vintage C-54 cargo plane in full NASA colors - loaded with equipment used for all kinds of testing, including a sandblaster (used to blow smoke out from the wingtips to research wing vortices).
- We also got a camper with an added 50 foot crank-up tower to do stationary testing along the runway up to 50 feet

MLS Flight Test - 2

- The flight tests involved taking measurements over the entire flight coverage area of the ground antennas
- We spent a lot of time bumping across the Virginia shoreline skies and bouncing off the runway ("touch-and-go": as soon as you touch down you gun the engines and go around again)
- Fun Fact – a long runway is mandatory for that one
- I usually kept tabs on our equipment and operated the data recorders. I had to lean over to stop the recorder as we touched down. (you heard right – standing up)
- In Harry Chapin's "Taxi" he mentions "we learned about love in the back of a Dodge". I learned about dramamine in the back of NASA438

A personal observation

- Flying in that environment is nothing at all like flying commercial.   No agents, no lines, no security checks, no flight attendants, nothing
- The ground crew would have the airplane sitting on the tarmac, hooked up to a power cart as I walked over and lugged our test set up the ladder to the open cargo door
- I would then pre-flight check the MLS hardware
- Then everyone else would climb up and settle in
- We had an intercom link to the flight crew and one of us was in constant communication
- We had the run of the plane at all times and when we weren't doing anything, I could sit with a commanding view of oil streaking from each engine nacelle over the wing

Our chariot, pulled by 6000 horses
Four 14 cylinder 2000 cu in radials
Love the NASA regalia on an antique

The Haunted Runway

- One day aircraft maintenance and I connected the analog azimuth and elevation signals to a crosspoint indicator on the instrument panel. Now the pilots could see what our system was doing in real time
- After the first flight with the new addition they told us that our system had a bump in it. Just before reaching the beginning of the runway the indicator would go up and down while the plane flew dead straight. Huh? Made no sense
- We borrowed a surveyors transit (think riflescope on a tripod) and the next flight a couple of us stayed on the ground and watched.
- The plane dipped and rose just as it flew over the airport fence. It was real, but WHY?

Haunted Runway - 2

- Just outside the fence was Mosquito Creek. Suddenly it all became clear
- The sun warmed the underbrush outside the airport and caused the warm air to rise. The cool water in the creek caused a slight downdraft.
- The plane would drop a bit as it flew over the creek and then rose afterwards
- This was too slight to see from the pilots seat, but it jumped out at you on the MLS
- So, makes perfect sense. The MLS was just more precise than we realized

Example 5 – Air Search Radar

- We are all familiar with the classic radar display with the beam sweeping in a circle and airplanes or clouds or whatever showing
- One common use is for air traffic control, where the air traffic controllers can see all the air traffic. A related military use is to track friendly and hostile military aircraft in a combat zone
- Note that a radar only tells you that there is a hunk of metal there, but an associated secondary radar ("IFF") is needed to indicate just WHICH hunk of metal that is. In a military environment, another key parameter can we be sure it is OUR hunk of metal. Air search radars seem to work best at about 400 Mhz with the secondary radar at about 1000Mhz.
- (Secondary radar is a specialty of mine; just not today)

My long time favorite: SPS-40B

- Just as I started my engineering career, the new nightmare was sea-skimming cruise missiles. The US Navy went big into developing defenses.
- I found myself working on the SPS-40B radar designed specifically for ships to counter those sea skimming missiles.
- It had improved sea-clutter rejection, and (doppler- based) emphasis on high speed incoming targets. The antenna had a normal rotation mode and a new high-speed mode to decrease the time between scans for fast moving targets
- It had an antenna that created a “fan beam” that rotated in a circle every few seconds. It was narrow in azimuth and in elevation it was quite wide, covering from the horizon up to steep angles (still had to watch for high flying stuff)

Air Search Radar Antenna

Anatomy of a Fan Beam

- The entire array continuously rotates mechanically with a complete scan of the environment every few seconds
- The higher the antenna the better the view, so it is always mounted high on the mast of a ship
- The transmitted and received signals go through a rotary joint to allow continuous rotation. A signal splitter drives several dipoles in parallel to create a signal that covers the entire mesh reflector
- The resulting antenna pattern depends on the reflector, which is very narrow horizontally and wide vertically, down to horizontal but not into the sea
- Interestingly the desired vertical curve matches a cosecant-squared curve. Despite hearing the term often in this context, I never hear it anywhere else
- The horizontally narrow and vertically wide “fan beam” detects any aircraft within range. Note that the range depends on aircraft altitude due to the curvature of the earth

TEASER – coming attractions

- Coming to you in Part 2
- When I started on the Navy's new radar plane, the E-2D, I became involved in the new radar, IFF, and their antennas
- I quickly learned that the radar was basically the same as the SPS-40B I worked on decades ago. I was excited to know I would learn what advances had taken place
- As I learned more, I was flabbergasted to learn just how much they both had in common. Yeah, it was 100% all new technology, but the signals in space were very much what I remembered.
- Except for the antenna. I am keeping you in suspense until I get to phased arrays in Part 2
- Stay tuned

Example 6 – Tracking Radar

- A search radar only shows the general position of an aircraft. Often a precise position is needed
- I have worked on two military tracking radars. One is used to land airplanes on the deck of an aircraft carrier. The other is used to aim antiaircraft guns. Two virtually identical radars to provide the precise location of an aircraft
- What happens next is someone else's problem
- The anti-aircraft radar was part of a matched set with the previously mentioned search radar. The search radar would detect incoming hostiles and the tracking radar would precisely monitor the position and velocity to aim the guns
- My work on this combined defense against sea-skimming missiles did have a downside though, as I lost out on an all-expenses-paid extended vacation to Southeast Asia

A pencil beam?

- A tracking radar needs a “pencil beam” – A very narrow beam in both horizontal and vertical directions
- Usually a parabolic dish is used to provide the extremely narrow pencil beams. Such systems are usually at very high frequencies (10 GHz and up) as the antenna focus depends on how wide it is in wavelengths. The smaller the wavelength the smaller the dish for the same focusing
- Note that it is a complex task to direct the tracking antenna to the proper coordinates for the desired target to be within the narrow beam
- There is a photo on the next slide. Be sure to watch for the round “dish” at the top with the skinny pole sticking forward, as well as the protrusions out the sides of the little house underneath. There will be a test.

Parabolic Dish Tracking antenna

If nothing is burning, why do we have Fire control?

- One of the weirdest examples of military-speak is fire control versus damage control. Putting out fires is damage control. Fire Control is actually aiming the big guns… (gun)fire control.
- The previous slide is a photo of a fire control system.
- Such gun directors date back to 1890 when they had telescopes and optical rangefinders (the round thingies on the side) to aim the ship’s cannons at other ships. Later on they added pivoting up and down for airplanes
- By the end of WW2 they had plopped radars on top. By the time I came of age those radars were in need of upgrades. Thus the SPG-53A radar
- The dish additionally can pivot to point up and down
- The entire gun director rotates, including the dish on top. It also is gyroscopically stabilized and moves as the ship rolls

Parabolic dishes

- We discussed moving the dish around. Now we discuss why
- When a target aircraft is detected by the air search radar, the coordinates are passed along and the gun director and dish are steered in that precise direction
- The dish is actually a reflector with a parabolic curvature. The skinny little stick out the middle is the waveguide with a gap and a small reflector that bounces the radar signal towards the large parabolic reflector dish (Cassegrain) , and then off into space as an extremely narrow “pencil beam”
- The idea is to point that narrow beam accurately enough that it “sees” the target.
- The target is moving. The ship is moving. What next?

Conical scan

- The little Cassegrain-style reflector ("splash plate") at the end of the waveguide in front of the dish is slightly off center, and to make it even worse, it is rotated off-center .
- The result is to add a small circular wobble to the beam. The position of the rotation is monitored and used to decode the resulting bobble in received signal strength.
- The idea is to move the antenna until the target is centered in the wobble, with a slightly reduced but consistent signal
- Now as things change, the conical scan detects changes and the antenna position is driven to follow (track) the target
- Meanwhile the antenna position (and range, but that is a different story) are relayed to a computer to aim the guns

Not-so-fun fact

- The first time I actually saw SPG-53A radar operator console, something caught my eye. A simple, basic toggle switch labelled “Battle Short.”   What is THAT?
- I found out. It bypasses ALL safety interlocks. Huh?
- The key word is “battle” If this radar shuts down for a loose cover plate, a major defensive weapon system is disabled, and the entire ship and crew could be lost.
- And, if you take one for the team, you might get a new destroyer named after you*
- Yeah, Necessity can be quite ugly.

- *Destroyers are often named after those who died in acts of extreme heroism

Another shameless plug for Part 2

- In part 2, we get into how phased array antennas have changed tracking radars

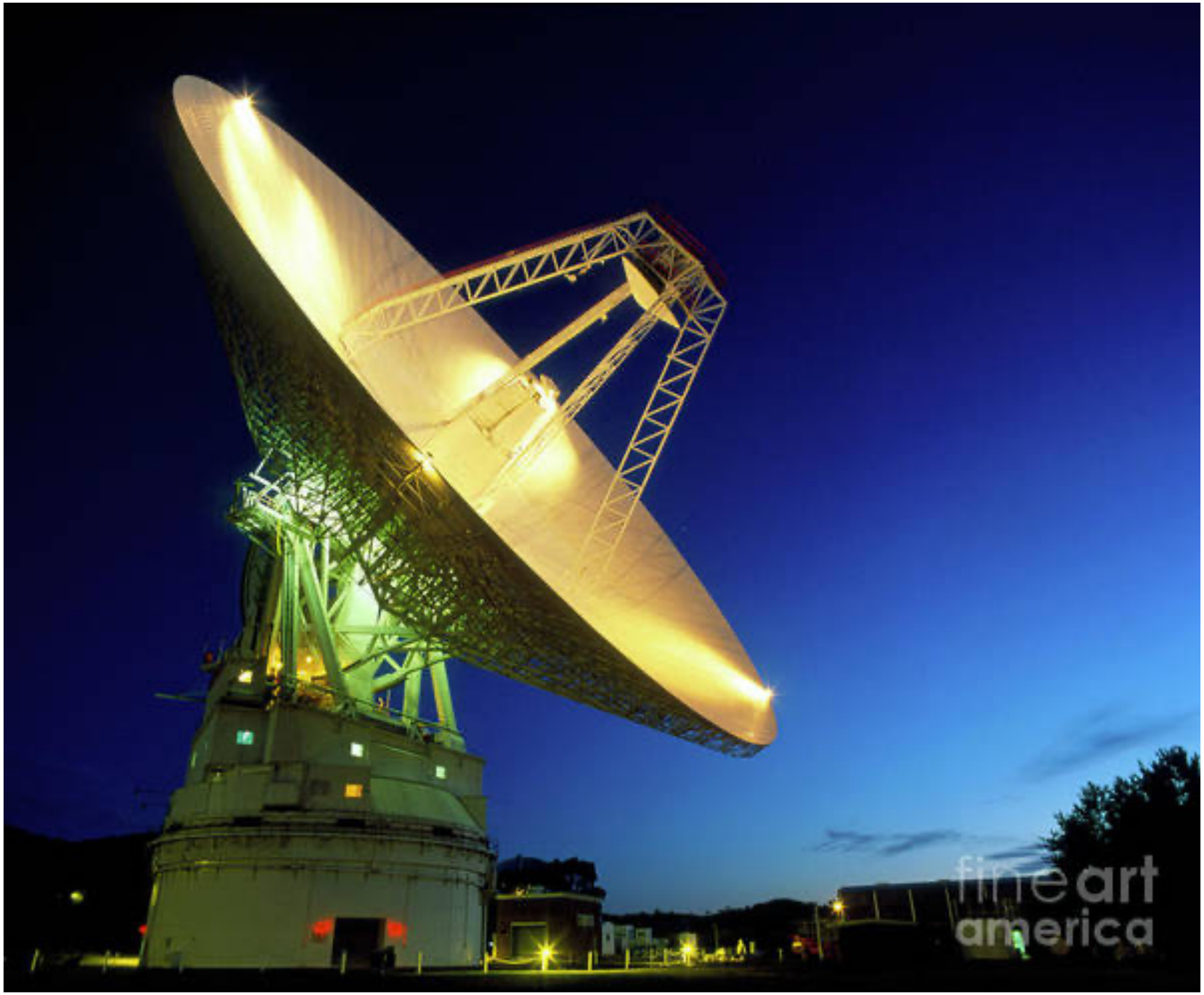
Example 6 – Deep Space Tracking

- Everything launched into space communicates with earth
- The spacecraft has severe constraints on power so the transmitter cannot be too powerful.
- The ground stations spare no expense to have the most sensitive receivers (see: -174dBm/Hz noise floor and cryogenically cooled front ends)
- But mostly, the antenna must be incredibly focused to gather as much signal as possible. That requires absolutely huge parabolic reflectors
- Such narrow beams require incredibly precise control to point precisely at the spacecraft, or it won't even be detectable.
- This ain't gonna be cheap.

Incredible challenges

- Again, you need to have an incredibly narrow beam pointed with an incredible precision for the spacecraft to be within the beam and thus can be communicated with
- Meanwhile, the spacecraft is moving at thousands of miles per hour
- But the biggie is the earth is rotating constantly.
- And such a huge antenna weighs thousands of tons
- Either the previously discussed conical scan is necessary to keep the spacecraft centered in the beam, or there must be incredibly precision programming of the dish coordinates … as the earth rotates.
- How’s that for a challenge?
- Ummmnnnn….. It can get worse. Just watch.

Deep space -2



Example 7 – Aracibo RadioTelescope

- Full disclosure: Aracibo is no more. A crying shame. RIP
- I saw the movie "Contact" some years ago. It starts with a young girl playing with daddy's ham radio, and in frustration she blurts out "I need a bigger antenna"
- The image fades and reforms. She is now an adult (Jodie Foster) and as the camera zooms back, I realized something that no one else in the theater did …. She is at Aracibo – Far and away the largest antenna in the world. Took all my willpower to not laugh out loud at the joke.
- They took a (literally) one mile wide valley in Puerto Rico and put in a fixed one mile diameter wire mesh parabolic dish
- If the dish is immovable, how do you steer the beam?

A one-of-a-kind masterpiece

Aracibo - 2

- Note the three towers and the unit suspended by cables over the dish.
- As the assembly suspended in space moves, the antenna peak is steered. The receiver (and possibly, transmitter) is in there. One of those support cables also carries all the signal and control cables
- The suspended unit is moved by pulling or relaxing the three cables to position it such that after reflecting off the primary reflector the signal path is in precisely the proper direction
- The required accuracy is at least that of the usual deep space antenna, but now we have it strung up on cables.
- Don’t know about you, but I find all the variables with those supporting cables totally mind boggling

Example 8 – Monopulse Tracking

- Conical scan has issues with maintenance of moving parts
- Also, in military use, systems were developed to counter it and actually drive the antenna away.
- Necessity is the mother of invention and monopulse was developed.
- Imagine at the focal point of a parabolic dish that there are four adjacent, but separate, antennas and receivers
- Instead of comparing the phase of a sinewave with the variations in the received signal, now there are four simultaneous signals of different amplitudes that can determine errors of left/right and up/down
- It actually generates corrections for each radar pulse

Monopulse - 2

- Imagine four antennas mounted to a small flat plate in a diamond pattern. Each one is connected to its own receiver
- Note that if signals are also transmitted, a fifth antenna is placed in the middle of the diamond.
- The receiver antennas are located left, right, up and down. The receiver gains are carefully matched
- Every antenna / receiver pair produces an output proportional to signal strength. The left-right and up-down pairs are compared to generate drive signals to move the antenna to center the target in the pattern
- At the expense of three more receivers, errors are detected instantaneously (i.e., each radar pulse)
- Nothing in this game comes cheaply

END