

Radio Design 201 Microwave Circuits and Antennas

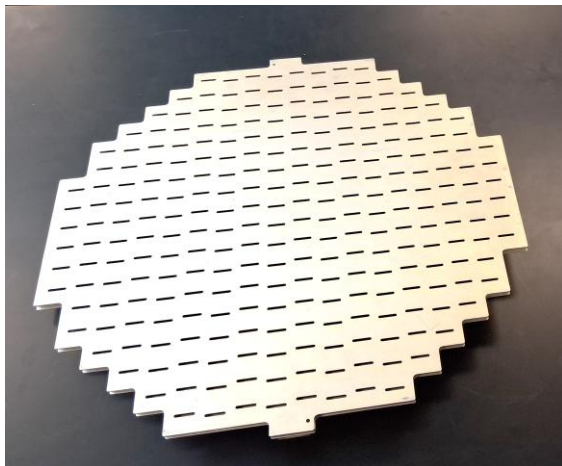
Episode 8 Phased-Arrays and Dish Antennas

Slides downloaded from: <https://ecefiles.org/>

Companion videos at: <https://www.youtube.com/playlist?list=PL9Ox3wpnB0kpOb7NdpHAK-jDpsZm3Xedx>

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This video provides a relatively comprehensive overview of how phased-array and parabolic dish antennas work. Derived from a university course, the material includes essential math formulas, but the presentation is intended for a wide audience from students, to radio amateurs, to practicing professionals. Several real-world examples are presented to provide a good grounding in this field.



Friis Equation(s)

Radio Design 201:

$$P_r = \frac{P_t G_t}{4 \pi d^2} A_r$$

(in free-space)

Classic Friis Equation:

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4 \pi d} \right)^2$$

Large wavelength is "better" ??

Remember: $G = \frac{4 \pi A_e}{\lambda^2}$

Original Friis Equation:

$$P_r = P_t \frac{A_t A_r}{d^2 \lambda^2}$$

Small wavelength is "better"



Credit: NASA

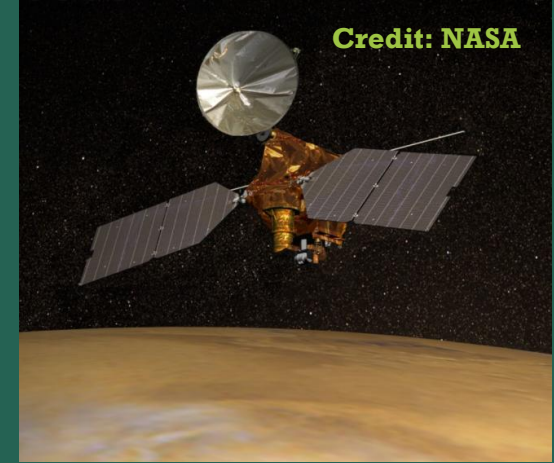
Microwave Circuits and Antennas

Radio Design 201 #8

Phased-Arrays and Dish Antennas



[MegawattKS - YouTube](https://www.youtube.com/channel/UCMgawattKS)



Credit: NASA



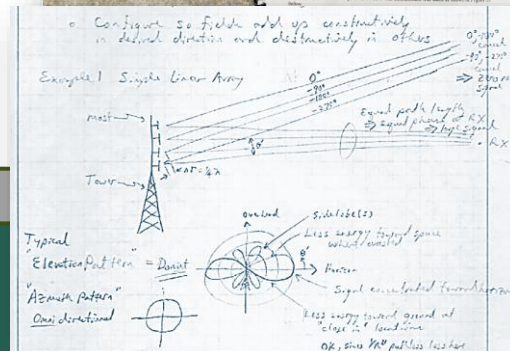
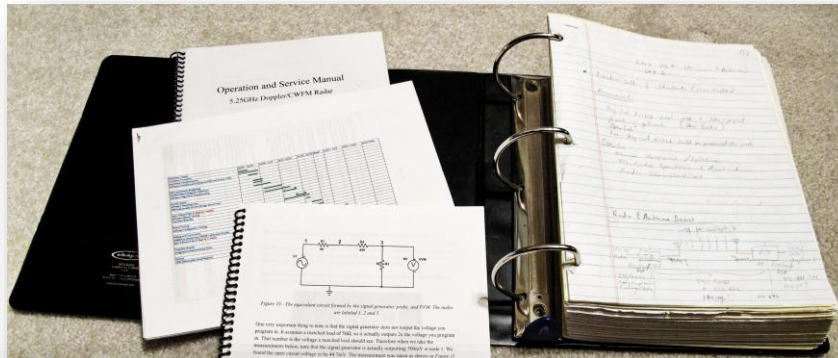
Credit: NASA

<https://ecefiles.org>

Today's "Lecture" Topics

Announcements

Review material from prior Episodes



Topics

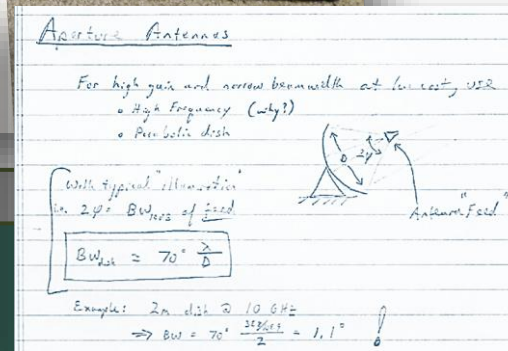
➡ **Phased Arrays (Theory and Measurement)**

Benefits of using Microwaves

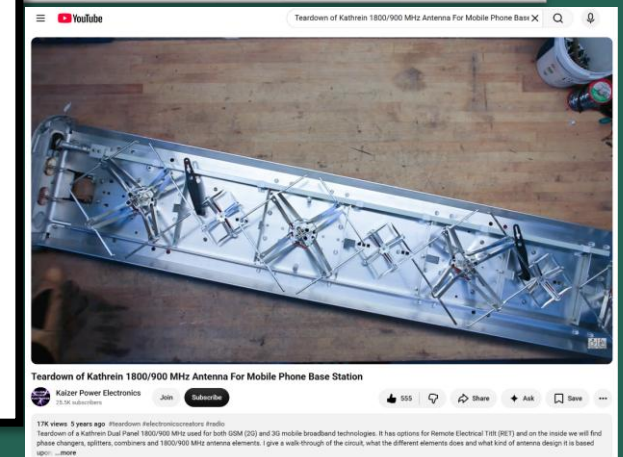
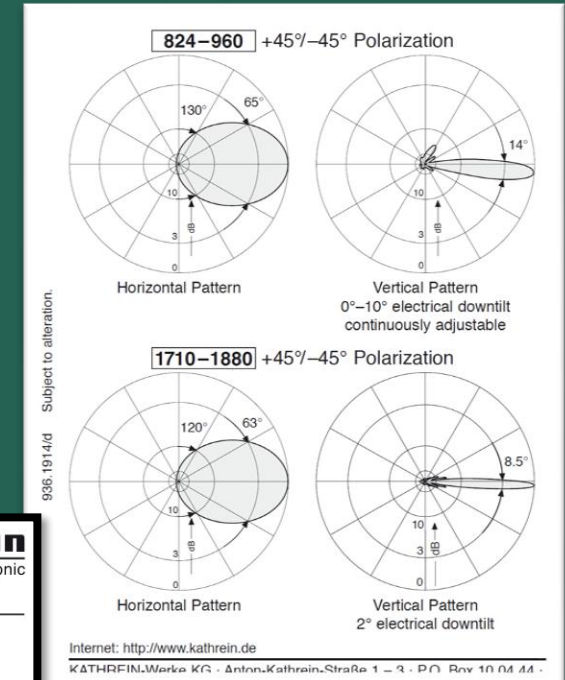
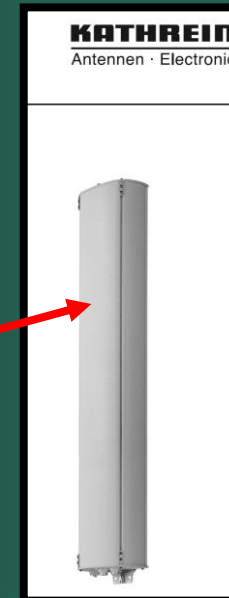
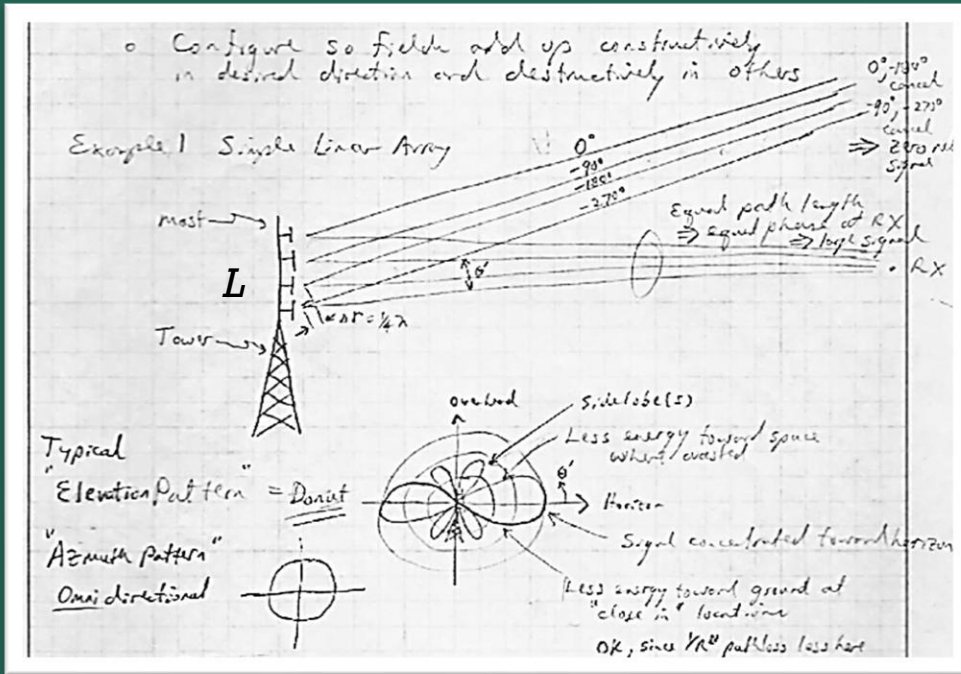
Derivation of Beamwidth & Gain Formulas

- 1D Discrete Arrays
- Extension to 2D Aperture Antennas
- Dish antennas (Illumination-angle, gain, sidelobes, ...)
- Feeds (Horns, Helix, Dipole/corner-reflector, ...)

Application to Real-World Products/Design



Patterns, Beamwidth, and Gain



Beamwidth

$$\theta_{3dB} \approx 50^\circ \frac{\lambda}{L}$$

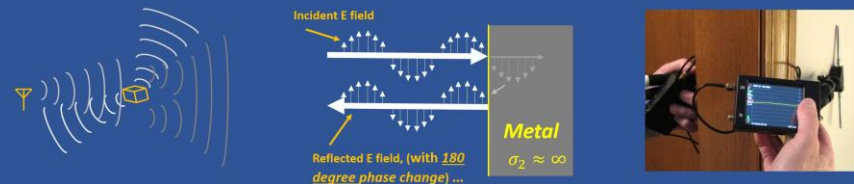
Directivity Gain

$$G \approx (200^\circ)^2 \frac{1}{\theta_{el} \theta_{az}}$$

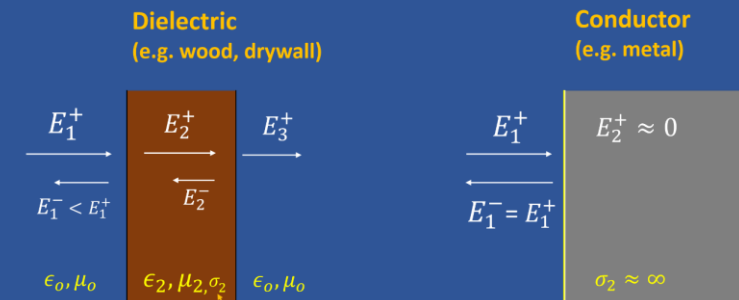
EM Wave Reflection

Antenna Briefs #7 – Part 2

Reflection of Radio Waves (and Diffraction, Absorption, ...)



Undergrad EM Textbook View

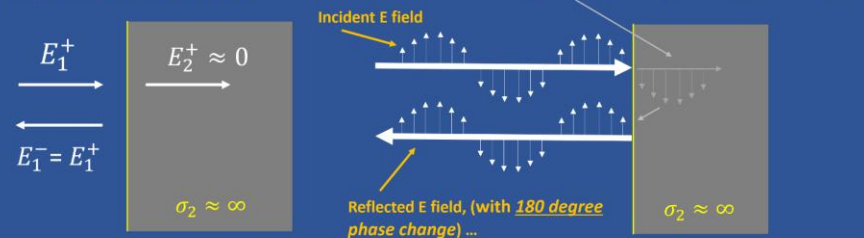


NOTE: Conductivity may be non-zero (or epsilon may be complex) for lossy dielectrics, resulting in absorption too...

How is Wave Reflected from Metal ?

$E_{\text{Tangential}} \rightarrow 0$ at surface of metal (else surface currents would be infinity)

RF currents induced in "skin" (surface) of metal, create reflected wave and stop transmission into the metal



Applications of Reflection Theory in Antenna Design



Microwave 1-D “Slot Array”



Where to Buy

RigExpert MINI-GUN RigExpert

reu-mini-gun.pdf

Ask Gemini

dxengineering.com/parts/reu-mini-gun?srsltid=AfmBOort9ad7NRcUJ5TWw1fWCwJD4bwxRwVh4TcjzEbEKPZ...

DX ENGINEERING

Keyword Search

Deliver To: USA
Change Location

RigExpert 5.8 GHz Minigun Directional UAV Antennas MINI-G...

★★★★★ (1) Part Number: REU-MINI-GUN

Estimated Ship Date from Ohio: Today

Recommended Parts

Overview

Specifications

Documentation

Applications

Reviews

Ease of Installation

PriceValue

Appearance

Quality

Customer Images and Videos

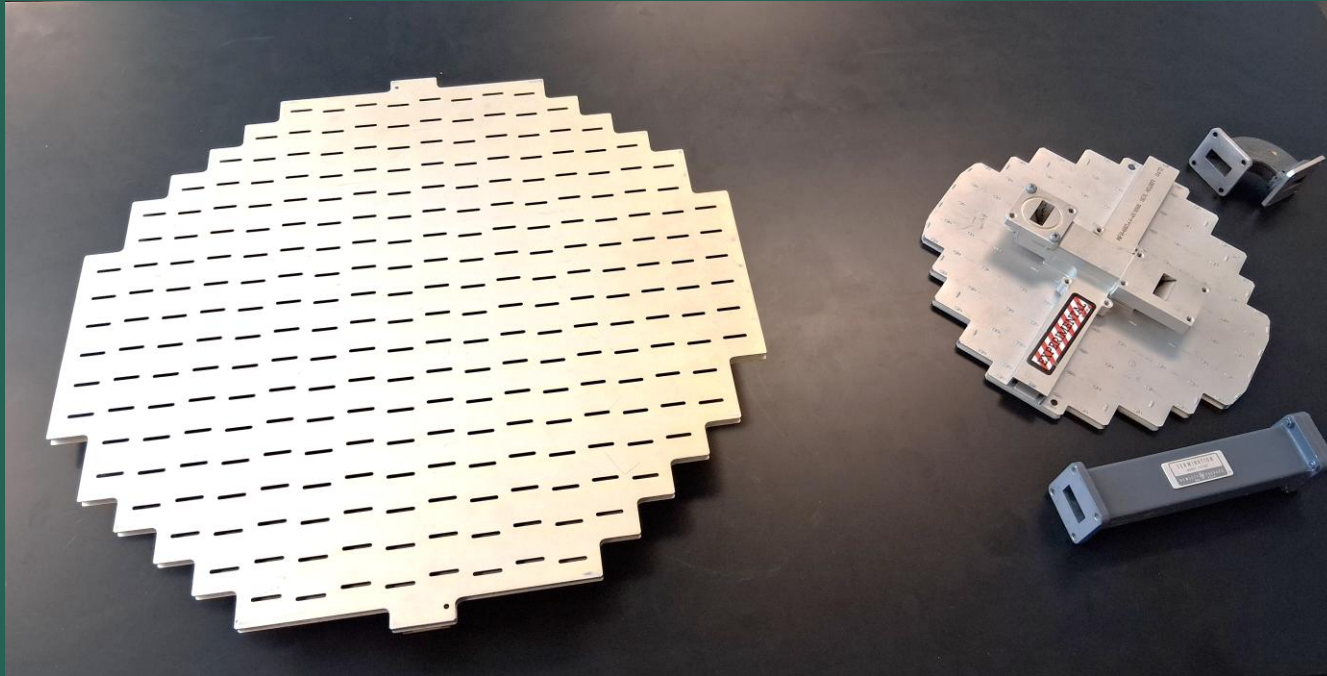
← → ↺ rigexpert.com/products/antennas/

Where to Buy

RigExpert Search

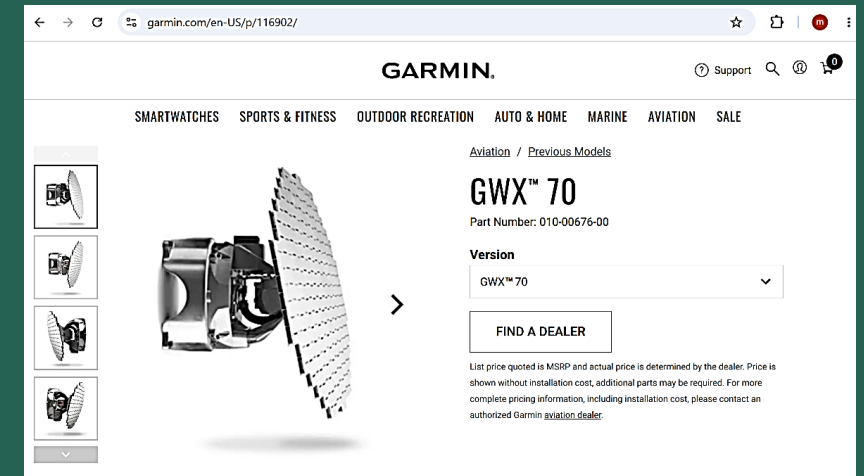
Gain	15 dBi
Polarization	Linear (Vertical)
Radiation pattern	H-Plane 90°, V-Plane 8°
Mounting	1/4" Screw
Dimensions	40mm x 25mm x 450mm

Microwave 2-D Slot Arrays



$$\theta \geq 50^\circ \frac{\lambda}{D}$$

$$G \approx (203^\circ)^2 \frac{1}{\theta_{el} \theta_{az}}$$



For Doppler Storm Tracking in Aircraft

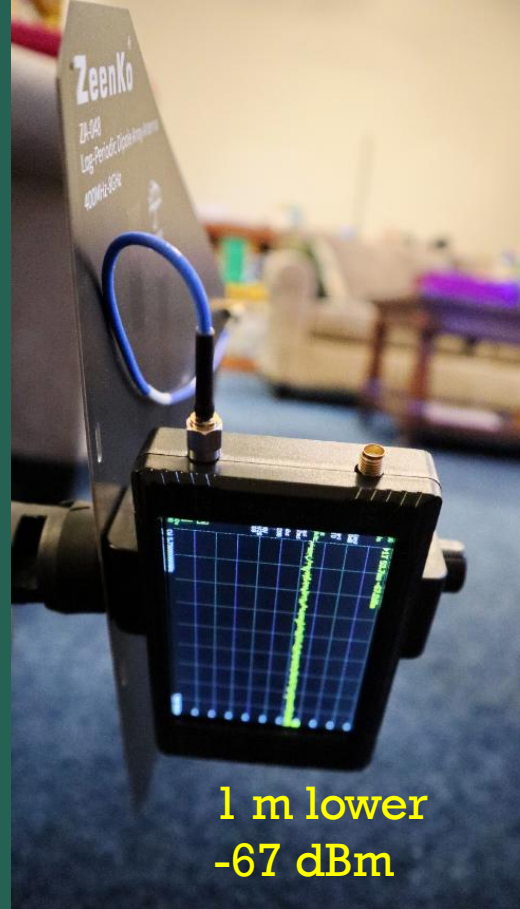
Home-Lab Indoor “Antenna Range” Measurements ☺



Transmitter is LiteVNA
in CW mode at 5.75
GHz



Receiver is TinySA Ultra in zero-span mode at
5.75 GHz with -50 dBm Ref level and 5 dB/div vert



Should be in the Far-Field, which
for this “electrically large”
antenna means a distance of:

$$D > \frac{2 L^2}{\lambda} = \frac{(2) 0.3m^2}{0.052m} = 3.5m$$

Need line of sight and minimal
multi-path reflections

We measured -14 dB at an elevation
angle of $\tan^{-1}(-1m/6m) = -13^\circ$

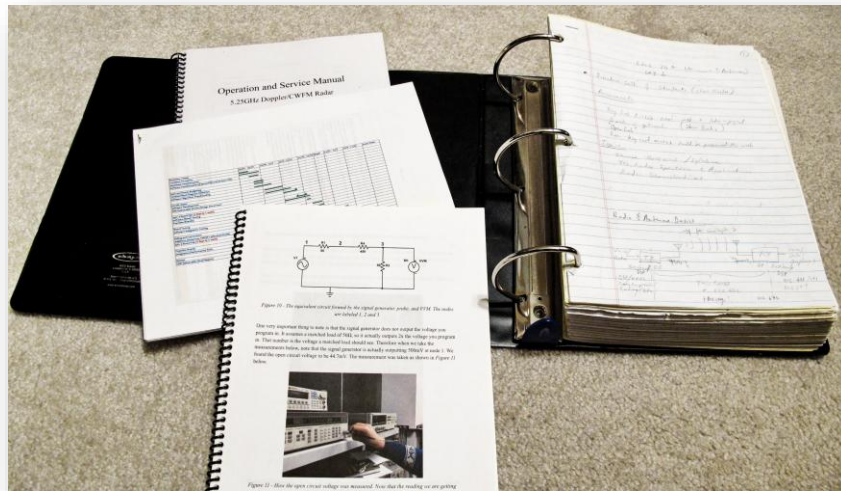
Receive antenna
is a wideband
log-periodic



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Topics

Phased Arrays (Theory and Measurement)



Benefits of using Microwaves

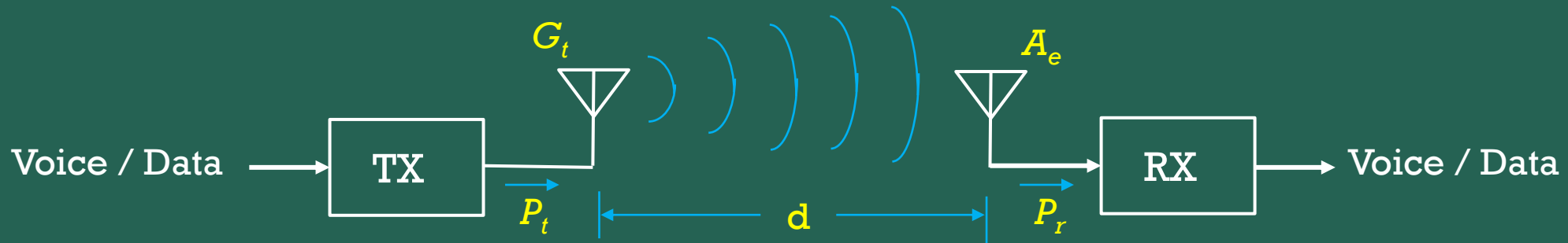
Derivation of Beamwidth & Gain Formulas

- *1D Discrete Arrays*
- *Extension to 2D Aperture Antennas*
- *Dish antennas (Illumination-angle, gain, sidelobes, ...)*
- *Feeds (Horns, Helix, Dipole/corner-reflector, ...)*

Application to Real-World Products/Design

Microwave Links and Received Signal Power

(from Episode 5)



$$P_r = \frac{P_t G_t}{4 \pi d^n} A_e$$

Make these large for
maximum range

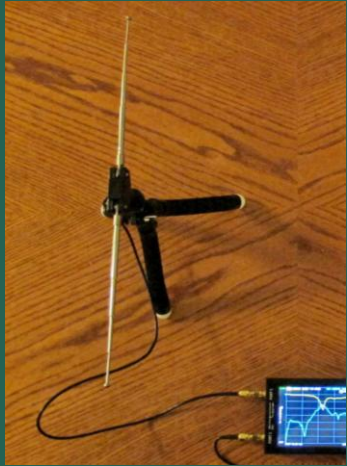
$\Rightarrow$ *Highly directional antennas !*

$\Rightarrow$ *Use Microwave frequencies (if $n=2$)*

$n=2$ for free-space
with line-of-sight

Gain and A_e vs Antenna Type

(from Episode 5)

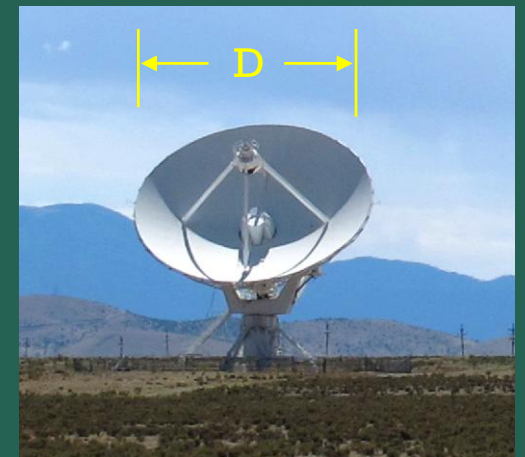


Single (half-wave) dipoles are relatively isotropic

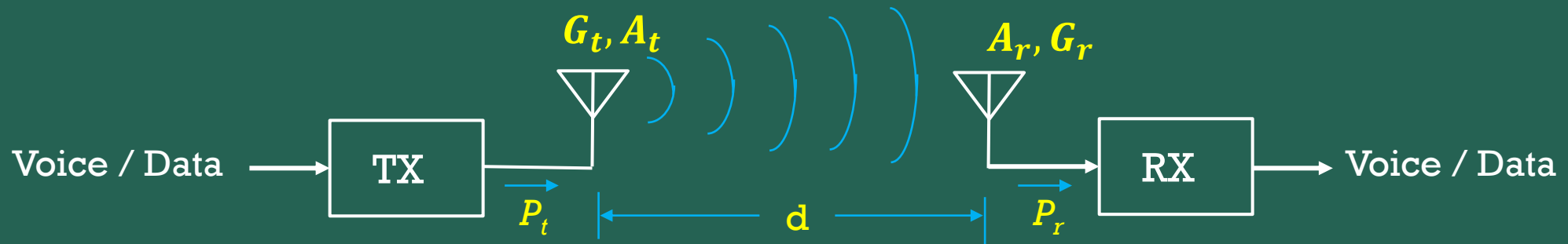
$$G \approx 1.6 \text{ (2 dBi)}, \text{ and } A_e \approx \frac{1}{\pi} \left(\frac{\lambda}{2} \right)^2$$

Dish antennas can have large effective apertures and very large gain at microwave frequencies

$$A_e \approx \pi \left(\frac{D}{2} \right)^2 \text{ and } G = \frac{A_e}{A_{ei}} = \frac{4\pi A_e}{\lambda^2}$$



Friis Equation(s)



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(in free-space)

Classic Friis Equation:

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Large wavelength is “better” ??

Remember: $G = \frac{4 \pi A_e}{\lambda^2}$

Original Friis Equation:

$$P_r = P_t \frac{A_t A_r}{d^2 \lambda^2}$$

Small wavelength is “better”

System-Level Examples



$$P_r = P_t \frac{G_t}{4\pi d^2} A_e$$
$$> P_{noise} = kTB$$

$d = 378E9$ meters (230 Million Miles)

$P_t = 100$ W
 $f = 8.4$ GHz
 $\lambda = 0.036$ m
3m dish
 $A_e = 4.9$ m²
 $G_t \approx 48,000$ (47 dB)
(@ 70% aperture efficiency)

*Rough estimates based on web search results

Goldstone 70m DSN dish

$A_e \approx 3800$ m²



$$P_r = 1.0E-14$$
 W (-110 dBm)
$$kTB = 1.4E-16$$
 W* (-129 dBm)
$$SNR = 71$$
 (19 dB)

* Assuming System noise temperature $T = 21$ K, downlink bandwidth = 500 kHz (e.g. 500 kbps BPSK)

Rover Relay Operations

Rovers included a UHF whip antenna, and a Microwave dish.

UHF was used for most proximity data transmission.

Why?

While the monopoles are nominally linearly polarized with a toroidally shaped gain pattern, the structures on the spacecraft create significant distortions to both gain and polarization. This is especially true for the RUHF, due to the vertical obstructions (mainly the LGA and PMA) present on the deck. A right-hand polarization pattern, as measured on a rover mock-up in the JPL antenna range, is shown in Figure 3-10.

Figure 3-10 shows the RUHF antenna pattern in polar coordinates, with the concentric grid markers (0 to 120°) representing the cone angle (angle from the boresight) and the radial grid lines (0 to 360°) representing the clock angle. The RUHF pattern is not symmetrical with respect to the clock angle. The asymmetry causes significant variations in returned data volume from pass (orbiter overflight) to pass. The data-volume variations result mainly from

- The elevation profile of the orbiter and thus the pass duration,
- The azimuth profile of the orbiter during the overflight, and
- The rover orientation (tilt from horizontal) on the surface.

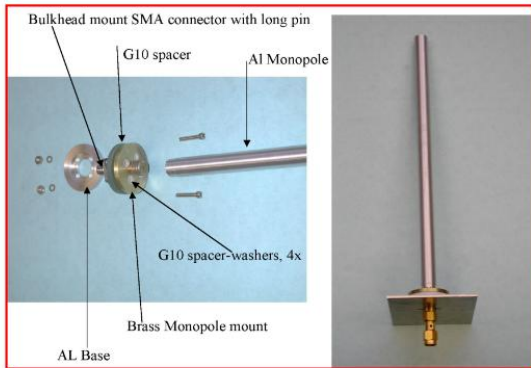


Figure 3-9. Rover UHF antenna.

29

Telecom Subsystem Hardware and Software

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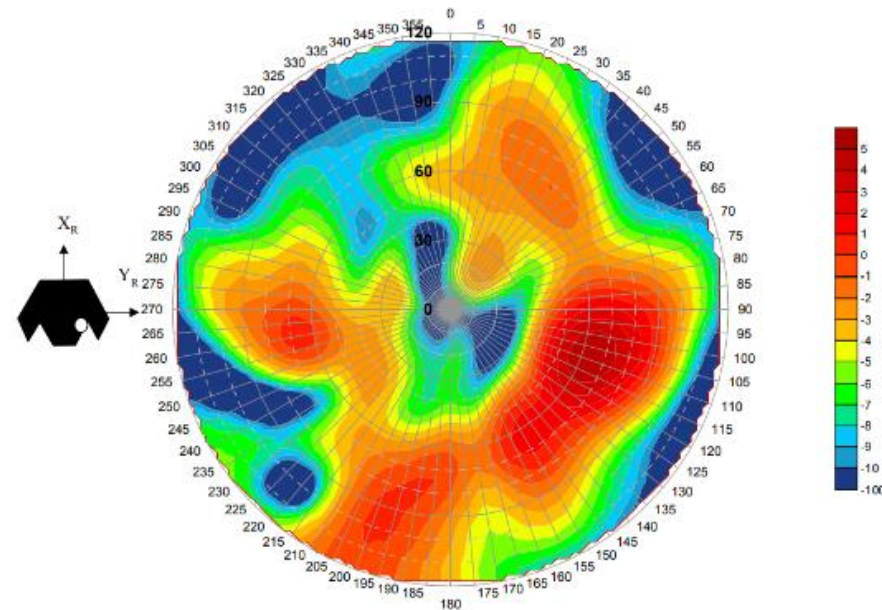
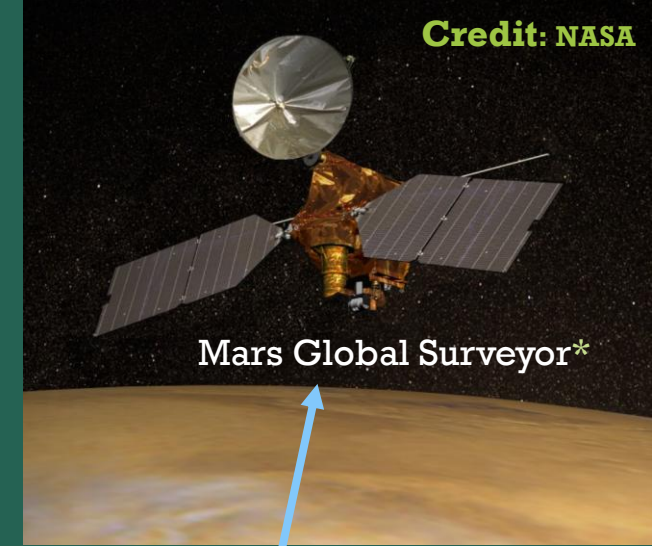


Figure 3-10. Rover UHF antenna pattern as measured on a mock-up at 402 MHz.

Credit: NASA



Mars Exploration Rover Telecommunications

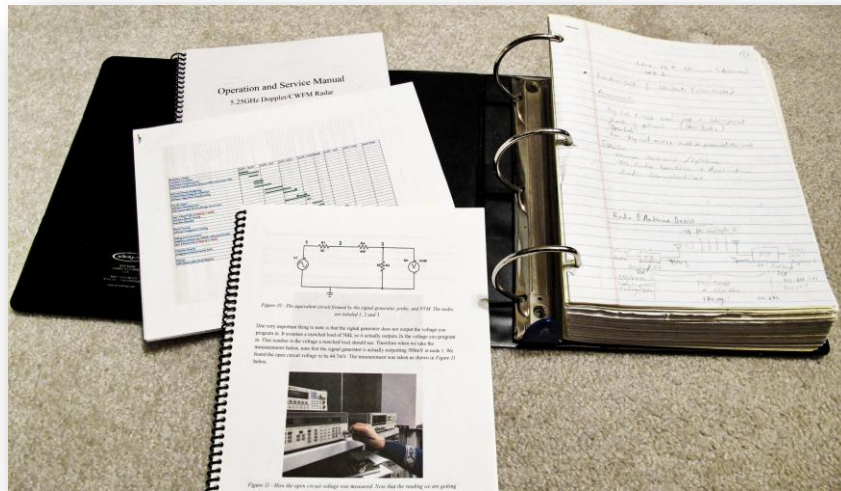


Jim Taylor, Andre Makovsky, Andrea Barbieri,
Ramona Tung, Polly Estabrook, and A. Gail Thomas
October 2005

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Benefits of using Microwaves



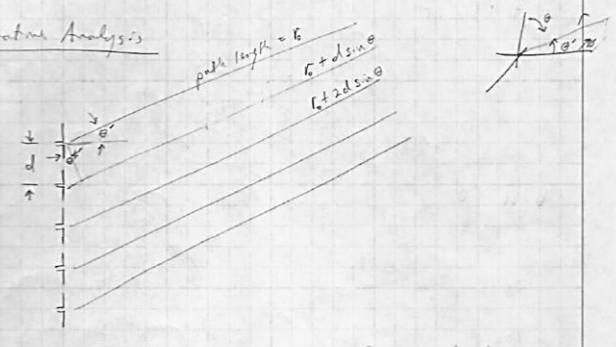
Derivation of Beamwidth & Gain Formulas

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Application to Real-World Products/Design

Discrete Array Beamwidth Derivation

Quantitative Analysis



Field at observation point (r, θ') from element n is (for short dipoles)

$$E_n(r, \theta') \approx 30 I_n L \beta \cos \theta' \frac{1}{r_n} e^{-j\beta r_n} \quad \text{where } \beta = \frac{2\pi}{\lambda}$$

OR, In general,

$$= F(\theta) \frac{1}{r_n} I_n e^{-j\beta r_n}$$

And total field is

$$E_{\text{tot}} = \sum_{n=0}^{N-1} F(\theta) \frac{1}{r_n} I_n e^{-j\beta r_n}$$

$$= F(\theta) \sum_{n=0}^{N-1} \frac{1}{r_0 + nd \sin \theta} I_n e^{-j\beta(r_0 + nd \sin \theta)}$$

$$\approx \underbrace{F(\theta) \frac{1}{r_0} e^{-j\beta r_0}}_{\text{Field of single element}} \sum_{n=0}^{N-1} I_n e^{-j\beta nd \sin \theta}$$

"Array Factor"

★ NOTES Array Factor $\sim$ (discrete) Fourier Transform of excitation currents I_n if $\beta d \sin \theta = \Omega$

→ Can pick I_n to give desired pattern using FT theory!

Examine Array Factor (substitute $\frac{\beta d \sin \theta}{2\pi} = \gamma$)

$$\sum_{n=0}^{N-1} I_n e^{-jn 2\pi \frac{d}{\lambda} \sin \theta'}$$

equal with $I_n = I_0 \delta_n$ & $d/\lambda = 0.5$

$$\Rightarrow AF = I_0 \sum_{n=0}^{N-1} e^{-jn\pi \gamma}$$

To simplify sum, let $\sin \theta' = \gamma$

$$\Rightarrow AF = I_0 \sum_{n=0}^{N-1} e^{-jn\pi \gamma}$$

$$= I_0 \sum_{n=0}^{N-1} e^{-jn\pi \gamma} = \sum_{n=0}^{N-1} e^{-jn\pi \gamma}$$

$$= I_0 \sum_{n=0}^{N-1} e^{-jn\pi \gamma} [1 - e^{-jN\pi \gamma}]$$

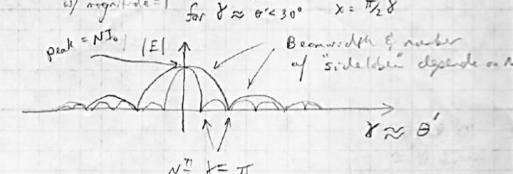
$$= I_0 \frac{1 - e^{-jN\pi \gamma}}{1 - e^{-j\pi \gamma}} = I_0 \frac{e^{-j\frac{N-1}{2}\pi \gamma} (e^{j\frac{N-1}{2}\pi \gamma} - e^{-j\frac{N-1}{2}\pi \gamma})}{e^{-j\frac{1}{2}\pi \gamma} (e^{j\frac{1}{2}\pi \gamma} - e^{-j\frac{1}{2}\pi \gamma})}$$

$$= I_0 e^{-j\frac{N-1}{2}\pi \gamma} \frac{\sin(\frac{N\pi \gamma}{2})}{\sin(\frac{\pi \gamma}{2})}$$

Peak = $N I_0$ at $\gamma = 0$

Beamwidth & number of sidelobes depends on N

⇒ Pattern =



1st null $\approx \theta'_{1st \text{ null}} = \frac{2}{N}$ radians $= \frac{110}{N}$ degrees

Example Suppose $N = 8$

⇒ First null when

$$\theta' \approx \gamma = \frac{2}{N} = \frac{2}{8}$$

$$\Rightarrow = 0.25 \text{ radians} = 15^\circ$$

⇒ Main-Null Beamwidth = 30° (actually 29°)

3dB point reached when

$$\frac{\sin(N\pi \gamma)}{\sin(\pi \gamma)} \approx 0.707 N$$

Value of AF at $\gamma = 0$

$$\Rightarrow \gamma \approx 0.11 \quad (\text{to give } N\pi \gamma = \pi/4)$$

$$\theta = \sin^{-1}(0.11) = 0.1102 \approx 0.11 \text{ rad}$$

$$= 6.3^\circ$$

⇒ 3dB Beamwidth $\approx 12.5^\circ$ for $N=8$

(Compare w/ $\approx 90^\circ$ for single dipole element)

Note Doubling # of elements halves beamwidth

N	BW _{3dB}	Array Dimension $L = N \frac{\lambda}{2}$
8	12.5°	4λ
16	6.3°	8λ
4	25°	2λ
2	50°	1λ

In general, (For uniform excitation & $N > 2$)

$$BW_{3dB} \approx 50^\circ \frac{\lambda}{L}$$

Total array dimension $= N \frac{\lambda}{2}$ for min spacing

2-D Array or Dish Beamwidth

Aperture Antennas

For high gain and narrow beamwidth at low cost, use

- High Frequency (why?)
- Parabolic dish

With typical "illumination"
i.e. $2\psi = \text{BW}_{\text{feed}}$

$$\text{BW}_{\text{dish}} \approx 70^\circ \frac{\lambda}{D}$$

Example: 2m dish @ 10 GHz

$$\Rightarrow \text{BW} = 70^\circ \frac{30\text{mm}}{2} = 1.1^\circ$$

Recall that narrow beam concentrates power
resulting in high Effective Isotropic Radiated Power

$$\text{EIRP} = P_t G_t$$

↑
Directivity gain of dish
Transmitter output power

Can be shown that

$$G_t \approx 0.5 \left(\pi \frac{D}{\lambda} \right)^2$$

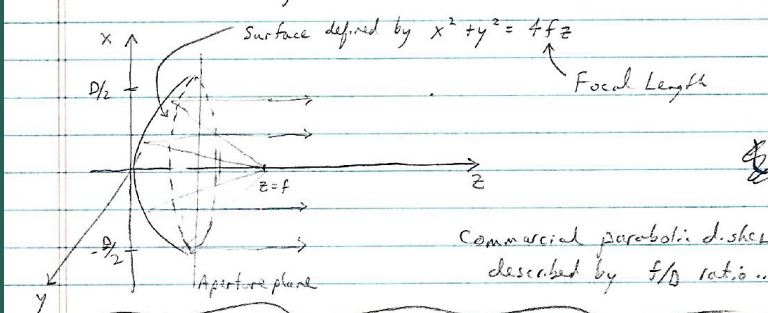
Example: 2m dish, 10 GHz, $P_t = 1\text{W}$

$$\Rightarrow G_t = 0.5 \left(\pi \frac{2}{0.03} \right)^2 = 44,000$$

$$\Rightarrow \text{EIRP} = 44\text{ kW}!$$

Safety concerns! ?

Dish Geometry

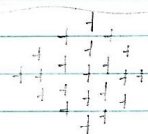


If dish "feed" antenna is at focal point ($z = f$),

- All rays leave dish parallel to z axis
- All path lengths are equal $\Rightarrow$ equal phase

$\Rightarrow$ Field is uniform throughout aperture (if uniformly illuminated)

$\Rightarrow$ Similar to field from (2D) discrete array



$\Rightarrow$ Similar for field pattern

1-D Dipole array

$$\text{BW} = 50^\circ \frac{\lambda}{L}$$

2-D Dish

$$\text{BW} = 70^\circ \frac{\lambda}{D}$$

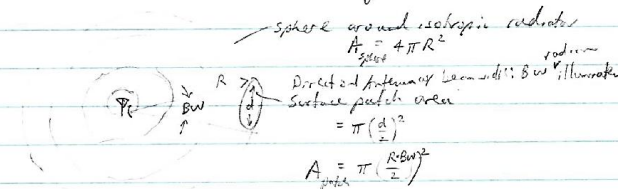
↑
Non-uniform
Excitation
in aperture plane

↓
Diameter taken
plus of length

Relationships between BW & Gain

Combine BW & G_t formula: $G \approx 0.5 \left(\pi \frac{70^\circ}{\text{BW}} \right)^2$

This can be shown to be true in general



Directivity Gain is then $G_t = \frac{A_{\text{sphere}}}{A_{\text{patch}}} = \left(\frac{4}{\text{BW}} \right)^2$ radians

OR, for degrees: $G_t = \left(\pi \frac{73^\circ}{\text{BW}^\circ} \right)^2$ in degrees

Benefits of Dish as Receive

- Intercepts large area of passing EM wave

$\Rightarrow$ more power received $P_r = P A_e$

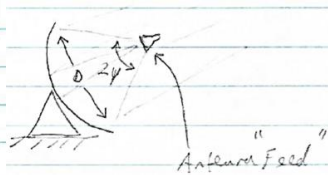
↑
Power Density Effective Aperture

- Provides good angular discrimination (benefit ??)

Feed Antennas

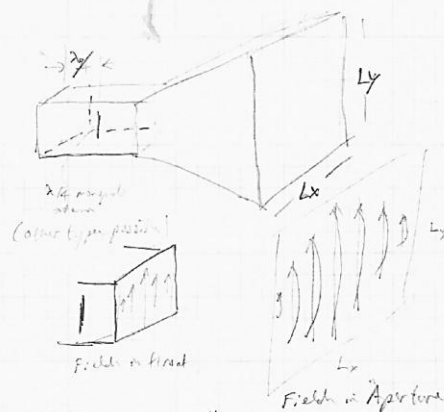
Antenna Feed Examples

- Patch
- Horn
- Helix
- Yagi-Uda
- Log Periodic
- Corner Reflector



Antenna Feeder

Rect Horn Antenna

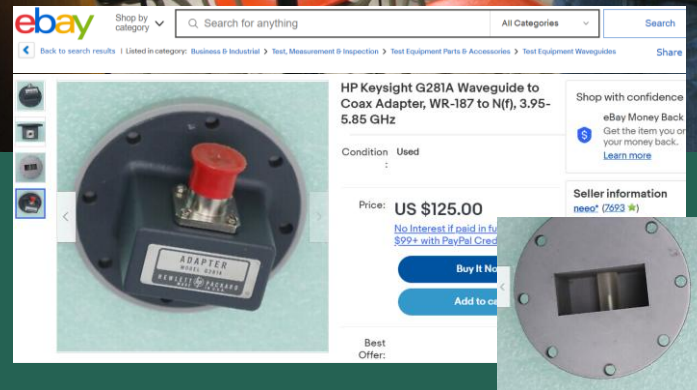
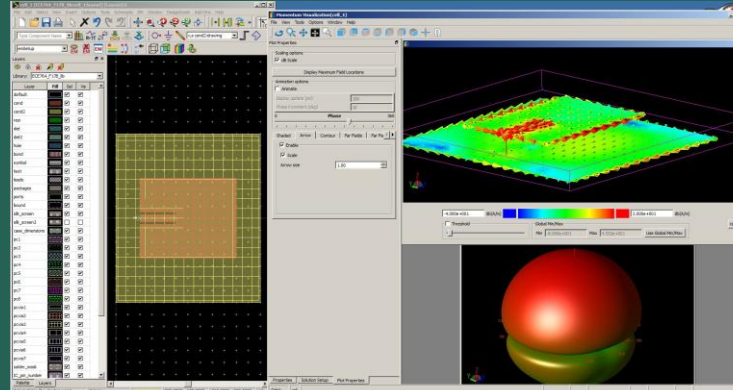


Notes:

- $BW_{3dB} = 2(50) \frac{\lambda}{L_x}$ in B-plane (Azimuth Here)
- $50 \frac{\lambda}{L_y}$ in E-plane (Elevation Here)

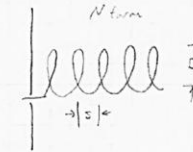
Design Limited by "field curvature" in aperture
 $\Rightarrow$ Upper limit to L_x, L_y
 $\Rightarrow BW \geq 15^\circ$

- Circular geometry similar



Other useful directed antennas ("end fire type")

Helix



Design

$$\frac{3}{4} < \frac{\pi D}{\lambda} < \frac{4}{3}$$

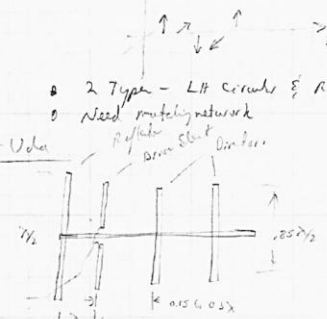
$$\frac{5}{\lambda} = 0.25$$

$$BW_{3dB} = \frac{100^\circ}{\frac{\pi D}{\lambda} \sqrt{N}}$$

$$G_t = 4N \left(\frac{\pi D}{\lambda} \right)^2$$

$$R_{Ant} = 140 \frac{\pi D}{\lambda} \Omega$$

Note: Fields are Circularly Polarized (Rotation if propagation)



2 Types - LH circular & RH circular, must get it right!
 Need matching network

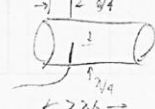
Yagi-Uda



Corner Reflector



Cylindrical Horn



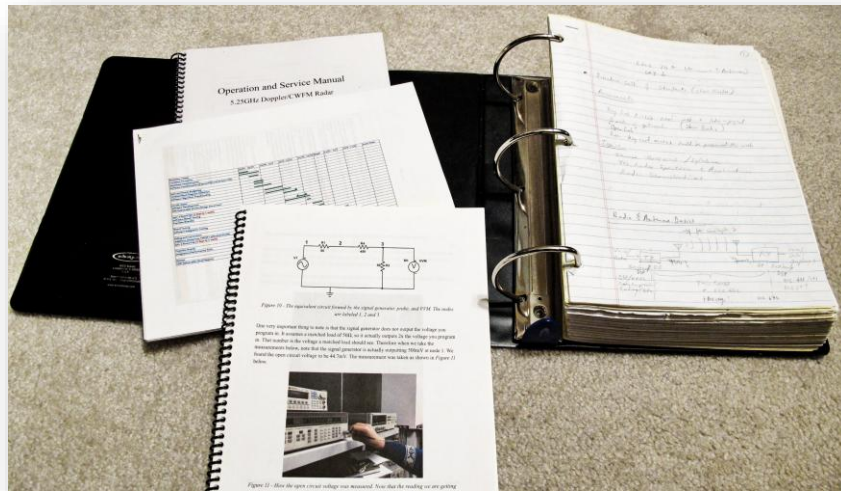
See antenna design books for more info

$BW_{3dB} = 50$ to 80°
 $G_t = 8$ to 13 dB
 $R_{Ant} \approx 10$ to 60Ω
 Also made in vertical Arrays for cell towers

Today's "Lecture" Topics

Announcements

Review material from prior Episodes



Topics

Phased Arrays (Theory and Measurement)

Benefits of using Microwaves

Derivation of Beamwidth & Gain Formulas

- *1D Discrete Arrays*
- *Extension to 2D Aperture Antennas*
- *Dish antennas (Illumination-angle, gain, sidelobes, ...)*
- *Feeds (Horns, Helix, Dipole/corner-reflector, ...)*



Application to Real-World Products/Design

Prime-Focus Dish with LPDA Feed

Bolton “Long Ranger” Parabolic Antenna

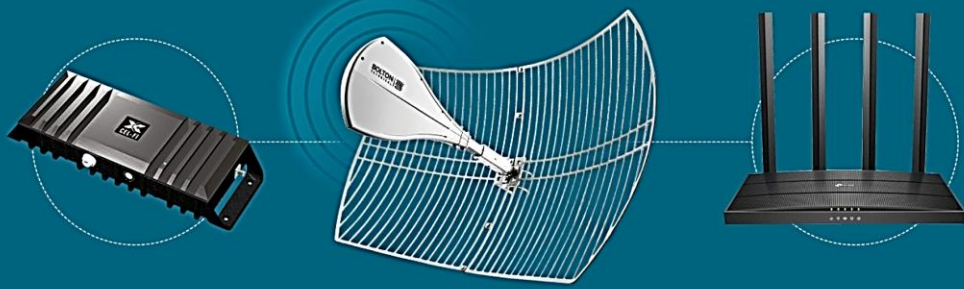
Amazon.com Shopping Cart x Amazon.com Shopping Cart x Amazon.com: Bolton Technical Lor x +

amazon.com/gp/product/B08FBN5LJ7/ref=ox_sc_act_image_1?smid=A3H9JF6OQF5L9G&psc=1

Top About this item Similar Product information Reviews

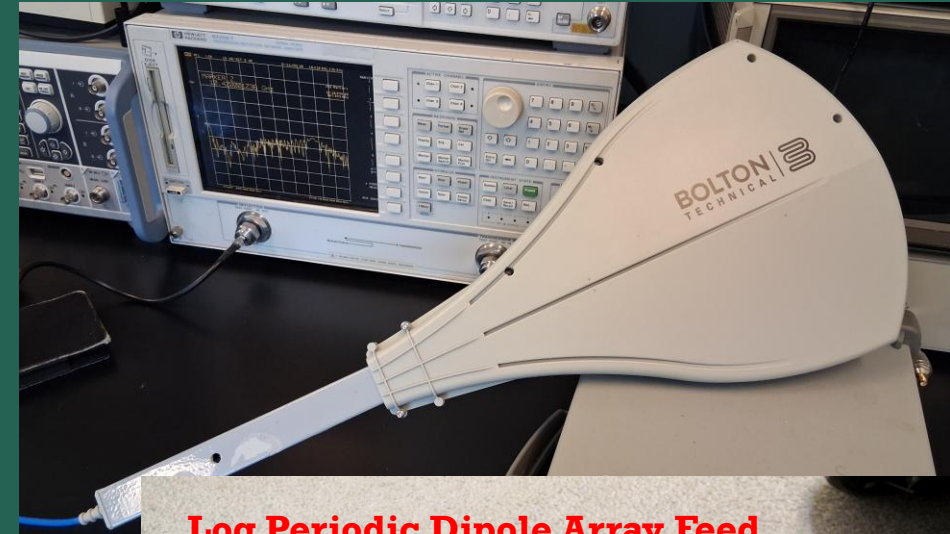
Bolton Technical Long Ranger Antenna (BT974822) \$199.99 Add to Cart

It works great with Cellular Signal Boosters and cellular Wifi Routers
**Cellular Signal Boosters and cellular Wifi Routers Sold Separately*



ELECTRICAL SPEC Spec Sheet Electrical Spec Mechanical Spec Radiation Pattern
Product Specifications may change without prior notice.

Item No.	BT974822				
Frequency Range	MHz	600-960	1700-2200	3000-6500	
Gain	dBi	8-15	20-28	10-26	
Polarization	Vertical or Horizontal				
Beam width	Horizontal	deg	23	10	7
	Vertical	deg	35	13	9
VSWR			≤2.5	≤2.0	≤2.5
Front-To-Back Ratio	dB	>11	20	>10	
Input Power, maximum	watt	100			
Impedance	ohm	50			



Inexpensive Dish with 1.4 GHz Dipole/Corner-reflector Feed

Exploring the Nooelec 21dBi Satellite Mesh Antenna



Exploring the Nooelec 21dBi Satellite Mesh Antenna

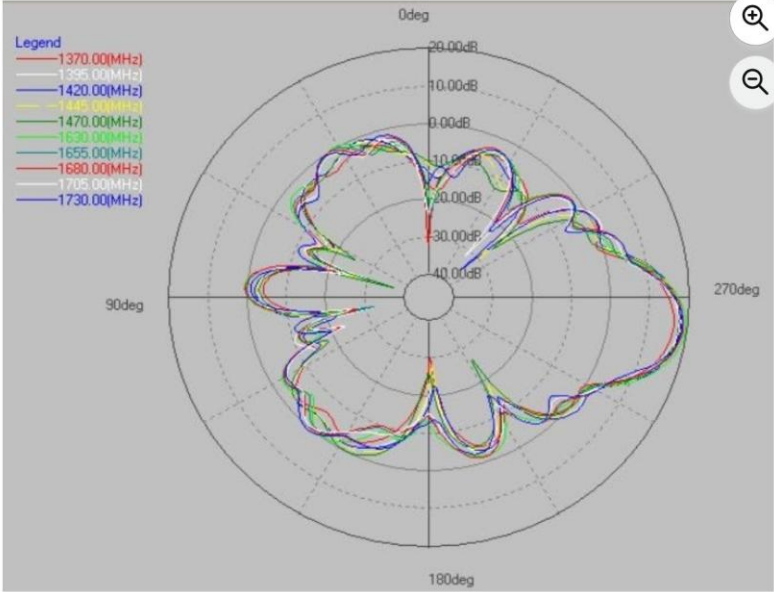
Tech Minds 154K subscribers

29K views 2 years ago #HamRadio #TechMinds #SDR

In this video we take a look at the GOES Parabolic Mesh Antenna from NooElec. Centre frequency is around 1.7 GHz, but with a bandwidth of more than 200MHz we were able to receive signals from Inmarsat and decode them.

...more

amazon.com: Nooelec Satellite Mesh Antenna Bundle for Inmarsat, Iridium, & Hydrogen Line Applications. 20dBi Parabolic Antenna w/ 1.4GHz Center Frequency, 300MHz+...



Nooelec Satellite Mesh Antenna Bundle for Inmarsat, Iridium, & Hydrogen Line Applications. 20dBi Parabolic Antenna w/ 1.4GHz Center Frequency, 300MHz+...

bandwidth greater than 300MHz, it encompasses many popular

Experiments in Modifying Dish for 10 GHz Satellite TV

Alternative/Preferred "Offset-Feed" Type Dish

youtube.com/watch?v=USvucnj51HA

Ku Band Geostationary Satellite Aiming, Blind Scanning, and Locking

Using a GTMEDIA V8 Finder 2 and a Small, Modified, 6 GHz Dish

Installation

1.48 FWHG 0.7601
DISEqC1.0 Disable
DISEqC1.1 Disable
22K On
LNB Power Auto
Motor Setup None
S 0%
Scan
Transponder 278 Confirm
Lock Charge

Credit: Wikipedia.org

Using GTMEDIA V8 in Blind Scan mode with small dish antenna

MegawattsKS
14.1K subscribers

1,181 views Mar 19, 2026

This is a follow-on to a video where we overviewed the menus in the GTMEDIA V8 Finder 2. In this follow-on video, we illustrate modifications to a Long Ranger dish antenna to make it work at 10 to 12 GHz and then take the setup outside to find Galaxy 16 (and/or 19) satellite(s) using the GTMEDIA V8. Several details are shown that may not apply to everyone, but hopefully they are interesting, and the use of Blind Scanning is highly recommended for all. Special thanks to the Claude AI for useful discussions during this project - especially for recommending the formula for estimating the focal distance for the LNB feed mounting position :-)

BUY 1, GET 1 AT 5% OFF (add 2 to cart) See all eligible items and terms

39" IN 9 CARTS

39" ELECTORICA

39 Inch KU SATELLITE DISH ANTENNA For FTA LINEAR Inb 36 X 39 For 97 95 GALAXY 19

ELECTORICA (44842)
95.6% positive Seller's other items Message seller

US \$124.99
as low as \$42.64/mo with Klarna. Learn more

Condition: New

Quantity: 1 More than 10 available - 88 sold

Buy It Now

Add to cart

Add to Watchlist

Additional service available
☐ 2-year protection plan from Allstate - \$9.99

Share

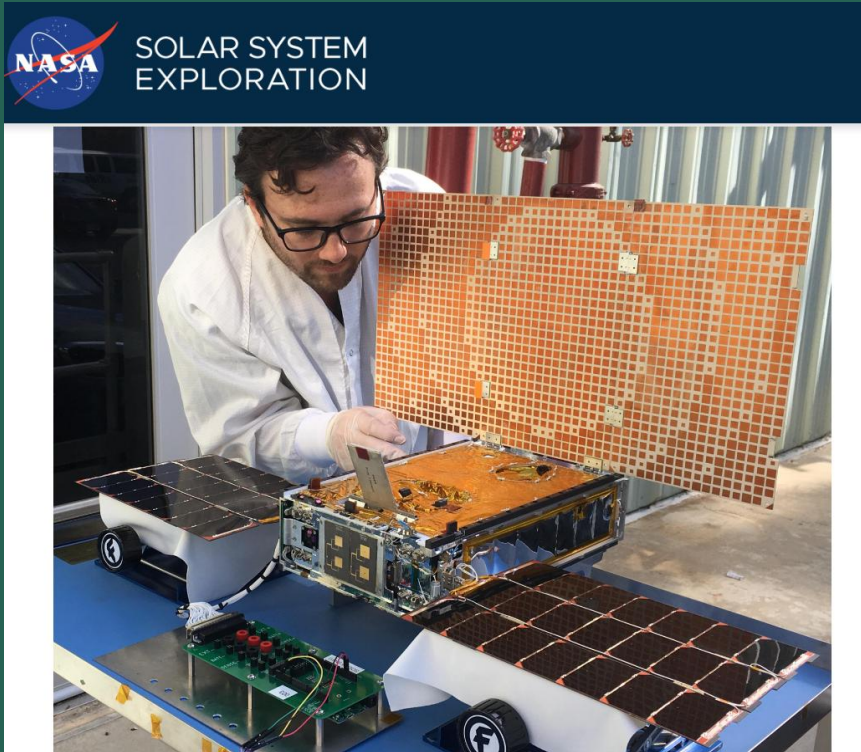
This one's trending. 88 have already sold.

People want this. 121 people are watching this.



LNB with circular waveguide feed

Advanced Phased-Array Designs (Microwave Aperture Antennas)



Engineer Joel Steinkraus uses sunlight to test the solar arrays on one of the Mars Cube One (MarCO) spacecraft.

<https://solarsystem.nasa.gov/missions/mars-cube-one/in-depth/>



<https://arstechnica.com/information-technology/2021/11/starlink-unveils-2nd-generation-satellite-dish-and-new-wi-fi-router/>



<https://www.youtube.com/watch?v=iOmdQnlnRo>

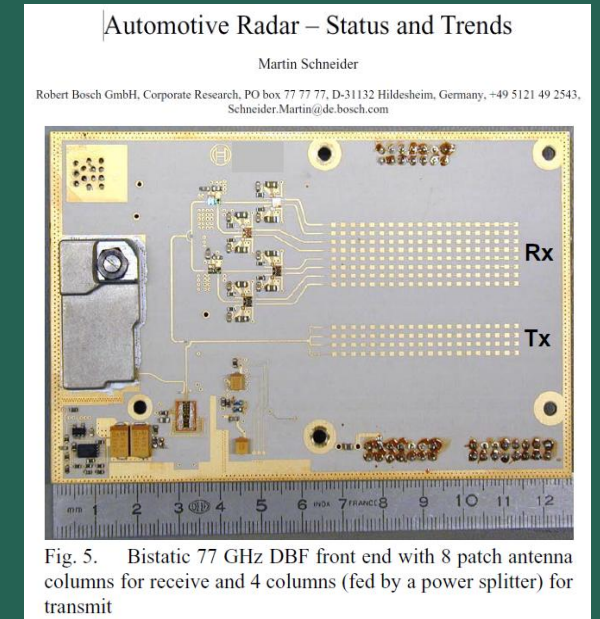


Fig. 5. Bistatic 77 GHz DBF front end with 8 patch antenna columns for receive and 4 columns (fed by a power splitter) for transmit

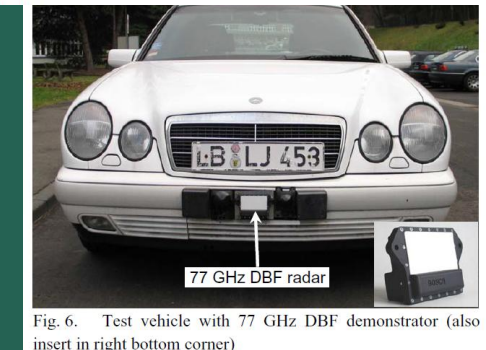


Fig. 6. Test vehicle with 77 GHz DBF demonstrator (also insert in right bottom corner)

www.scribd.com/document/94178930/5-3-Radar-Sensors

Future Episodes

Transmission-line Theory

Smith Charts

Microstrip

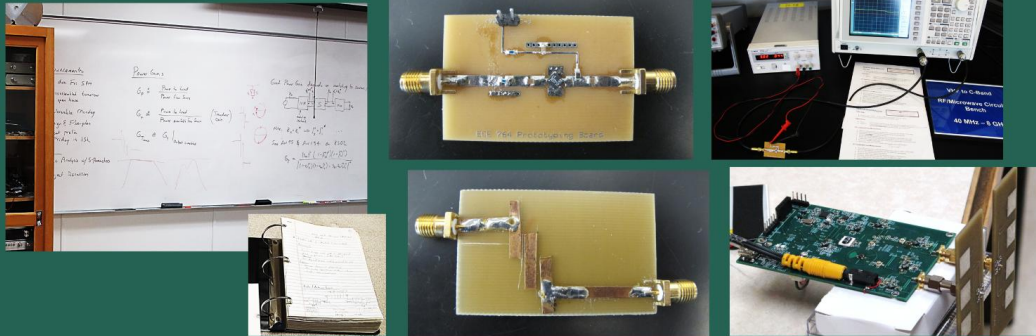
Microstrip Circuits

Radar or uWave Transverter Project

Radio Design 201 #3

Microwave Circuits and Antennas

Project-oriented Learning

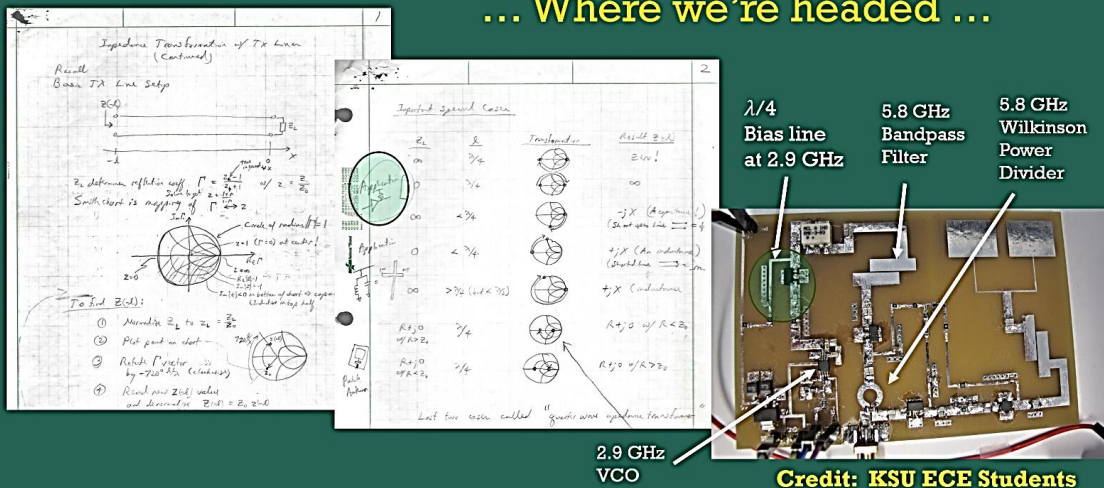


MegawattKS - YouTube

<https://ecefiles.org>

Microwave Circuits

... Where we're headed ...



Wires & Transmission Lines
at RF

Result TX Systems

Transmission Line Characteristics

- "No" radiation (if wires "closely spaced" ($d \ll \lambda/4$))
- Single connection ($Z_{ANT} = Z_{0}$) if length $\ll \lambda/4$
- Distributed LC circuit if length $\geq 0.1\lambda$ ($\geq 0.1 \times 1066$)
 $\Rightarrow Z_{ANT} \neq Z_{0}$ (except in special case of $Z_{ANT} = Z_{0}$ of line) Length of pin on PCB

TX Line modeling

$\Delta I = \frac{V}{Z_{0}} = j\omega C \Delta L$ where C per unit length
 (Typically 10-30 pF/inch)

$\Delta V = j\omega L \Delta I$ with $L = \frac{1}{C}$ (Typically 5-20 nH/inch)

OR "Two-wire" OR PCB "microstrip" trace

Current ΔI drawn thru ΔC , Voltage drop across ΔL (but no power loss if L & C are lossless)

$\Rightarrow V, I$ change phase along line

$\Rightarrow$ "Guided wave" propagates away from source toward load

IMPORTANT

At RF & microwave, any "node" $Z \approx 0.05\lambda$ is NOT a node - it's a complicated LC network!

At 2.6 GHz $\lambda = 0.15$ m
 $\Rightarrow \lambda/20 = 7$ mm!
 $\Rightarrow \lambda/20 = 1/3$ inch

*Thanks For
Watching !*