

Radio Design 201

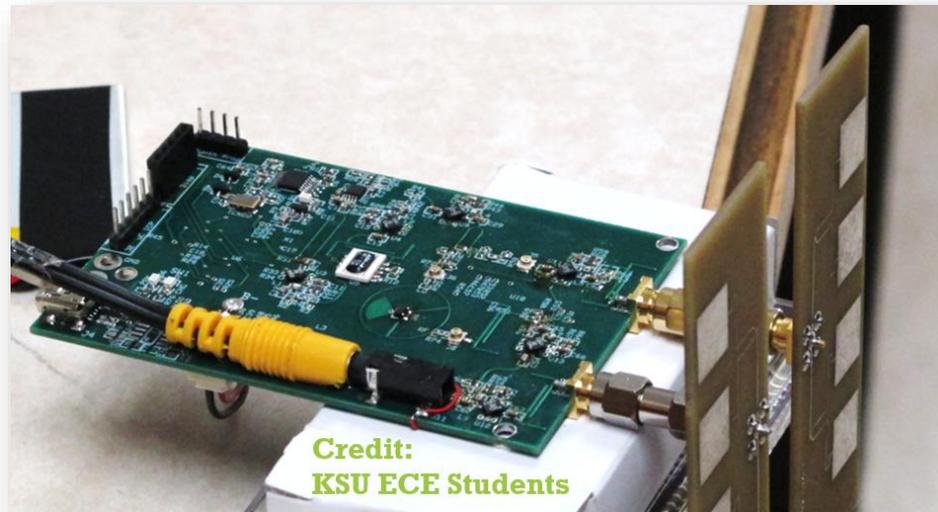
Episode 1 - Microwave Circuits and Antennas

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

Companion videos at: <https://www.youtube.com/playlist?list=PL9Ox3wpmB0kpOb7NdpHAK-jDpsZm3Xedx>

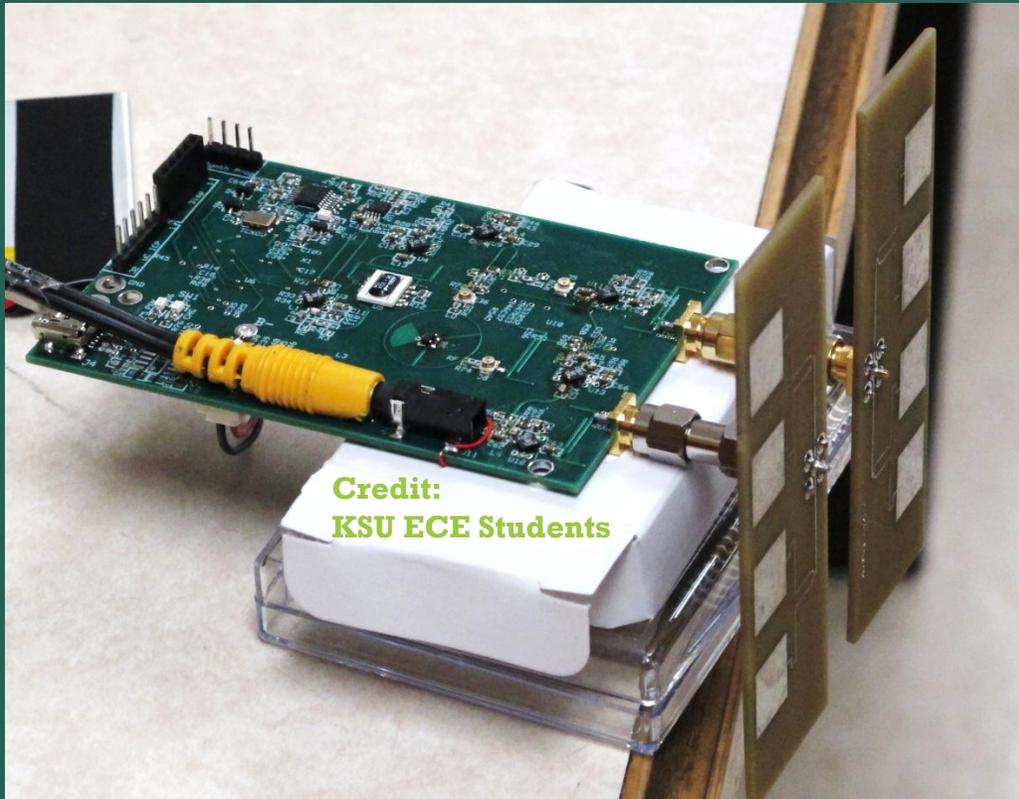
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This episode introduces the Radio Design 201 series. Like Radio Design 101, Radio Design 201 is abstracted from a senior-level university course on circuits and systems, with a strong hands-on emphasis - but focuses on design in the GHz frequency range. In this episode, we define "microwaves" in terms of what it means for building circuits, explain why the study of this material is important, and show an example of the projects that have been done in university course offerings. The introduction continues in Episodes 2, 3, and 4 before we step into the core lecture material making up the "course".



Radio Design 201 #1

Microwave Circuits and Antennas



University Course Lectures, Labs, and Projects

New Radio Design 101 series
Abstracted from a senior-design University class

Radio Design 101 - Episode 1 - Transceivers and Filters - Part 1

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This video overviews radio / wireless transmitters and receivers, circuit component impedances, voltage divider circuits, and simple one-pole lowpass / bandpass filters. The material is based on a University senior-design course, but is intended for anyone interested in the nuts and bolts of electronics and radio circuits. This is part 1 of @ ...more

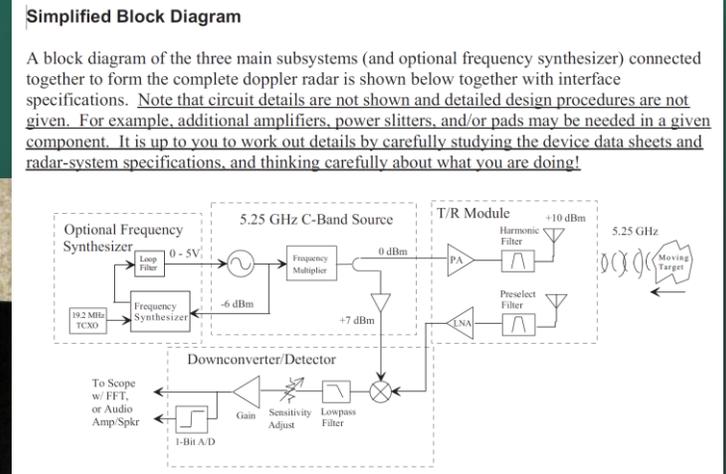
Radio Design 201

Operation and Service Manual
5.25GHz Doppler/CWFM Radar

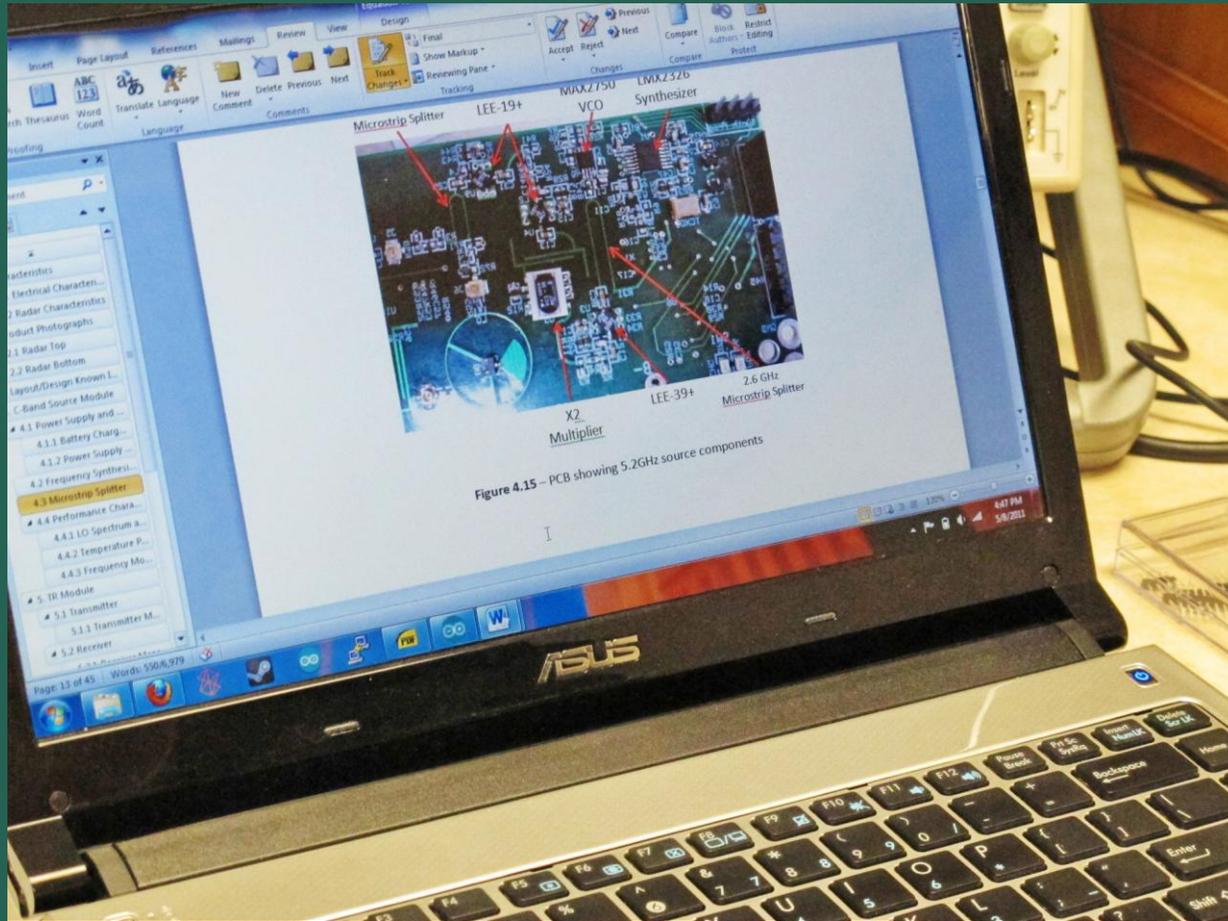
Figure 10 - The equivalent circuit formed by the signal generator, probe, and VVM. The nodes are labeled 1, 2 and 3.

One very important thing to note is that the signal generator does not output the voltage you program in. It assumes a matched load of 50Ω, so it actually outputs 2x the voltage you program in. That number is the voltage a matched load should see. Therefore when we take the measurements below, note that the signal generator is actually outputting 500mV at node 1. We found the open circuit voltage to be 44.7mV. The measurement was taken as shown in Figure 11 below.

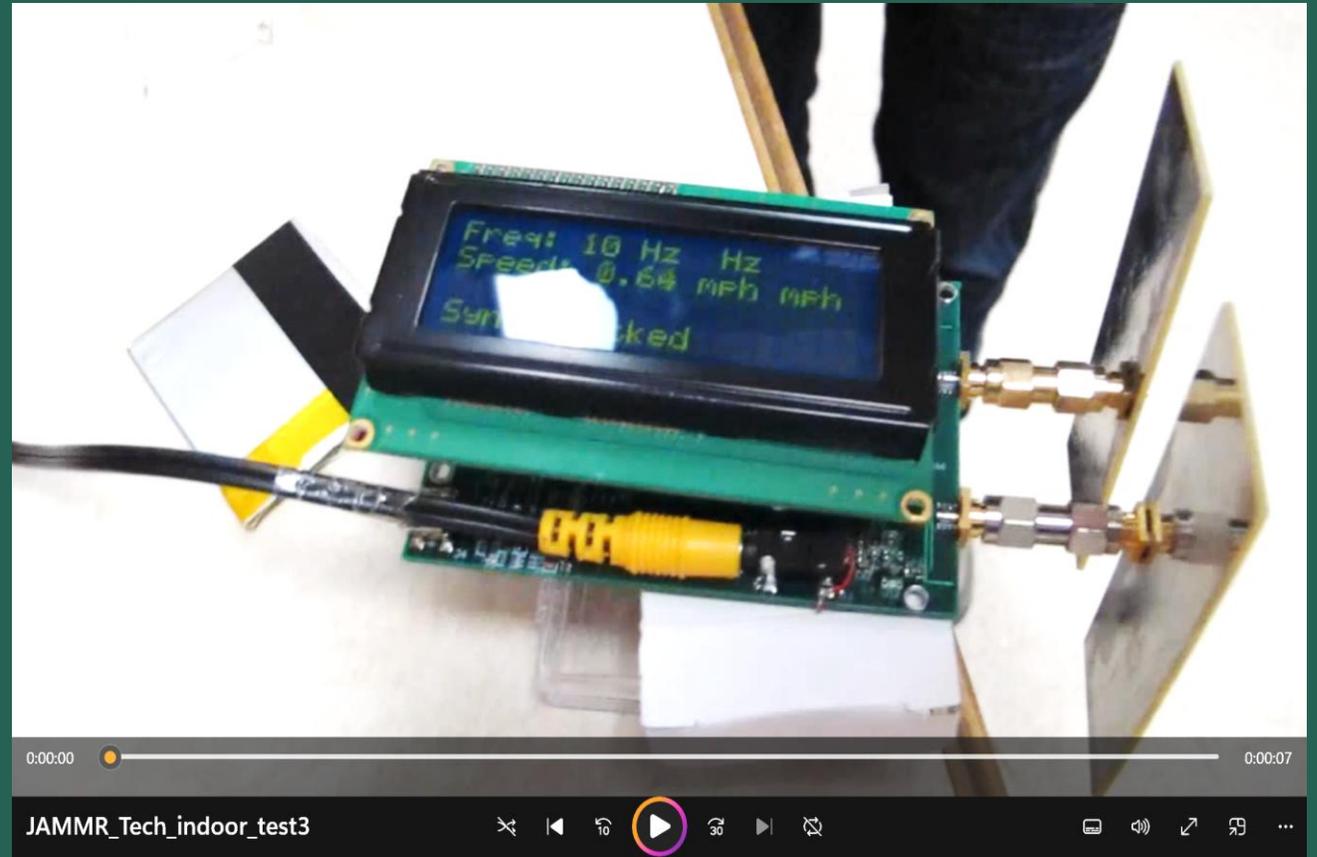
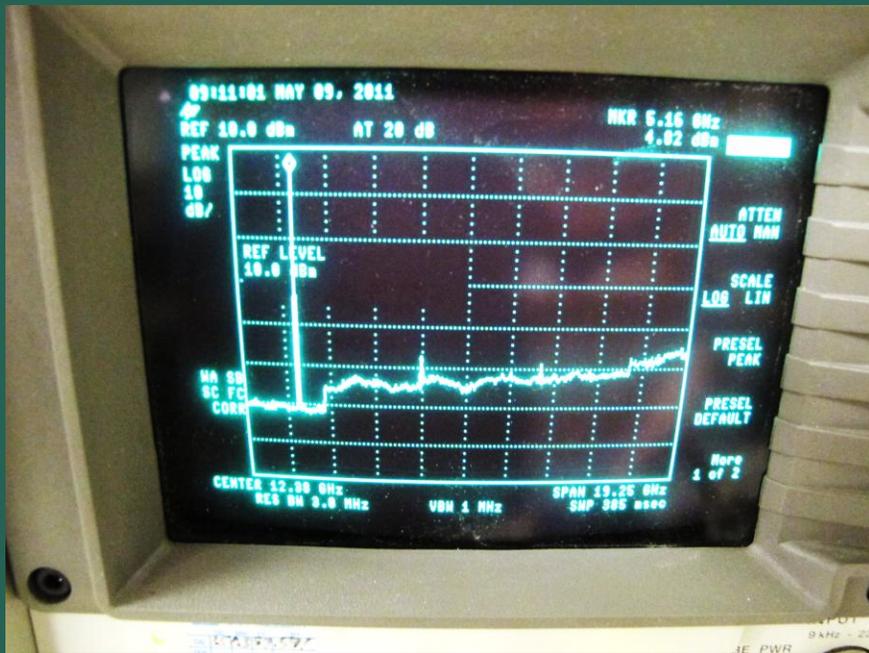
Figure 11 - How the open circuit voltage was measured. Note that the reading we are getting



Student-Designed Doppler Radar 😊



Initial Indoor Testing



Real-World Testing



Design of a Microwave Radar

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Definitions of “Microwave”

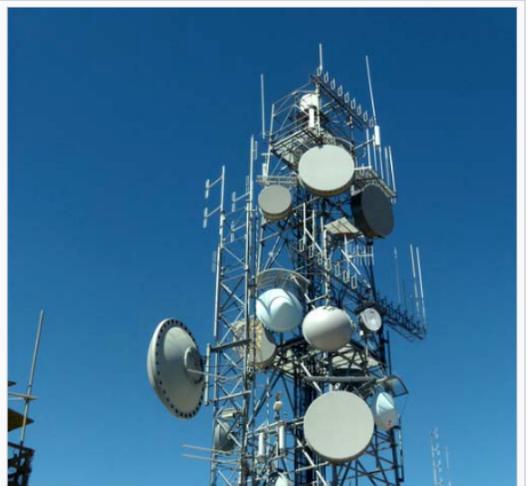
 **Microwave** 🌐 84 languages ▾

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From Wikipedia, the free encyclopedia 

This article is about the electromagnetic wave. For the cooking appliance, see [Microwave oven](#). For other uses, see [Microwaves \(disambiguation\)](#).

Microwave is a form of [electromagnetic radiation](#) with [wavelengths](#) shorter than other [radio waves](#) but longer than [infrared](#) waves. Its wavelength ranges from about one meter to one millimeter, corresponding to [frequencies](#) between 300 MHz and 300 GHz, broadly construed.^{[1][2][3]} A more common definition in [radio-frequency engineering](#) is the range between 1 and 100 GHz (wavelengths between 30 cm and 3 mm),^{[4]:3} or between 1 and 3000 GHz (30 cm and 0.1 mm).^{[5][6]} In all cases, microwaves include the entire [super high frequency \(SHF\)](#) band (3 to 30 GHz, or 10 to 1 cm) at minimum. The boundaries between [far infrared](#), [terahertz radiation](#), microwaves, and [ultra-high-frequency](#) (UHF) are fairly arbitrary and differ between different fields of study.^{[4]:3}



<https://en.wikipedia.org/wiki/Microwave>

An Alternative Definition

- Radio frequencies where the size of the electronic components and /or interconnects used is larger than about $1/10^{\text{th}}$ to $1/20^{\text{th}}$ of a wavelength

Speed of Light

$$\lambda = \frac{c}{f}$$

Wavelength

Frequency

Frequency (f)	Wavelength(λ)	$\lambda/20$	Microwave ?
100 MHz	3 meters	15 cm (6 inches)	Nope. Just VHF
2.4 GHz	12.5 cm	6 mm (240 mils)	Yes? Depends ...
24 GHz	1.25 cm	600 um (24 mils)	Yes, for PCB design. Maybe for IC design. Yes, for (most) packaging.

Why Study “Microwaves” ?



- Basic circuit-theory is not sufficient for circuit design involving Microwave frequencies
- Need to add transmission line theory and field theory
- Massive Amounts of Spectrum Available
- Highly Directional Antennas Possible
- Very Low Path-loss and Long Range Possible (for line-of-sight paths)



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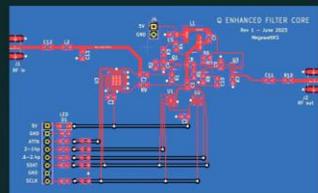
From Radio Design 101 Appx C

Radio Design 101
Appendix C

RF Circuit Construction & EMC
(The How and Why)

30 MHz





77 GHz





Considering E field only:

$$V_{victim} \approx V_{aggressor} \frac{(Z_{C2} \parallel R_{out} \parallel R_{in})}{Z_{C1} + (Z_{C2} \parallel R_{out} \parallel R_{in})}$$

$$Z_{C2} \approx Z_{C2a} + Z_{C2b} \ll Z_{C1}$$

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Class Handout on Parasitics

Component Parasitics at RF

Resistors

Ideal Model: 

Model at RF: 

Impedance vs. Frequency: 

Capacitors

Ideal model: 

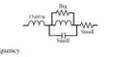
Model at RF: 

Impedance vs. Frequency: 

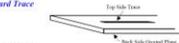
Inductors

Ideal Model: 

Model at RF: 

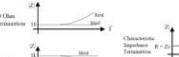
Impedance vs. Frequency: 

PC Board Trace

Top Side Trace: 

Bottom Side Trace: 

Model at RF: 

Impedance vs. Frequency: 

PCB traces, wires, etc are transmission lines at "high frequency".

Important if length is $> 1/10$ wavelength

$$\lambda = \frac{c}{f} v_r$$

$$v_r \sim 0.5$$

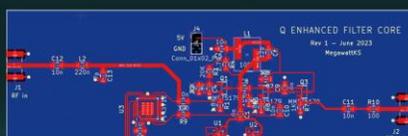
$$\Rightarrow \frac{\lambda}{10} \approx 1.5 \text{ cm at } 1 \text{ GHz}$$

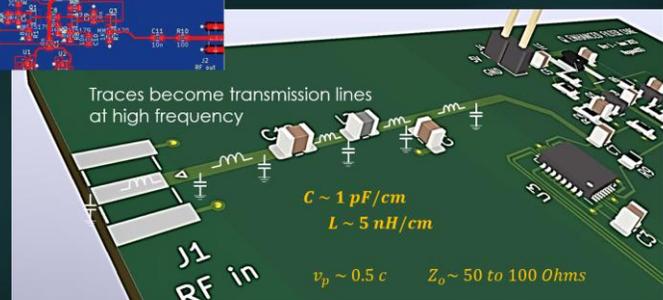
L, C, and characteristic impedance varies with trace width and board interlayer thickness

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PCB Traces above Ground Plane
("Microstrip" Traces)

30 MHz





Traces become transmission lines at high frequency

$C \sim 1 \text{ pF/cm}$
 $L \sim 5 \text{ nH/cm}$
 $v_p \sim 0.5 c$ $Z_0 \sim 50 \text{ to } 100 \text{ Ohms}$

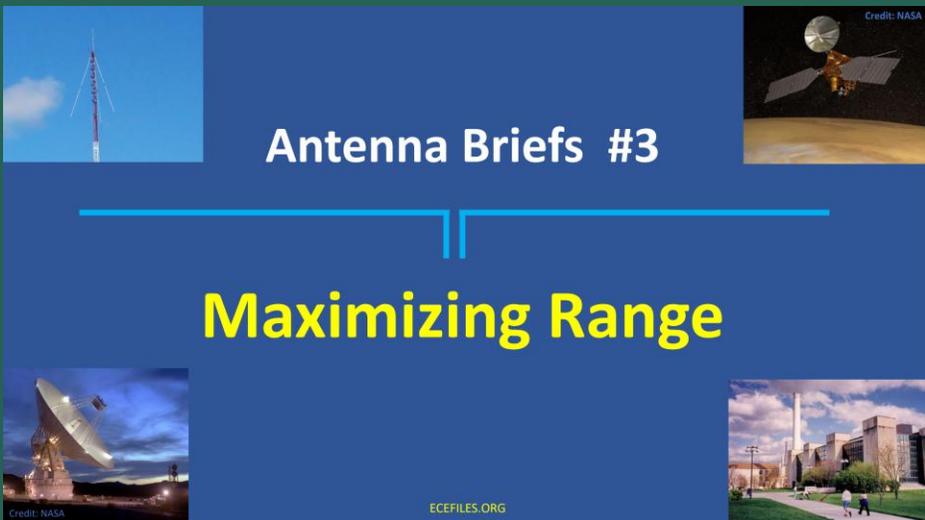
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Possible Future Videos

- Transmission Lines
 - The math $v_p, Z_0, \Gamma, S_{ij}, \text{ etc ...}$
 - Coax, Microstrip, Coplanar Waveguide, Stripline,
- Crosstalk Measurements and Shielding
- Planar Microwave Circuits

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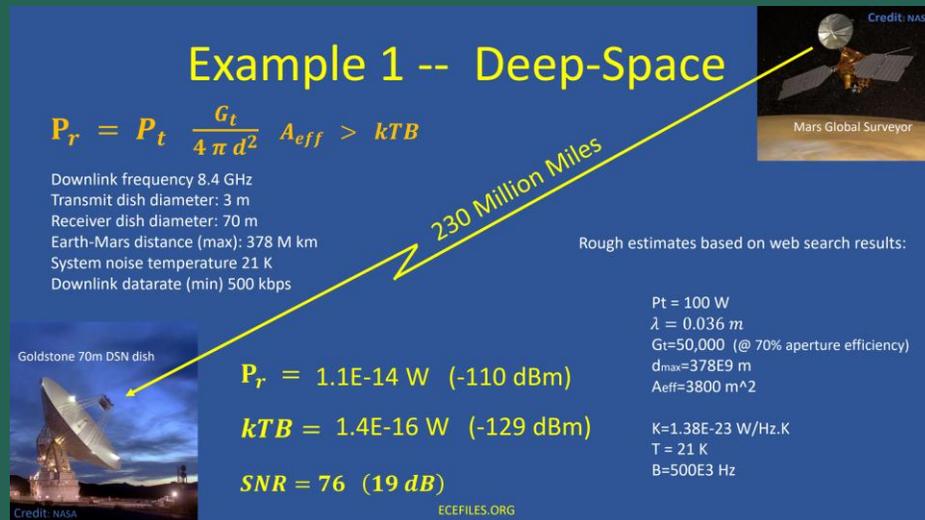
From "Antenna Briefs" Series



Antenna Briefs #3

Maximizing Range

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Example 1 -- Deep-Space

$$P_r = P_t \frac{G_t}{4\pi d^2} A_{eff} > kTB$$

Downlink frequency 8.4 GHz
 Transmit dish diameter: 3 m
 Receiver dish diameter: 70 m
 Earth-Mars distance (max): 378 M km
 System noise temperature 21 K
 Downlink datarate (min) 500 kbps

230 Million Miles

Mars Global Surveyor

Rough estimates based on web search results:

$P_t = 100 \text{ W}$
 $\lambda = 0.036 \text{ m}$
 $G_t = 50,000$ (@ 70% aperture efficiency)
 $d_{max} = 378 \text{ E9 m}$
 $A_{eff} = 3800 \text{ m}^2$

$K = 1.38\text{E-}23 \text{ W/Hz.K}$
 $T = 21 \text{ K}$
 $B = 500\text{E}3 \text{ Hz}$

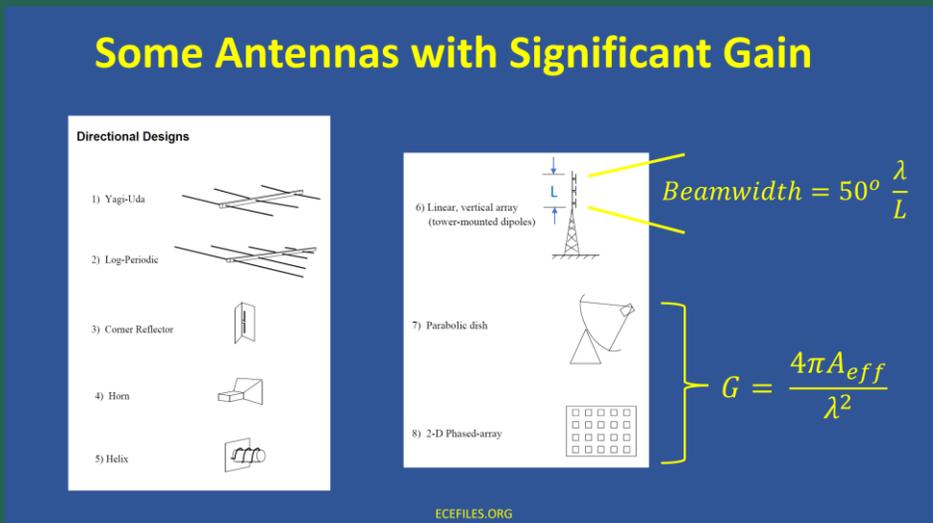
Goldstone 70m DSN dish

$$P_r = 1.1\text{E-}14 \text{ W} \text{ (-110 dBm)}$$

$$kTB = 1.4\text{E-}16 \text{ W} \text{ (-129 dBm)}$$

$$SNR = 76 \text{ (19 dB)}$$

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Some Antennas with Significant Gain

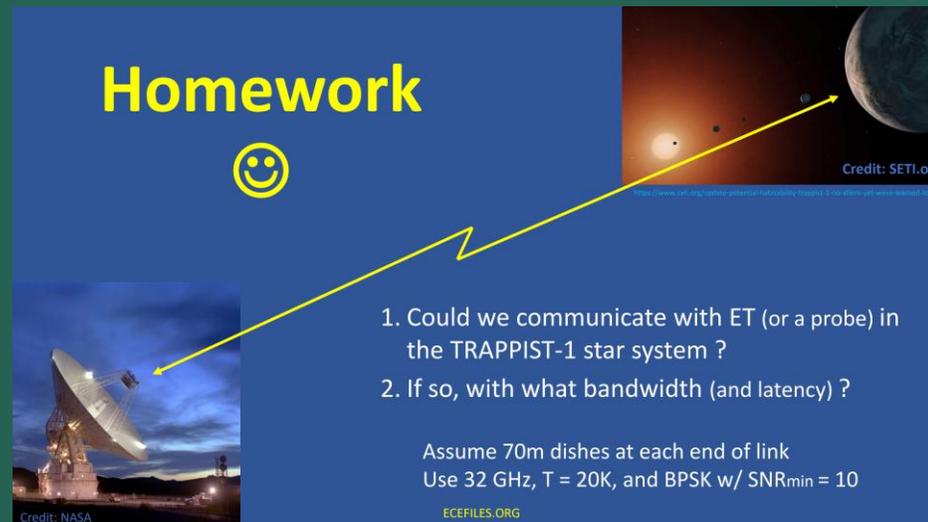
Directional Designs

- 1) Yagi-Uda
- 2) Log-Periodic
- 3) Corner Reflector
- 4) Horn
- 5) Helix
- 6) Linear, vertical array (tower-mounted dipoles)
- 7) Parabolic dish
- 8) 2-D Phased-array

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

$$G = \frac{4\pi A_{eff}}{\lambda^2}$$

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Homework

😊

1. Could we communicate with ET (or a probe) in the TRAPPIST-1 star system?
 2. If so, with what bandwidth (and latency)?

Assume 70m dishes at each end of link
 Use 32 GHz, T = 20K, and BPSK w/ SNR_{min} = 10

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*Thanks For
Watching !*

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