Antenna Briefs #3 -- Maximizing Range

Slides downloaded from: https://ecefiles.org/rf-design/

Companion video at: https://www.youtube.com/watch?v=tlG8_lopkUA

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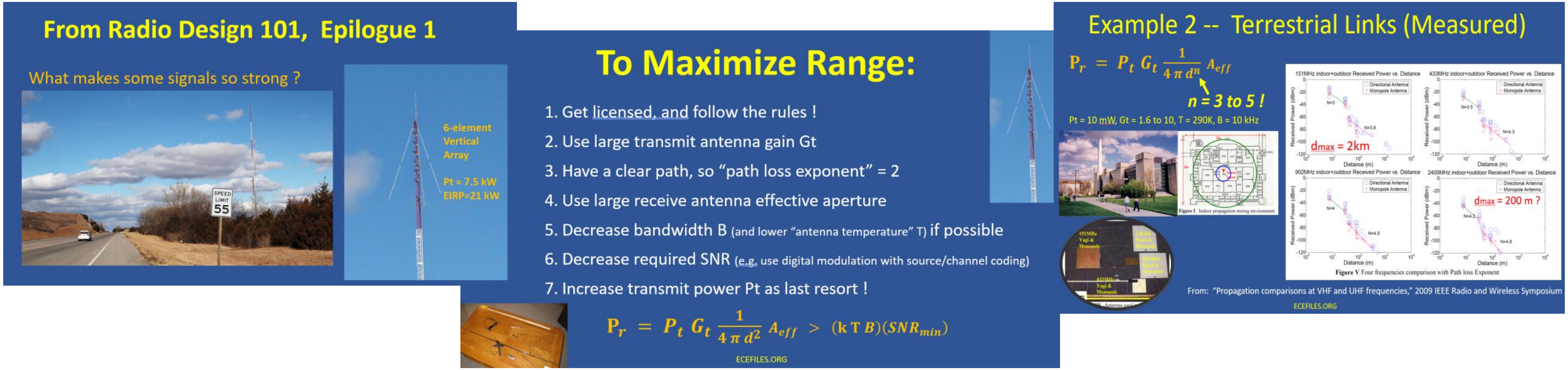
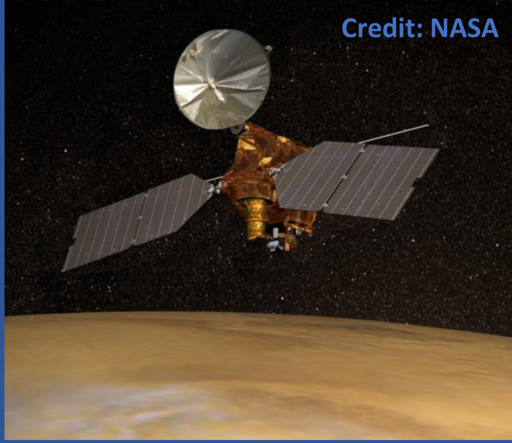
This episode identifies the factors involved in maximizing received power from a radio / wireless transmitter, and how to maximize the transmission range. Examples of deep space links are covered and contrasted with terrestrial (indoor / outdoor) propagation paths. Key equations are presented for the link budget, and for the antennas involved, including the relationship between antenna gain and effective area (aperture).





Credit: NASA

Antenna Briefs #3

Maximizing Range

Credit: NASA

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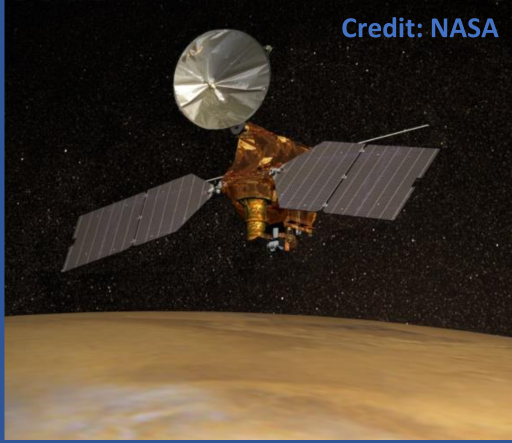


Topics

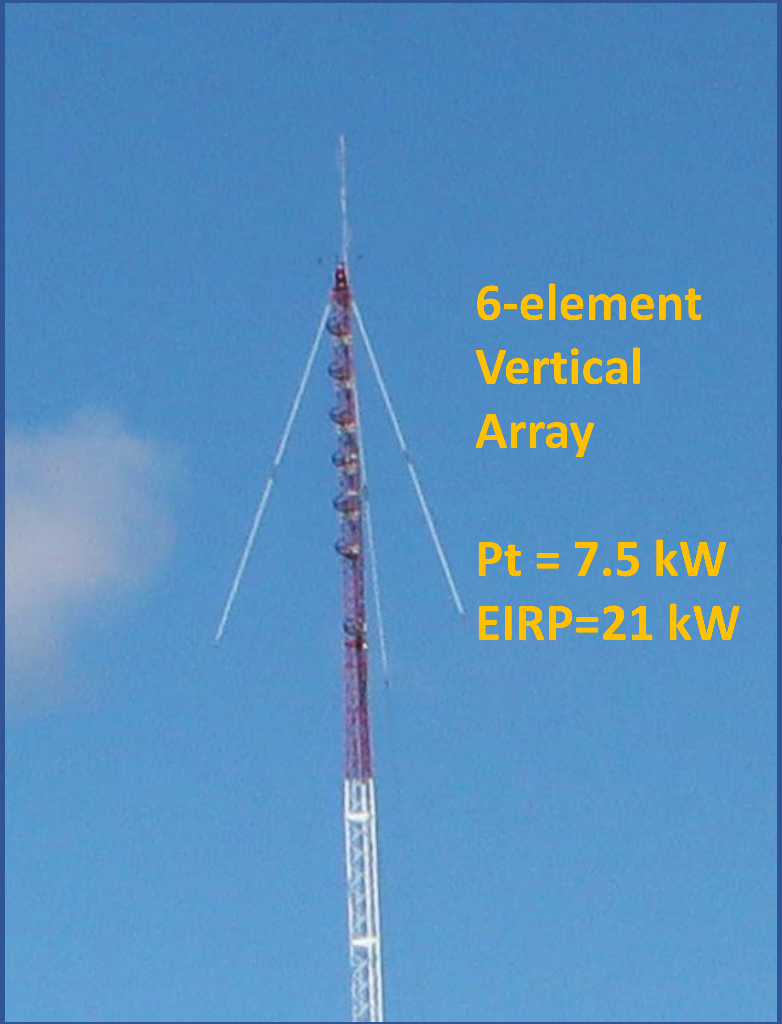
- Received power
- Noise power
- How to maximize range
- Beamwidth, Aeff, and gain
- Friis Transmission Equation
- Examples
  - Deep-space link (Earth-Mars)
  - Indoor/outdoor terrestrial link measurement results

Announcements

Homework #1 assigned
Due before episode 4 ☺

From Radio Design 101, Epilogue 1

What makes some signals so strong ?

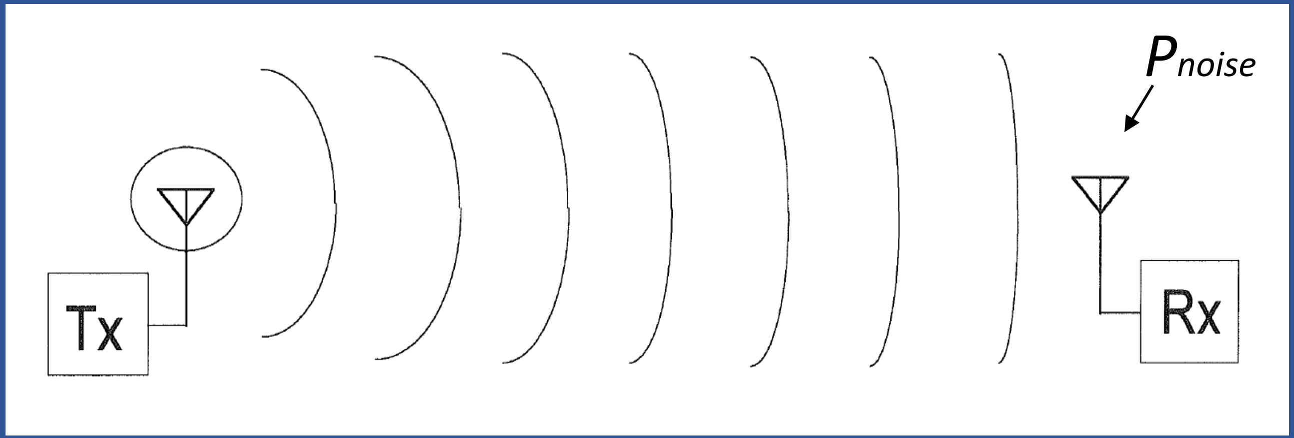


Key Equations From Antenna Briefs #2

Assuming "line of sight" propagation
with no obstructions or multipath…

$$P_{density} = \frac{P_t\, G_t}{4\,\pi\, d^2}$$

$$P_t = \frac{{V_t}^2}{R_{ant}}$$

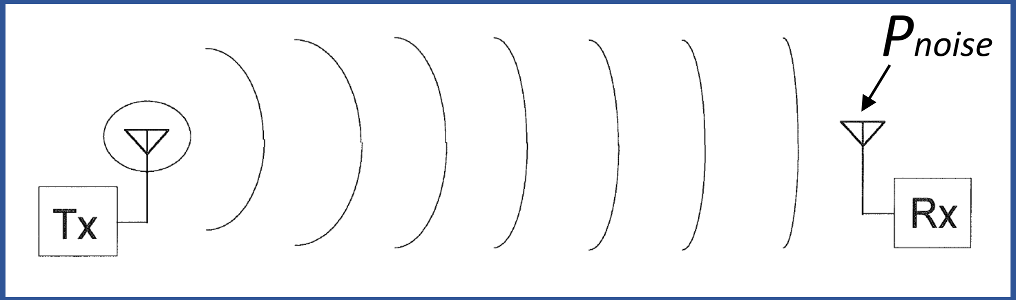


d

$$P_r = P_{density}\, A_{eff}$$

$$P_{noise} = kTB$$

Putting The Equations Together



d

$$P_{density} = \frac{P_t G_t}{4\pi d^2}$$

$$P_r = P_{density} A_{eff}$$

$$P_r = P_t G_t \frac{1}{4\pi d^2} A_{eff}$$

Make this big enough:
i.e. Pr > Pnoise , where

$P_{noise} = k\,T\,B$

k=1.38E-23 W/Hz.K,

T is temperature in Kelvin

B is bandwidth in Hz

To Maximize Range:

1. Get licensed, and follow the rules !
2. Use large transmit antenna gain Gt
3. Have a clear path, so “path loss exponent” = 2
4. Use large receive antenna effective aperture
5. Decrease bandwidth B (and lower “antenna temperature” T) if possible
6. Decrease required SNR (e.g. use digital modulation with source/channel coding)
7. Increase transmit power Pt as last resort !

$$\mathbf{P}_r = P_t\, G_t \frac{1}{4\,\pi\, d^2} A_{eff} > (\mathbf{k}\,\mathbf{T}\,B)(SNR_{min})$$

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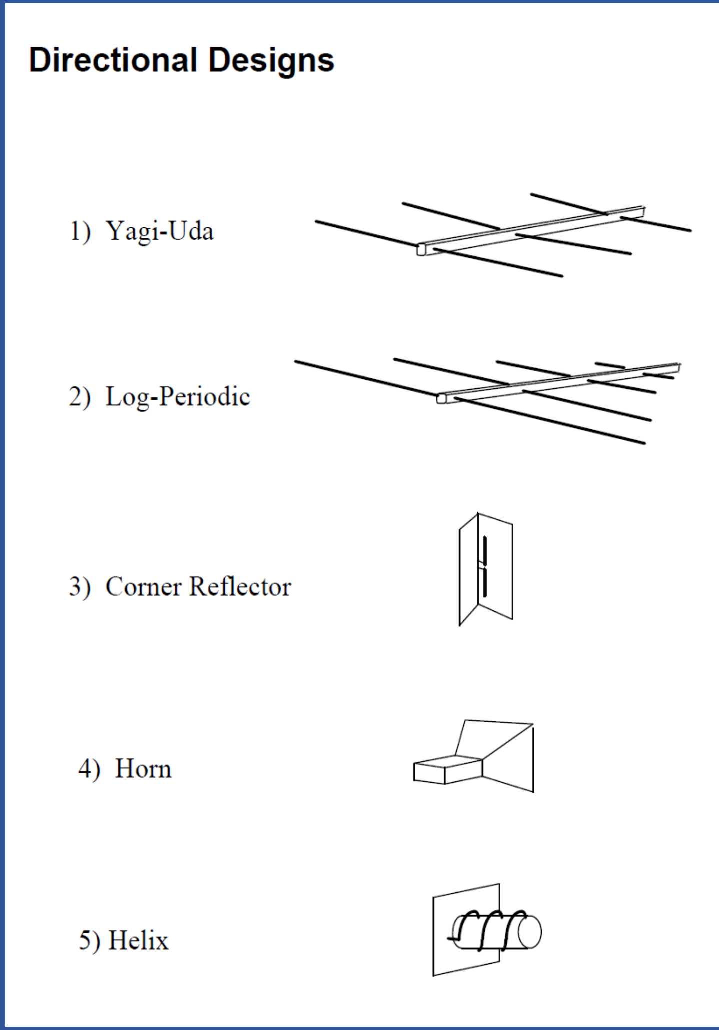
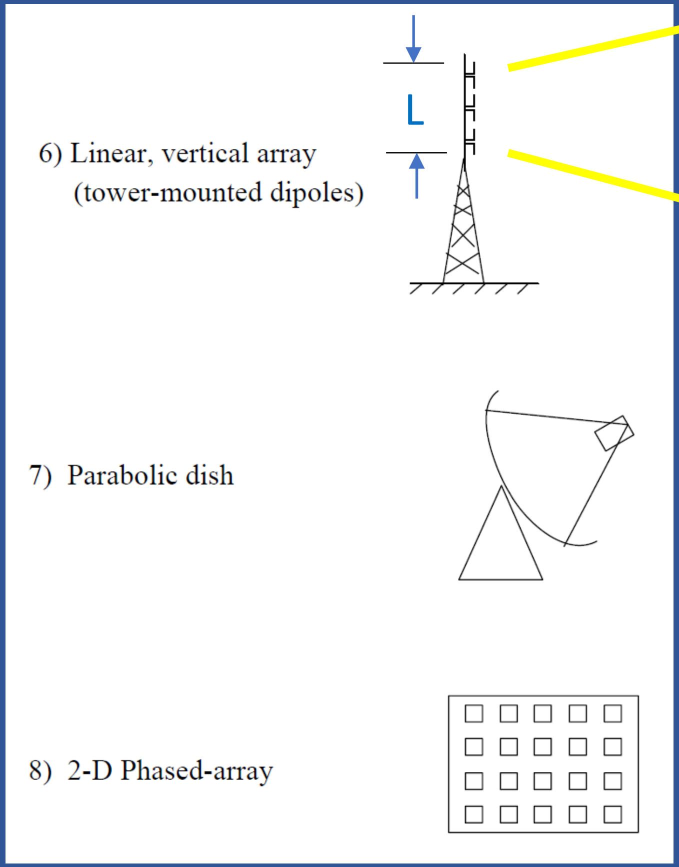
Some Antennas with Significant Gain

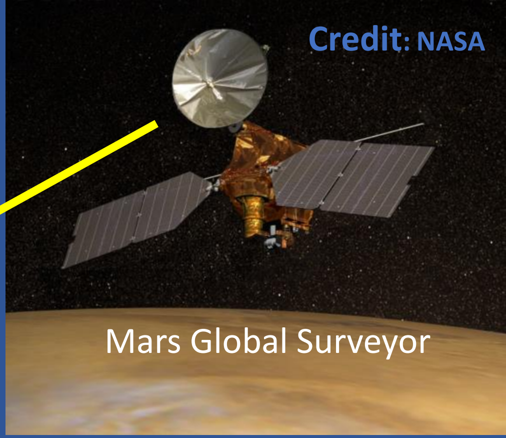




$$Beamwidth = 50^o \frac{\lambda}{L}$$

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

Example 1 -- Deep-Space



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

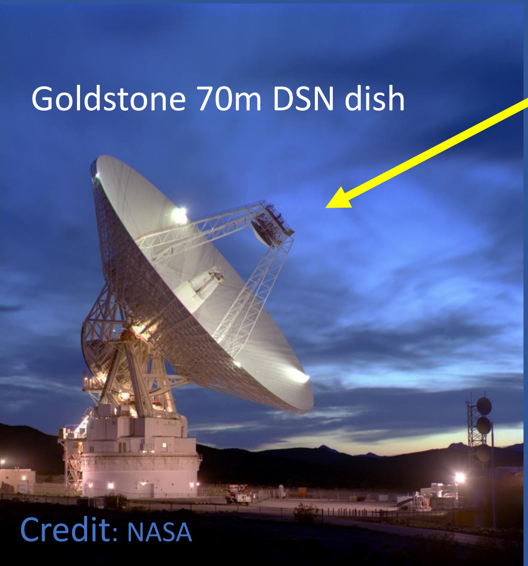
Downlink frequency 8.4 GHz
Transmit dish diameter: 3 m
Receiver dish diameter: 70 m
Earth-Mars distance (max): 378 M km
System noise temperature 21 K
Downlink datarate (min) 500 kbps

230 Million Miles

Rough estimates based on web search results:

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

K=1.38E-23 W/Hz.K
T = 21 K
B=500E3 Hz



P_r = 1.1E-14 W (-110 dBm)

kTB = 1.4E-16 W (-129 dBm)

$SNR = 76 \ \ (19\ dB)$

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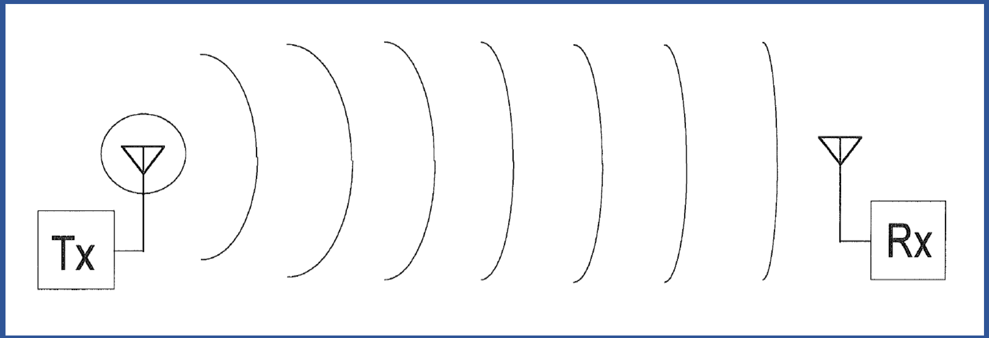
Alternative Formulation (Friis Equation)

From: https://en.wikipedia.org/wiki/Friis_transmission_equation



Contemporary formula [edit]

Few follow Friis' advice on using antenna effective area to characterize antenna performance over the contemporary use of directivity and gain metrics. Replacing the effective antenna areas with their gain counterparts yields

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

Somewhat misleading.
Seems to imply small lambda is bad…

where G_t and G_r are the antenna gains (with respect to an isotropic radiator) of the transmitting and receiving antennas respectively, λ is the wavelength representing the effective aperture area of the receiving antenna, and d is the distance separating the antennas.[1] To use the equation as written, the antenna gains are unitless values, and the units for wavelength (λ) and distance (d) must be the same.

To calculate using decibels, the equation becomes:

$$P_r^{[\text{dB}]} = P_t^{[\text{dB}]} + G_t^{[\text{dBi}]} + G_r^{[\text{dBi}]} + 20\log_{10}\left(\frac{\lambda}{4\pi d}\right)$$

Wrong units !

Powers should be in “dBW”, or “dBm”
“dB” is only defined for ratios !

Example 2 -- Terrestrial Links (Measured)

$$P_r = P_t\, G_t \frac{1}{4\,\pi\, d^n} A_{eff}$$

n = 3 to 5 !

Pt = 10 mW, Gt = 1.6 to 10, T = 290K, B = 10 kHz

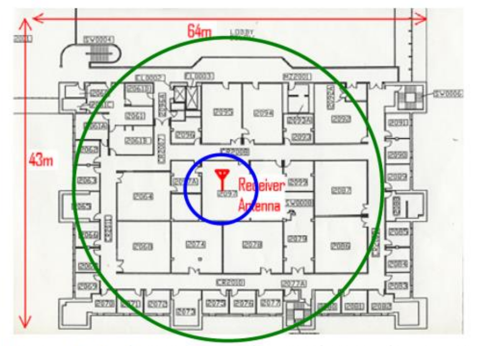
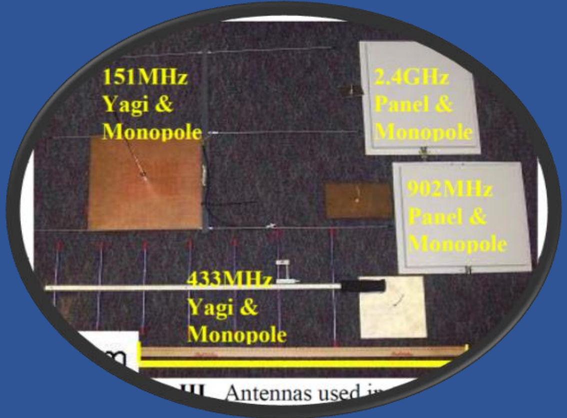


Figure I. Indoor propagation testing environment.



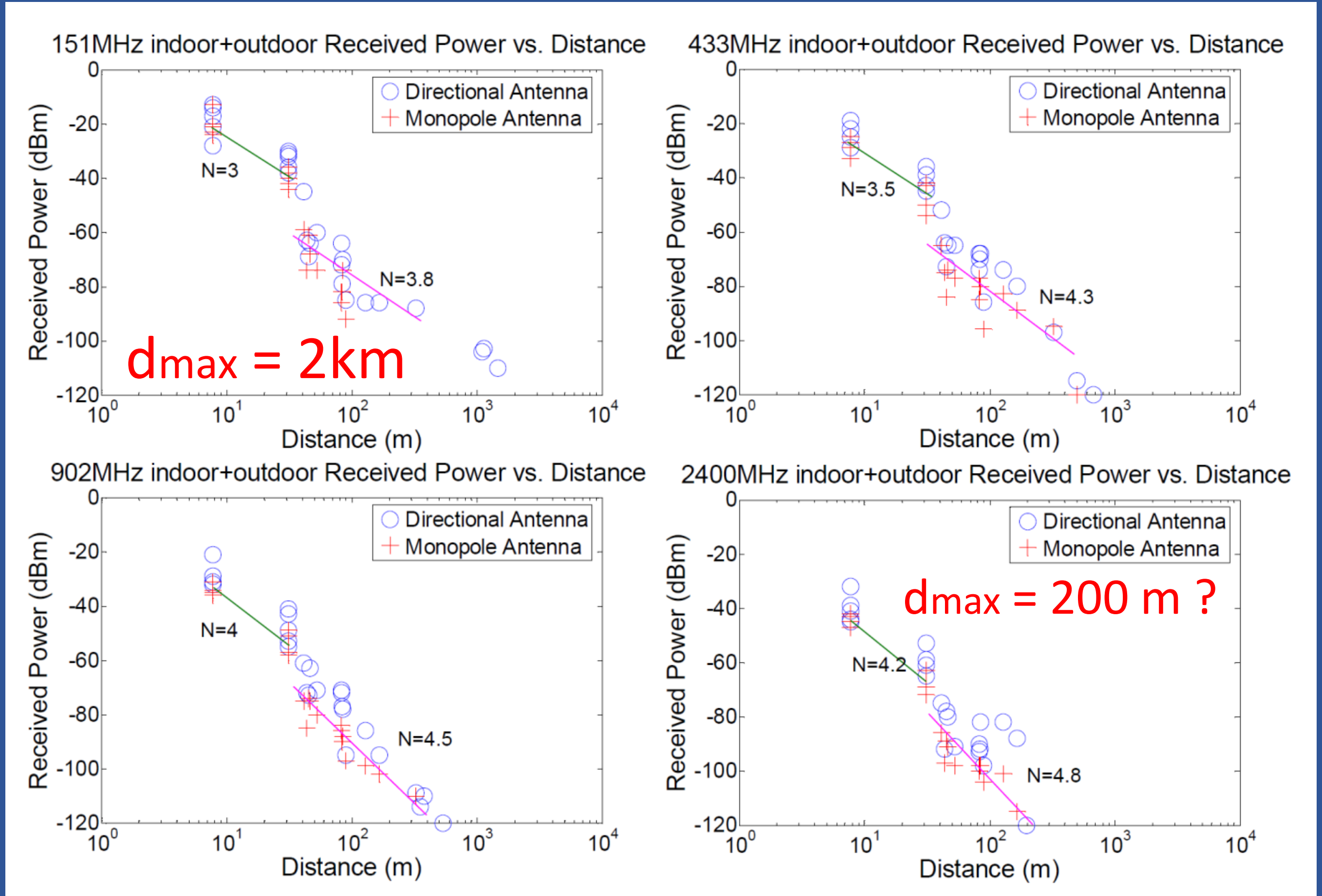


Figure V Four frequencies comparison with Path loss Exponent

From: "Propagation comparisons at VHF and UHF frequencies," 2009 IEEE Radio and Wireless Symposium

Review and Elaboration

1. Get licensed, and follow the rules !
2. Use large transmit antenna gain Gt (if possible and legal)
3. Have a clear path *where possible* (so “path loss exponent” n = 2)
4. Use large receive effective aperture if possible (large receive gain Gr)
5. Decrease bandwidth B (and lower “antenna temperature” T) if possible
6. Decrease required SNR (e.g. use digital modulation with source/channel coding)
7. Increase transmit power Pt as last resort

$$\mathrm{P}_r = P_t\, G_t \frac{1}{4\,\pi\, d^n} A_{eff} > (\mathrm{k\,T}\,B)(SNR_{min})$$

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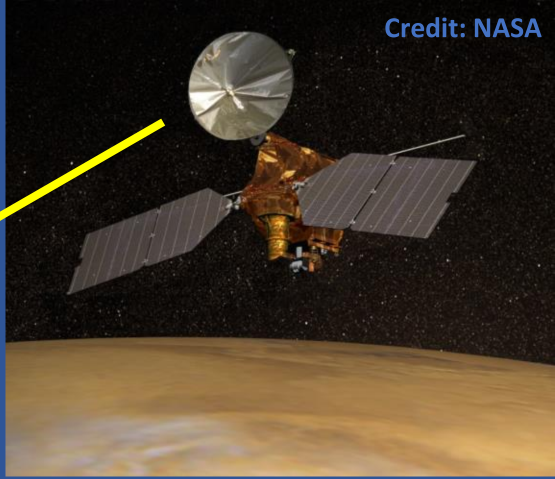

Credit: NASA

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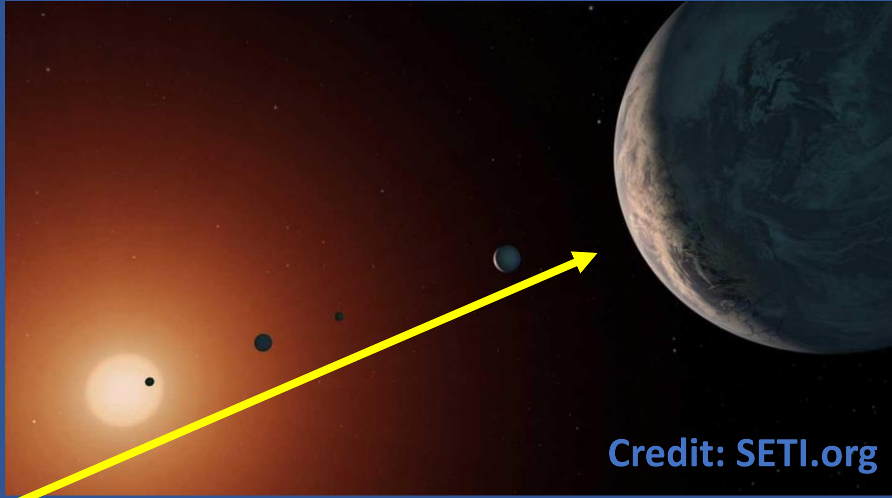
Homework

☺



https://www.seti.org/update-potential-habitability-trappist-1-no-aliens-yet-weve-learned-lot

Credit: NASA

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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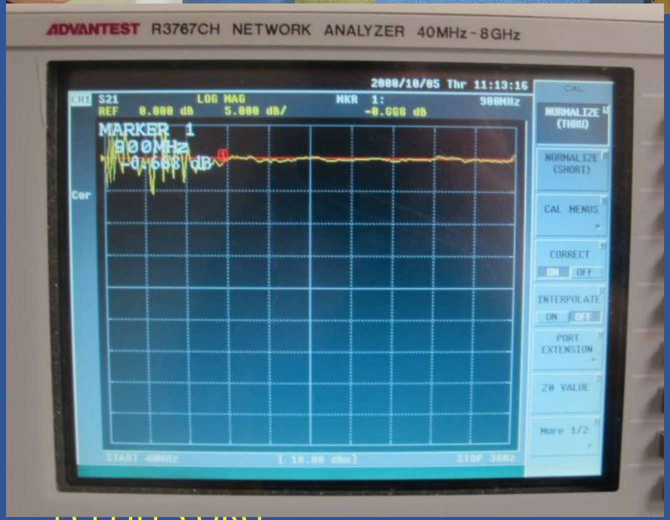
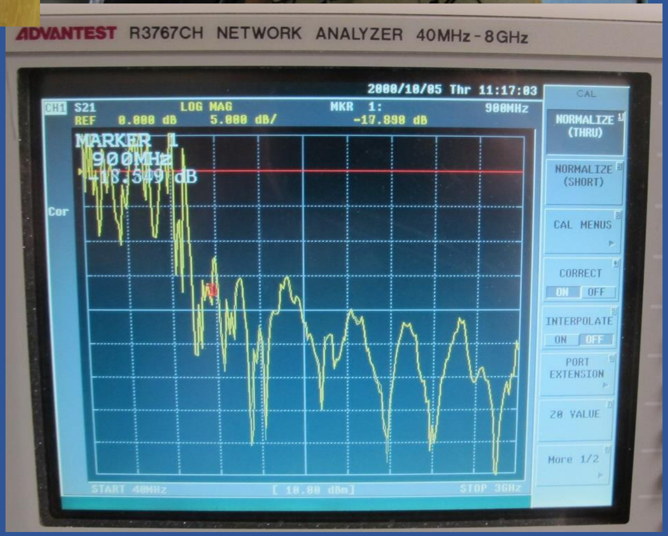
Transmission through Triple-Pane, Coated Glass

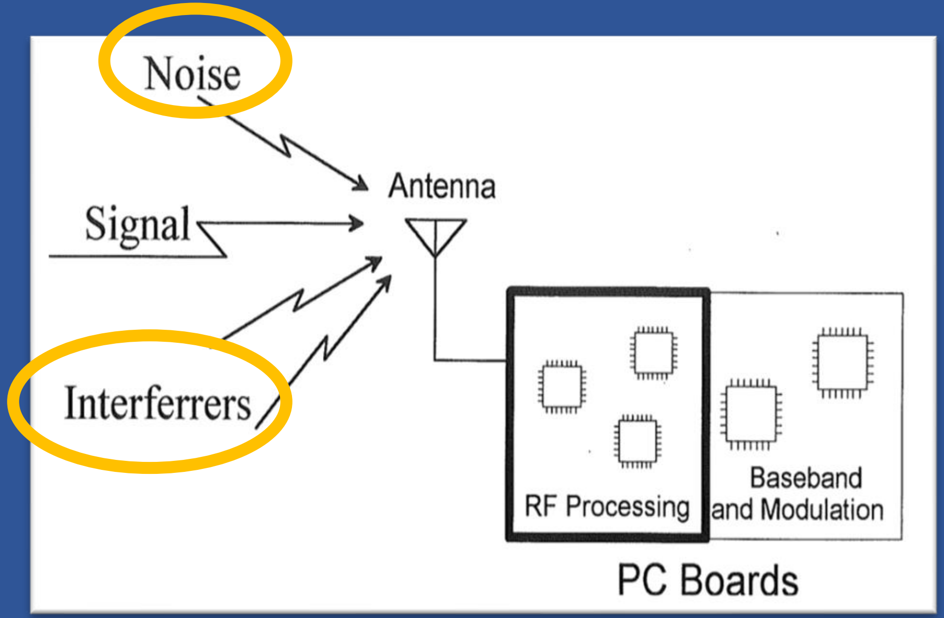
- Setup includes two 900 – 2600 MHz log periodic antennas
- Network analyzer normalized with clear path
- Next, glass sample is placed in path
- ***Attenuations of 20 to 40 dB measured !***



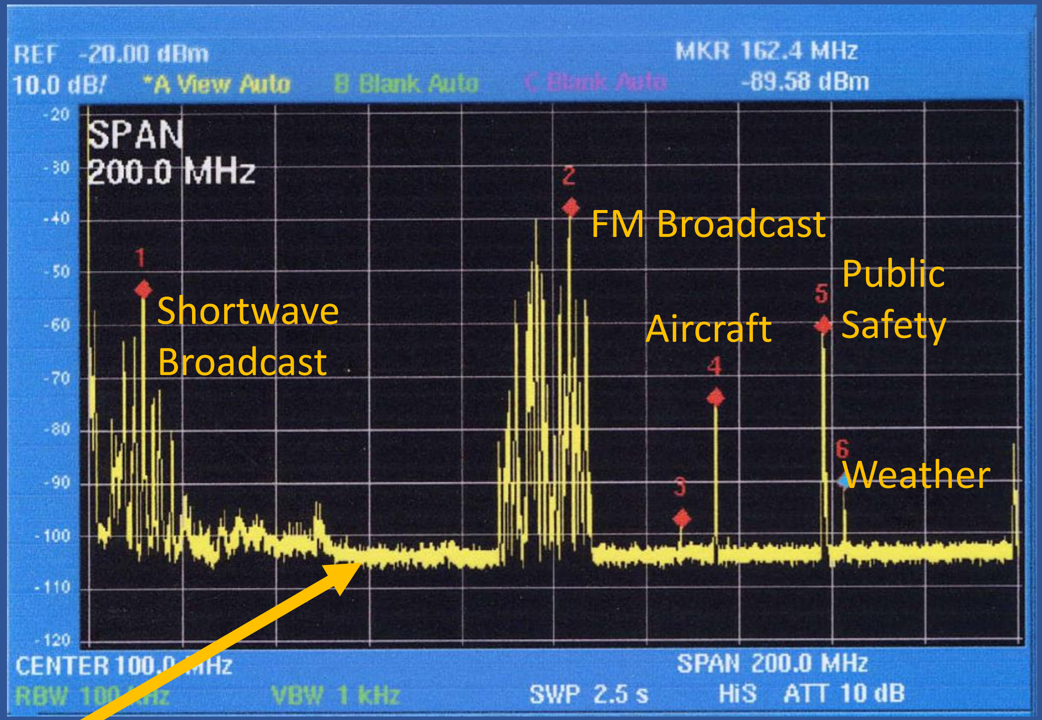




Limits to Receiver Sensitivity



0 to 200 MHz, 100 kHz RBW

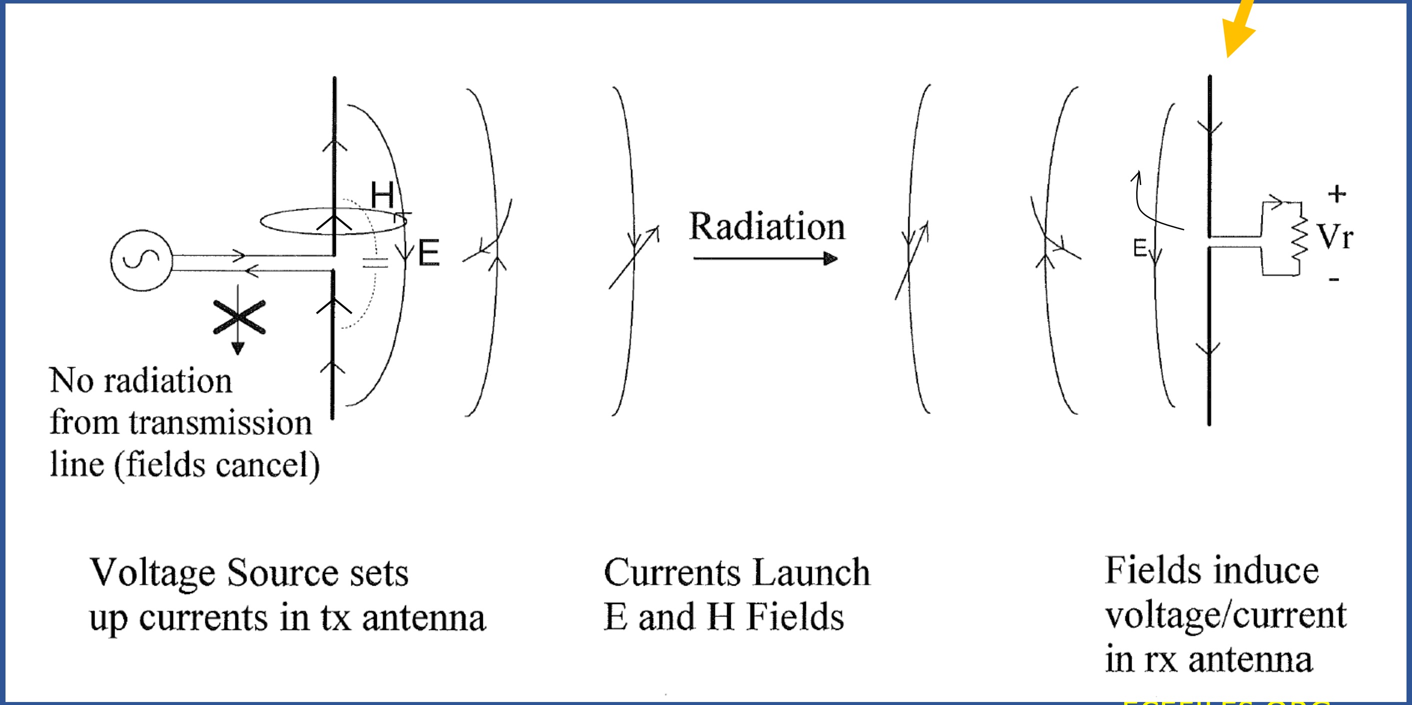


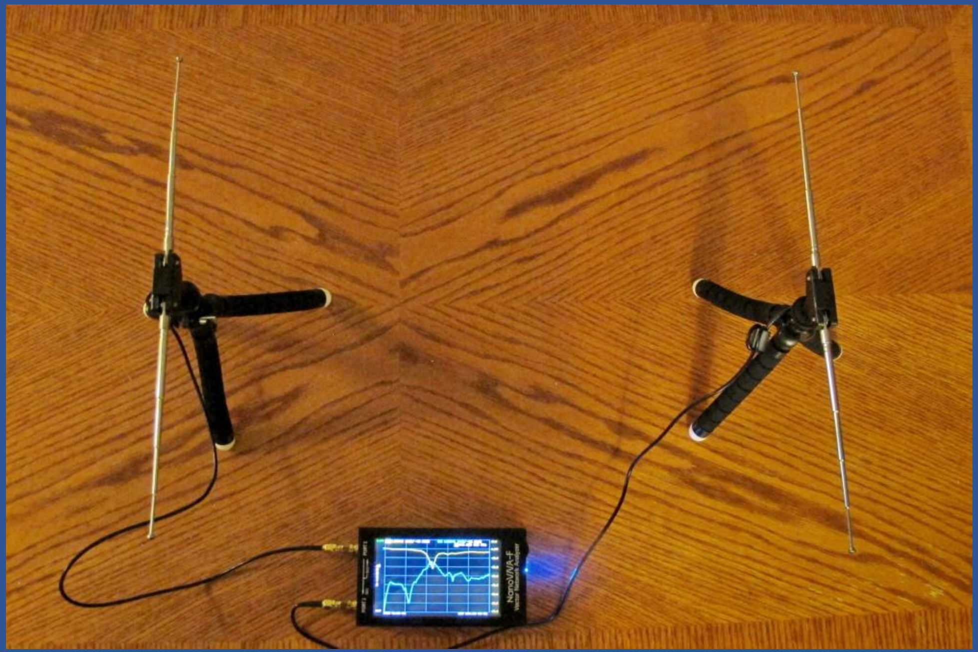
Noise Floor

Transmission – Theory and Practice

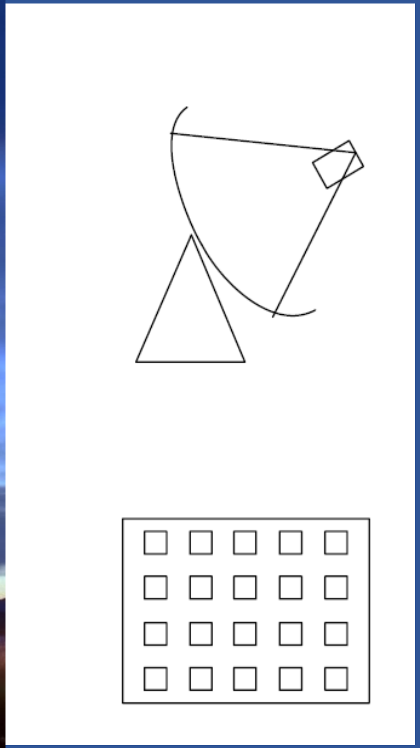
Halfwave receive diple interacts with fields and pulls in power from an area of about

$$A_{eff} \approx 0.5\left(\frac{\lambda}{2}\right)^2$$





Gain Increases as $1/\lambda^2$



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