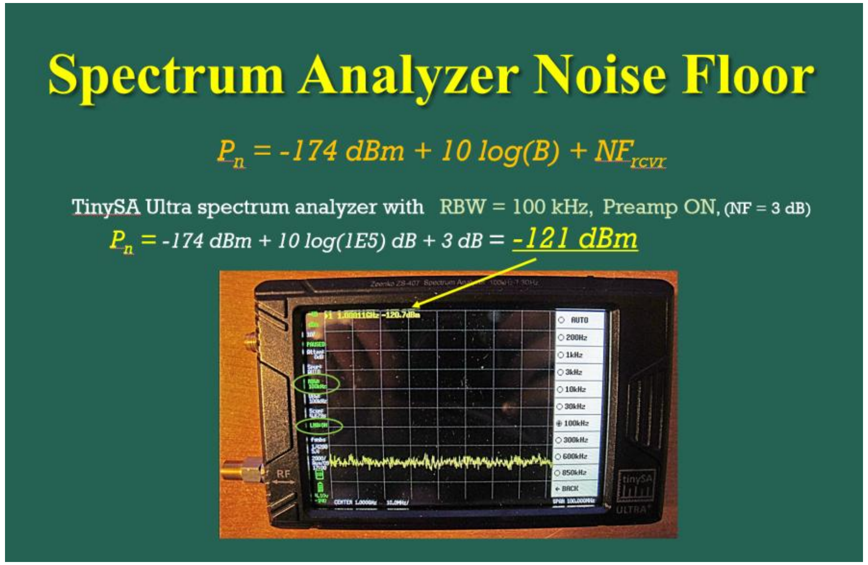
Radio Design 201 Microwave Circuits and Antennas

Episode 5 - Gain, Path Loss, Spectrums, and Noise

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

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

This episode of Radio Design 201 (Microwave Circuits and Antennas) focuses on fundamentals of communication links, including how to calculate received signal level, and the role of noise in a system's ability to detect and demodulate the signal. At microwave frequencies, the antennas used often have high directivity and gain, allowing for very long-range communication. Signal path-loss is considered and the use and effects of path-loss exponents from 2 to 5 is explained. The video concludes with demonstrations of spectrum analyzers, including a TinySA Ultra and a comparison of the TinySA to an older high-performance Hewlett Packard unit.



Radio Design 201 #5

Microwave Circuits and Antennas

Gain, Path Loss, Spectrums, and Noise

MegawattKS - YouTube

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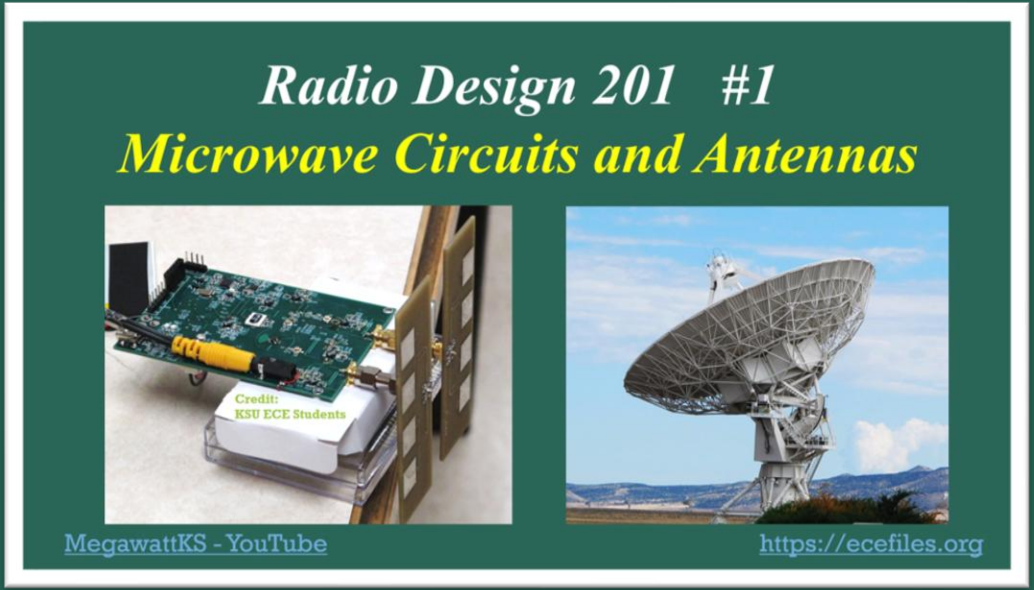

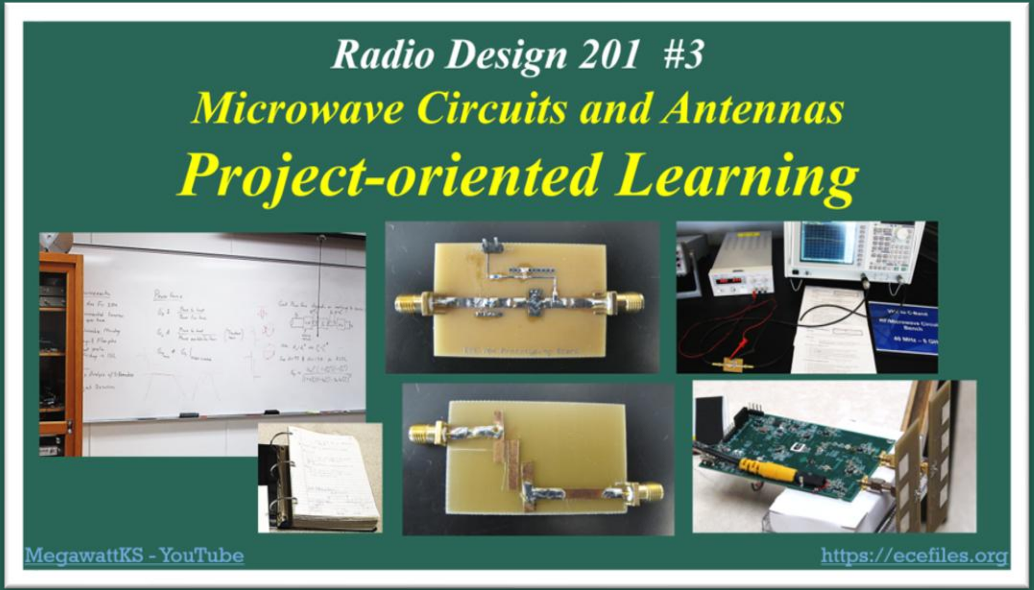

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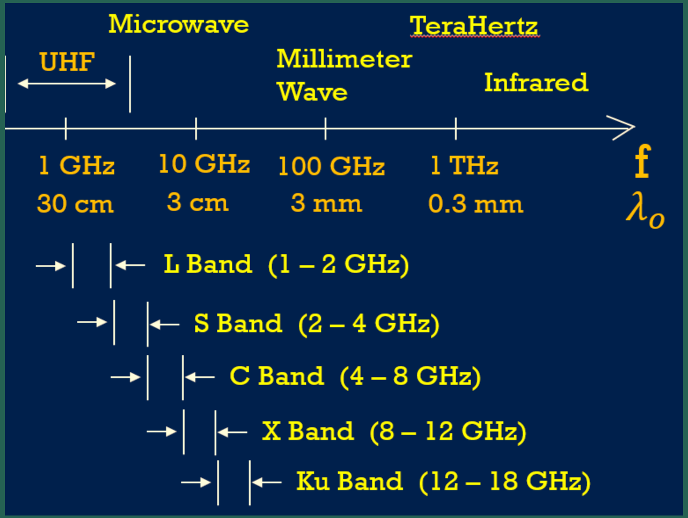


Why Use "Microwaves" ?

- Massive Amounts of Spectrum Available
- Highly Directional Antennas Possible
- <u>Very</u> Long Range (for line-of-sight paths)

Today's "Lecture" Topics

Announcements

Welcome to Episode 5

See Episodes 1 through 4 for

- *Definitions of "microwave",*
- *Example semester projects, and*
- *Day 1 lecture material*
- *Free and low-cost software and test equipment*

Today's Topics

➡ *Finding received power levels in free-space*

Noise and Minimum Discernable Signal (MDS) levels

Spectrum Analyzer Usage and Demos

Today's Episode in Context

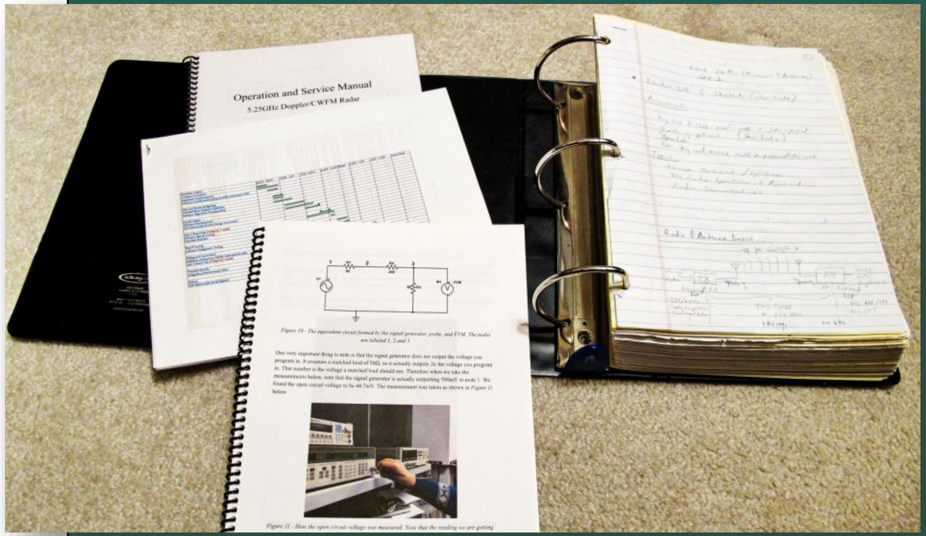
In Episode 3
(p/o 4-part introduction)

This Episode

ECE 764 Spring 2017 Schedule

(Tentative)

Week	*Material*	*Assignments*
1	Introduction to comm systems, frequencies, and wavelengths Calculating and measuring received signal strengths	Verify you have lab access Lab 1 assigned
2	EM theory review and demos Basic antenna theory	Purchase lab kit
3	Basic antenna types: dipoles, monopoles, loops Antenna characterisitics: polarization, patterns, and impedance	Lab 1 due
4	Measurement of antenna patterns and signal reflection/transmission Transmission lines and reflection coefficient	Lab 2 assigned
5	Introduction to Smith Charts, plotting of impedance/admittance Simulation with Agilent ADS	
6	Lambda/4 lines and impedance transformation with microstrip Microstrip components and coupled-line microwave filters	Lab 2 due
7	PC board design, layout, and parasitics Two-port circuits and S-parameters	Lab 3 assigned
8	Circuit analysis and simulation with S-parameters Amplifier insertion gain, matching, stability, noise figure, and compression specs	Lab 3 due
9	Project discussion (including needed baseband, ADC and DSP functions) Basic mixer concepts and hybrid-ring microstrip implementations	Project assigned
10	Voltage controlled oscillators Frequency multipliers	Prototype design/layouts due
11	Project discussions (pads, RF connector test points, test planning)	Probotype boards back
12	Frequency synthsizers and phase-locked loops	
13	Project testing/debugging discussions	Test, debug, respin boards Submit final board layouts
14	Analysis and design of directional antennas: Array theory Dish antennas and antenna feeds: e.g. helix, horn, and patch antennas Antenna simulations with ADS, EZNEC and other tools	
15	Additional radar and wireless performance issues	



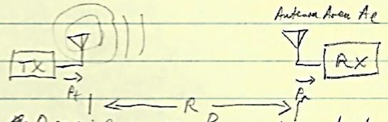
Today's Lecture Notes

Transmit & Receive Power Levels

Problem

Consider a transmitter TX with output power P_t

And a receiver RX with antenna of size A_e (effective aperture)



Find Receive power P_r at distance R

Solution:

Assume TX antenna is isotropic

Propagation medium is free space (no obstructions/etc)

Then, from power conservation:

Power density at distance R is

$$\rho = \frac{P_t}{4\pi R^2} \quad \left(\frac{W}{m^2}\right)$$

($4\pi R^2$: Area of sphere around TX antenna)

And

$$P_r = \rho A_e = \frac{P_t}{4\pi R^2} A_e$$

Note: If R varies from 1 m to 10 km (10^4) (6.2 mi)

Then P_r varies by 10^8 — Eight orders of magnitude

⇒ Watts or mW → μW to pW

P_r therefore commonly measured in log terms w/ dB units expressed by

$$P_r\Big|_{dBm} = 10 \log \frac{P_r}{1\,mW}$$

(dBm: dB relative to 1 mW)

P	dBm
1W	+30
1mW	0
1μW	−30
1nW	−60
1pW	−90
1fW	−120

Minimum Discernable Signal

Weakest power receivable is called MDS sensitivity

Limited by "noise floor"

$$P_n = kTB$$

(k: Boltzmann's Constant $= 1.38 \times 10^{-23}$ W/K Hz; T: Temp in Kelvin; B: BW of receiver's "detector" in Hz)

Example: $T = 290\,K$ (room temperature)

$B = 10\,kHz$ (modulation & receiver dependent)

⇒ $P_n = MDS = 4 \times 10^{-17}$ watts $= 4 \times 10^{-14}$ mW

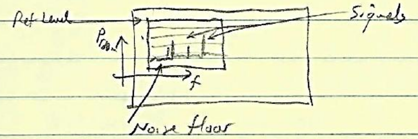
OR

$$P_n\Big|_{dBm} = -134\ dBm$$

NOTE: Effective P_n & MDS of RX is higher by X dB where X = "Noise Figure"

Spectrum Analyzers

Radio receiver with power vs frequency readout display



Typical sensitivity may be 10 to 30+ dB worse than theoretical value above, depending on settings

See handout / KSOC for more info

Spectrum Analyzer Demo (Pass out cheat sheets!)

Freq Sweep Settings:
- Start / Stop for wide range
- Center / Span for close in inspection
- Freq accuracy limited by RBW, Span / # points taken

Amplitude Settings:
- Scale typically 10 dB/div vertical
- Ref Level may default to 0 dBm
- Need higher for large power
- Damage Level ≈ +20 dBm!
- Need lower for weak signal observation

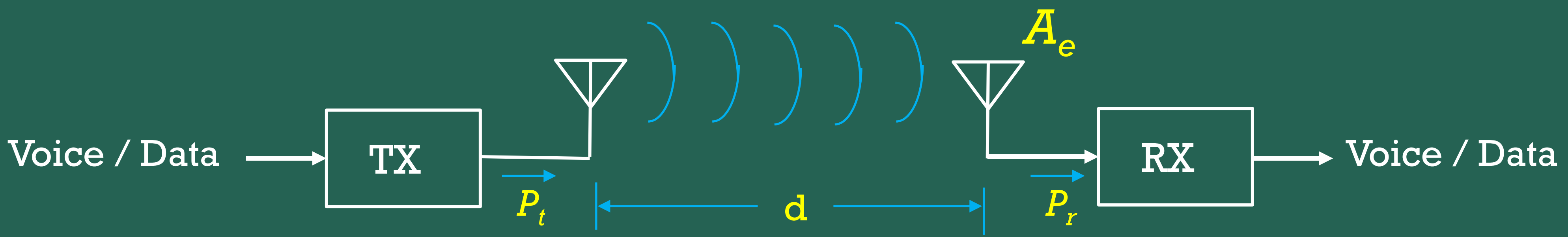
RBW & VBW
- RBW is detector BW
- Decrease to decrease Noise floor
  - (also lower Ref Level
  - enable preamp
  - decrease atten (But NOT below 10 dB!)

Additional Functions
- Marker, Peak select, Mkr → CF
- F count
- Preset

Transmit & Receive Power Levels

Consider at transmitter TX with output power P_t *Watts*

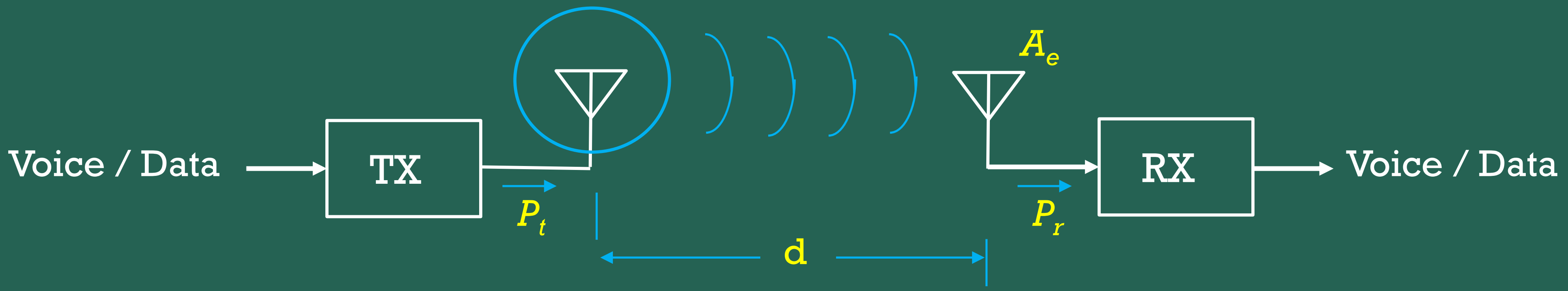
And a RX with antenna area ("effective aperture") A_e m^2



Problem:

Find the received power P_r at distance d

Solution (basic / simplified)



Assume TX antenna is "isotropic" (non-directional)
RX antenna and feedline is well matched to RX input impedance
Propagation medium is free-space (no obstructions/reflections)

Then Power *density* $P_{density}$ at distance d is:

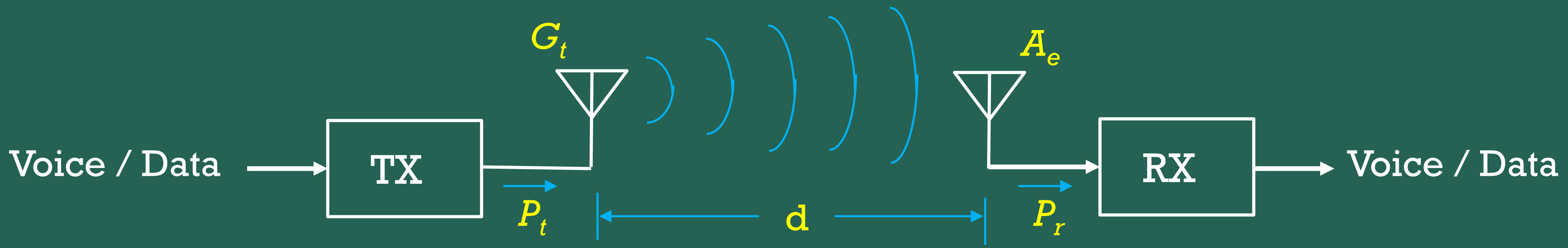
$$P_{density} = \frac{P_t}{4\pi d^2} \quad Watts/m^2$$

Surface area of a sphere of radius d surrounding "isotropic" TX antenna

And received power P_r is:

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

Antenna Gains and Path Loss Exponent



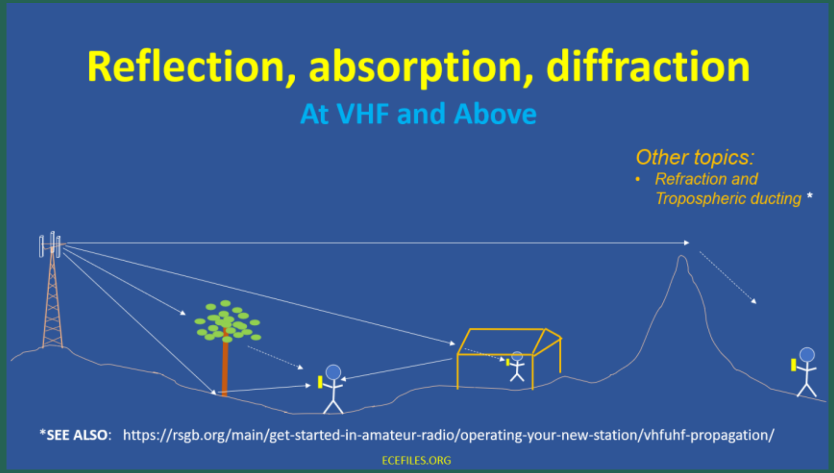
Real TX antennas have directivity and associated "gain" (G_t)

(and so do RX antennas …)

Terrestrial propagation paths may have obstructions / reflections, so "path loss exponent" in denominator is often approximated as n = 2 to 5

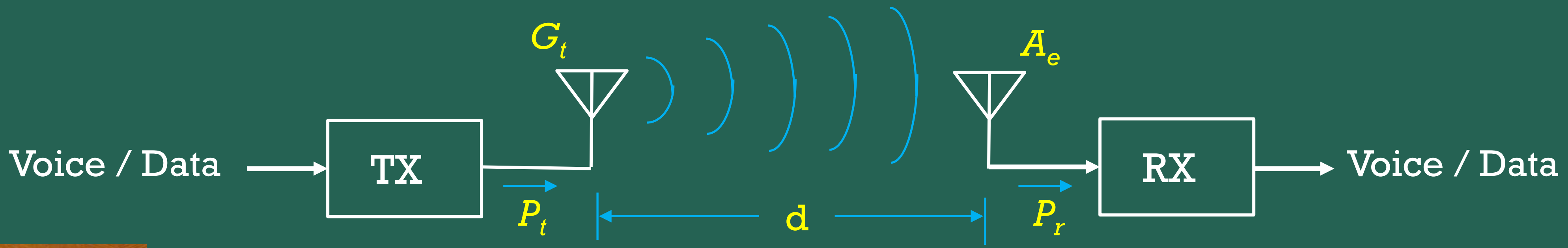
And P_r formula becomes:

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



See: Antenna Briefs, Episode 7

Important Notes:

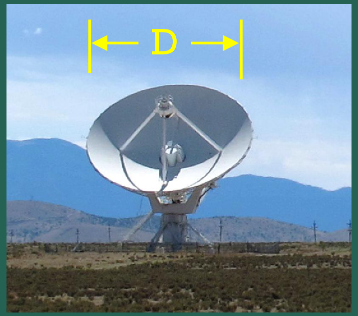


Basic (half-wave) dipole antennas have gain of

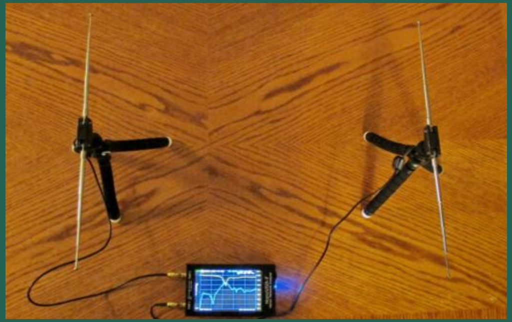
$$G \approx 1.6 \quad (2 \text{ dBi}), \text{ and } A_e \approx \frac{1}{\pi}\left(\frac{\lambda}{2}\right)^2$$

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

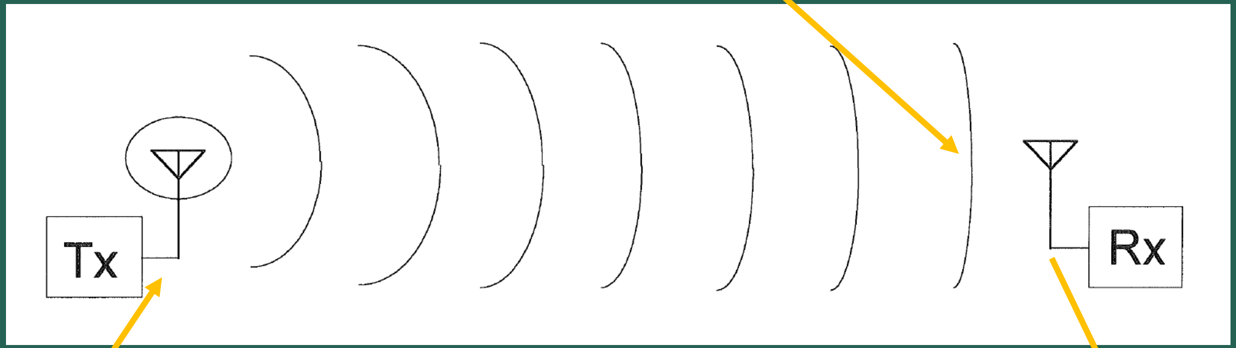
$$A_{eff} \approx \pi\left(\frac{D}{2}\right)^2 \text{ and } G = \frac{A_{eff}}{A_{ei}} = \frac{4\pi A_{eff}}{\lambda^2}$$



Example / Demo



$$P_{density} = \frac{P_t G_t}{4\pi d^n} \quad Watts/m^2$$



d

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

Example: 1 V_{rms}, 50 Ohms

=> **Pt = 20 mW**

NOTE: NanoVNA actually puts out less …

$n \approx 2$ *here?*

Why?

$$P_r = P_{density} A_{eff} \quad \text{Watts}$$

Example: Gt = 1.6, d = 0.5m

=> $P_{density}$ = 10 mW/m^2

Then with Aeff ≈ 1/3.14 $(0.34m)^2$

=> **Pr ≈ 0.4 mW**

(About 10 log(0.4/20) = 17 dB less than Pt)

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Today's Topics

Finding received power levels in free-space

➡ *Noise and Minimum Discernable Signal (MDS) levels*

Spectrum Analyzer Usage and Demos

Power in dBm units

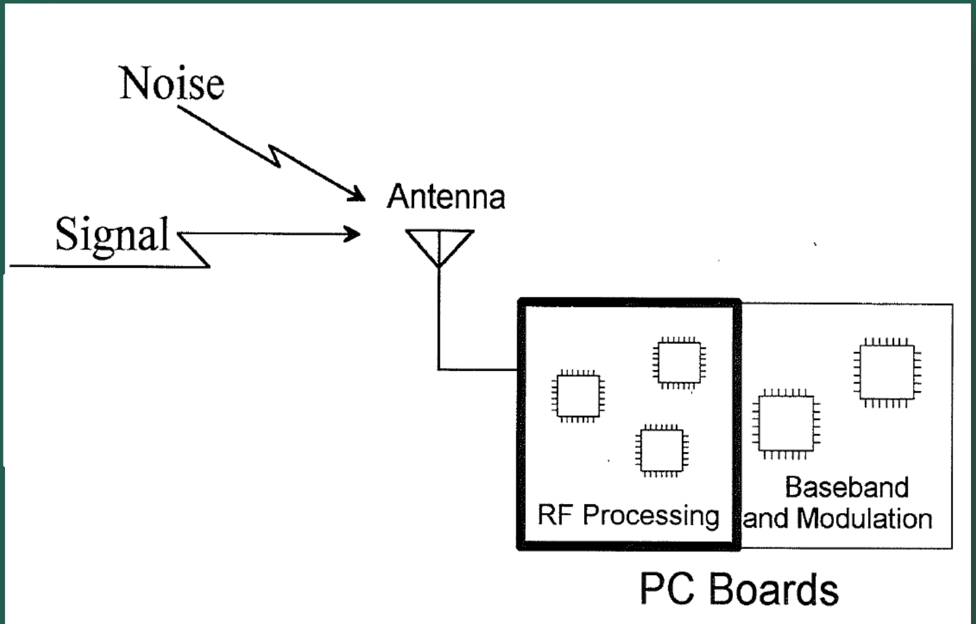
- Received power Pr is usually orders of magnitude lower than Pt
- If d varies from 1m to 10 km (about 6 miles), Pr decreases by a factor of 10^8 ! (e.g. from 0.1mW to 1 pW, for n=2. Much worse for n=4)
- So Pr often expressed in dB relative to 1mW, or "dBm"

$$P_r|_{\text{dBm}} \triangleq 10log\frac{P_r}{1mW}$$

Power	dBm
1 Watt	+30
1 mW	0
1 uW	-30
1 nW	-60
1 pW	-90 ☺
1 fW	-120 😐
1 aW	-150 ☹

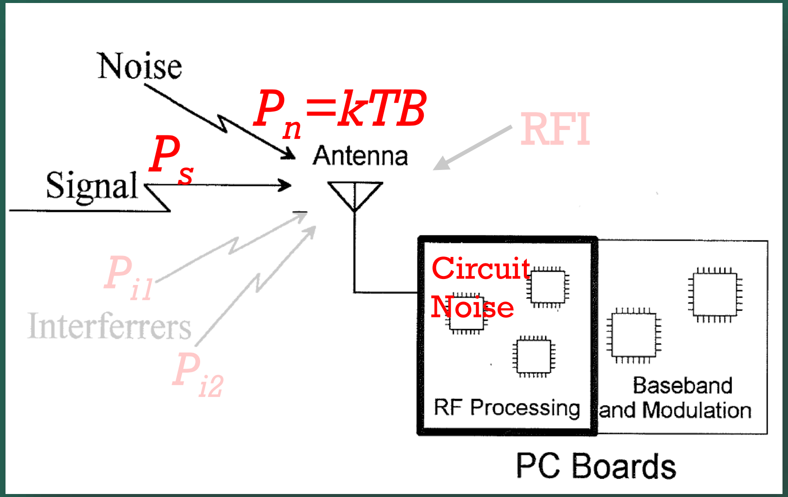
Minimum Discernable Signals

- Weakest power receivable often taken as the level of incoming noise
- Called the Minimum Discernable Signal level, or MDS
- Actual minimum depends on receiver design, modulation, coding, …



Overall Receiver Sensitivity

See Radio Design 401, Episode 2 for details



$$P_{n\,dBm} = 10log\left(\frac{kTB}{0.001}\right)$$

$$= 10log\left(\frac{kT}{0.001}\right) + 10log(B)$$

-174 dBm @ T=290K

$$P_n = -174\ dBm + 10\ log(B)$$

$$P_{s\_min} = P_n + NF_{rcvr} + S/N_{min}$$

Example: TinySA Ultra spectrum analyzer with B=100 kHz, NF = 3 dB,

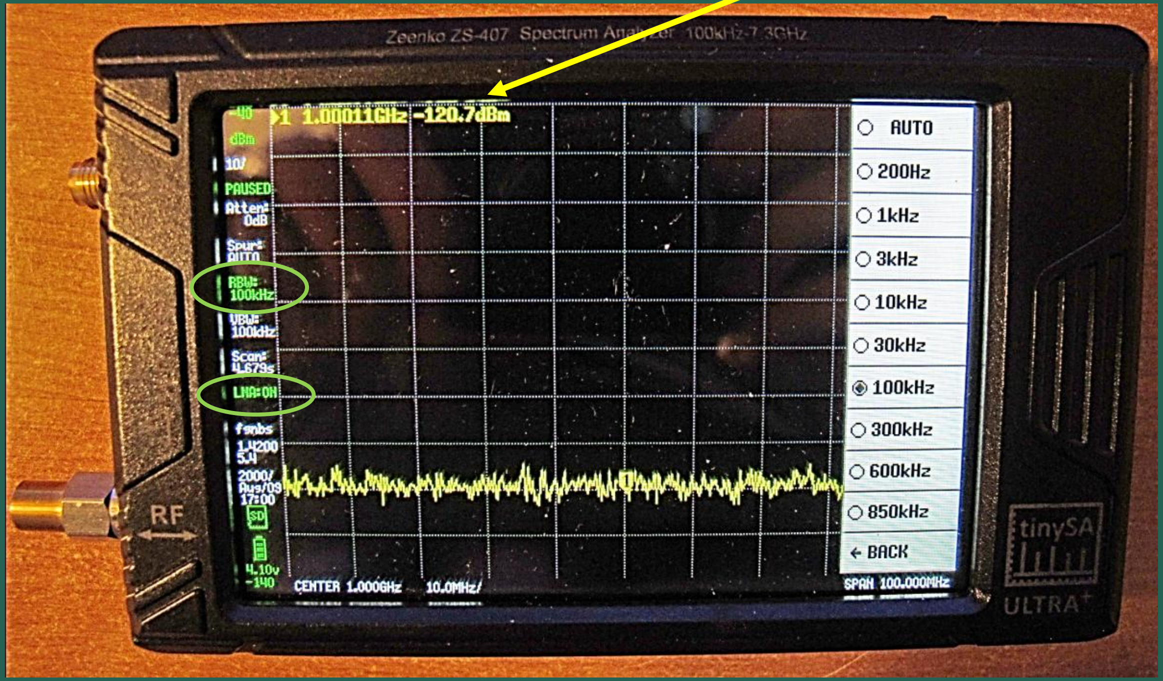
=> P_n = -174 dBm + 10 log(1E5) dB + 3 dB = -121 dBm

Spectrum Analyzer Noise Floor

$$P_n = -174\ dBm + 10\ log(B) + NF_{rcvr}$$

TinySA Ultra spectrum analyzer with RBW = 100 kHz, Preamp ON, (NF = 3 dB)

$$P_n = -174\ dBm + 10\ log(1E5)\ dB + 3\ dB = \underline{-121\ dBm}$$



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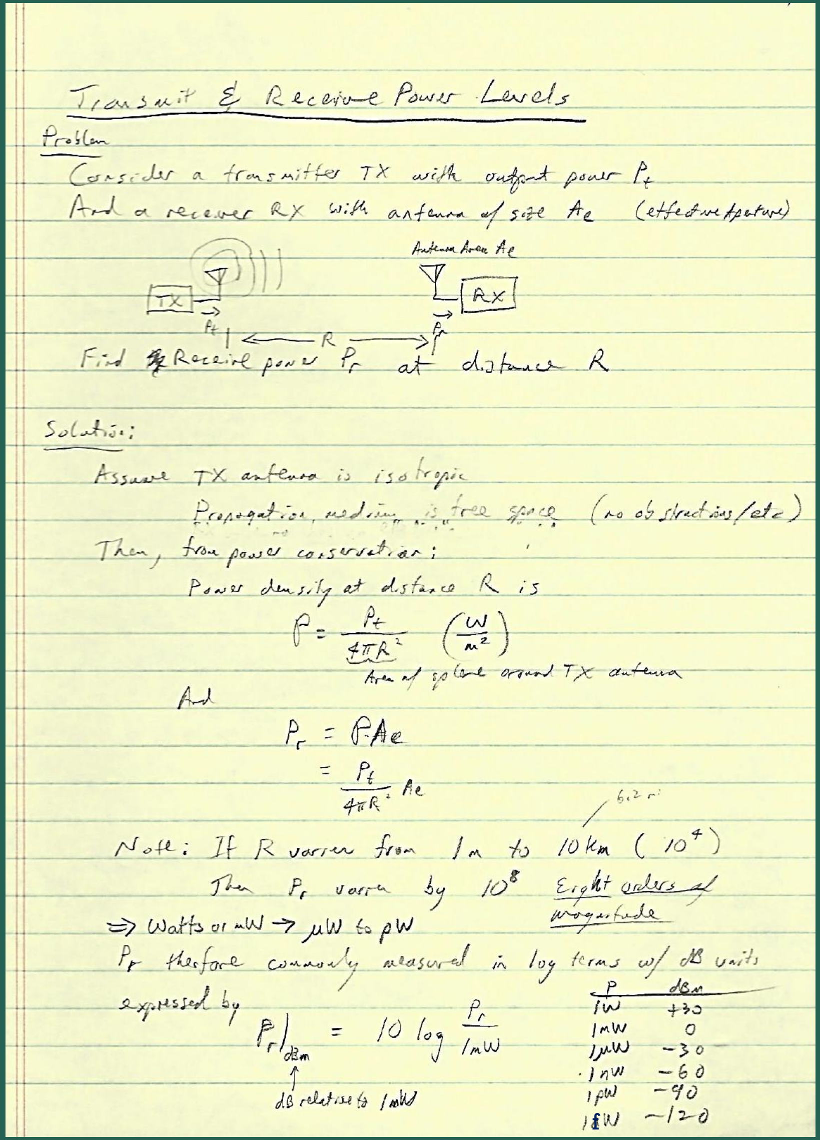
➡ *Spectrum Analyzer Usage and Demos*

Today's Lecture Notes



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($4\pi R^2$ = Area of sphere around TX antenna)

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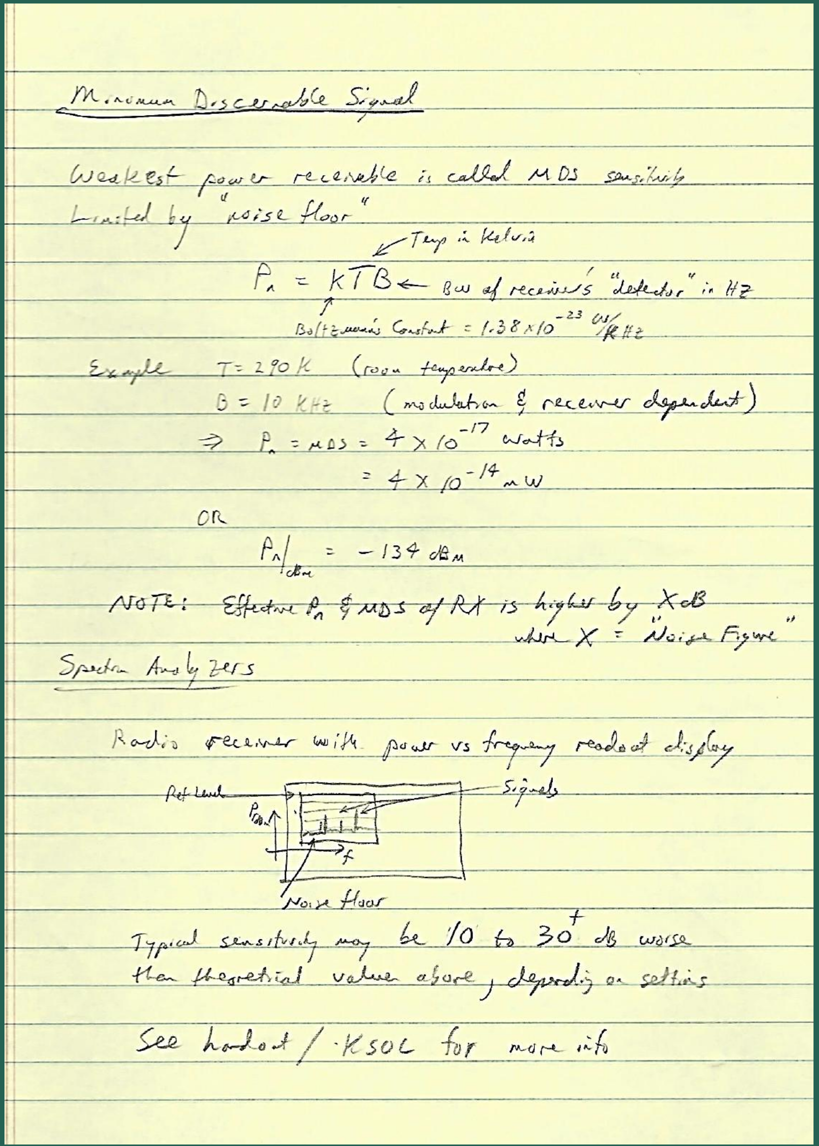

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$\Rightarrow P_n = MDS = 4 \times 10^{-17}$ watts

$= 4 \times 10^{-14}$ mW

OR

$P_n\big|_{dBm} = -134$ dBm

NOTE: Effective P_n & MDS of RX is higher by X dB where X = "Noise Figure"

Spectrum Analyzers

Radio receiver with power vs frequency readout display

Typical sensitivity may be 10 to 30+ dB worse than theoretical value above, depending on settings

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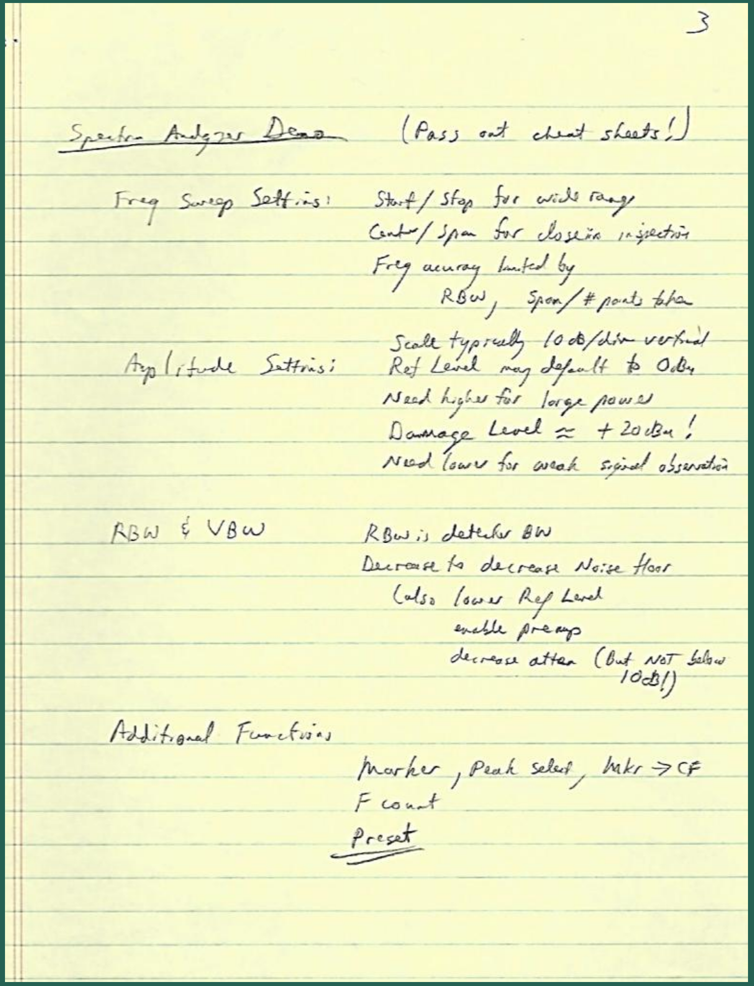

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Spectrum Analyzer Demo (Pass out cheat sheets!)

Freq Sweep Settings: Start/Stop for wide range
Center/Span for close in inspection
Freq accuracy limited by
RBW, Span/# points taken

Amplitude Settings: Scale typically 10 dB/div vertical
Ref Level may default to 0dBm
Need higher for large power
Damage Level ≈ +20dBm!
Need lower for weak signal observation

RBW & VBW: RBW is detector BW
Decrease to decrease Noise floor
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enable preamp
decrease atten (But NOT below 10dB!)

Additional Functions: Marker, Peak select, Mkr → CF
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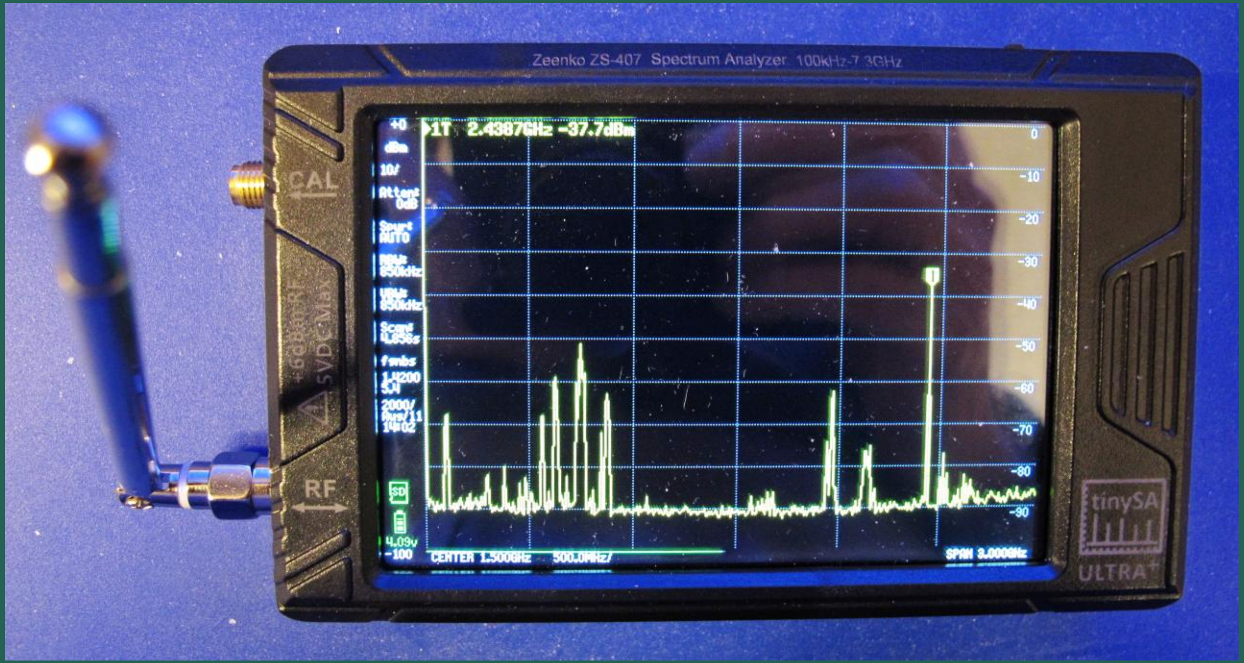
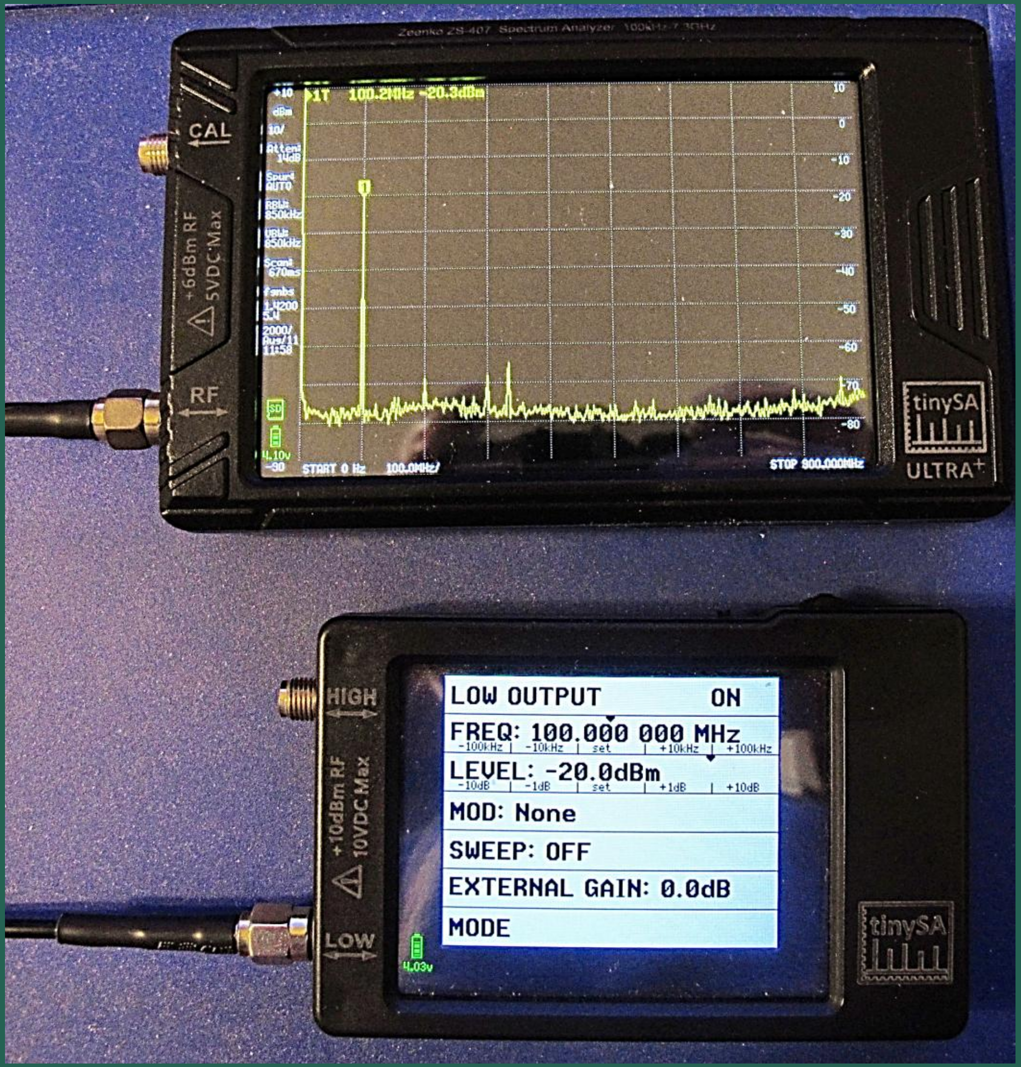
Spectrum Analyzer Demos





Thanks For Watching !