

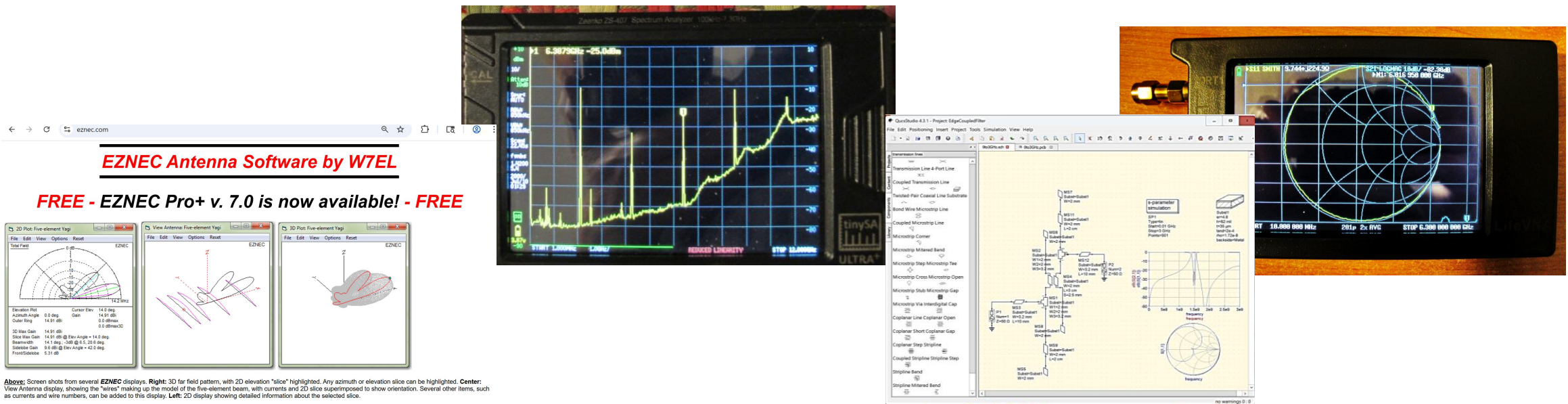
Radio Design 201 Microwave Circuits and Antennas Episode 4 - Outfitting Microwave Labs on a Budget

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In this episode we show software and hardware options for building a home or university lab on a budget. In particular, we discuss antenna simulation and EM software that can be used for free, and recently introduced TinySA Ultra, NanoVNA, and LiteVNA spectrum and vector network analyzers that can be bought for relatively low prices. For those interested in course/class design, we also discuss lab assignments and projects, including ones we may implement during future episodes.



Radio Design 201 #4

Outfitting Microwave Labs On a Budget

Outfitting an RF/Microwave Lab on a Budget 2001 - 2020

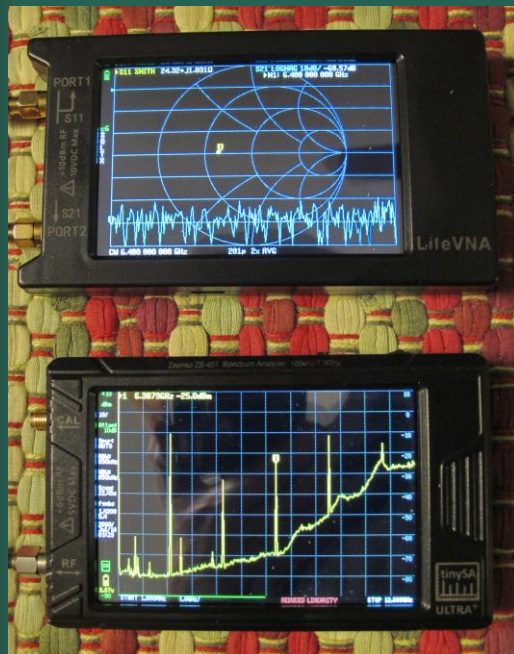


Modern RF and microwave test equipment is awesome. It can provide accurate measurements to 20 GHz and above in relatively small, lightweight packages with bright color screens and many time-saving data-reduction options. But it is also extremely expensive. The photo at left is an HP8753E we bought from the refurbished market. Newer models sell for \$50K to \$100K depending on frequency range!

For those of us who must live within reasonable means, such instruments are usually outside our reach. However, there *are* ways to continue working in this business - if we are willing to give up on some of the fancy looks and features. Fortunately, this does NOT include giving up on basic performance (much). The picture at right is a 20 GHz network analyzer assembled from pieces bought for less than \$2K total, after scouting Ebay and used-line.com.



2026



Today's "Lecture"


Announcements

*Welcome to Episode 4
(Final episode in 4-part introduction)*

See Episodes 1 through 3 for

- *Definitions of "microwave",*
- *Example semester projects, and*
- *Day 1 lecture material*

Today's Topics

 *Example Project and Lab Assignments*
Radio Design 201 Lab and Project Ideas

Free *Software Examples*

"Low Cost" Test Equipment Examples

Project/Lab-Oriented Learning in Open Laboratories (See Episode 3)

Homework: Work in this course centers around the design, construction, testing, and documentation of real-world antennas, circuits, and systems. Therefore, there are no classic homework problems. Rather, “homeworks” consist of lab and project assignments and associated documentation.

Labs/Projects: During the first half of the semester, we will be covering antennas, propagation, and transmission line fundamentals. We will be learning through lectures, lab exercises, and associated writeups. *The lab exercises will be done in teams of 2 or 3* and will include:

- ◆ Lab 1: Measurement of radio propagation in the field
- ◆ Lab 1: Basic antennas and performance measurements.
- ◆ Lab 3: Circuit component parasitics, transmission lines, matching networks, and other “microstrip” component design.

During the second half of the semester, we will be designing, building, and testing a microwave system - a Doppler/FMCW radar operating in the 5.8 GHz Industrial, Scientific, and Medical (ISM) frequency band. This will be accomplished in two stages:

- ◆ Prototyping of main radar functions (e.g. amplifiers, filters, etc.)
- ◆ Full radar product design, construction, and testing.

As with the labs, the radar designs will be done in teams (in this case, of 3 or 4 person “companies”). Each person within your company will be responsible for a separate part of the design, and the whole company must work out interfaces between sections and get the product functional by the end of the semester.

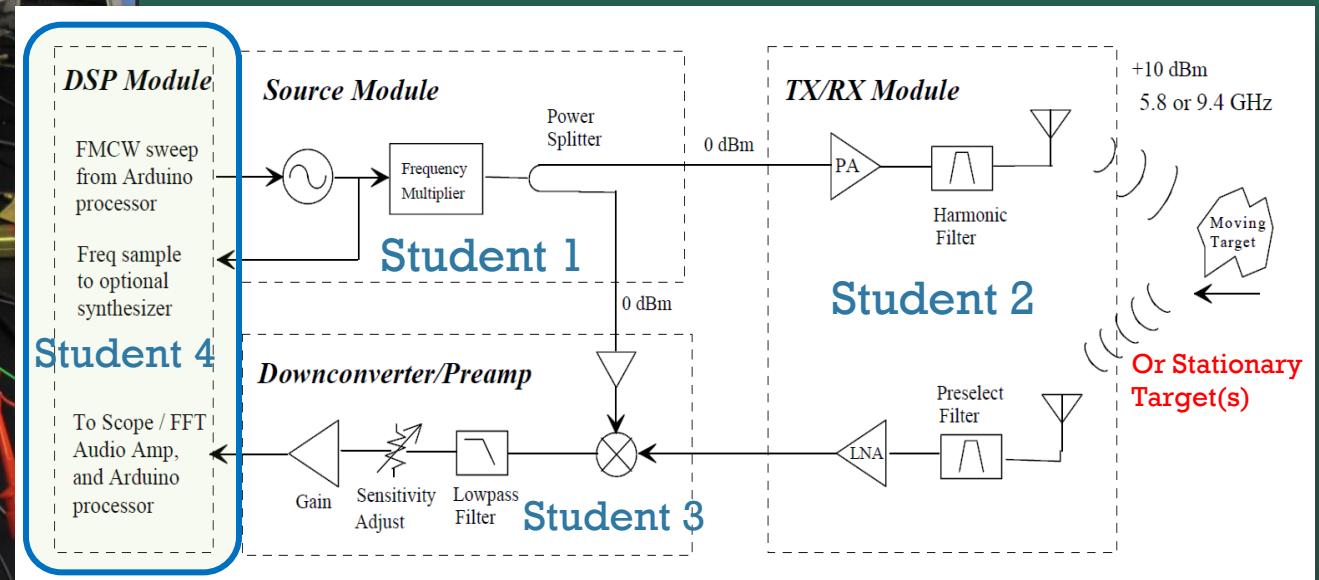
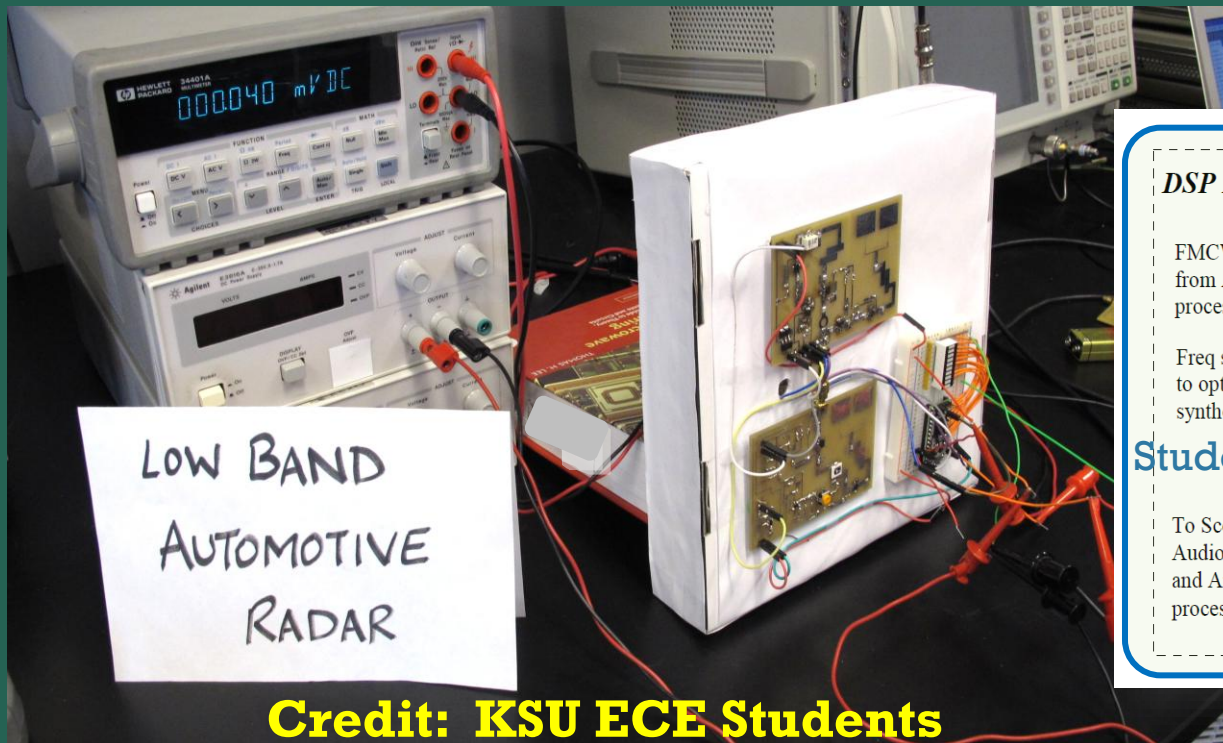
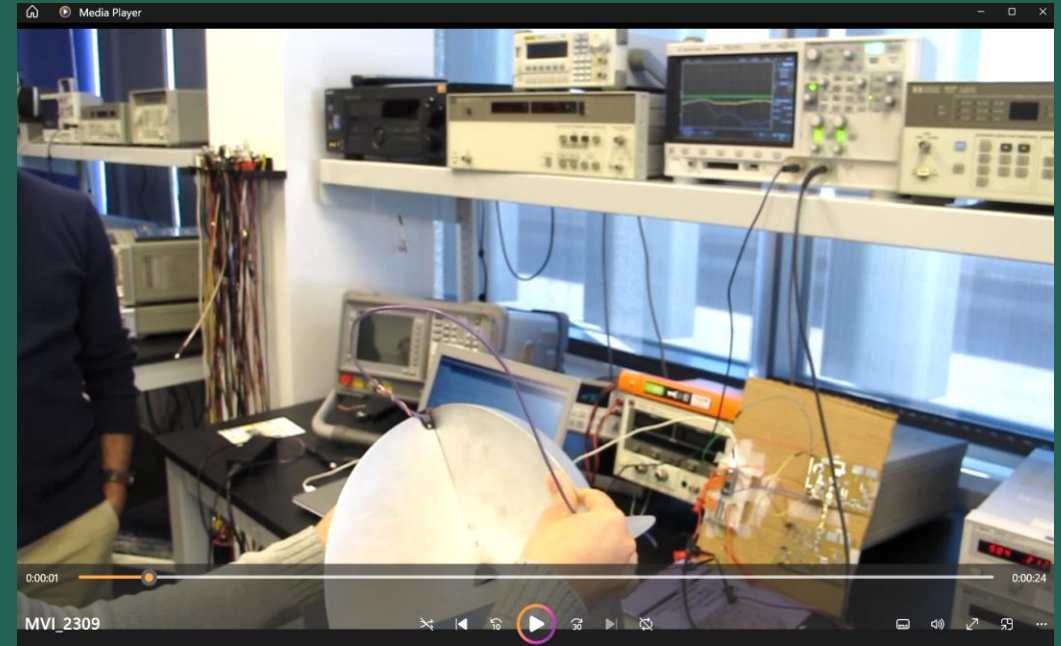
For the final project demos, we will run tests in the lab to prove that you can measure speed and distance. We may also go out to the street and check the speed of some cars driving by if it is not too cold at the end of the semester :-)

Exams: The final-exam will be this demonstration of your project plus a company report with each student writing his/her section.

Project Kit: You will need to purchase a project kit that contains the core components required to complete the labs/project. This kit may be obtained from the ECE shop and is in two parts. *Each student needs to purchase one individual kit and one group kit.* Some of the larger parts as well as fabrication of PCBs will be available with proof-of-purchase.



Example Class Project at 5.8 GHz: FMCW Radar (See Episode 2)



Credit: KSU ECE Students

Example Lab3 Assignment (Page 1)

(Spring 2020)

ECE 764 Lab 3 - Introduction to Microstrip Circuits Due Friday, March 20, 2020

Purpose

This lab will familiarize you with designing, building, and testing microwave circuits on PC boards, in preparation for the upcoming radar project. You will be introduced to Keysight's ADS software that will be used extensively in the project. You will also learn several important issues with board design including parasitic inductances of vias and capacitances of PC board traces. While often a problem, we will also see how these parasitics can be embraced in microwave design to form bandpass filters. Finally, you will build and test microwave amplifiers and filters to learn about circuit layout, surface-mount construction techniques, S-parameter measurement using vector network analyzers (VNAs), and some important system design issues such as amplifier compression points and stability.

Teams

As before, the assignment is constructed for *teams of two persons*. You should help each other out. However, in this project **each person is responsible for their own simulations, circuit measurements, and associated writeup sections**. By having each person focus on a different amplifier, frequency of operation, etc., the lab will allow teams to learn about the range of options you may encounter in the upcoming project.

Lab Overview

Circuits to be simulated, designed, constructed, measured, and documented include:

- Simple simulations of PC board vias and traces to learn about inductive and capacitive parasitics.
- Bandpass filters.
- Lambda/4 bias decoupling lines used in amplifier biasing.
- ~~Single-stub and lambda/4 impedance-transformer-based matching networks (simulation only).~~
- Building and measuring amplifier boards to learn about their performance.
- Using "cal kits" and identifying associated "reference planes" when measuring S-parameters.
- Measuring the cascaded response of amplifiers.
- Adding bandpass filters and attenuation "pads" to address excess low-frequency gain and potential stability problems in amplifier cascades.

Operating Frequencies

In the project we may have circuits operating at *2.45 or 5.2 GHz*. **Each person on a team must select a different frequency to use in their investigations.**

2/24/2020 WBK

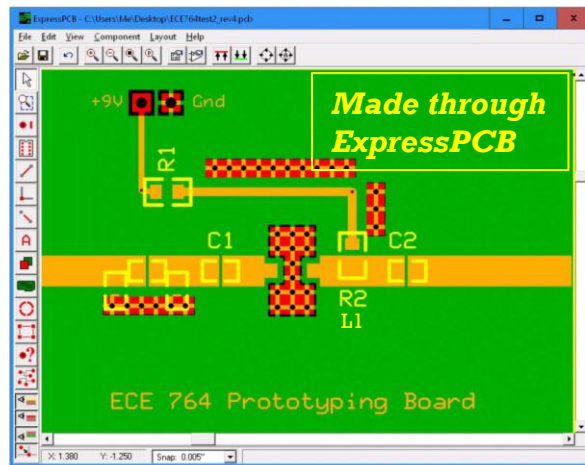
Lab Assignment (Pgs 2 – 4)

(Spring 2020)

PC Boards and Amplifiers

For this lab we will use 0.062" (62mil or 1.6mm) thickness, double-sided "FR4" (fire-retardant fiberglass-epoxy) printed circuit boards. Connections to test equipment will be through female SMA end-launch connectors. You will work with pre-designed amplifier boards and populate them with amplifier ICs and surface-mount biasing components. In addition, you will prototype simple bandpass filters, build them, and combine them with your amplifier(s).

Each person on a team must chose a different amplifier (LEE-39 or Gali-2). Be sure to read the datasheets for the amplifiers before making final selections to be sure you understand their biasing and performance, and can get reasonable gain at the frequency you selected above. A picture of the PC boards on which you will build your amplifier circuit is shown below.



Lab Instructions

The sections below give an outline of what you should do and document in this lab. Additional details for some parts (e.g. using ADS, building circuits, and operating the VNA equipment) will be presented in class. As always, if you are not sure what to do or how to do something, ask someone.

Part I Interconnect, Via, and Component Parasitics at Microwave Frequencies

At high frequencies, wires or PC board traces can no longer be treated as simple nodes. When their length exceeds more than about 1/20th of a wavelength (e.g. 1.5 mm at 5 GHz for $v_p = 0.5c$), the phase shifts from one end to the other are significant enough that they cannot be ignored. In general, the line has distributed inductance and capacitance that must be modeled using the transmission-line theory as we have elaborated in class.

Engineers use transmission-line theory extensively to model PC board interconnect behavior in the GHz frequency regimes. However, if the line is shorter than 1/8th of a wavelength, one can sometimes simplify and talk about the "parasitic" inductance of a grounded trace or via or the parasitic capacitance of an open trace. For longer lines (in particular, $\frac{1}{4}$ lambda), much more interesting things occur as discussed in class. This part of the lab investigates some of these issues using the ADS simulator.

1. Behavior of ground connections at microwave frequencies

- Read the handout on operation of ADS and then draw a schematic consisting of a short (400 mil = 0.4 inch) length of trace on a printed circuit board, with one end connected to ground. Use the MLIN element from the ADS TLines-Microstrip components menu, and the ground symbol from the top menu bar.
- Enter a width value of 10 mil and a length of 400 mil for the PC board trace modeled by the MLIN element. Then place an "MSUB" item from the TLines-Microstrip menu and configure it with the parameters of our FR4 PC board material: (H=62 mil, $\epsilon_r=4.6$, TanD=0.01).
- Switch to the Simulation-S_Param menu and place a Term (with ground) on the other end of the MLIN, and an "SP" simulation setup item anywhere on the schematic. The Term item acts as a 50 Ohm source or load and will be used to emulate measurements made with a network analyzer. Edit the simulation setup item to sweep from 1 MHz to 8 GHz, with a step size of 10 MHz.
- Print out a readable copy of your resulting schematic to include in your writeup
- Run the simulation using the Gear icon on the top menu bar and plot the result by placing a Smith Chart item in the resulting display window and selecting "S(1,1)" to plot.
- Place markers at the lowest and highest frequencies, and at your particular frequency (2.45 or 5.2 GHz). Print out the result. Notice the curve begins near $Z = 0$ as one would expect for a grounded trace at 1MHz, where the line is much shorter than a wavelength. At higher frequencies, the impedance is of the form $Z = 0 + jX$, which is inductive, and it eventually wraps around to an open-circuit on the right and then into the capacitive region of the chart past 5 GHz.
- Below the frequency where $Z = 0 + j50$, the impedance is approximately proportional to frequency, so that this shorted line can be reasonably well modeled as an inductance to ground at this lower frequency range. Place additional markers to find the frequencies where the Z value is $+j50$, where it is $+j25$, and where it is $+j12.5$ to verify this. Is the reactance reasonably proportional to frequency?
- Use these values to estimate the inductance of the wire. What is this approximate inductance per unit length implied? Does it agree roughly with the often used estimates of 1 nH/mm or 20 nH / inch?
- Modify the trace to be 100 mils wide and repeat to determine the inductance per unit length. How does width of the trace affect the inductance?
- At a sufficiently high frequency, the impedance of a grounded trace actually becomes an *open circuit*. Find this frequency by placing a marker at the $Z=\infty$ point on the chart (right side) and use it to estimate the velocity of propagation on the 100 mil x 400 mil line. (Recall that it should become an open circuit when the length of the line is $\lambda/4$). Find the velocity of propagation expressed as a percent of c .

2. Behavior of vias to ground on PC boards

One difficulty we will need to deal with when building our radars if we use 1/16" thick FR4 board is the fact that even if there is no trace length leading to the ground connection, the vias needed to make connection to the back-side ground plane will show inductive behavior themselves. For example, the ground pin on our amplifiers will not really be truly at ground. It will be separated from ground by an inductive connection through the via (as well as its physical pin). In this part, you will estimate how large this inductive impedance may be at your chosen frequency and look at some solutions to the problem.

- Replace the ground symbol on the right side of your schematic with a VIAGND item from the TLines-Microstrip menu.
- Edit the MLIN to make it only 5 mils long (effectively 0), so that we will be simulating only the via's inductance. Print the resulting schematic.
- Simulate and use markers to find the complex impedance and then the inductance at your frequency. Print the resulting Smith Chart and write the inductive reactance in Ohms and the implied inductance on it.
- Since this value is pretty high relative to the signal impedances (50 Ohm source and load values) elsewhere in the circuits we will build, microwave engineers often use multiple vias (as well as multiple ground pins on the ICs). Add a second VIAGND in parallel, but connect it to the first one using a short MLIN to model that it is not physically in the same location. Use a 100 mil wide line with a 25 mil length to represent a realistic distance given the hole sizes in the via.
- Simulate and comment on how much it lowered the inductive parasitics in the ground-via connection. Why is it not half of the previous value?
- Examine the amplifier board on page 2 and note that 7 vias are used on each of the two amplifier ground pins. Estimate what the net inductive parasitic impedance would be in this case. (Don't sim. Just reason through it to arrive at an educated guess. Sims are great - but they don't provide as much insight as actual thinking !)

3. Behavior of open-circuit "stubs" on PC boards

Just as a shorted line acts as an inductance and can become an open, an open line can act as a capacitance and become a short at sufficiently high frequency. Later, we will use this to make simple LC bandpass filters in our experiments and possibly in our radars. In this part, we will just look at the effects with simulation.

- Remove the vias from the previous schematic and restore the original trace to its 400 mil length (with 100 mil width).
- Simulate the resulting open-circuit line and find the capacitance per unit length and propagation velocity. Explain how you did this and print your schematic and Smith chart results to back-up your estimates.

Part II Designing and simulating microstrip circuits

Most microwave amplifiers are designed to have close to 50 Ohm input and output impedances so that they can use 50 Ohm transmission lines to connect to other circuits without the need to deal with impedance transformations. While such amplifiers purchased commercially are typically "well-matched", user-designed matching networks can sometimes be useful to achieve somewhat higher gains. To save time, we will go over this topic in class, but not do it here. Instead, we will concentrate on the basics of biasing, decoupling, and DC-blocking in amplifiers, and on their performance in terms of the maximum power levels they can be used at. This will

Lab Assignment (Pgs 5 – 7)

(Spring 2020)

be needed when you do your radar designs. We will also look at some simple bandpass filter design techniques.

1. Simulating amplifiers and effects of bias lines and DC blocking capacitors

- Create a new ADS schematic using an S2P item from the Data Items menu with a 50 Ohm Term on both the input and the output. Download the S-parameter model file from Minicircuits or our class webpage and set the File parameter to point to the S2P model file.
- Simulate from 100 MHz to 8 GHz (without any MLIN traces at input or output) to verify the S11 and S21 (input impedance and gain behaviour) in the datasheet. Just plot dB graphs, not Smith charts. Compare with the datasheet.
- Modify your schematic by adding a lambda/4 bias decoupling line at the amplifier output pin. Such lines are often used to supply Vdd power to the device as discussed in class. The lambda/4 decoupling line should be a simple 10 mil wide MLIN trace with length of lambda/4 at your operating frequency. Place a 10nF capacitor to ground at the end opposite the amplifier. Do not include any resistors or inductors here, since we want to investigate the frequency selectivity caused by the lambda/4 decoupling line first. Adjust the line's length as needed to account for the via inductance and the length of the 0603 capacitor and pads we will use in the actual construction.
- Next, add DC blocks (AC coupling caps) at the input and output. For these DC blocks (AC coupling caps), use the C component from the Lumped Components menu as for the bypass cap, but also add a 40 mil long by 20 mil wide MLIN trace to model the impedance-bump the capacitor creates (since it is not 105 mils wide, and the transmission line in this part will therefore have a higher Zo value than 50 Ohms). Use reasonable standard-value capacitances that will have an impedance of about 0.1 Ohm at your targeted operating frequency.
- Simulate S21 from 100 MHz to 8 GHz and confirm the gain at your targeted frequency is not significantly changed from the datasheet and simulation values before the bias lines were added. Why is the gain now less than before at low frequencies? (There may be multiple reasons).
- Simulate S22 and see if the output return loss is OK at your frequency. What is it at low frequencies and why?
- Print your schematic and your S21 and S22 plots and include in your writeup to support your answers.

3. Filter Design

- Using the techniques discussed in class, design a one or two pole bandpass filter at your personal selected frequency, with a fractional bandwidth of 10% to 30% and add it on the input side of your amplifier. NOTE: Each person on your team should build a different type of filter (in addition to being at a different frequency than that of your teammate). For example, one person may make the inductor needed out of an open-circuit line which is slightly longer than lambda/4, while the other may make the inductor out of an electrically short grounded line. Or one person can do a single-pole while the other does a two pole design.
- Create a schematic of the filter in Agilent ADS. Simulate it alone (with Terms on both the input and the output) and refine it until the center frequency and bandwidth are correct to within about 5 percent, the shape is good, the insertion loss is reasonable, and the in-band input and output return loss values are at least 10 dB. Be sure to use appropriate "microstrip T's" to account for the stubs merging into the main line.
- Print/plot your final schematic and response plot(s).
- Add the filter to the input side of your amplifier and simulate the composite design. Plot and comment on S21. Does the filter help reduce gain at the frequencies outside of the designed frequency band? In particular, does it help to reduce low-frequency gain and make the gain concentrated reasonably well around f_c ?

Part III Measurement of Amplifier Parameters

In this last part, you will gain experience in biasing and soldering an amplifier and characterizing its performance. The construction of your amp will help you with design/layout decisions when you are called to make your own circuit boards in the project, and the data you collect will help you in making choices on which amplifiers to use in which situations and whether or not to add filters and/or attenuation "pads" to improve stability. More details will be provided in the coming week while the circuit boards are being sent out for fab, but here is a brief outline.

1. Biasing and Construction

- Decide how you want to configure the bias circuits per discussions in class. Assume a 9V DC supply (since that is what we will design for in the project) and see the device datasheet for your amp for more information on the current and voltage needed at the output pin.
- Solder the main components on your board, including the bias resistor and decoupling line capacitor, the DC blocking capacitors, the amp itself, and the SMA connectors.

2. Smoke-(and oscillation)-Test and Initial Scalar Gain Measurements

- Connect it to a power supply with the supply off and the voltage knob turned all the way down (CCW). Using the signal generator supply an RF input signal and monitor the output power. IMPORTANT: You should input a reasonably low level RF signal (e.g. -20 dBm) since the amplifier will not show the proper gain (and could even be damaged) if the input signal is too high and the output saturates.
- Connect the output of the amplifier to a spectrum analyzer.
- Slowly increase the DC supply voltage toward 12V while monitoring the current. Verify the amplifier draws a reasonable amount of current. Stop if the current exceeds 50 mA, which could be enough to damage it.
- Check to see if the circuit is stable. This is very important at microwave frequencies, as we will come to learn. Verify that the spectrum analyzer shows only the expected output (as well as possible low-level harmonics of course). This should be done on a spectrum analyzer that goes to at least 8 GHz or more, since the amplifier still has some gain at such frequencies. If there are other substantial magnitude spectral lines (other than harmonics) - you have stability problems that need to be fixed. If you do not see other spectral lines, try disconnecting the cable on the input and see if you see any outputs. Sometimes amplifiers will oscillate if their ports are not well terminated (in 50 Ohms).
- Verify that the amplifier has reasonable gain, recording the value and comparing it with the expected gain from the datasheet and your simulations. NOTE: The signal generator and spectrum analyzer may each be off by as much as a dB, and the interconnect cables could have a dB or more of loss, so don't expect exact gain values. Try to setup a good method to measure "insertion gain" to address these error sources. Record/document your procedure and measurement results.

3. Compression Point Measurements

- The amplifier input was specified as -20 dBm above since the amplifier gain will not be correct if it is "overdriven". In this part, we will find the critical input signal level where the gain begins to fall due to excess input signal power.
 - Slowly increase the signal input power in 1 or 2 dB steps. Record data of output power versus input power in dBm until the gain falls by at least 1 dB from the value at low input levels. Record the input power at which this happens as the *1dB input-referred compression point*. You should ideally adjust for cable loss here. How does the compression point compare to the published value? Which is the data sheet using, input referred or output

referred? (If output referred, divide by the gain to see what the data sheet thinks the input referred compression point is...

- Take additional data beyond the compression point until the output power does not increase any further. Typically you should go about 5 or 10 dB higher to see what the maximum output power is, assuming that is in the safe range. (**BUT - don't exceed the max allowed value at the input for the specific amplifier device or the maximum allowed output the test equipment can accept without damage !**)
- Plot your results (Pout vs Pin) in dBm and label the 1dB compression point - both input-referred on the horizontal axis and output-referred on the vertical axis. Also label the maximum output power.

4. Vector Network Analyzer (VNA) Measurement of S-Parameters

- Using the instruction sheet near the VNA, set its output power to -20 dBm to prevent overdriving the amp. This typically involves setting the Port-1 attenuator in the unit to 20 dB.
- Set the frequency range to cover 40 MHz to 8 GHz (for the Advantest VNA), or 2 to 12 GHz (for the HP8510 VNA).
- Calibrate the analyzer for measuring S21 using the cal-board's through path. Use the "response-cal" method. Then remove the cal board and put the amp in its place.
- Measure and plot/photograph the amplifier gain in a log-magnitude dB format. Set a marker at your frequency, record the gain value, and compare the measured value with the expected gain from the datasheet and from the previous measurement method. Is it reasonable, based on published values in the data sheet? How does it compare to the scalar measurement above? Discuss which may be more accurate and why and if you can't decide, discuss what your gain uncertainties are.
- Next, calibrate for S11 using the 1-Port cal method and the cal board's SOL standards (as discussed in class). Then measure/plot the amplifier input impedance using Smith Chart format. (Be sure to terminate port 2 in 50 Ohms during this measurement!)
- Set the markers at various frequencies, print/plot/photograph the screen, and compare the measured values with that in the datasheet and/or S2P file.
- Turn your board around so that you are measuring S12 (isolation) and S22 (output reflection coefficient/impedance) and repeat.

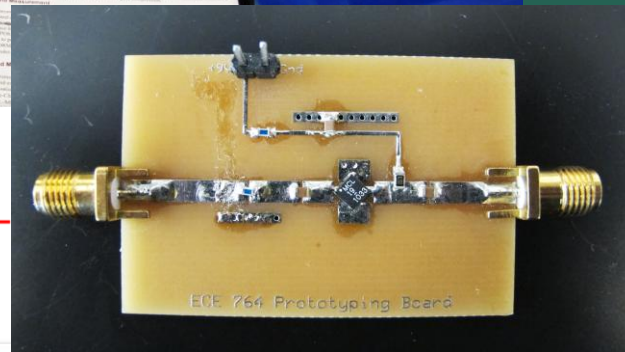
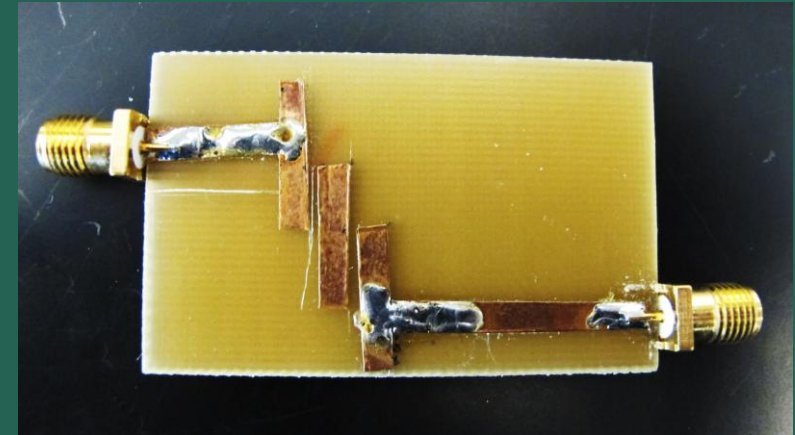
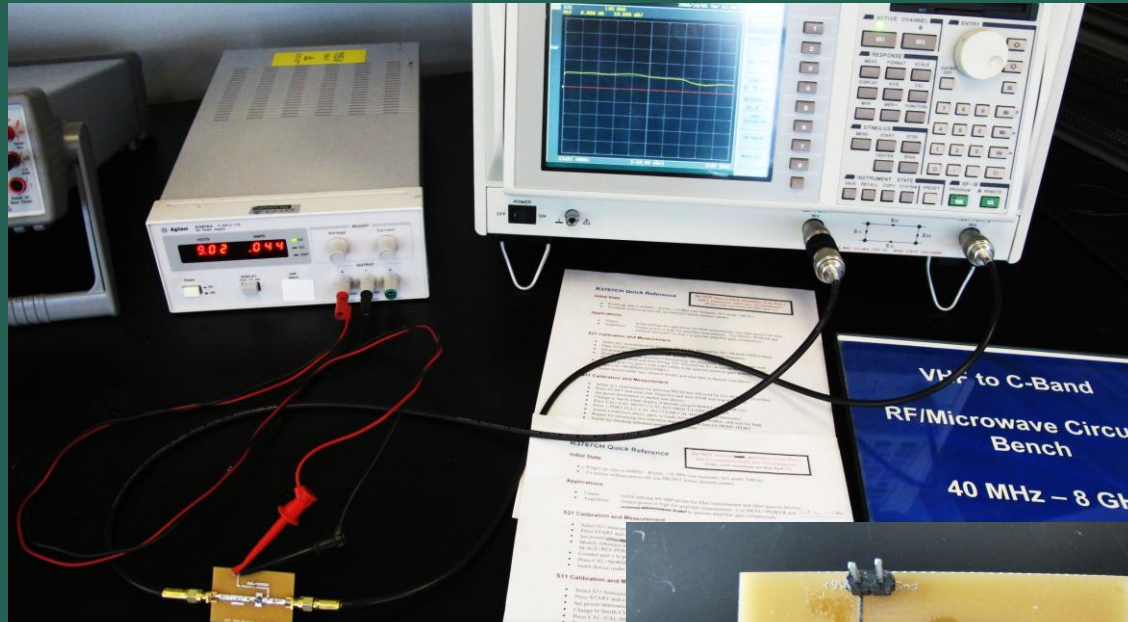
2. Filter Testing

- Build your filter designed in Part II. Use the one-sided blank board from your kit and copper tape. Solder the tape at the T or cross junction with the mainline. Measure the filter response from at least 100 MHz to 8 GHz. (Measuring to 6 GHz is OK in this part if your filter is designed for 2.45 GHz.)

3. Cascaded Amplifiers and Filters

- Try cascading with your partners' amp and measuring the overall gain. WARNING: You may need to use more than 20 dB attenuator setting to keep the input power low enough since the total cascaded gain may be more than 30 dB.
- Do the same, but with the filter added at the input of the cascade.
- If you experience problems with stability, try adding a 3dB "pad" at the input to the first amp (to address out-of-band reflections from the filter), or between the amps. See class discussion/notes for information on pads.

Construction/Testing (Spring 2020)



Surface Mount Monolithic Amplifier

DC-8 GHz

Product Features

- DC-8 GHz
- Output power, 10.2 dBm typ.
- Excellent package for heat dissipation, exposed metal bottom
- Flat output power to 10 GHz
- Aqueous washable
- Protected by US Patent 6,943,629



LEE-19+

Typical Applications

- Cellular
- PCS
- Communication receivers & transmitters
- Satellite communication, military

Function	Pin Number	Description
RF IN	1	RF input pin. This pin requires the use of an external DC blocking capacitor chosen for the frequency of operation.
RF-OUT and DC-IN	3	RF output and bias pin. DC voltage is present on this pin; therefore a DC blocking capacitor is necessary for proper operation. An RF choke is needed to feed DC bias without loss of RF signal due to the bias connection, as shown in "Recommended Application Circuit".
GND	2,4	Connections to ground. Use via holes as shown in "Suggested Layout for PCB Design" to reduce ground path inductance for best performance.

Mini-Circuits
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RF/MICROWAVE COMPONENTS

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Page 1 of 4



Today's "Lecture"

Announcements

*Welcome to Episode 4
(Final episode in 4-part introduction)*

See Episodes 1 through 3 for

- *Definitions of "microwave",*
- *Example semester projects, and*
- *Day 1 lecture material*

Today's Topics

- ✓ *Example Project and Lab Assignments*
- ➡ *Radio Design 201 Lab and Project Ideas*

Free Software Examples

"Low Cost" Test Equipment Examples

Possible Radio Design 201

Labs/Demos

- Antenna simulations and experiments using EZNEC, TinySA and NanoVNA (See also Antenna Briefs series)
- Simulation, construction, and measurement of microstrip lines, filters, and amplifiers using QucsStudio, and NanoVNA

Radio Design 201

“Project” Ideas

- 2.4 GHz ISM Band Doppler Radar with Dish Antenna
- 2.4 or 5.8 GHz Doppler + FMCW Radar
- 2.4, 3.4*, or 5.8 GHz Transverter (to/from VHF)
- 5 or 10 GHz Moon-Bounce (EME*) -- as “stretch goal” ☺

(* Amateur/Ham Radio License Required for transmit ...)

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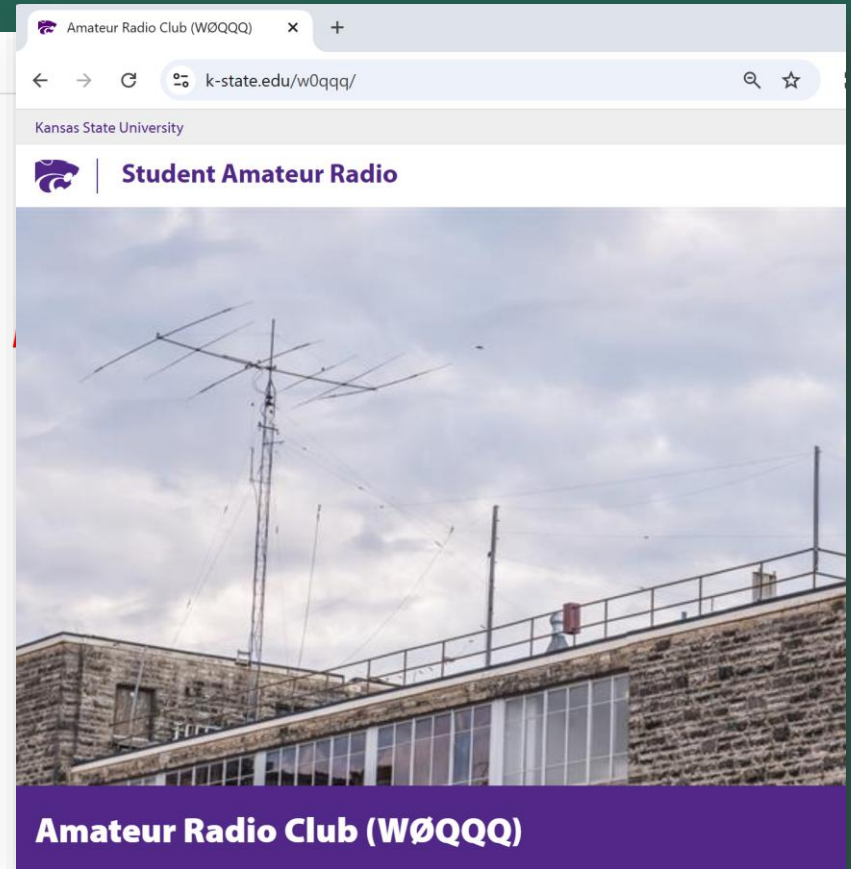
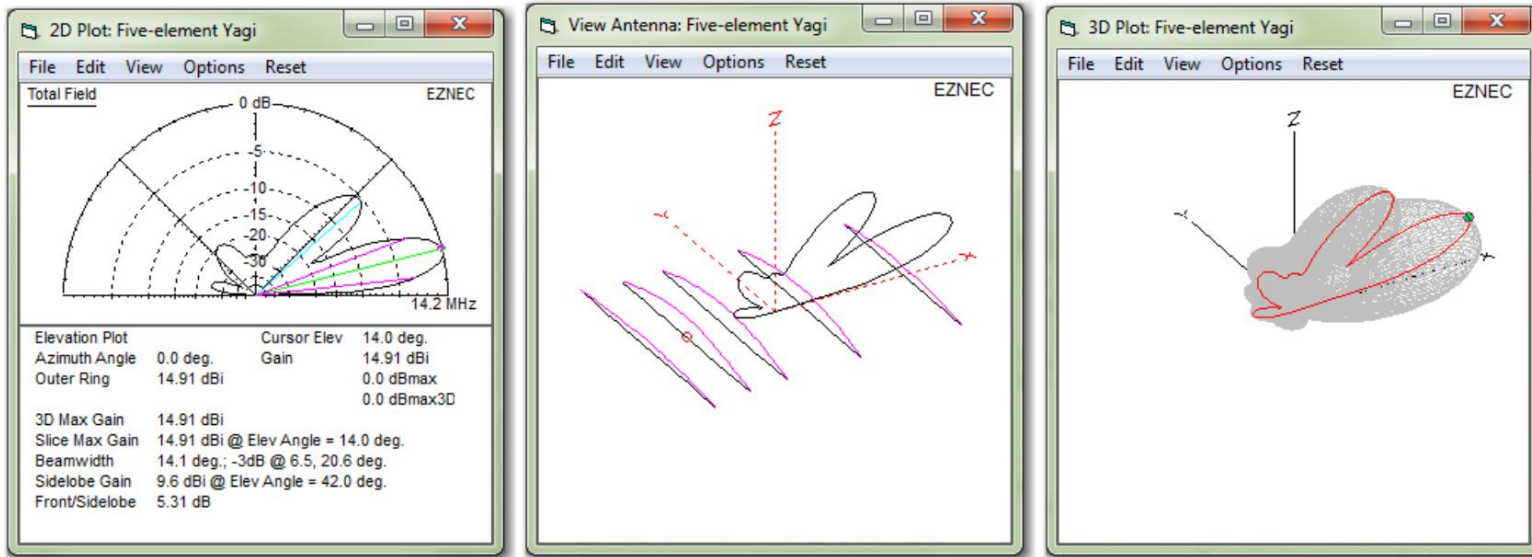
- ✓ *Example Project and Lab Assignments*
- ✓ *Radio Design 201 Lab and Project Ideas*
- ➔ *Free Software Examples*
- "Low Cost" Test Equipment Examples*

Free Antenna Simulators

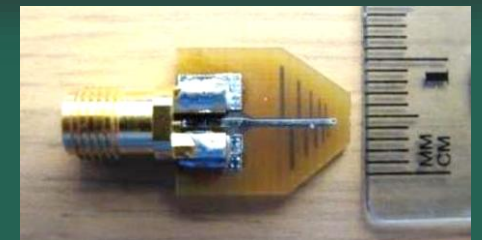


EZNEC Antenna Software by W7EL

FREE - EZNEC Pro+ v. 7.0 is now available! -



Above: Screen shots from several **EZNEC** displays. **Right:** 3D far field pattern, with 2D elevation "slice" highlighted. Any azimuth or elevation slice can be highlighted. **Center:** View Antenna display, showing the "wires" making up the model of the five-element beam, with currents and 2D slice superimposed to show orientation. Several other items, such as currents and wire numbers, can be added to this display. **Left:** 2D display showing detailed information about the selected slice.



Some Free EM Simulators

https://www.sonnetsoftware.com/products/lite/

Sonnet Lite™

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System Requirements
Support

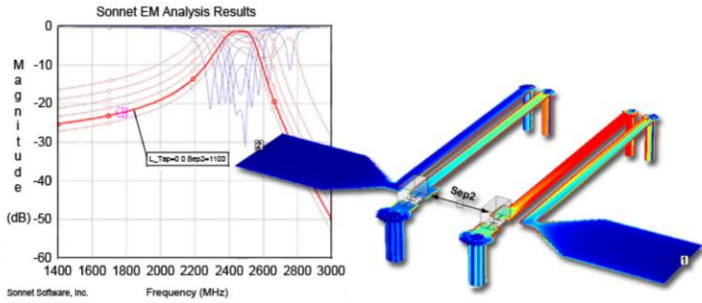
FREE 3D Planar High-Frequency Electromagnetic Software

New version (18.53) is now available. This version has many new features and expanded capabilities. For Sonnet Lite Plus users, this free version includes all Plus features.

Sonnet Lite™ is a free feature-limited version of Sonnet's professional Sonnet Suites, which provides EM analysis to thousands of companies across the globe. Many major manufacturers of high-frequency components and boards depend on Sonnet to analyze their predominantly planar high-frequency designs from 1 MHz through several THz.

Download it right now - it's FREE!

Sonnet Lite provides a full-wave EM solution for 3D planar circuits such as this reduced-size edge-coupled microstrip bandpass filter with Ideal Surface Mount Capacitors:

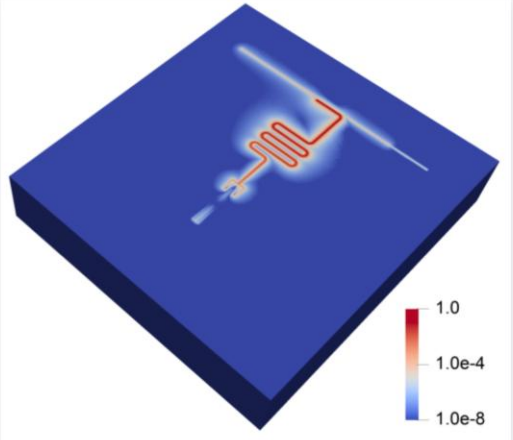


The image shows a 3D model of a microstrip bandpass filter on a blue substrate. To the left is a graph titled 'Sonnet EM Analysis Results' showing Magnitude (dB) on the y-axis (ranging from -60 to 0) versus Frequency (MHz) on the x-axis (ranging from 1400 to 3000). The graph displays a passband with a peak at approximately 2400 MHz. A 3D model of the filter is shown to the right of the graph, with a 'Sep2' label indicating a gap in the structure.

Open-Source Electromagnetic Sim... x +

epsilonforge.com/post/open-source-electromagnetics/

EpsilonForge Home Blog About Services Contact Us



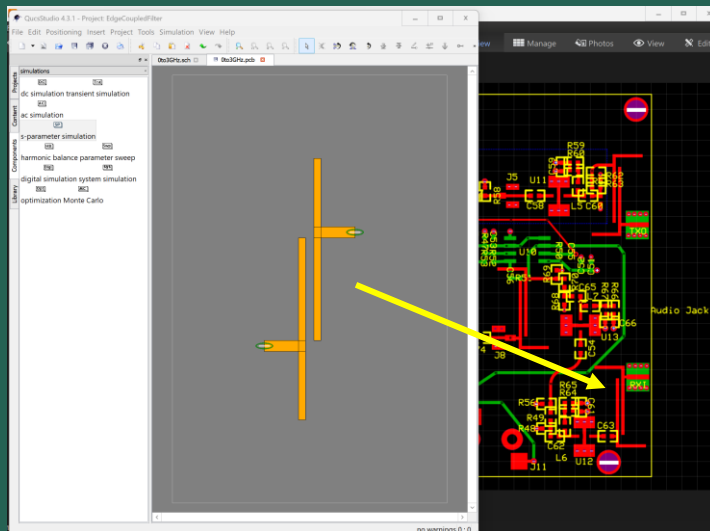
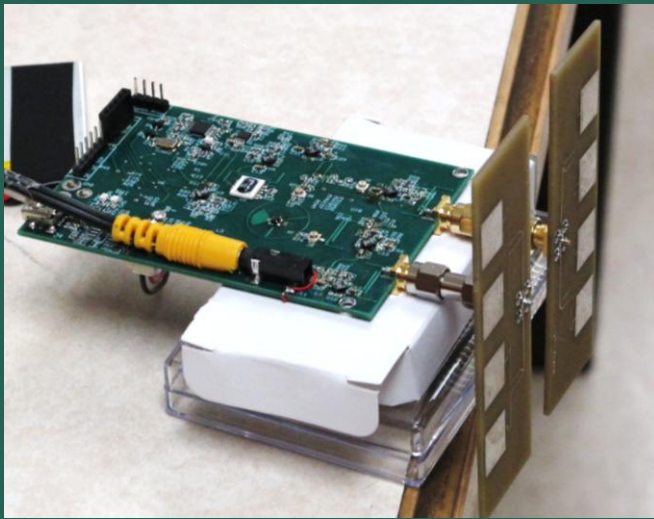
Mar 19, 2025

Open-Source Electromagnetic Simulation: FDTD, FEM, MoM

An up-to-date review of the best open-source projects in Computational Electromagnetics, including FDTD, FEM and BEM/MoM methods.

The image shows a 3D visualization of an electromagnetic simulation. It depicts a blue rectangular substrate with a red circuit trace on top. A color scale on the right indicates field intensity, ranging from 1.0e-8 (blue) to 1.0 (red). The simulation shows the field distribution around the circuit trace.

Microstrip Simulation with QucsStudio (aka "uSimmics")

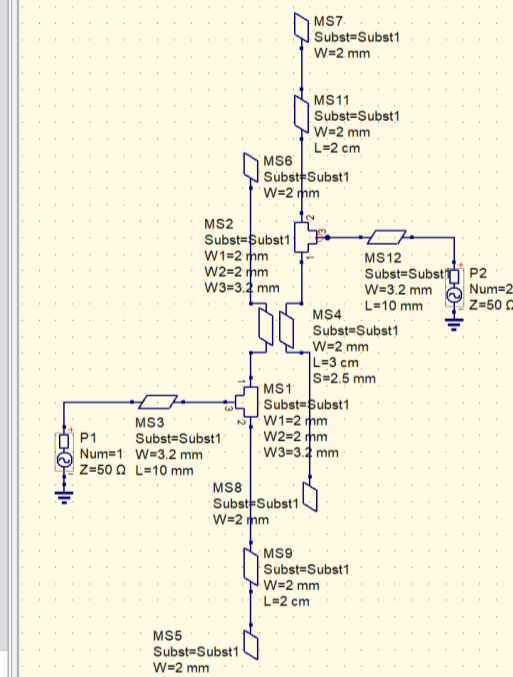


QucsStudio 4.3.1 - Project: EdgeCoupledFilter

File Edit Positioning Insert Project Tools Simulation View Help

transmission lines

- Transmission Line 4-Port Line
- Coupled Transmission Line
- Twisted-Pair Coaxial Line Substrate
- Bond Wire Microstrip Line
- Coupled Microstrip Line
- Microstrip Corner
- Microstrip Mitered Bend
- Microstrip Step Microstrip Tee
- Microstrip Cross Microstrip Open
- Microstrip Stub Microstrip Gap
- Microstrip Via Interdigital Cap
- Coplanar Line Coplanar Open
- Coplanar Short Coplanar Gap
- Coplanar Step Stripline
- Coupled Stripline Stripline Step
- Stripline Bend
- Stripline Mitered Bend



MS7 Subst=Subst1 W=2 mm

MS11 Subst=Subst1 W=2 mm L=2 cm

MS6 Subst=Subst1 W=2 mm

MS2 Subst=Subst1 W1=2 mm W2=2 mm W3=3.2 mm

MS12 Subst=Subst1 W=3.2 mm L=10 mm

MS4 Subst=Subst1 W=2 mm L=3 cm S=2.5 mm

MS1 Subst=Subst1 W1=2 mm W2=2 mm W3=3.2 mm

MS8 Subst=Subst1 W=2 mm

MS9 Subst=Subst1 W=2 mm L=2 cm

MS5 Subst=Subst1 W=2 mm

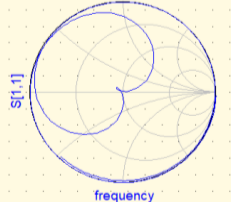
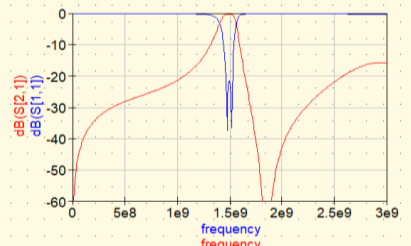
P1 Num=1 W=3.2 mm Z=50 Ω L=10 mm

P2 Num=2 Z=50 Ω

s-parameter simulation

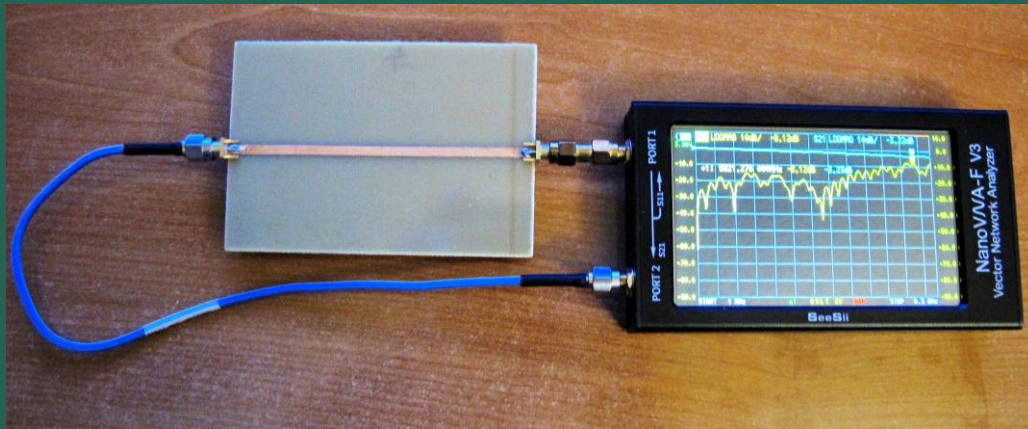
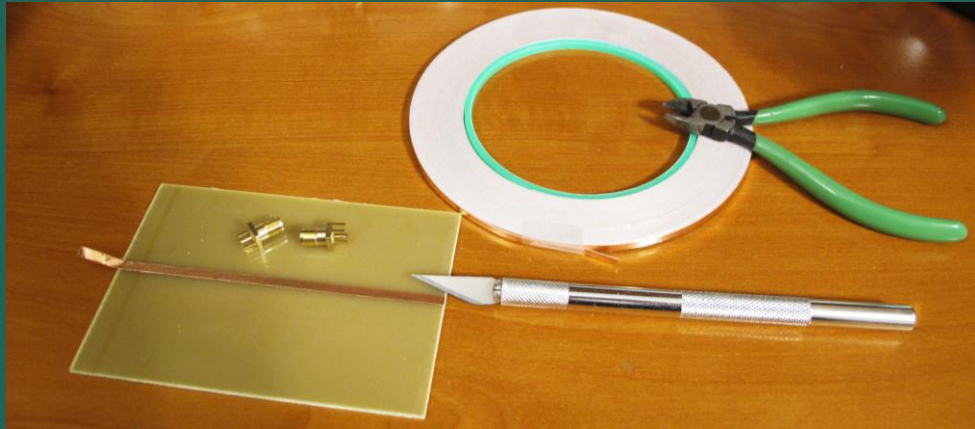
SP1
Type=lin
Start=0.01 GHz
Stop=3 GHz
Points=501

Subst1
er=4.8
h=62 mil
t=35 μ m
tand=2e-4
rho=1.72e-8
backside=Metal



no warnings 0 : 0

Microstrip Construction and Measurement



QucsStudio 4.3.1

File Edit Positioning Insert Project Tools Simulation View Help

BasicLineWithZbump.sch

Subst1
er=4.8
h=1.6 mm
t=35 μ m
tand=4e-2
rho=1.72e-8
backside=Metal

s-parameter simulation
SP1
Type=lin
Start=0.1 MHz
Stop=1.5 GHz
Points=1001

frequency: 879MHz
dB(S[1,1]): -44.4

frequency: 448MHz
dB(S[1,1]): -22.5

dB(S[2,1])
dB(S[1,1])
frequency

frequency

QucsStudio Transmission Line Calculator 4.3.1

File Help

Choice Microstrip Line

Parameters
Frequency 1 GHz

Dimensions
W 3.2 mm
L 100 mm

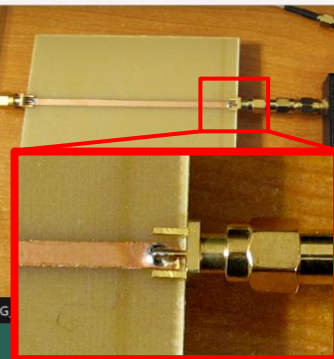
RF Properties
Z0 46.5422 ohms
Angle 228.491 degree

Results
Skin Depth: 2.0873 μ m
effective ϵ : 3.62054
Conductor Losses: 0.0316871 dB
Dielectric Losses: 0.00315161 dB
Radiation Losses: 0.041546 dB
Single-Mode Range: 0 Hz ... 17.8 GHz

Copy Component to Clipboard
Copy to Clipboard inclusive Circuit

Properties
 ϵ 4.8
tan δ 2e-4
Resistivity 1.72e-8
Conductor μ 0.999994
Roughness 0.1 μ m
T 20 μ m
H 1.6 mm

9/18 IMG Date: 12/27/2025 11:06:15 AM 30%



Today's "Lecture"

Announcements

*Welcome to Episode 4
(Final episode in 4-part introduction)*

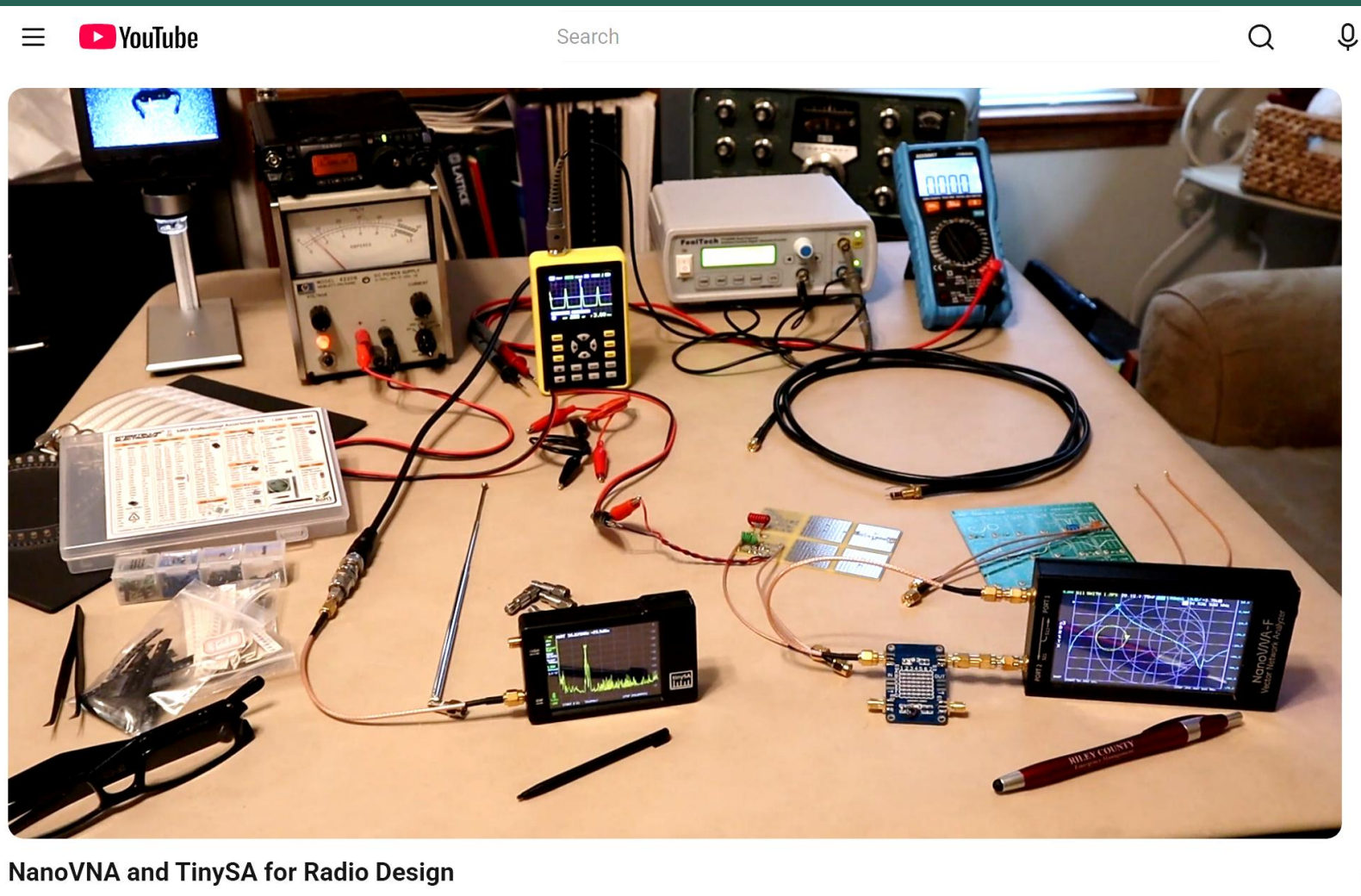
See Episodes 1 through 3 for

- *Definitions of "microwave",*
- *Example semester projects, and*
- *Day 1 lecture material*

Today's Topics

- ✓ *Example Project and Lab Assignments*
- ✓ *Radio Design 201 Lab and Project Ideas*
- ✓ *Free Software Examples*
- ➡ *"Low Cost" Test Equipment Examples*

Home-Office RF/Microwave Lab (2021)



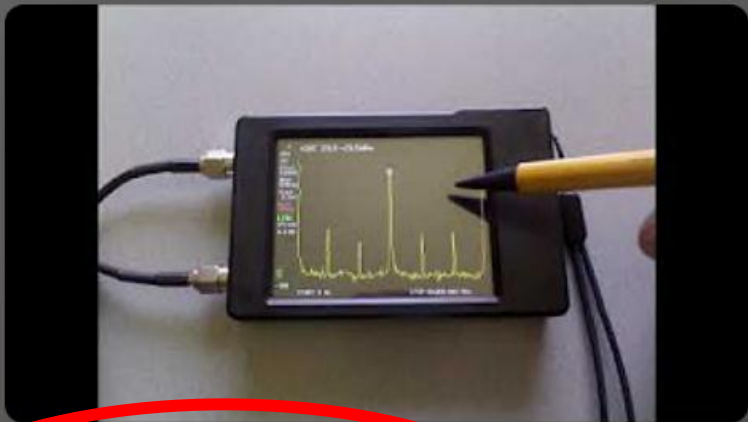
NanoVNA and Radio Frequency / Mi... ×

MegawattKS - 1 / 12

↻ ↺

- ▶ **NanoVNA and TinySA for Radio Design**
MegawattKS
18:57
- 2 **NanoVNA - Overview and antenna measurements with...**
MegawattKS
9:48
- 3 **NanoVNA Demonstrations - Coax line reflections and Smi...**
MegawattKS
20:26
- 4 **NanoVNA - Measuring RLC Components**
MegawattKS
30:16
- 5 **NanoVNA - Measuring Impedances**
MegawattKS
14:03
- 6 **NanoVNA as a synthesized CW signal generator**
MegawattKS
16:15
- 7 **NanoVNA Calibration - When, Why, and How to cal a VNA**
MegawattKS
25:55

TinySA Spectrum Analyzers



tinySA

 by Erik Kaashoek

Playlist · 53 videos · 135,837 views

A series of videos exploring the tinySA and the tinySA Ultra, two small but well performing spectrum anal...more

38

tinySA
quick comparison of
clone vs genuine

4:56

tinySA quick comparison of clone vs genuine

Erik Kaashoek · 19K views · 4 years ago

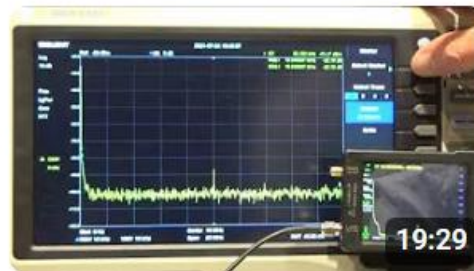
39



tinySA and noise source

Erik Kaashoek · 13K views · 4 years ago

40



tinySA versus Siglent SSA3021X+

Erik Kaashoek · 17K views · 4 years ago

TinySA and TinySA-Ultra Spectrum Analyzers

www.amazon.com/s?k=tinysa+ultra&adgrpid=1335908335883717&hvadid=83494551121902&hvbm=bp&hvdev=c&hvlocphy=921... ☆ ✓ ⚙️ | ☆ 👤 ... 🗺️ Chat

AURSINC

Upgraded Tinysa and Tinysa ultra+ for Ham Radio

Sponsored ⓘ | Top 10 best-selling brand in spectrum analyzers | [Shop AURSINC >](#)



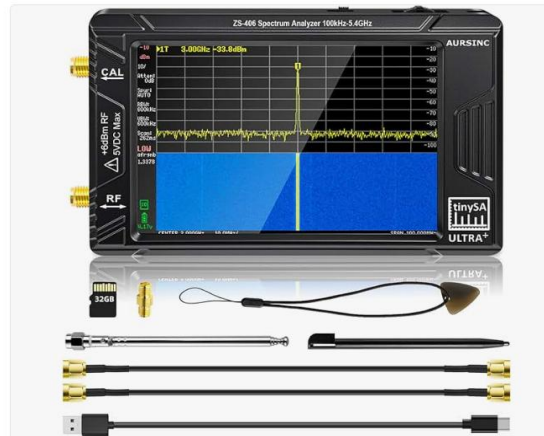
Portable Tinysa Spectrum Analyzer, AURSINC V0.3.1 Handheld Frequency Analyzer, Signal Generator 100kHz to **960MHz** MF/HF/VHF UHF Input ESD Prot...

4.5 ★★★★★ 412

\$65.89

List: \$75.89

prime



AURSINC TinySA Ultra+ ZS406 Spectrum Analyzer, 4.0 Inch 100kHz-**5.4GHz** Handheld Frequency Analyzer with 32Gb Card, HW V0.4.6, 2-in-1 Signal Generator...

4.8 ★★★★★ 140

-10% \$168.99

\$186.90



AURSINC TinySA Ultra+ ZS407 Spectrum Analyzer, 4.0 Inch 100kHz-**7.3GHz** Tinysa Handheld Frequency Analyzer, 2-in-1 RF Signal Generator 100kHz to 900MHz MF...

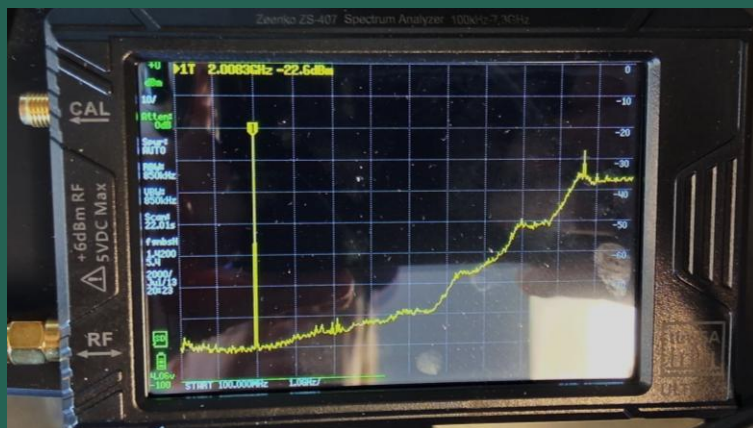
4.1 ★★★★★☆ 18

\$260.90

prime

TinySA Ultra+ ZS407

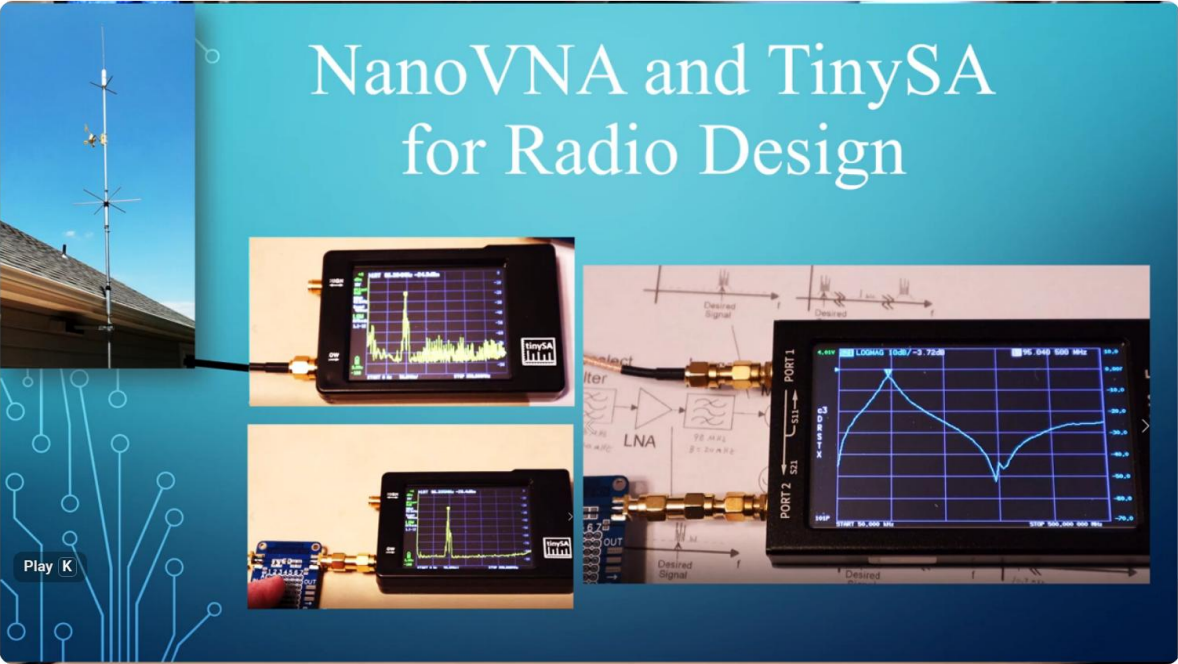
2 to 10 GHz (over-range test)



NanoVNA Instruments

youtube.com/watch?v=B7DFOq9rM_M

YouTube Search



NanoVNA and TinySA for Radio Design


MegawattKS
12.9K subscribers

Analytics Edit video

907 likes Share Promote Ask

34K views 5 years ago

Using the NanoVNA and TinySA to illustrate how radio / wireless devices work. This video concentrates on showing the front-end filtering and amplification in a superhet FM broadcast band receiver design. It also overviews some key instruments that have become reasonably affordable in recent years, allowing a home RF lab to be assembled for a few hundred dollars. ...more



AURSINC Upgraded NanoVNA-F V2 Vector Network Analyzer, 50KHz-3GHz HF VHF UHF VNA Antenna Analyzer, 4.3inch Touchscreen, 5000mAh Battery,...

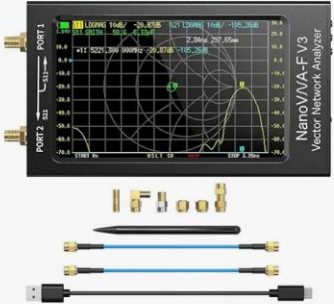
4.4 ★★★★★ (82)
50+ bought in past month

\$125⁹⁰ List Price: \$139.99
Exclusive Prime price

prime Two-Day
FREE delivery Fri, Apr 3

Add to cart

Purchased Dec 2025



Seesii NanoVNA-F V3 Vector Network Analyzer, [Upgraded] 1MHz-6GHz 4.3 Inch HF VHF UHF VNA Antenna Analyzer, Measuring S-Parameter Voltage...


4.4 ★★★★★ (32)

\$299⁹⁹

prime
FREE delivery Sat, Apr 4

Add to cart

Purchased Feb 2025



[Upgraded] AURSINC NanoVNA-H Vector Network Analyzer, 9KHz -1.5GHz Latest HW V3.7 HF VHF UHF Antenna Analyzer, Measuring S Parameters, SWR, Phase,...

4.6 ★★★★★ (1.5K)
500+ bought in past month

\$47⁴⁹ Typical price: \$49.99
Exclusive Prime price

prime Two-Day
FREE delivery Fri, Apr 3

Add to cart

Lower-Cost 6 GHz “NanoVNA”

amazon prime Deliver to William Manhattan 66503 Industrial & Scientific Search Amazon Hello, EN Acco

LiteVNA-64 VNA Analyzer 50KHz-6.3GHz Portable Vector Network Analyzer Antenna Analyzer 4" Display

Brand: TZT
4.1 ★★★★★ (27) | Search this page
Amazon's Choice

\$179⁰⁰
Or \$44⁷⁵ /2 weeks (x4). Select from 2 plans
✓prime Two-Day
FREE Returns

Usable to 8+ GHz!

Brand	TZT
Power Source	Battery Powered
Style	Digital
Color	Black
Item Weight	8.27 Grams

About this item

- with multiple internal RF switches for S11 and S21 measurements, and IFFT calculations for TDR and DTF measurements.
- the LiteVNA-64 now brings faster scanning speeds and more scan points in addition to a wider measurement range
- Combined with an easy-to-use interface consistent with the NanoVNA, the LiteVNA-64 can now be easily used as a field test tool.
- With a measurement range of up to 6.3GHz, the LiteVNA-64 is capable of meeting common amateur radio and IoT applications, as well as emerging 5GHz testing, enabling the application of the latest 5.8GHz wifi and 5.8GHz image transmission

› See more product details


Click to see full view

Ask Rufus

Can it measure antenna performance?

Does it come with a carrying case?

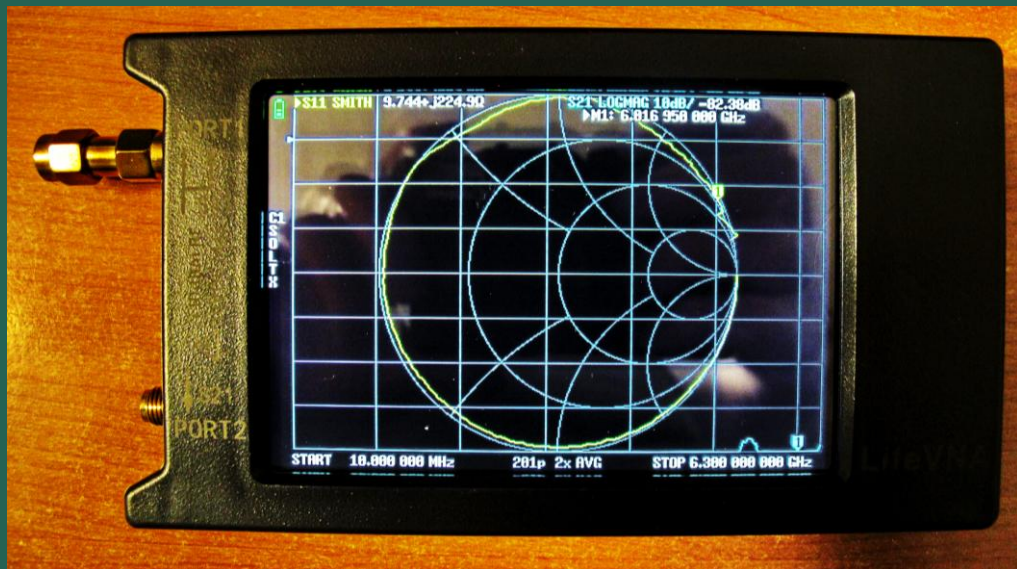
Is it compatible with Windows? Ask something else



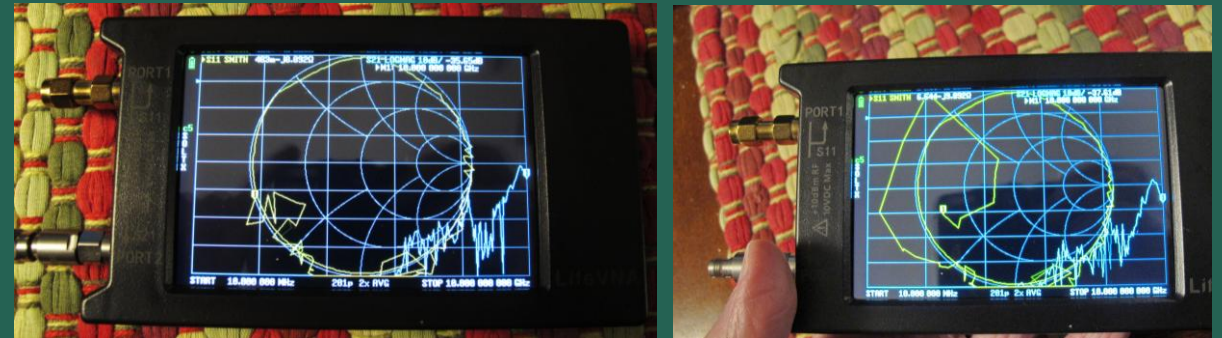
LiteVNA-64 Cal Verifications

Including over-range Testing

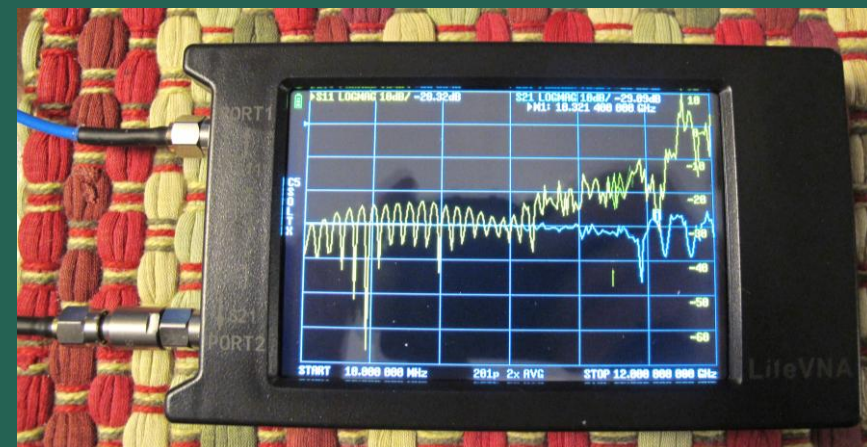
Calibration check/verification:
Looking at 2 cm open line after
calibration thru rated 6.3 GHz



S11 Cal-verification thru 10 GHz



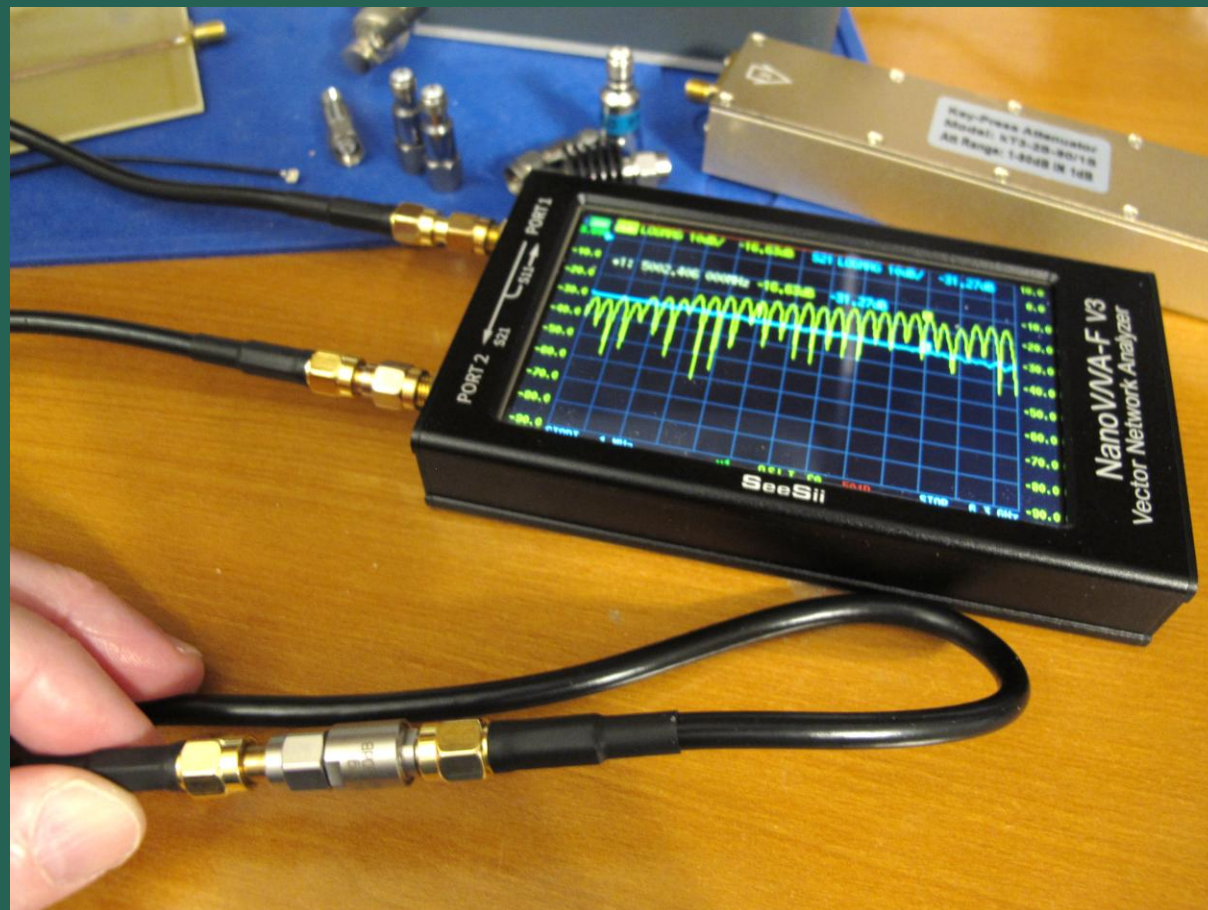
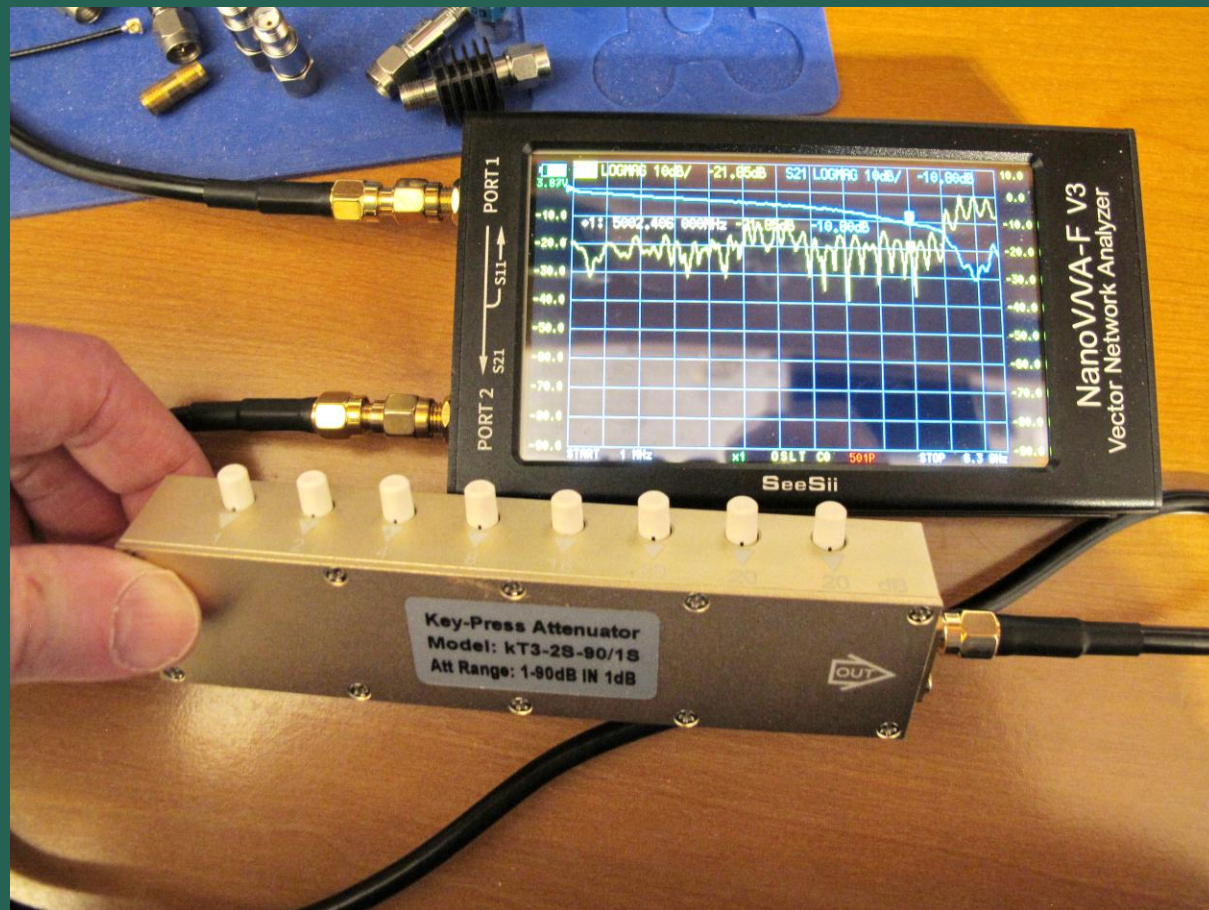
Looking at 30 dB attenuator thru 12 GHz...



TinySA, LiteVNA, and NanoVNA as Signal Generators



Attenuators



Low Cost Microwave Antennas

The screenshot shows two Amazon product listings. The top listing is for a "Broadband UWB Antenna - Ultra Wideband 2.4GHz - 10.5GHz PCB Material" priced at \$776. It features a green square antenna with a gold SMA connector. The bottom listing is for a "UWB Ultra Wide Band 1.35GHz-9.5GHz Log-Periodic Directional RF Antenna with SMA Connector" priced at \$798. It features a green triangular antenna with a gold SMA connector. Both listings include product details, customer reviews, and an "Ask Rufus" chatbot.

Product 1: Broadband UWB Antenna - Ultra Wideband 2.4GHz - 10.5GHz PCB Material

- Price: \$776
- Brand: Walfont
- Color: Gold, Green
- Number of Channels: 1
- Impedance: 50 ohm
- Product: 2"L x 2"W

Product 2: UWB Ultra Wide Band 1.35GHz-9.5GHz Log-Periodic Directional RF Antenna with SMA Connector

- Price: \$798
- Brand: Walfont
- Color: Gold, Green, Silver
- Product: 4.13"L x 3.15"W x 0.04"H
- UPC: 663862498059
- Manufacturer: Walfont
- Number of Items: 1

The advertisement features a large parabolic grid antenna mounted on a roof. The text reads: "BOLTON TECHNICAL ULTRA GAIN LONG RANGER PARABOLIC GRID ANTENNA 20+ MILES, 32+ KM". The background is a blue sky with white clouds.

BOLTON TECHNICAL

ULTRA GAIN LONG RANGER

PARABOLIC GRID ANTENNA

20+ MILES, 32+ KM

*Thanks For
Watching !*

[MegawattKS - YouTube](#)

<https://ecefiles.org>

Related Microwave and Lab-on-a Budget Info

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[RF & MICROWAVE INDUSTRY NEWS](#) [TEST & MEASUREMENT CHANNEL - LEADING MANUFACTURER NEWS, ARTICLES & CONTENT](#)

Very Low-Cost RF Test Equipment for the DIY Engineer or Student (<\$1,000)

Get one for your favorite engineer for the holidays!

December 11, 2020 *Pat Hindle, Editor, Microwave Journal* 5 Comments

[f](#) [x](#) [r](#) [in](#) [✉](#) [📄](#)

Dec 2020

RF/Microwave Passive Probes


RF active probe 0.1-1500 MHz ban x AUBURN Products Page x +

← → ↻ ⚠ Not secure auburntec.com/auburn_INFO%20P20B.html ☆ 🔍 📄 🌐 ⋮

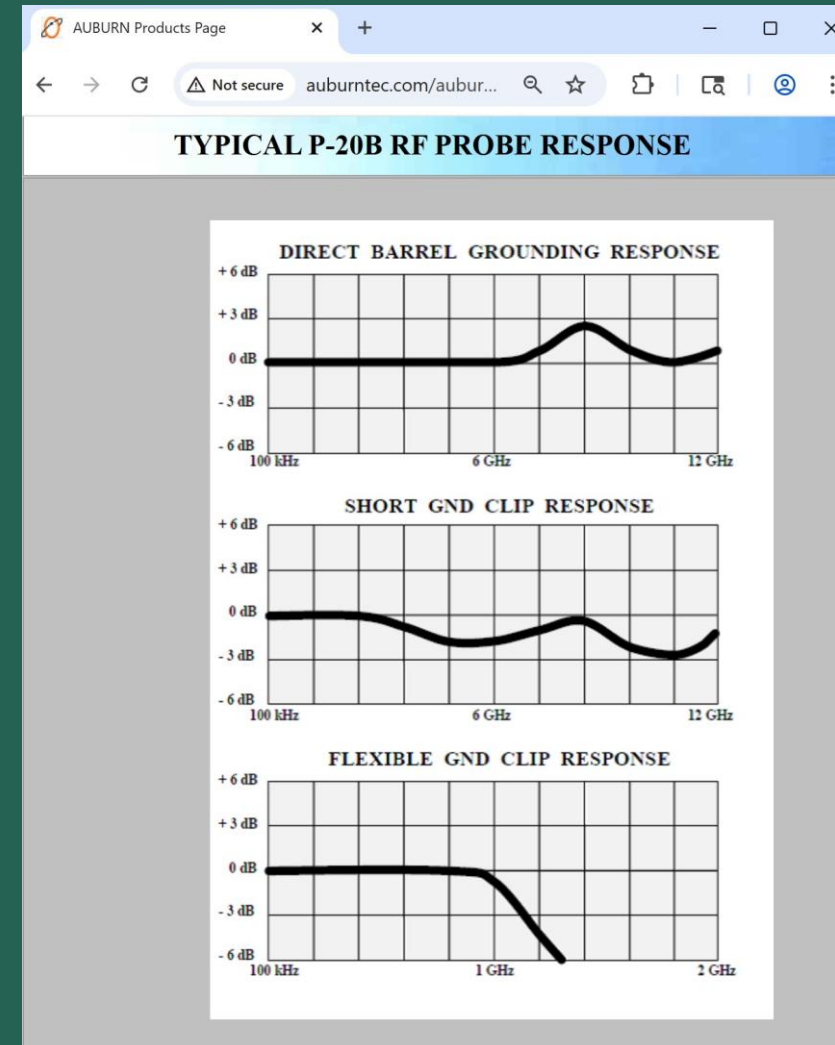
Description
Theory of Operation
RF Grounding
Typical P-20B RF probe response
RF Voltage measurements
RF Power measurements
Correction factor for loading effects
Power level conversion
RF Signal injection
Performance verification
Cross reference level chart
Specifications
Limited warranty
Auburn Technology Home Page

Auburn Technology Corporation

Model P-20B



12 GHz RF Probe



RF/Microwave Active Probes

The screenshot shows an eBay product page for an RF Active Probe. The browser address bar shows the URL `ebay.com/itm/286791320333`. The page features the eBay logo, a search bar, and navigation links. A blue banner at the top promotes a live streaming event. Below this, a section titled "People who viewed this item also viewed" displays six related products with their prices and delivery options. The main product listing includes a large image of a hand holding a probe on a green PCB, a smaller thumbnail image, and a product title. The seller's name "janilab" and a "100% positive" rating are shown. The price is listed as "US \$29.98". The condition is "New" and the quantity is "1" out of "5 available". Three buttons are visible: "Buy It Now", "Add to cart", and "Add to Watchlist".

rf active probes - Google Search x RF Active Probe + DC Out for debi x

ebay.com/itm/286791320333

Sign in or register Deals Brand Outlet Gift Cards Help & Contact Sell Watchlist My eBay

Shop by category Search for anything All Categories Search Advanced

LIVE Streaming now Shop exclusive items from trusted sellers Join event

People who viewed this item also viewed

- Tektronix TekConnect Interface Board &... \$40.00 + \$70.00 delivery Sponsored
- Tektronix P6243 GHz, 10X, 8V, Low-Voltage Active... \$120.00 Free delivery
- Agilent 8447D 0.1-1300MHz 25dB Amplifier \$200.00 Free delivery
- WR22 33-50GHz Waveguide Calibration Parts... \$180.00 Free delivery
- HP Q373D 33-50GHz Waveguide 20dB Directional... \$160.00 Free delivery

RF Active Probe + DC Out for debugging, measurement

janilab (1454) 100% positive Seller's other items Message seller

US \$29.98

Condition: New

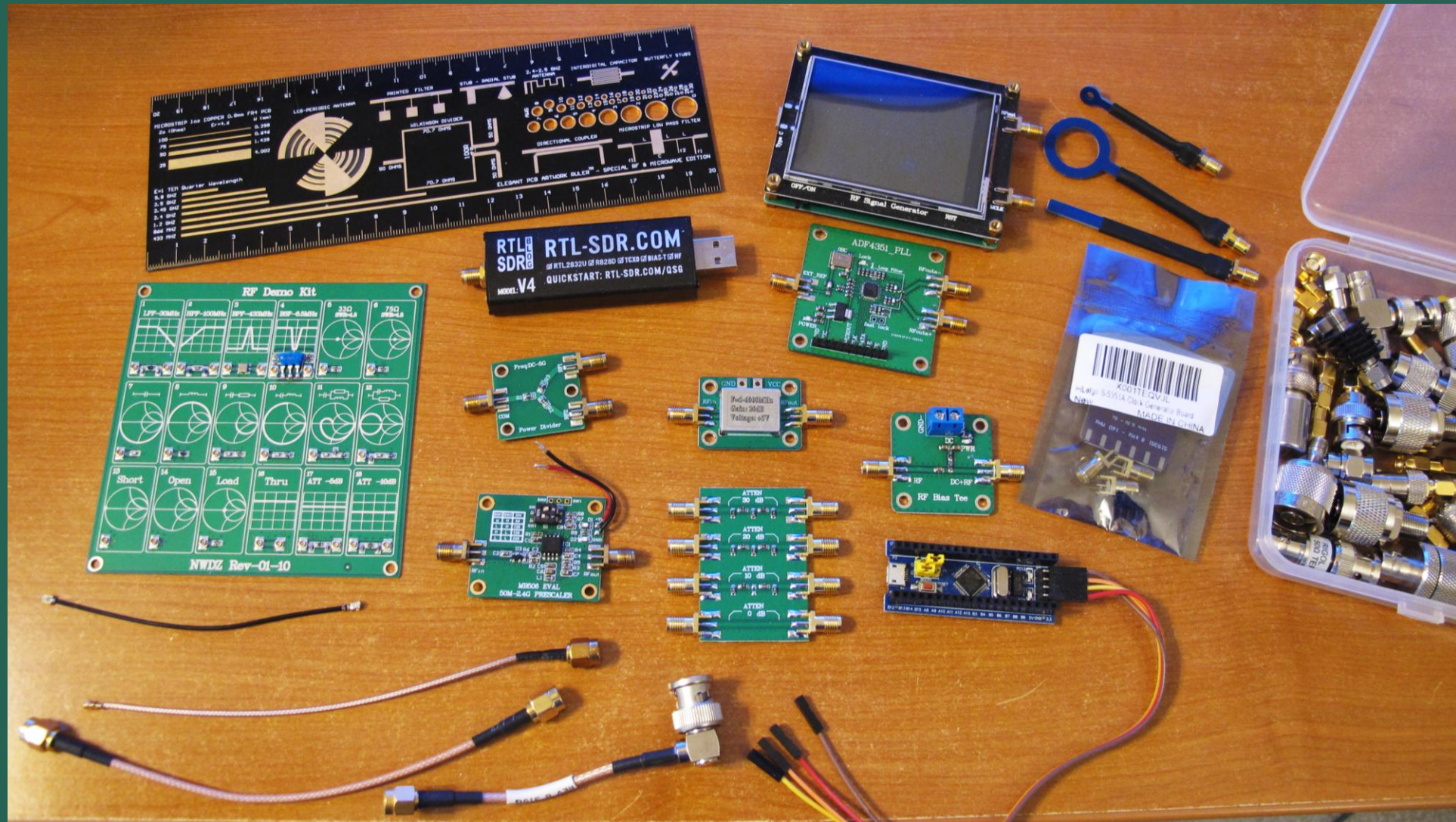
Quantity: 1 5 available

Buy It Now

Add to cart

Add to Watchlist

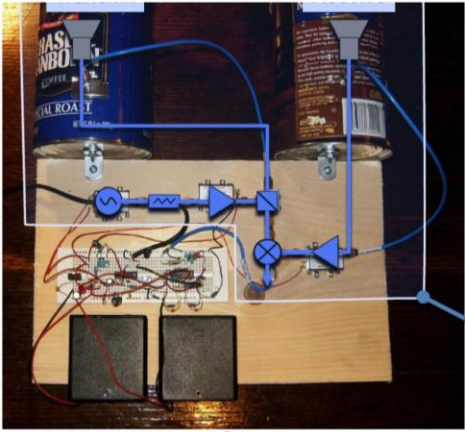
Miscellaneous Stuff ☺



Some Related Videos/Sites

youtube.com/watch?v=DB5TkXgpaW4

YouTube



Coffee-Can Radar*
Total BOM Cost : \$360

- RF BOM: \$236
- Antenna BOM: \$54

Size ~ 15x12"

Redesign this RF radar core

ni.com/awr

© Gregory Charvat, Jonathan Williams, Alan Peon, Steve Kagon, and Jeffrey Hard. RES-LI-003 Build a Small Radar System Capable of 30-mile Range. 2014 OpenCourseWare: A Virtual Radar Imaging, January IAP 2015. (Massachusetts Institute of Technology MIT OpenCourseWare), <https://ocw.mit.edu> (Accessed 11 Mar, 2015). License: [Creative Commons BY-NC-SA](https://creativecommons.org/licenses/by-nc-sa/4.0/)

Design Example: Coffee Can Radar System

AWR Design Environment
5.52K subscribers

14,531 views Jul 2, 2015

The MIT OpenCourseware Coffee Can Radar project provides free lectures and plans for building a working DIY radar system. This basic homodyne radar system design is capable of Range, Doppler, and Synthetic Aperture imaging and can be built with off the shelf connectorized components that operate in the 2.4GHz open ISM bands.

This talk takes the original Radar System and analyze it with a true system tool so that a designer can easily look at metrics relevant to radar engineers. Different components for the transmitting power amplifier, receiving low noise amplifier, and the homodyne systems mixer are used in Visual System Simulator system tool to determine the effect on distance ranging, probability of detection, and velocity uncertainty.


Finally, an optimized system is presented that takes the original connectorized implementation and converts it to an all surface mount design with an integrated planar antenna. The new design embraces a full bits-to-beams implementation within Visual System Simulator and Microwave Office (AXIEM and Analyst software too) of the antenna as well as the board layout and circuit co-simulation with radar system metrics to reveal a successfully working design prototype prior to being built.

S451KN Amateur Radio Station - E

dxer.site

Another notable QSO was with Petros, SV3AAF. He experienced even stronger wind, which affected the stability of his antenna. The contact required many periods to complete, but we succeeded. I am grateful to Petros for his persistence in completing this difficult QSO.

The self-echoes from the Moon were exceptional during the portable session, and when Michael SA6BUN requested a CW QSO, I realized that I had forgotten my CW key at home. SNR was indeed sufficient for a CW contact that day - next time.



“Antenna Briefs” Playlist

youtube.com/watch?v=w2S6pbnoQew

YouTube Search

Antenna Briefs #1

Frequency, Wavelength, and Antenna Size

0:01 / 28:00 Intro >

Antenna Briefs #1 - Frequency, Wavelength, and Size

MegawattKS 12.8K subscribers

771 Share Promote Ask

25K views 3 years ago

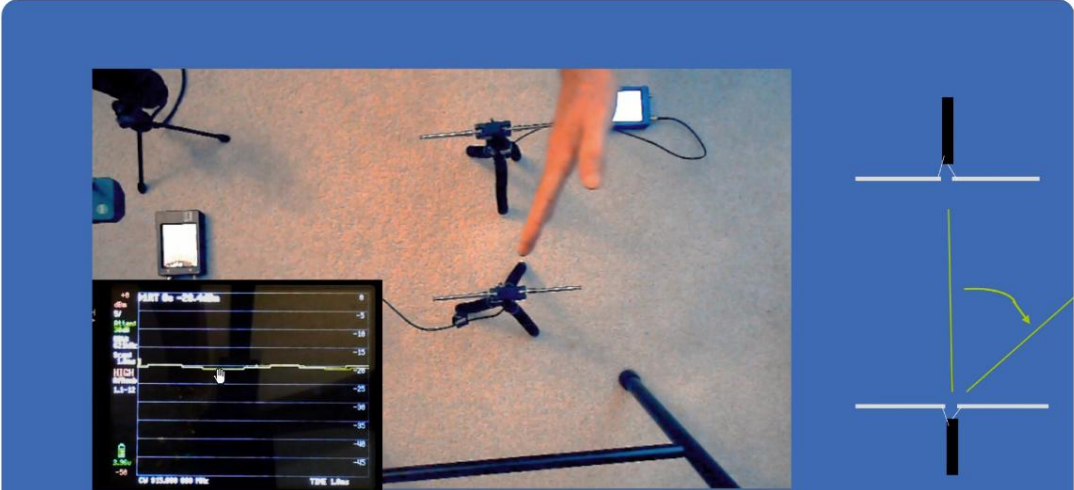
This is the first in a series of videos on antennas and how they work. It is based on and supports a university course, but covers material without any deep math. In Episode 1 we overview key elements of radio antenna operation and signal propagation. We start with the first antennas created by ...more

51 Comments Sort by

- 2 **Antenna Briefs #2 - Power, Range, and Licensing**
MegawattKS • 7.1K views • 3 years ago
23:00
- 3 **Antenna Briefs #3 - Maximizing Range**
MegawattKS • 5.8K views • 3 years ago
32:30
- 4 **Antenna Briefs #4 - Interstellar Communication and SETI (Revised)**
MegawattKS • 2.5K views • 3 years ago
11:25
- 5 **Antenna Briefs #5 - Electric Fields, Magnetic Fields, and EM Waves**
MegawattKS • 7K views • 3 years ago
25:27
- 6 **Antenna Briefs #6 - Analysis, Simulation, and Measurements**
MegawattKS • 5.4K views • 3 years ago
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- Antenna Design (plus EMC) - Episode 8 of Antenna Briefs - Part 1**

Demos in Home Lab

YouTube Search



Using *TinySA* instruments with *RTL-SDR antenna kits* in a not-so-good home "antenna range"

Antenna Briefs #6 - Analysis, Simulation, and Measurements

MegawattKS
12.7K subscribers

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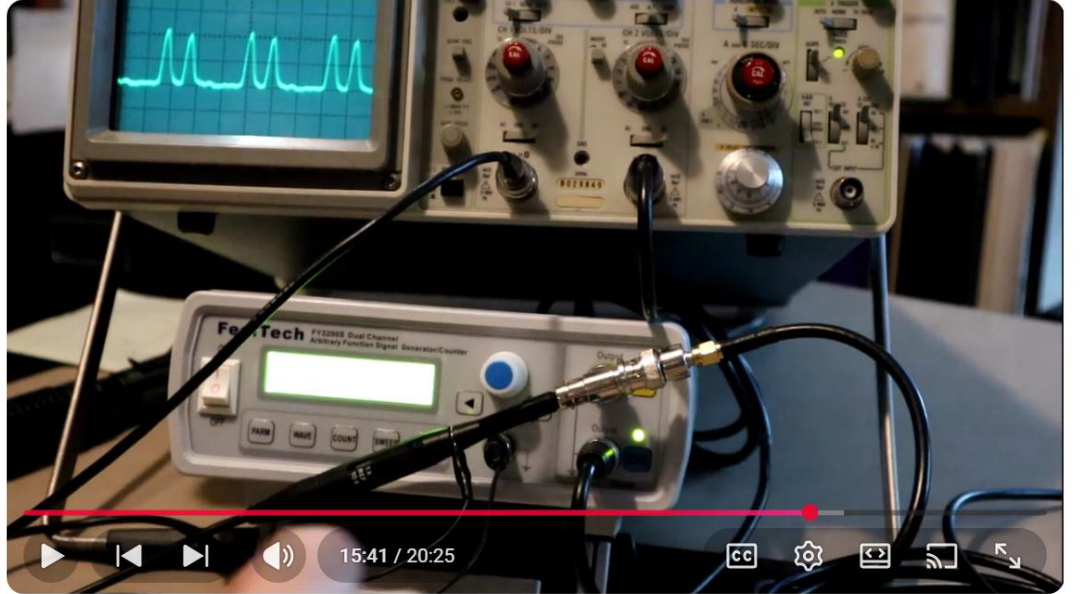
170

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This episode looks at how antennas are analyzed and simulated. It starts with real-world measurements to set the stage and illustrate key issues like antenna patterns. We then dive into some of the mathematical theory behind pattern formation. But as always, the focus is on understanding the theory that is relevant to engineering. Information ...more

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NanoVNA Demonstrations - Coax line reflections and Smith charts

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607

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Demonstrations of reflection coefficients (S_{11}) on coax lines, and use of a NanoVNA (a vector network analyzer) to understand polar and Smith chart impedance presentation formats. Derived from a university senior/graduate level course lecture/demo, but presented in a hopefully intuitive way without the math. ...more

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File Edit Arrange View Grid Design info Order Boards Help

Anytime 0.0595 in 0.012 in 0.056 in 0.029 in

Test Plus 2.0 V1

0.056 in 0.029 in

Top Silkscreen Top Copper Bottom Copper Turn Over

Colors & Visibility Layer View Arrange

Tools Select Hole or Pad Part Trace Line Text Rectangle Polygon Arc Ellipse Image Note Continuity Zoom By Mouse 317%

Gnd +5V In Out Common Base Class A RF Amp

Gnd +5V Out Common Base Colpitts Voltage Controlled Oscillator

0.9398, 2.5427 in (move over element)

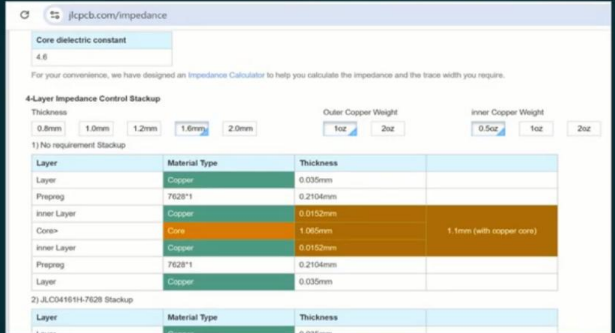
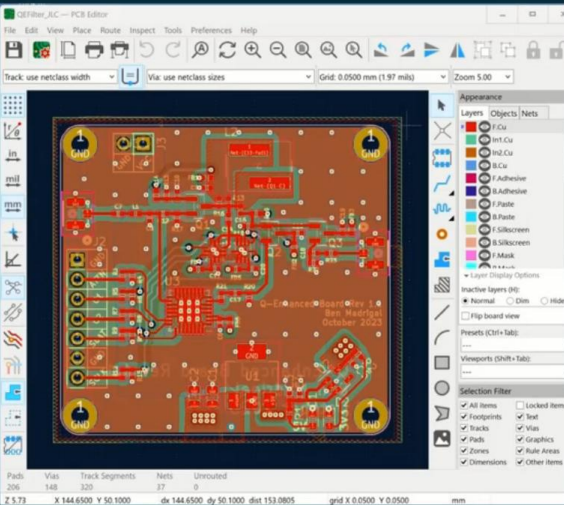
KiCad Layout Software

and typical Fab vendor (non-US-based)

youtube.com/watch?v=26fABQ9WOTQ&list=PL9Ox3wbnB0kqekAyz6blg4YdvoEMoJNjY&index=15

Search

4-Layer board, KiCad & JLCPCB 28



1. Top (front) layer for components, interconnect
2. Internal layer 1 typically used for ground plane
3. Internal layer 2 typically used for power
4. Bottom (backside) layer may be used for components, interconnect

Layer	Material Type	Thickness
1) No requirement Stackup		
Layer	Copper	0.035mm
Prepreg	7628*1	0.2104mm
Inner Layer	Copper	0.0152mm
Core	Cores	1.065mm
Inner Layer	Copper	0.0152mm
Prepreg	7628*1	0.2104mm
Layer	Copper	0.035mm
2) JLC04161H-7628 Stackup		
Layer	Material Type	Thickness

Layout in KiCad

Example Stackup from JLCPCB

RF Circuit Construction - Part 1 - Radio Design 101 Appendix C

MegawattKS 13K subscribers

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Radio Design 101

MegawattKS - 15 / 16

- Radio Design 101 - FM Demod and Finishing the Receiver... MegawattKS 35:05
- Receiver Performance - Radio Design 101 Epilogue 1 MegawattKS 32:18
- Troubleshooting - Radio Design 101, Epilogue 2 MegawattKS 33:41
- Receiver Architectures - Radio Design 101 Final Epilogue (... MegawattKS 57:42
- Appendix A - Transistors and Amplifiers at RF MegawattKS 58:46
- Radio Design 101 Appendix B - RF Impedance Conversions f... MegawattKS 45:08
- RF Circuit Construction - Part 1 - Radio Design 101 Append... MegawattKS 28:32
- RF Circuit Construction with Examples - Appendix C Part ... MegawattKS 33:28

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