Teaching Electronics with the NorCal 40A:

A Hands-On Method for Teaching Electronics to Electrical Engineers

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and

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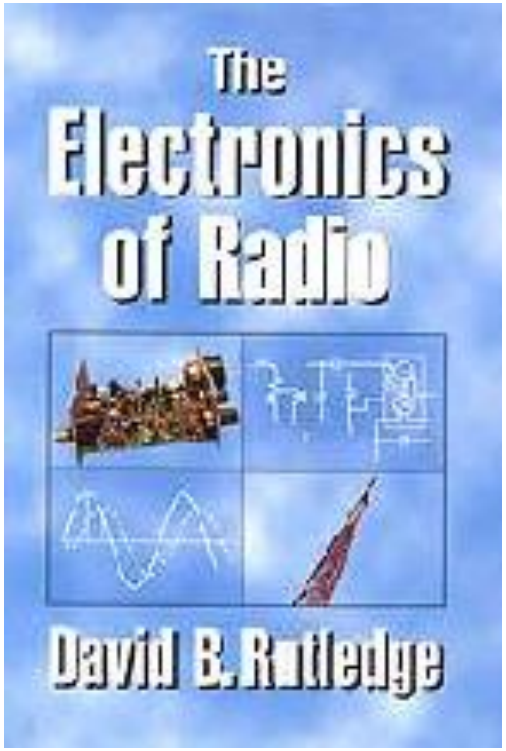
Genesis

Whites' use of the NorCal 40A as a teaching tool for electrical engineering students began in the Spring-Summer of 2000.

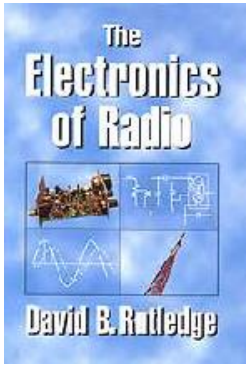
He was an Associate Professor (with tenure) in the Electrical and Computer Engineering (ECE) Department at the University of Kentucky.

The department head approached him on developing a course on "Wireless Communications." Whites had recently received a copy of Rutledge's excellent text "The Electronics of Radio." He pitched the course, and it was approved…with a hefty budget for outfitting a lab with equipment! First taught in Spring 2001 at UK.



His vision was to create a wireless communication electronics course that provides both a strong theoretical and hands-on education for ECE students.

Wireless Communication Course



As mentioned, this course is based on an excellent text written by Prof. David Rutledge of the California Institute of Technology (CalTech). This was a course for their engineering freshmen! My intention was a senior level EE digging deeply into the topic.

During the semester, the students slowly build and thoroughly analyze the NorCal 40A radio, which is a low power (QRP) Morse code (CW) transceiver (i.e., a combination transmitter and receiver).

This course is nontraditional in the sense that all "homework" is assigned in the form of laboratory problems. Students build and test a transceiver.

The course at UK was the first adoption that I was aware of outside of CalTech. (Two years later I brought the course to the South Dakota School of Mines and Technology.)

Is There Need for Such RF Skills?

There is a **large industrial and government demand** for radio frequency and microwave engineers, especially American citizens. The aim was to provide students with those skills through coursework and later through their participation in research projects.

There are many applications of the RF and microwave engineering:

- Position, Navigation, and Timing (PNT)
  - » P: Geographical locating
  - » N: Calculating a path and monitoring progress
  - » T: Calculating duration of travel
- Electronic warfare
- Space communications
- RADAR
- Microwave comms
- RF measurements

(US Government)

Course Overview

In addition to lecture material, the students work through a carefully selected set of 39 lab problems designed to:

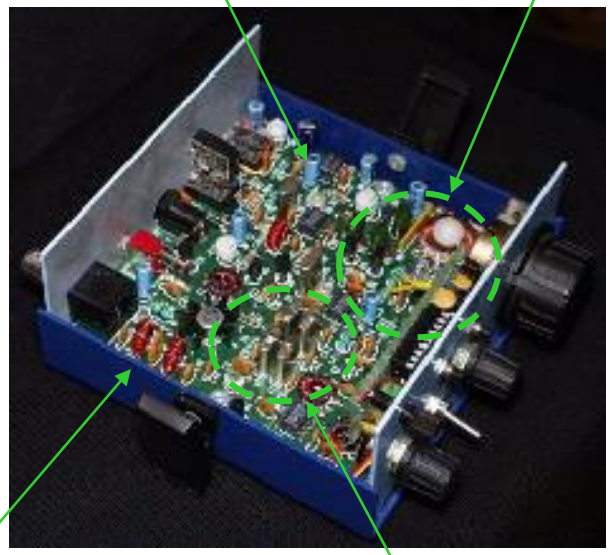
1) allow them to build a working transceiver, and

2) theoretically "dissect" its operation.

Plus quizzes, exams, final exam, and oral final.

The photo shows the NorCal 40A transceiver the students build from a kit:

- Superheterodyne receiver
- Operates at 7 MHz (40-m band)
- Morse code (CW)
- 2-W output power (QRP)



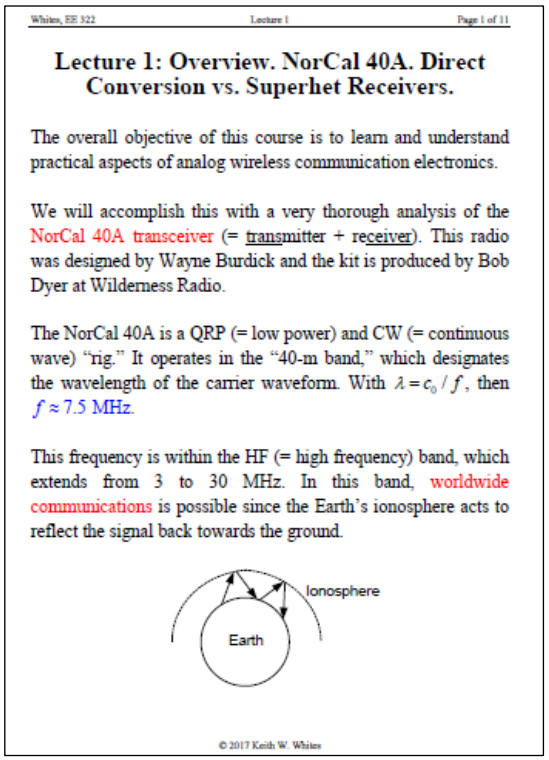
Course Materials Developed

- No answers or solutions manual for the problems in Rutledge's book
- Whites spent a few months in the Fall of 2000 carefully working through the entire book, building a few NorCal40A's

That effort and his lab notebooks formed the basis for his

- *Lecture Notes* and
- *Clarifications and Additional Instructions*

The latter were written for all text problems to help make the workload tractable for students



Whites, EE 322 Lecture 1 Page 1 of 11

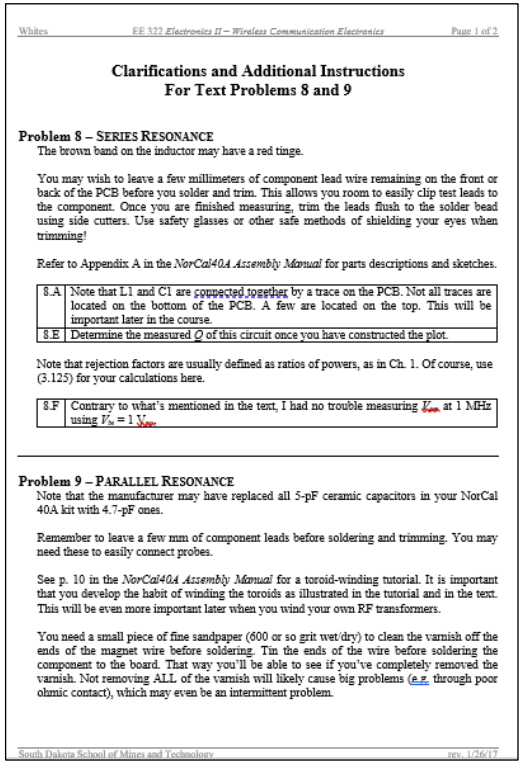
Lecture 1: Overview. NorCal 40A. Direct Conversion vs. Superhet Receivers.

The overall objective of this course is to learn and understand practical aspects of analog wireless communication electronics.

We will accomplish this with a very thorough analysis of the NorCal 40A transceiver (= transmitter + receiver). This radio was designed by Wayne Burdick and the kit is produced by Bob Dyer at Wilderness Radio.

The NorCal 40A is a QRP (= low power) and CW (= continuous wave) "rig." It operates in the "40-m band," which designates the wavelength of the carrier waveform. With $\lambda = c_0 / f$, then $f \approx 7.5$ MHz.

This frequency is within the HF (= high frequency) band, which extends from 3 to 30 MHz. In this band, worldwide communications is possible since the Earth's ionosphere acts to reflect the signal back towards the ground.



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Clarifications and Additional Instructions For Text Problems 8 and 9

Problem 8 – SERIES RESONANCE

The brown band on the inductor may have a red tinge.

You may wish to leave a few millimeters of component lead wire remaining on the front or back of the PCB before you solder and trim. This allows you room to easily clip test leads to the component. Once you are finished measuring, trim the leads flush to the solder bead using side cutters. Use safety glasses or other safe methods of shielding your eyes when trimming!

Refer to Appendix A in the *NorCal40A Assembly Manual* for parts descriptions and sketches.

8.A	Note that L1 and C1 are connected together by a trace on the PCB. Not all traces are located on the bottom of the PCB. A few are located on the top. This will be important later in the course.
8.E	Determine the measured Q of this circuit once you have constructed the plot.

Note that rejection factors are usually defined as ratios of powers, as in Ch. 1. Of course, use (3.125) for your calculations here.

8.F	Contrary to what's mentioned in the text, I had no trouble measuring V_{out} at 1 MHz using $V_{in} = 1$ V_{pp}.

Problem 9 – PARALLEL RESONANCE

Note that the manufacturer may have replaced all 5-pF ceramic capacitors in your NorCal 40A kit with 4.7-pF ones.

Remember to leave a few mm of component leads before soldering and trimming. You may need these to easily connect probes.

See p. 10 in the *NorCal40A Assembly Manual* for a toroid-winding tutorial. It is important that you develop the habit of winding the toroids as illustrated in the tutorial and in the text. This will be even more important later when you wind your own RF transformers.

You need a small piece of fine sandpaper (600 or so grit wet/dry) to clean the varnish off the ends of the magnet wire before soldering. Tin the ends of the wire before soldering the component to the board. That way you'll be able to see if you've completely removed the varnish. Not removing ALL of the varnish will likely cause big problems (e.g. through poor ohmic contact), which may even be an intermittent problem.

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Theory and Hands-on

The unique aspects of the course include:

- Combining theory with extensive hands-on experience
- Theoretical and practical experience with a wide range of circuit components:
  - ◊ varactors
  - ◊ two other types of diodes
  - ◊ mixer/oscillator ICs
  - ◊ RF chokes, inductors, transformers
  - ◊ five types of capacitors
  - ◊ quartz crystals
  - ◊ transistors (BJT, FET)
- A wide range of topics important to analog electronics are covered, including:
  - ◊ superheterodyne receivers
  - ◊ ladder filters
  - ◊ mixers
  - ◊ transistor amplifiers
  - ◊ power amplifiers (classes A, B, C)
  - ◊ oscillators
  - ◊ quartz crystal filters
  - ◊ transmission lines, antennas
  - ◊ audio circuits

NorCal 40A Block Diagram

Here is a block diagram of the NorCal 40A to help orient you to the transceiver:

Transmitter side

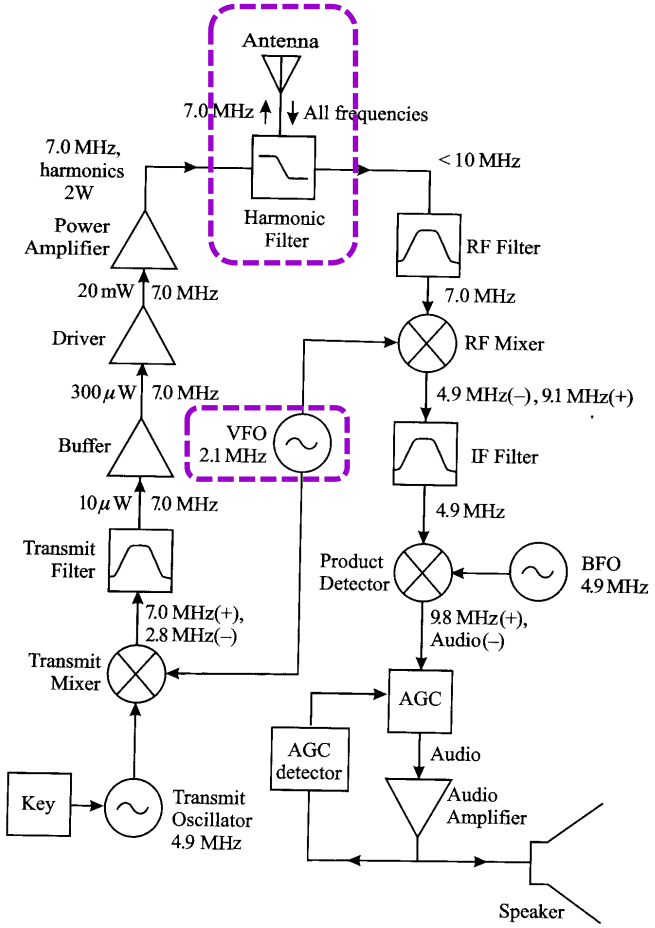


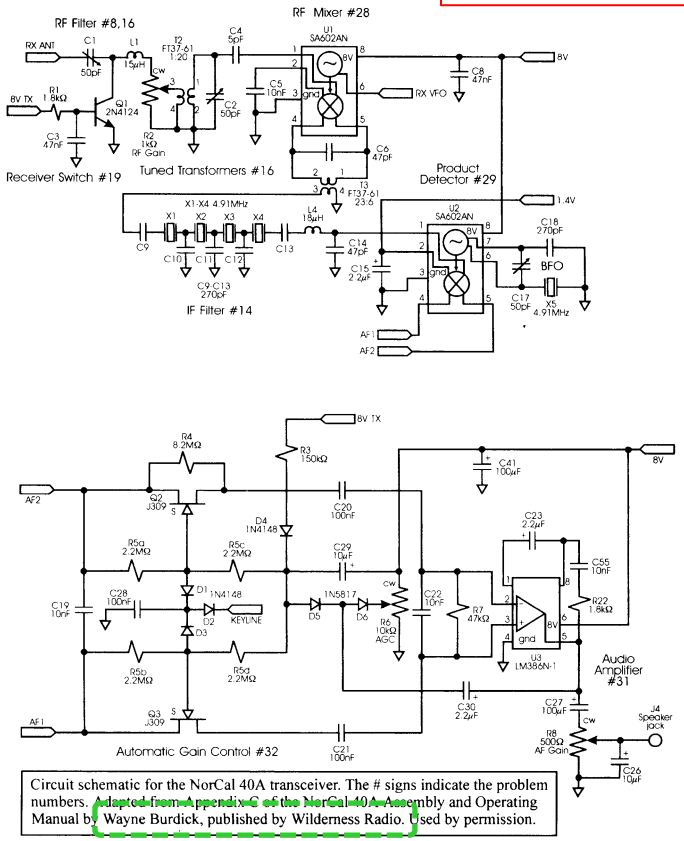
Figure 1.13. Block diagram for the NorCal 40A. Sum frequencies are noted by + signs, and difference frequencies by – signs. Adapted from Appendix C of the *NorCal 40A Assembly and Operating Manual*, by Wayne Burdick, published by Wilderness Radio. Used by permission.

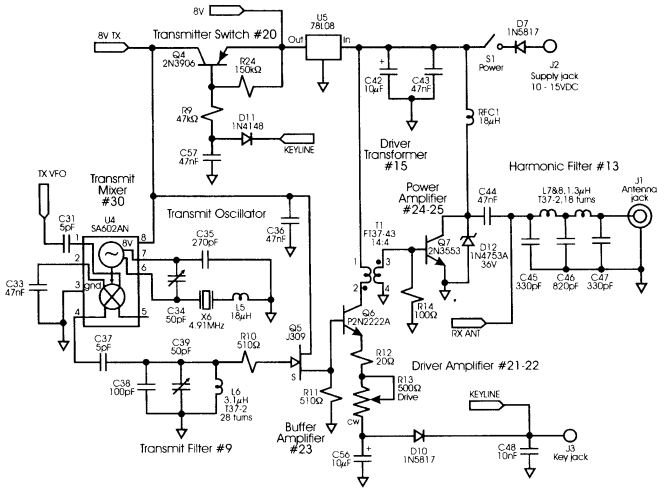
Receiver side

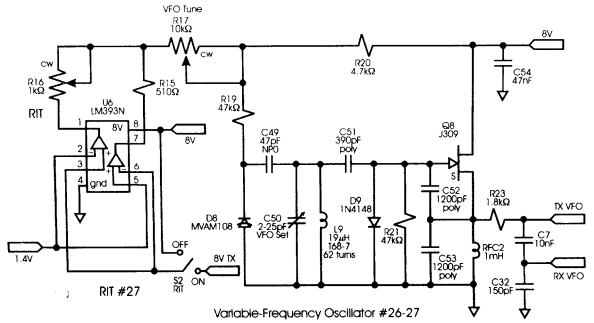
Wayne Burdick

The fundamental reason that a detailed electrical engineering course like this could use the NorCal 40A is that it was designed by Wayne Burdick superbly and correctly.

All analog electronics

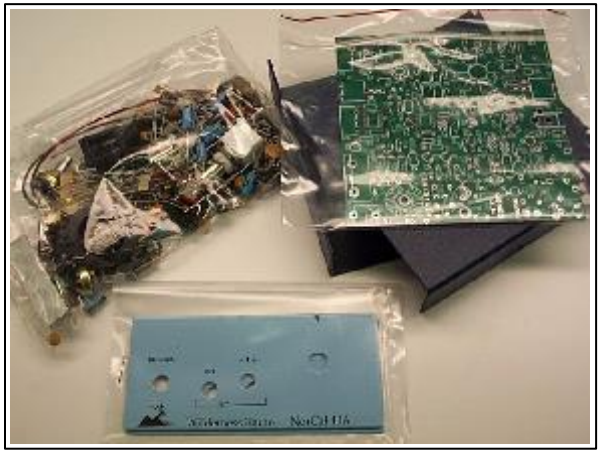






Transceiver Construction

Begin with parts kit:



After two weeks:

After six weeks:

After ten weeks (completed):

Course Equipment

Arbitrary waveform generator (4.91xxxx MHz)

Digital oscilloscope

Multimeter

12 volt power supply

Soldering Station (we do a lot of soldering and desoldering!)

Also used:

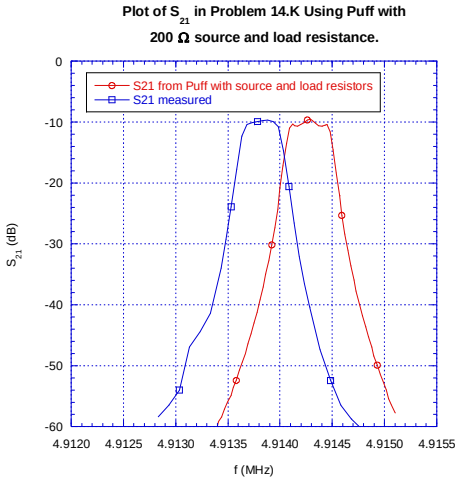
- frequency counter
- power combiner
- digital multimeter
- adjustable attenuator
- dipole antenna

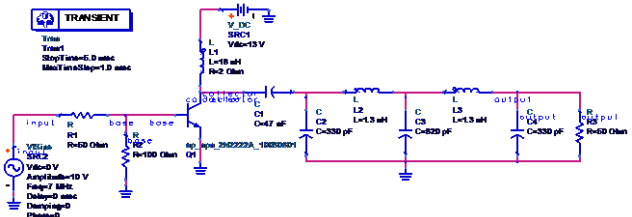
Circuit Simulation

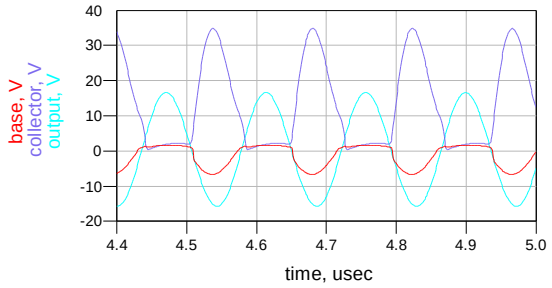
This is not a quick, kit assembly of the NorCal 40A. This is a course to learn about analog electronics. Use theory and circuit simulation to make predictions. Then compare with measurements.

- PUFF came with the original textbook (3.5" diskette)
  - This is a microwave circuit simulator written at CalTech
  - Calculates S parameters, which junior-level students aren't familiar (later in senior level *Microwave Engineering*)
  - Passive components only

- Converted course to Advanced Design System by Keysight (Agilent)
  - Extremely powerful: but like driving a Lamborghini down the block to get groceries ☺







Final Checkout: Oral Exam (1/3)

Students have known throughout the semester that their radio must meet "spec" during an oral final exam. May have worked in a team, but this checkout is solo:

Transceiver Final Checkout

Name:_____ Date:_____

#	Score	Description
1.	/5	Present your transceiver for inspection. The instructor will check for complete hardware assembly (such as knobs, switches and feet) and centered RIT and VFO knobs.
2.	/15	Connect your transceiver to the equipment shown in the figure below. Find a weak signal that is transmitted somewhere in the frequency range 7.000 to 7.040 MHz. You have a maximum of five minutes to locate the tone. 
3.	/15	The instructor will change the transmit frequency slightly. Use only your RIT to reacquire the transmitted signal.
4.	/15	Attach a 50-Ω dummy load to J1 in the figure above. Key the transmitter and demonstrate that the sidetone is within ±40 Hz of the received audio tone. (It is very important that you do not accidentally change the VFO setting before keying your transmitter. You will have only one opportunity to key the transmitter.)
5.	/15	Connect J1 to a frequency counter along with a 50-Ω load. Demonstrate that the transmit frequency is within ±120 Hz of the received signal frequency. (As in the previous part, you will have only one opportunity to key the transmitter.)

6.	/15	Connect J1 to the power meter as shown in the circuit below. Key the transceiver and demonstrate that your transmitter produces at least 2-W RF output power. 
7.	/5	Remove the top and bottom covers and present your PCB to the instructor. He will check the quality of the solder joints and electrical assembly.
8.	/15	The instructor will point to different parts of your transceiver and have you identify and describe certain characteristics about it. These may include such items as the name and function of circuit components and/or subsystems and the flow of the signal in the circuit, among others.
	/100	**TOTAL SCORE**

You are not allowed to talk to anyone about this oral examination until after the course final exam.

Final Checkout: Oral Exam (2/3)

Students have known throughout the semester that their radio must meet "spec":

- ✓ detect a "small signal" from 7.000 to 7.040 MHz
- ✓ use RIT to reacquire,
- ✓ transmit sidetone within +/-40 Hz of receive tone,
- ✓ transmit frequency within +/-120 Hz of received frequency,
- ✓ At least 2W time average output power,
- ✓ Well built

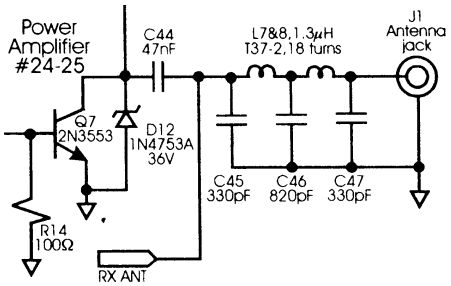
Final Checkout: Oral Exam (3/3)

Once this is finished, the student removes PCB from case and the instructor begins about 5-10 minutes of quizzing on the radio: parts, subsystems, signal flow, frequencies, etc.

Selected Knowledge Nuggets

This course provides students with practical and useful experiences seldom found elsewhere in an ECE curriculum:

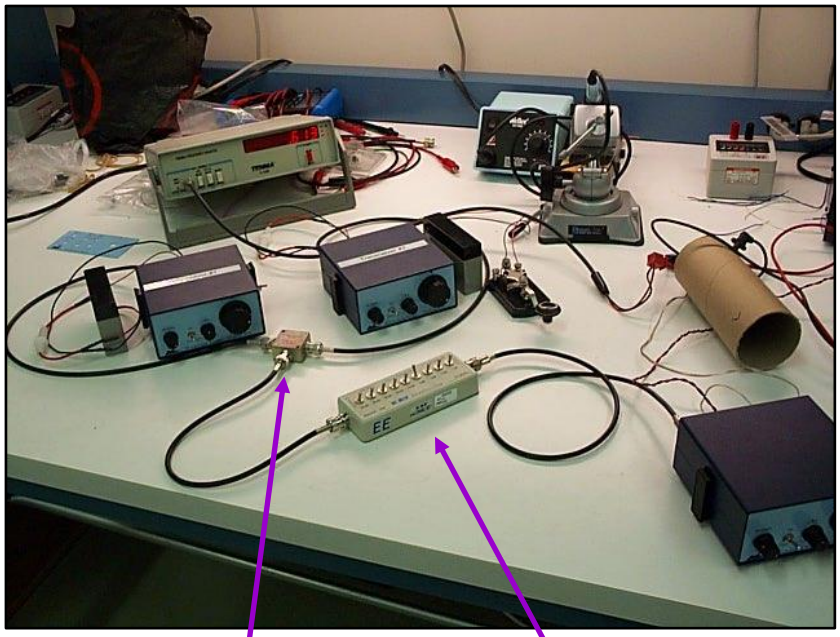
- Cascading analog subcircuits is usually not like connecting "Legos" together (low output impedance connected to high input impedance). Generally, each circuit affects the other
- The marketplace is inundated with counterfeit electrical components. Authentic power amplifiers (2N3553) almost impossible to locate, but counterfeits everywhere

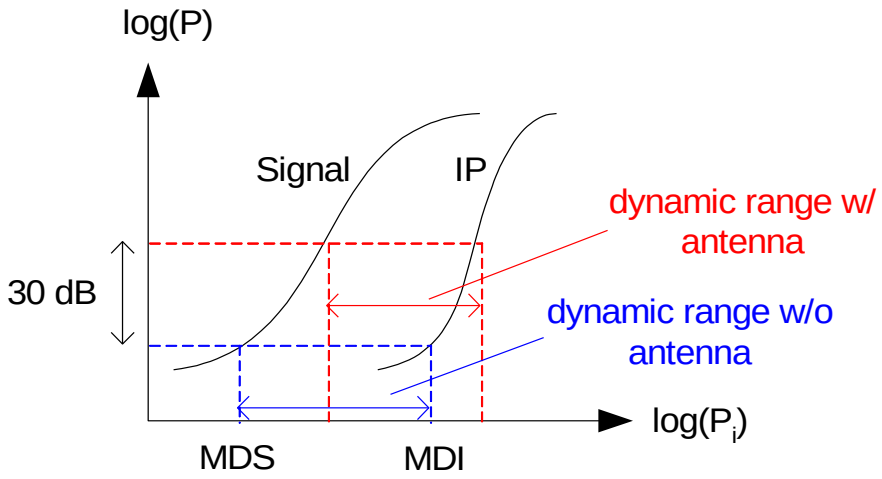


- Electrical circuits are also affected by the physical elements: temperature, humidity, etc. (VFO frequency change with temperature)
- Nonlinear circuit behaviors can be very useful (Class C amplifier, mixers, etc.) but can have unintended consequences (IP's)
- The act of measuring often "changes" the circuit, sometimes is surprising ways! (JFET input current?!)
- A VFO magically creates a sinusoid! How?

Intermodulation Products (IP's)

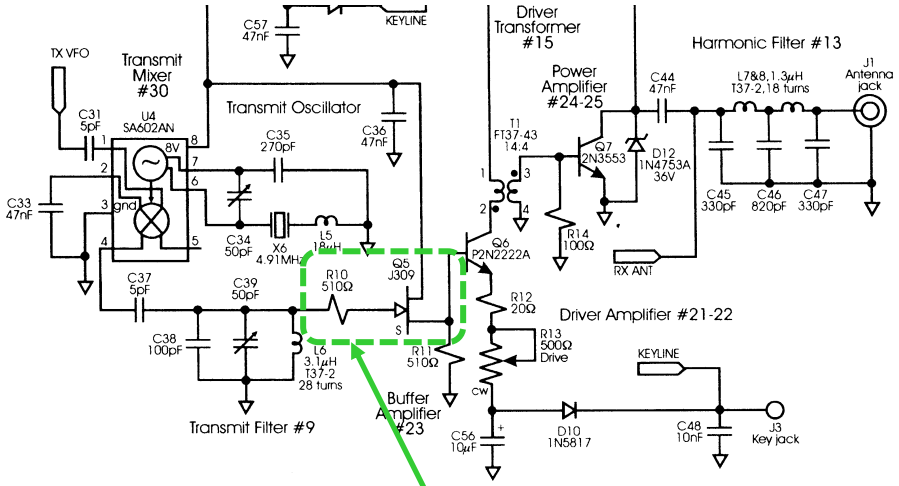
While nonlinear/time-varying circuits (such as mixers) are hugely beneficial, these can have some unintended effects.

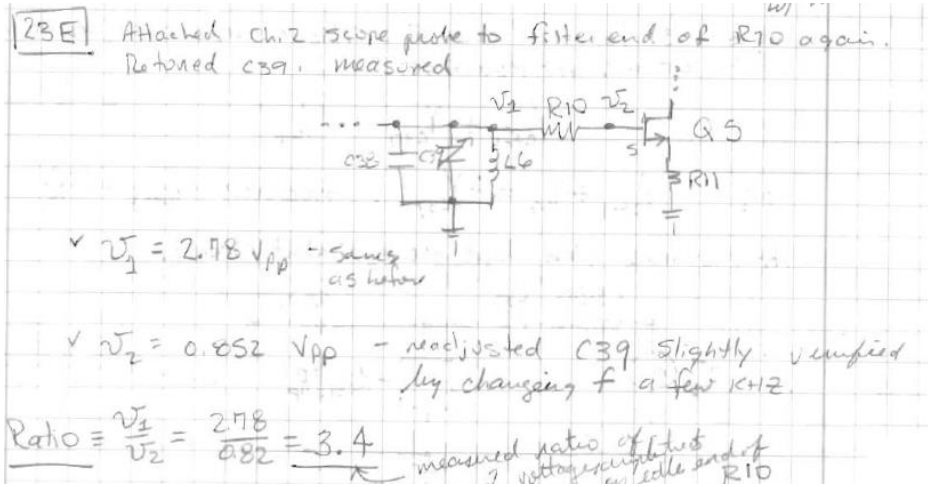




But Isn't JFET Input Current = 0?

I believe the JFET Q8 is used to buffer the input impedance changes of the Buffer Amplifier Q6 from the Transmit Filter.

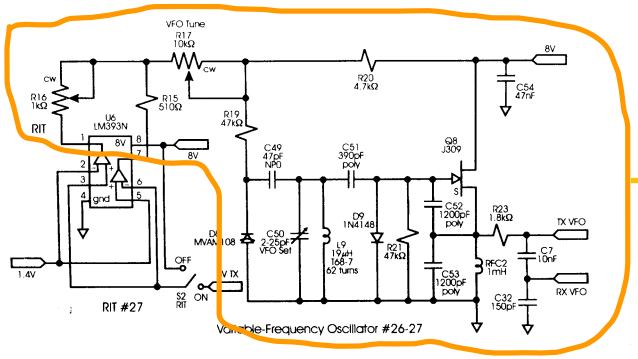


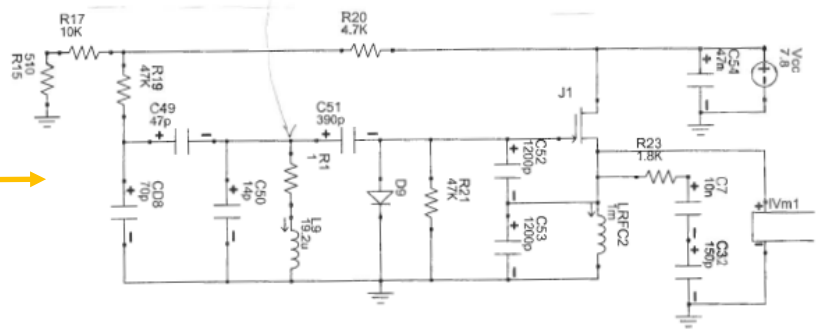


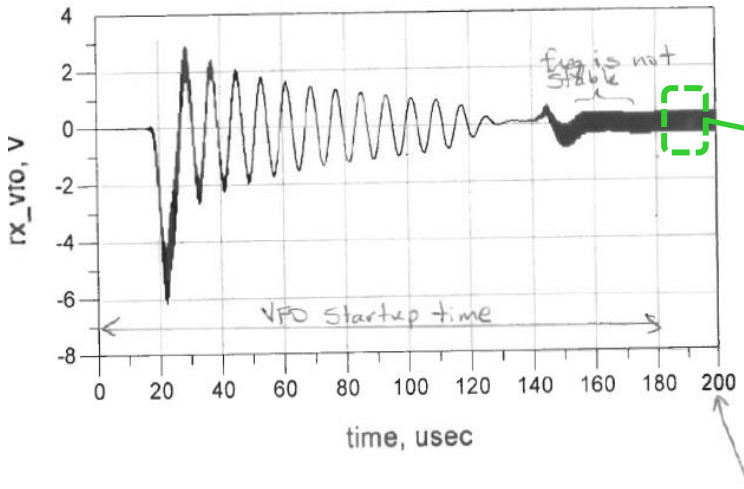
In one of the laboratory problems, we're asked to measured the ratio of voltages across R10. But the input current to a JFET is zero. The ratio is measured as ~3.4 but must be zero. Is Ohm's Law at fault?!

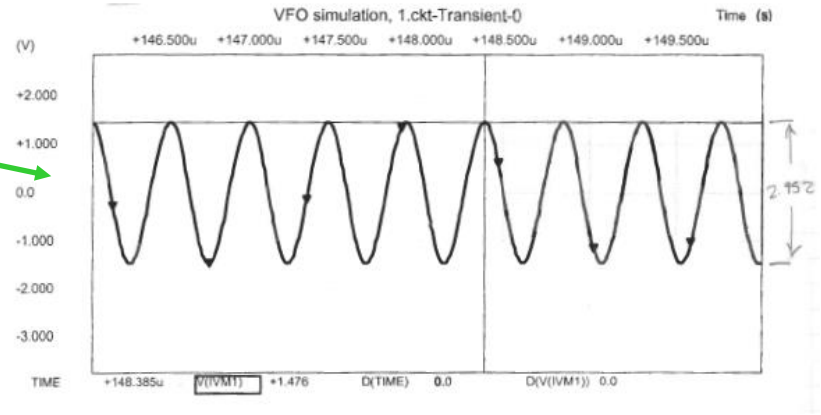
VFO Startup: The Birth of a Sinusoid

Oscillator circuits are just magical to me. From no more than a battery and electrical noise, a rock-solid sinusoid rises from this nothingness and the frequency can be varied by just turning a knob! But quite complicated when you look under the hood:









(Notionally: the right-side plot is not from this exact simulation)

Wireless Communication is Amazing!

This is perhaps my favorite figure from teaching this course to students. Approximate power levels between two NorCal 40A transceivers separated by 2000 km:

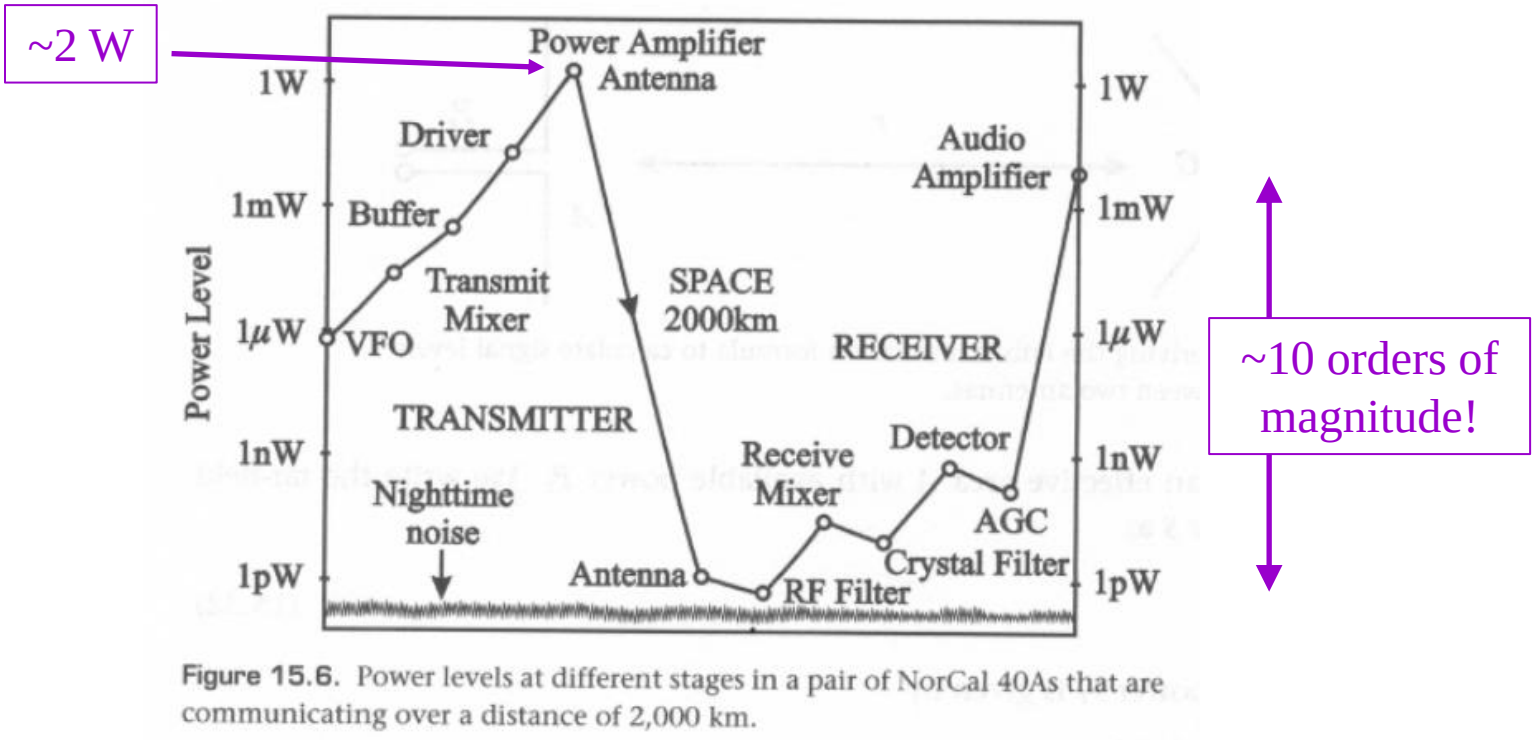


Figure 15.6. Power levels at different stages in a pair of NorCal 40As that are communicating over a distance of 2,000 km.

This amazing thing we call QRP Wireless Communication!

What do the Students Think?

- This is an ambitious course for students (and the teaching staff!)
- But tremendous learning potential for students: the course has proven its value for 20 years as an effective advanced course in analog electronics at SDSMT
- What do the students think about this course?
- From exit interviews with graduating seniors: 66-75% of these students mention EE 322 *Electronics II* during their interview as they answer the question "What was the most memorable course taken and why?"
- A sampling of these responses referring to *Electronics II* is:
  - "I think it is a very unique way to learn the material- hands-on. Being able to produce a final finished product that is functional is an excellent way to learn."
  - "…valuable and good to discuss during job interview."
  - "…was most memorable both in a good and bad way-very hard but learned more than in any other course I took. Would like more courses like it."
  - "…very time consuming but I learned a lot."

For the Future

- This *Electronics II* course based on the NorCal 40A is alive and well at SDSMT
- As would be expected of a course that is 20 years old, some of the electrical components are no longer available
- Faculty and fans of the course have been working to revitalize the design with modern components to replace them, while the stockpile of kits steadily dwindles: the NorCal 40A kit can no longer be purchased
- NE602 mixers in an 8-pin DIP package are being replaced by SA612 mixers, which are only available in surface-mount
- 2N3553 RF output transistor being replaced with a MOSFET
- Goal of modernization is to extend the life of this course using the NorCal 40A transceiver so that another generation of students may benefit from the very practical hands-on learning experience and the enthusiasm it generates among them

Contact Information

If you would like to know more about this course, or other related topics, please get in touch with us. We would be happy to converse with you by email or telephone. Contact information:

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