QEX

November/December 2020

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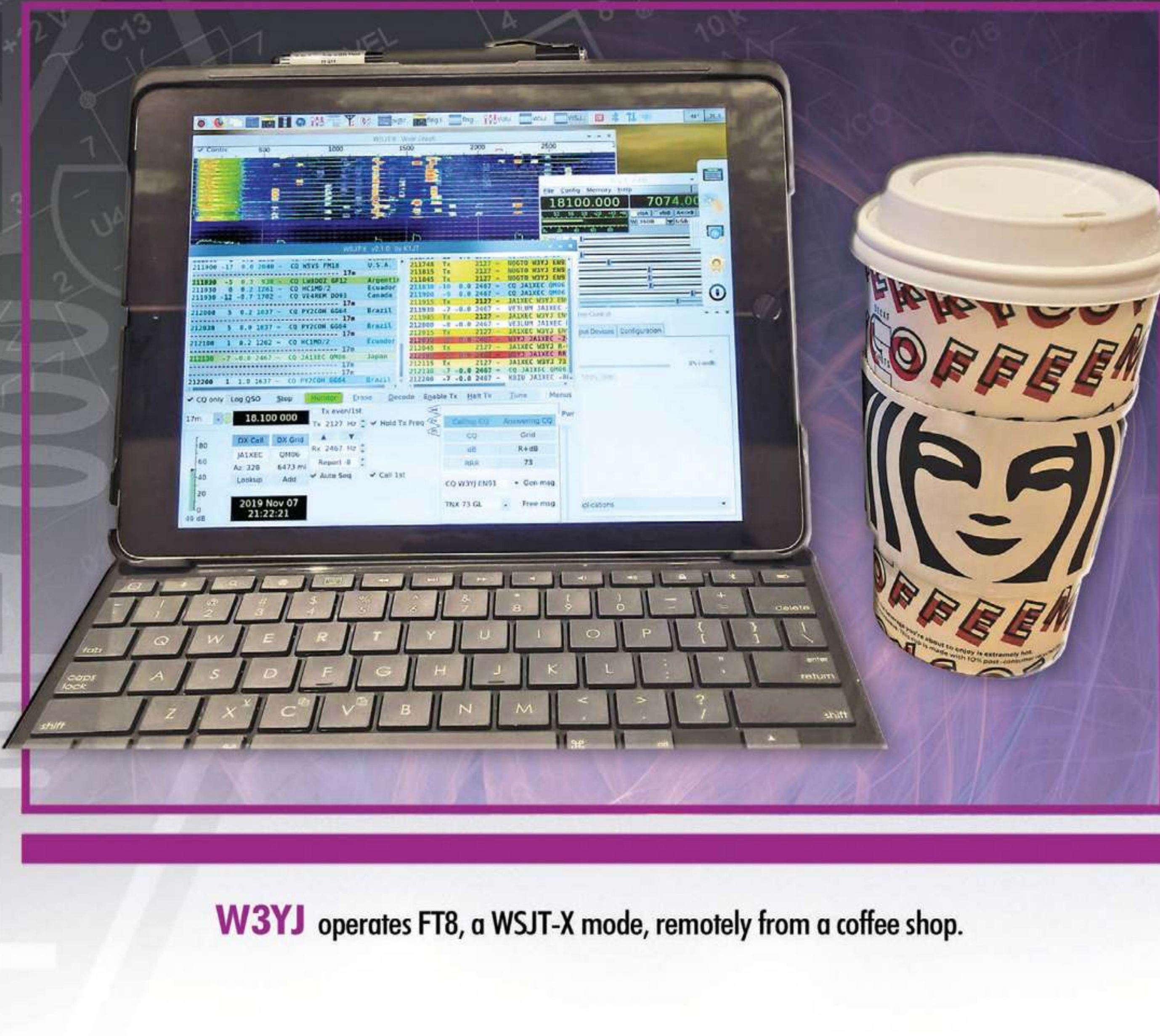
A Forum for Communications Experimenters

Issue No. 323



W3YJ operates FT8, a WSJT-X mode, remotely from a coffee shop.

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QEX

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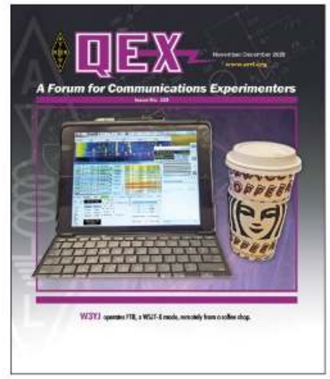
About the Cover



Harry Bloomberg, W3YJ, interfaces several key pieces of technology to operate CW, digital modes, and SSB remotely. The first piece is the Raspberry Pi single-board computer that runs a distribution of the Raspberry Pi OS (Raspbian) Open Source Linux operating system. The next pieces are *Fldigi* and *Flrig*, part of the *NBEMS* software suite developed by Dave Freese, W1HKJ. *Flrig* enables you to control a transceiver through a USB interface. You can change frequency, adjust power, and control other major parameters on a variety of transceivers. *NBEMS* runs on Windows, MacOS and Linux, including the Raspberry Pi. You can use *Flrig* to act as rig control for *WSJT-X* digital modes. [Harry Bloomberg, W3YJ, photo.]

In This Issue

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The American Radio Relay League

The American Radio Relay League, Inc, is a noncommercial association of radio amateurs, organized for the promotion of interest in Amateur Radio communication and experimentation, for the establishment of networks to provide communications in the event of disasters or other emergencies, for the advancement of the radio art and of the public welfare, for the representation of the radio amateur in legislative matters, and for the maintenance of fraternalism and a high standard of conduct.

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The purpose of *QEX* is to:

1) provide a medium for the exchange of ideas and information among Amateur Radio experimenters,

2) document advanced technical work in the Amateur Radio field, and

3) support efforts to advance the state of the Amateur Radio art.

All correspondence concerning *QEX* should be addressed to the American Radio Relay League, 225 Main St., Newington, CT 06111 USA. Envelopes containing manuscripts and letters for publication in *QEX* should be marked Editor, *QEX*.

Both theoretical and practical technical articles are welcomed. Manuscripts should be submitted in word-processor format, if possible. We can redraw any figures as long as their content is clear. Photos should be glossy, color or black-and-white prints of at least the size they are to appear in *QEX* or high-resolution digital images (300 dots per inch or higher at the printed size). Further information for authors can be found on the Web at **www.arrl.org/qex/** or by e-mail to **qex@arrl.org**.

Kazimierz "Kai" Siwiak, KE4PT

Perspectives

The March to Modules

Radio began with purely mechanical devices, at first with spark-gap transmitters and spark-gap receiving loops of Heinrich Hertz. Then as we marched through technical innovations, receiving of radio waves improved by the introduction of electrical detectors and coherers. Spark could by then provide actual wireless transmission and reception of messages over usable distances. We then entered the era of vacuum tubes and electronics; the excess bandwidths of spark-gap transmissions — Class B (damped wave) emissions — could no longer be tolerated, and were prohibited internationally by 1934 (but recently permitted once again under the *Ultra-wide Band Operation* provisions of FCC Part 15 subpart F). Radio became carrier-wave based, and the spectrum was carved up and allocated in relatively narrowband slivers of *frequencies*. We radio amateurs got our fair share of these band segments.

Vacuum tube electronics led to semiconductors and then to ICs (integrated circuits). By 1930 Julius Lilienfeld had already patented (US 1,745,175) the forerunner of the field effect transistor. At each stage of technical innovation transmitters and receivers became less costly, more capable and more compact. Today sophisticated application-specific ICs are driving the development of highly compact versatile modules, such as frequency synthesizers, tiny single-board computers, display modules, mixer modules, and real-time clock modules.

You can now easily build a very capable radio transceiver from readily available modules. Welcome to the world of modular electronics!

In This Issue

Harry Bloomberg, W3YJ, describes an inexpensive configuration that lets you operate an all-mode station remotely.

Eric Nichols, KL7AJ, in his Essay Series discusses setting up a home electrical engineering lab.

Bob Fontana, AK3Y, uses a NanoVNA to design an SSB ceramic resonator filter for digital modes.

Joe Purden, W6AYC, describes limitations of the transmission line resonator approach to broad banding dipoles.

Steve Stearns, K6OIK, describes *HOBBIES*, a series of computational electromagnetic analysis programs that use the method-of-moments with higher-order basis functions.

Al Yerger, K2ATY, exploits the quadrature coupling of power amplifiers to provide redundancy in a UHF power amplifier design.

Writing for *QEX*

Please keep the full-length *QEX* articles flowing in, or share a **Technical Note** of several hundred words in length plus a figure or two. *QEX* is edited by Kazimierz "Kai" Siwiak, KE4PT, (**ksiwiak@arrl.org**) and is published bimonthly. *QEX* is a forum for the free exchange of ideas among communications experimenters. All members can access digital editions of all four ARRL magazines: *QST*, *On the Air, QEX*, and *NCJ* as a member benefit. The *QEX printed edition* annual subscription rate (6 issues per year) for members and non-members is $29 in the United States. First Class mail delivery in the US is available at an annual rate of $40. For international subscribers, including those in Canada and Mexico, *QEX* printed edition can be delivered by airmail for $35 annually, see **www.arrl.org/qex**.

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Very kindest regards,
Kazimierz "Kai" Siwiak, KE4PT
QEX Editor

Harry Bloomberg, W3YJ
201 Delafield Rd., Pittsburgh, PA 15215; **w3yj@arrl.net**

Remote Operating with a Raspberry Pi, *Fldigi/Flrig*, *WSJT-X*, and *NoMachine*

This inexpensive configuration lets you operate an all-mode station located remotely.

My primary residence is on a small suburban lot where putting up a good HF antenna is a challenge. A few years ago I inherited five acres of woods and an old Amish farmhouse 85 miles away. I hung some antennas from tall walnut and pine trees on the property and spent weekends and holidays operating from there.

I started researching how to access the station located at my wooded location from my primary residence. Some solutions were quite expensive and complex. However, I discovered three key pieces of technology that allowed me to operate CW, digital modes, and SSB remotely and inexpensively.

The first piece was the Raspberry Pi, a small inexpensive single-board computer that is used in many embedded applications. It runs a distribution of the Raspberry Pi OS (Raspbian) Open Source Linux operating system. I purchased a Raspberry Pi 4 with 4 GB of RAM as part of a kit containing important accessories at a cost of US $99.

The next pieces were *Fldigi* and *Flrig*, part of the *NBEMS* suite developed by Dave Freese, W1HKJ. *Flrig* enables you to control a transceiver through a USB interface. You can change frequency, adjust power, and control other major parameters on a variety of transceivers. *NBEMS* runs on Windows, MacOS and Linux, including the Raspberry Pi. You can also use *Flrig* to act as rig control for *WSJT-X*.

The final piece was the *NoMachine* remote operating software. I looked into various ways of logging onto the Pi. Then a good friend told me about how *NoMachine* was used to log securely onto computers at a major government lab. *NoMachine* is free for personal use and will stream audio both to and from the Raspberry Pi. I joined a *NoMachine* support forum and soon learned how to interface *NoMachine* to the audio system on the Raspberry Pi. *NoMachine* makes clients

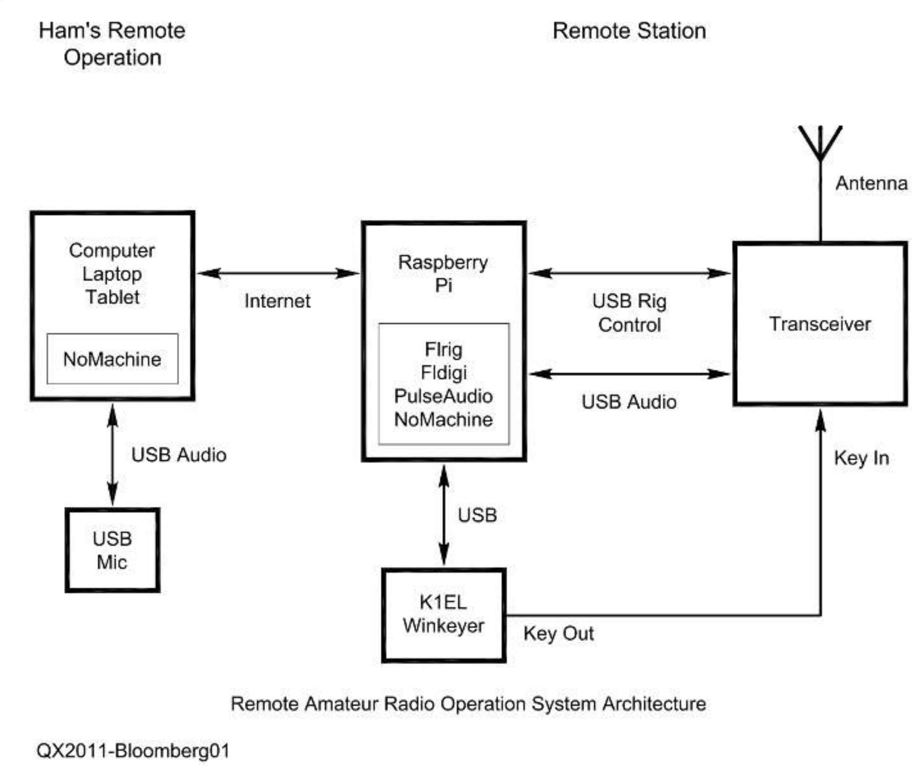


Figure 1 — Block diagram of the system architecture.

for all major platforms including Windows, MacOS, iOS and Android that can connect to the *NoMachine* server on the Pi. *NoMachine* for all platforms along with installation instructions, documentation, and support is available from **www.nomachine.com**.

I knew my remote system was fully operational when I connected to my station from a coffee shop and worked *FT8* stations from my iPad with *WSJT-X*, and then made a CW contact with a special events station using *Fldigi*. I also made several SSB contacts in the Pennsylvania QSO Party from a hotel room in Michigan.

The advantage of this method of remote operating is that it is very inexpensive. The only additional hardware you need to purchase is a Raspberry Pi. You must, however, learn Linux system administration. Most ham clubs have some members who are familiar with Linux who might be able to help you.

Integrating NoMachine with the Raspberry Pi

Figure 1 shows a block diagram of the system. At the center of everything is a Raspberry Pi Model 4. I initially made a prototype system with a Pi Model 3B+, but on occasion the IC-7200 would lock up and lose the audio connection to the Pi. This has never happened with the Pi 4. I suspect the Pi 4 works better because it is much more powerful than the Pi 3.

The IC-7200 is particularly well suited for connecting to a computer because both audio and rig control commands are carried over the USB cable. I have also operated an Elecraft KX3 remotely with the Pi, but an external USB soundcard and cables going to the microphone and headphone jacks are required.

Audio is processed on the Pi by a package named *PulseAudio*, which acts as an audio server, sending and receiving streams of audio much as a webserver sends and receives internet data. *NoMachine* interfaces with *PulseAudio*. A common commercial use for *NoMachine* is logging onto remote systems and streaming audio remotely to remote microphones and speakers for VoIP communications. Hams of course want to hear audio coming from the transceiver and send audio to a microphone input on the radio. Some Linux shell commands are run once after logging into the Pi to redirect these audio streams.

A detailed explanation of how to interface *NoMachine* with *PulseAudio* is "beyond the present scope. Please see **www.w1hkj.com/W3YJ/** for detailed tech notes. But, only a handful of Linux shell commands are required. I have written a Perl program that probes your Raspberry Pi for soundcards and writes the shell commands for you. This script is named write_script.pl and is also available for download from **www.w1hkj.com/W3YJ/**. *PulseAudio* refers to audio inputs like mics as "sources" and output devices like speakers as "sinks". Figure 2 shows sinks and sources when my IC-7200 is connected to the Pi and how the Linux shell commands cause sinks and sources to be reconfigured to interface the IC-7200 to NoMachine. The tech notes explain how to obtain the names of sources and sinks for your USB soundcard."

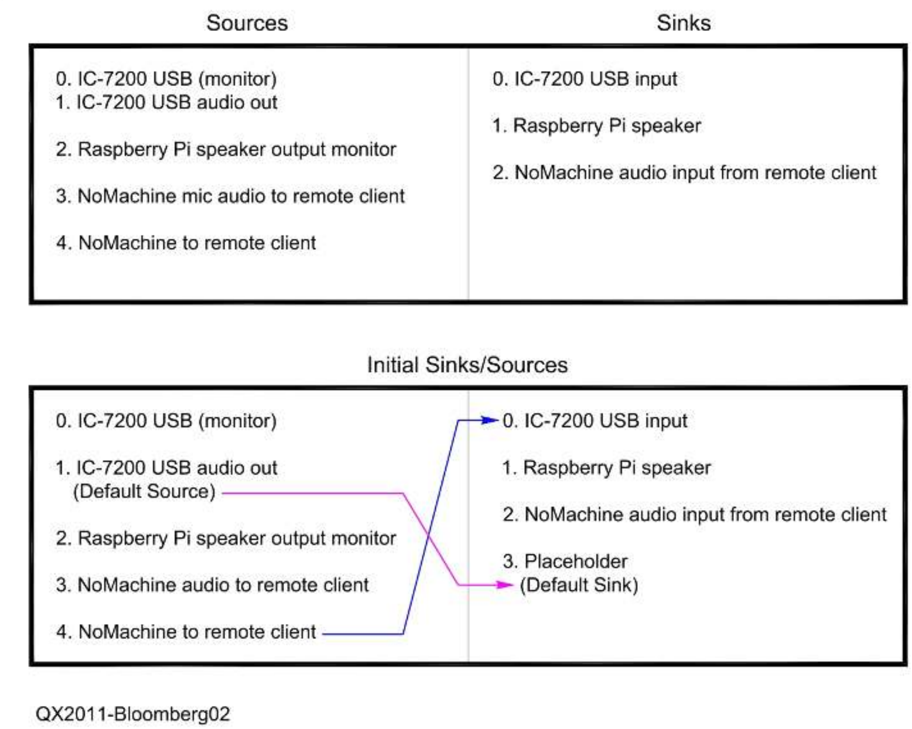


Figure 2 — Summary of sinks and sources when the IC-7200 is connected to the Raspberry Pi.

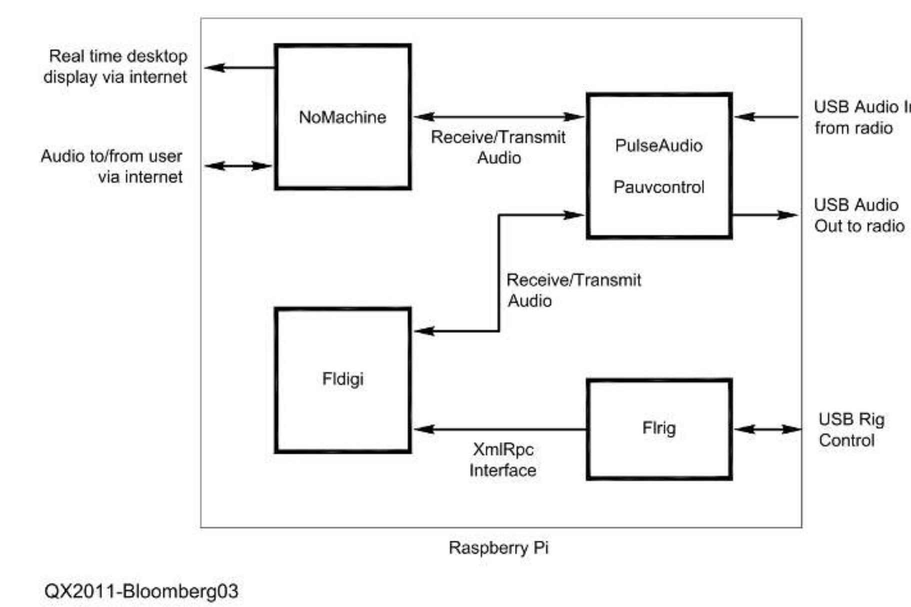


Figure 3 — PulseAudio sources and destinations controlled by pauvcontrol.

Adding *Fldigi* and *Flrig*

There are two ways to install *Fldigi* and *Flrig*, see **Figure 3**. The easiest way is to use the Pi *Add/Remove* software utility. Unfortunately, this will install a version of the software from a Raspberry Pi repository that is quite old, and you will not have the latest features or bug fixes. An alternative is to build the software from source code. Excellent instructions can be found at the W1HKJ web page **[1]**. You will need to open a terminal and enter some Linux shell commands.

Once *Fldigi* and *Flrig* have been installed, you must first configure *Flrig*. Go into the Configure menu and select your transceiver and USB communications parameters. You'll know *Flrig* is configured correctly when you see your transceiver's frequency correctly displayed in *Flrig*.

Next, configure *Fldigi* to use *Flrig* for Rig Control. Go to the Configure > Rig Control menu and click on the checkbox to use *Flrig*. Again, you'll know *Fldigi* is properly configured when you see the correct frequency displayed in *Fldigi*.

You are now ready to tell *Fldigi* to use *PulseAudio* for audio and to connect *Fldigi* to your USB soundcard devices. In *Fldigi*, go to the Configure > Soundcard menu. Select the Devices tab and click the checkbox for *PulseAudio*. Leave the box for Server String empty because you're accessing *PulseAudio* on this computer.

To connect *Fldigi* to the correct USB soundcard devices, open the *pavucontrol* utility. You can install *pavucontrol* using the Raspberry Pi *Add/Remove* software utility. Go to the Recording tab. You'll see one audio stream with the *Fldigi* icon next to it. This is the volume control for audio being directed into *Fldigi*. Select your USB soundcard device from the drop down. Then adjust your audio level and make sure you see signals on the waterfall. A good rule of thumb for adjusting the input level is that the waterfall is mostly blue with signals in yellow. If you see signals that are red, your level is too high and you won't get the full benefit of your soundcard dynamic range.

The process is similar for *Fldigi* transmit audio. Go to the Playback tab and find the stream that has a small *Fldigi* icon. Change the dropdown to your USB audio device. Adjust the output level so that your radio ALC just moves a little bit. Note that if you click on the *Flrig* SWR meter while transmitting, you'll see ALC displayed.

My favorite way to have *Fldigi* generate CW and key the transceiver is by installing a *WinKeyer* by K1EL. I have had great success with both the *WKUSB-SMT* and *WKmini*. The K1EL web page **[2]** has full instructions, as does the W1HKJ *NBEMS* web page **[3]**. *Fldigi* can also control a nanoKeyer **[4]**.

I made a few CW contacts in the Worked All Europe (WAE) contest while staying in a hotel room on a vacation. To configure *Fldigi* as a contest logger, go to Configure > Contest/Logging > Contest. The Contest drop-down menu allows you to set up *Fldigi* for a variety of popular contests including ARRL Field Day. *Fldigi* can also check for dupes and automatically generate serial numbers. Macro keys can be edited to automate contest exchanges and logging. Logs can be exported in a variety of formats including ADIF, CSV and Cabrillo. *Fldigi* has an excellent CW modem to help you copy CW.

Remotely Logging Onto Your Raspberry Pi

Perform the following steps to log onto your Raspberry Pi.

1) Right click on the *NoMachine* icon on the toolbar at the top of your Pi screen. Go to the Show the Service status menu. Note the *nx:* address that has a global IP address, which is an IP address that is not on you local network. Also write down the port number. This is the number that is separated from the IP address by a colon.

2) Enter this *nx:* address into *NoMachine* on your computer or tablet device.

You can now connect to your Raspberry Pi from your computer or tablet. To ease this in the future, you may want to subscribe to a service like NoIP so that you can connect to your Pi by the machine's name instead of IP address, which could be changed by your Internet provider.

Configuring *NoMachine* Audio

When you log onto your Raspberry Pi using *NoMachine*, run the shell script (described in the Tech Notes) to connect *PulseAudio* to *NoMachine*. You must do this while logged in using *NoMachine*. If you try to run the script while logged directly onto Pi, the *PulseAudio* sources and sinks for *NoMachine* won't be available and the script will fail.

To adjust the volume of the audio from your radio that is being sent to your device, open *pavucontrol*, go to the Recording tab, and adjust the level of the *NoMachine* slider. You may need to change the value of the drop down for this slider to "Monitor of Null Output."

I have found that often the default audio setting for the *NoMachine* client is to have audio muted. You may have to go into *NoMachine* settings, then go to the audio icon, and click on the left speaker icon to un-mute. This control also gives you another audio level for the volume of the audio coming from your radio.

Configuring for SSB Operation

Using *NoMachine* for remote operating works most simply if you want to operate CW or digital modes. But SSB operation is also possible with a USB microphone connected to your computer or using the microphone built into your computer. You must change the audio settings on your *NoMachine* client on your computer to unmute your microphone, **Figure 4(A)**. You can also adjust levels in your *NoMachine* microphone settings, **Figure 4(B)**. In addition you'll need to adjust levels on your computer and select PTT, **Figure 4(C)**. Finally, you must go to the Playback tab on the *pavucontrol* program and change the output for the *NoMachine* audio stream to your radio USB soundcard device. Note that you cannot do this unless your microphone is enabled in *NoMachine*.

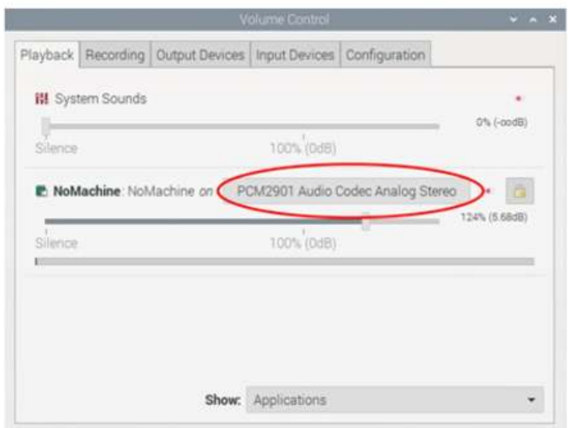
Operating *WSJT-X* with *NoMachine*

WSJT-X has a built-in radio interface to *Flrig* that will simplify radio configuration. In *WSJT-X* go to File > Settings > Radio and select "FLrig" as the radio and CAT as the PTT control. This allows *Flrig* to control *WSJT-X* and saves you having to configure your radio directly through *WSJT-X*.

For *WSJT-X* audio settings, go to the Audio tab and select your USB soundcard. Setting audio levels with *WSJT-X* and *pavucontrol* is a little tricky. A quirk of *WSJT-X* is that the audio input from *PulseAudio* is by default always set to 100%. You will need to change this every time you start *WSJT-X*. To reduce the level, go to the Recording tab in *pavucontrol* and find the stream with the *WSJT-X* icon labeled QtPulseAudio. Use this control to reduce the input audio level. I find a setting around 50% works for me.

You can only adjust the audio level for transmitting while actually transmitting. To set the audio level, first reduce the power level on your transmitter in *Flrig* to a very low value to minimize interference. Press the *WSJT-X* Tune button. While

(A)



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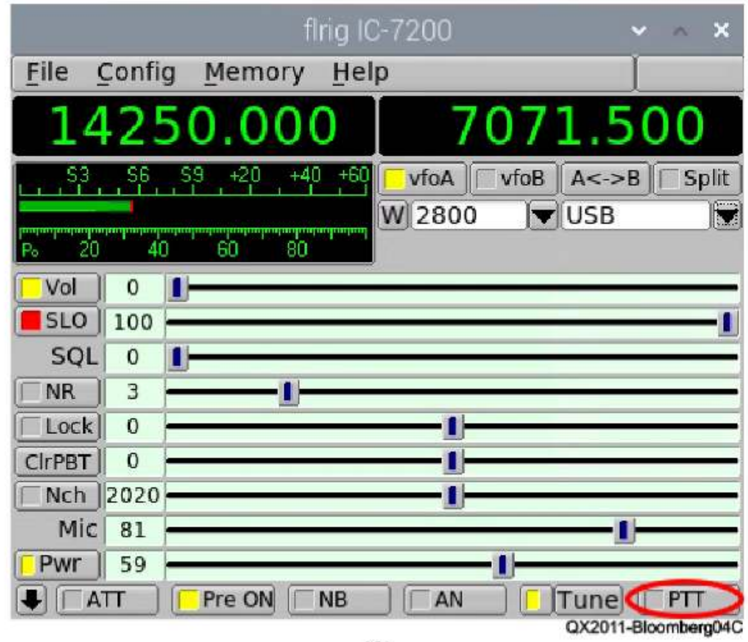

(C)

Figure 4 — Configuring for SSB, (A) unmute the audio at 'Mic in'; (B) set audio level for the NoMachine audio codec; (C) select PTT in Flrig IC-7200.

transmitting, go to *pavucontrol* on the Playback tab. Find the stream with the *WSJT-X* icon labeled QtPulseAudio. Adjust this level until you see a small amount of ALC on your transmitter. Fortunately, this needs to be adjusted once and will stay the same every time you execute *WSJT-X*.

Remote Station Considerations

Should something go wrong with your remote station, you cannot be there to pull the kill switch on your radio or cycle power to your Raspberry Pi. I have installed Wi-Fi controlled ac power sockets for both my IC-7200 and Pi. This allows me to cycle power to both devices using an app on my cell phone. To increase the reliability of my home network, the ac power for both my wireless router and the Raspberry Pi are connected to a UPS. I also have the Raspberry Pi directly plugged into the wireless router using an Ethernet cable.

Putting It All Together

Are there a lot of moving parts in this method for remote operation? Absolutely! You are almost guaranteed to have total failure if you install *NoMachine*, *Fldigi*, *Fldigi*, and run your PulseAudio scripts all at the same time. It is very important to add one feature at a time, make sure each new feature works, and then move on to the next step. You should add functions in the following order:

1) Build *Fldigi* and *Flrig* on your Pi from the source, or install from the repository.

2) Connect to your rig using *Flrig* and make sure all the major controls in *Flrig* work with your rig.

3) Set up *Fldigi*. First, make sure it works with *Flrig*. Next, make sure you can send and transmit audio using *PulseAudio*. Adjust audio levels with *pavucontrol*.

4) Connect your K1EL Winkeyer and make sure you can key your radio with *Fldigi* in CW mode.

5) Install *WSJT-X* and use *Flrig* as rig control. Adjust audio levels with *pavucontrol*.

6) At this point you can make digital and CW contacts using your Raspberry Pi. Spend some time on the air to become familiar with operating using your Pi.

7) Run the *write_script.pl* Perl program **[5]** to identify your USB audio device and to write the shell commands to reroute audio streams.

8) Install *NoMachine* on your Pi and your computer or tablet.

9) Log onto your Pi using *NoMachine* from your local network.

10) Run the scripts written by *write_script.pl* to redirect audio. Enable your speaker and microphone in *NoMachine*.

You are now ready to connect to your remote system. Try it out in your shack before you head to your favorite coffee shop (**Figure 5**).

EmComm Applications

Installing an HF antenna at a mobile or portable command post can be problematic due to the nature of HF antennas, especially for the 80-meter band. Yes, you can use a portable or mobile antenna, but even the best of these will not work as well as a full-size antenna. You might consider connecting to a remote HF station during a deployment. Think back to your most recent Field Day operation and remember how long it took to set up your HF station and how much planning was required. Think of all the little things that can go wrong like a bad piece of coax or a poorly soldered RF connector. Now imagine setting up an HF station under the duress of a drill or actual emergency deployment. You may be better off trying to connect to a well-maintained permanent station if a network is available, rather than hastily setting up an HF station with a poor-performing temporary antenna at the deployment site

Does this add a layer of complexity to a deployment? The same was said years ago about NBEMS, Winlink, and mesh networking. They're now standard parts of our EmComm toolbox. Also think back to your most recent ARRL Field Day operation and remember how long it took to set up your HF station and how much planning was required. Think of all the little things that can go wrong, like a bad piece of coax or a poorly soldered RF connector. Now imagine setting up an HF station under the duress of a drill or actual emergency deployment. You may be better off trying to connect to a well-maintained permanent station if a network is available rather than hastily setting up an HF station with a temporary antenna at the deployment site.

Future Considerations

With a price of $35-55, the Raspberry Pi is easily affordable. It also has many input/output ports that can be adopted for controlling equipment in a ham shack. The Linux operating system is an ideal platform for amateur radio operators because it is open source and therefore suitable for tinkering and experimenting. Vendors of commercial amateur radio equipment should consider porting their rig control and radio programming software to Linux so their software can run on a Raspberry Pi. Why write this article? One reason is fame and fortune. Another is to ask for help from other hams. I worked on this alone and your collective wisdom is welcomed. Please review my work! Is there another way to do this? I love NoMachine but I'd rather be using software that is Open Source. Is there something out there that works as well as NoMachine and supports so many different platforms? And, what can be done to simplify all this so that a ham with minimal Linux admin skills can make this work?

Acknowledgements

Thanks to Juan Manfredi, NAØB of the Panther Amateur Radio Club of the University of Pittsburgh; to *NoMachine* Tech Support for helping me configure the interface with *PulseAudio*; and to Dave Freese, W1HKJ, the leader of the NBEMS team and everyone else working on the project.

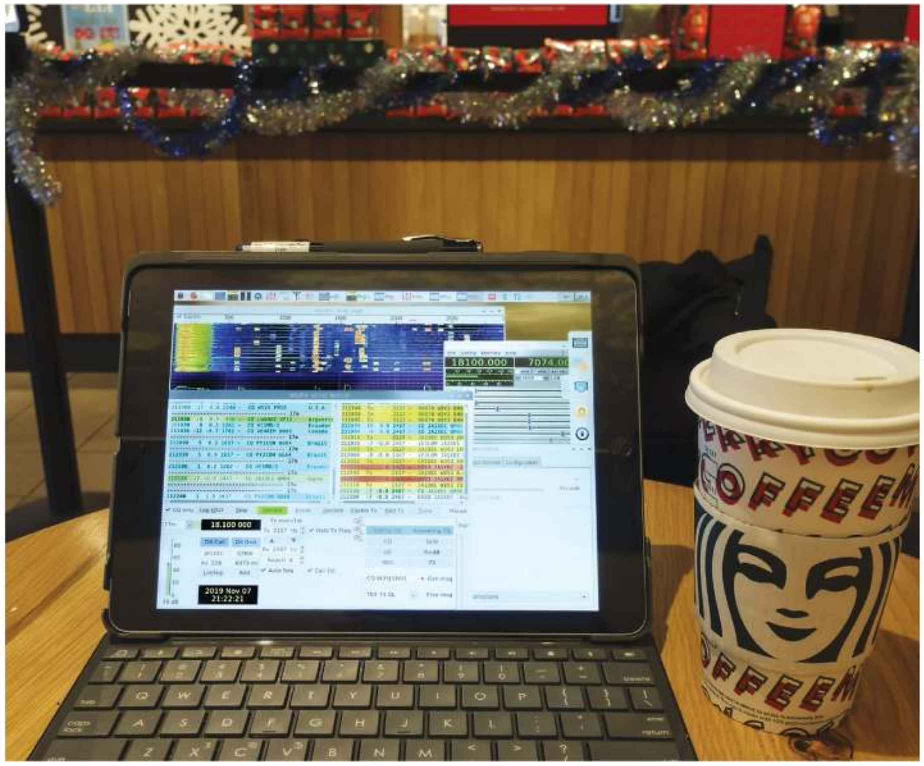

Figure 5 — Operating FT8 remotely from a coffee shop, before the current pandemic.

Harry Bloomberg, W3YJ, was first licensed in 1972 as WN3TBL. He recently retired after many years working as a software engineer. Harry graduated from the University of Pittsburgh in 1979 with a BSEE degree. He also holds a Masters of Mathematical Sciences degree from the University of Texas at Dallas. Harry is an alumni member of Panther Amateur Radio Club (PARC) at the University of Pittsburgh. He also belongs to Mercer County ARC and Skyview Radio Society. Harry enjoys CW contesting and working many digital modes. He has had three articles published in QST *about NBEMS and wrote a chapter in the* ARRL Public Service Communications Handbook *on NBEMS.*

Notes

[1] **https://sourceforge.net/p/fldigi/wiki/debian_howto/**
[2] **https://www.hamcrafters2.com/**.
[3] **www.w1hkj.com**.
[4] **https://nanokeyer.wordpress.com/**.
[5] Download the script from **www.w1hkj.com/W3YJ/write_script.tar.gz** or from **www.w1hkj.com/W3YJ/**.

Errata

In John E. Post, KA5GSQ, "Generation and Reception of Single-sideband Signals using GNU Radio Companion," *QEX* Sep./Oct. 2020:

In the last paragraph of the section, "Filter Methods of SSB Generation," the next to last sentence should read: "The result of passing the double-sided representation, **Figure 5**, through the sideband filters, **Figure 6**, is shown in **Figure 7(a)**…"

In the first paragraph of "Filter Method of SSB Reception", the last sentence should read: "The frequency xlating FIR block also includes a low pass filter whose width must be set to f_m to pass both sidebands shown in **Figure 18(a)**, or whose width must be set to $f_m/2$ to pass the sideband configuration shown in **Figure 18(b)**.

Equation **(A6)** should read:

$$\mathcal{F}^{-1}\left\{\text{sgn}f\, M\left(f\right)\right\} = j\hat{m}\left(t\right)$$

In **Figure 8** the file name in the file source blocks should be "test_audio_36k". Delete "Cuttof Freq: 3k" in AGC2 block.

In **Figure 16** Set Gain = −1 for lower low pass filter. Arrow should enter File Sink Block.

In **Figure 20** sample rate for Band Pass Filter Block should be 36 KSPS.

In **Figure 26** Rcv_frequency WX GUI Slider Default Value should be 430.05M. Tx_attn WX GUI Chooser Choices should be 89.75, 50.

Robert J. Fontana, AK3Y

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Using the NanoVNA to Design an SSB Ceramic Resonator Filter

There are many uses for the versatile NanoVNA RF measurement tool besides finding antenna impedances.

The NanoVNA, a two-port vector network analyzer (VNA) capable of covering anywhere from 9 kHz to over 1500 MHz depending upon firmware and software versions, was recently reviewed by Phil Salas, AD5X in the May 2020 issue of *QST* **[1]**. While many amateurs are using this VNA purely for antenna impedance and SWR measurements, there are so many other uses for this amazing little RF measurement tool.

Until recently, VNAs were very pricey pieces of test equipment. While sometimes available surplus at ham fests or online, not many hams could afford these for general use in the shack. While nearly indispensable for microwave circuit analysis and construction, even fewer hams utilized VNAs at HF where S-parameters are not commonly used. With the advent of sub-$100 units, however, the situation has changed — and much for the better.

In this article, we use the NanoVNA to design and build a single-sideband filter using inexpensive ceramic resonators that can be had for as little as a penny each. In doing so, we will illustrate how to accurately and quickly match components, determine the transfer response and input impedance of the resulting design, export design parameters to an open source Smith chart program, and graphically determine the correct network to match the filter to a 50 Ω source impedance.

My design process makes extensive use of the NanoVNA and, hopefully, my experience will be of inspiration to other hams to fully exploit the benefits of this remarkable little device.

Using the NanoVNA for Component Matching

The impetus for this project came from my desire to build a digital version of my Tuna Tin "S" QRPp transmitter **[2]**.

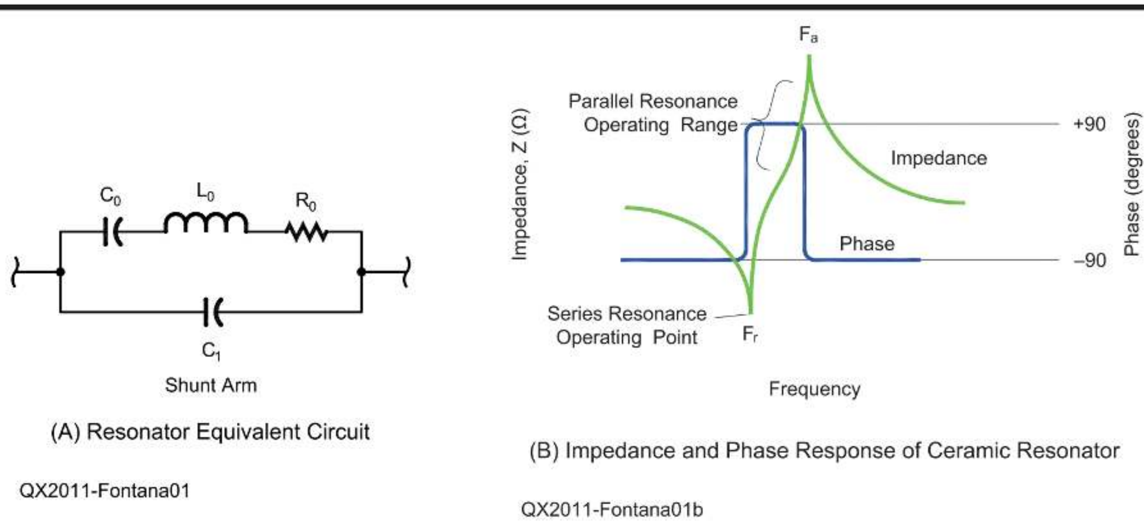

Figure 1 — Properties of ceramic resonators: (A) equivalent circuit; (B) impedance and phase response.

Unfortunately, several commonly available QRP transmitter designs are being used with double-sideband (DSB) modulation when operating in the digital FT4, FT8 or WSPR modes. Designed for upper-sideband modulation to further minimize spectral occupancy, these modulations will produce lower-sideband (LSB) "splatter" if generated with a DSB modulator. The extraneous and undesirable LSB signal is also spectrally inverted, hence not decodable, and simply acts as a source of intentional interference on already crowded digital bands. A single-sideband filter is a must for such operation, and unfortunately, available quartz crystal and mechanical filters can be expensive and physically large.

I recently purchased a large bag of 500 Kyocera ceramic resonators (with 500 kHz nominal center frequency) for $5 **[3]** and, in the spirit (i.e., frugality) of the Tuna Tin design, wanted to see if I could turn these into a usable single-sideband (SSB) filter. At one cent each, the price seemed right, and their physical size (5/16" by 5/16" by 1/8") made them ideal for inclusion in a compact QRPp design.

The first step was to obtain a reasonably well-matched set of ceramic resonators for my design. These resonators have a nominal accuracy of ±2 kHz, which is a bit too wide to simply select resonators at random. Fortunately, however, these resonators are quite stable with temperature, very rugged mechanically and are much smaller and lower cost than quartz crystal filters.

To select a matched set of resonators, I first made use of the fact that ceramic resonators, as with quartz crystals, exhibit both resonant and anti-resonant frequencies. See reference **[4]** for the expressions for these resonances in terms of the equivalent circuit parameters that are shown in **Figure 1**.

Since these resonances are quite sharp and well-defined for ceramic resonators — and the same is also true for quartz crystals, which have an identical equivalent circuit model albeit with different Qs — the NanoVNA will be used to display the real and imaginary components of the input reflection coefficient S11 which should exhibit a pronounced variation near resonance. The test circuit for this measurement is shown below in **Figure 2**.

Here, a short length of RG-58 coax was used to connect to the device under test. An SMA connector is placed on one end to attach to port CH0 of the NanoVNA; and the center conductor and coax shield are used on the other end to touch to the two terminals of the resonator. In the calibration procedure for the NanoVNA, this additional length of coax is not taken into account since the frequency of operation, 500 kHz, has a wavelength many orders of magnitude larger than the length of coax used, and thus its effects are extremely small. If this were being done, however, at much higher frequencies (for example VHF), one would need to calibrate out the effects of the coax, connector and end probe terminations.

The Real and Imaginary components of S11 are shown in **Figure 3** as measured using *NanoVNA Saver*. *NanoVNA Saver* **[5]** is a software package — available under the GNU General Public License — that can display, analyze and save data from the NanoVNA. Aside from the obvious benefit of having access to a large screen display rather than the 3" display on the NanoVNA or the 4.3" display on the NanoVNA-F, *NanoVNA Saver* can

Figure 2 — Test circuit for measuring S11.

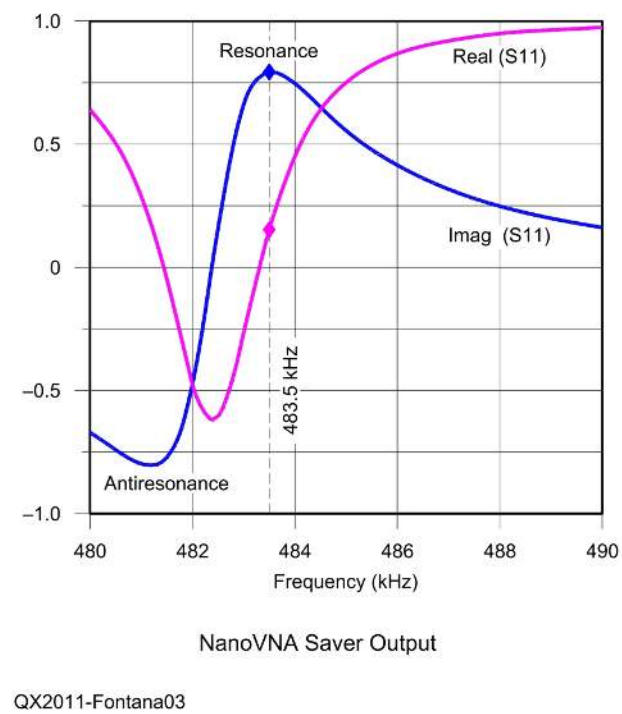

Figure 3 — Real and Imaginary components of S11 for a nominally 500 kHz ceramic resonator.

provide swept frequency spans in multiple segments to gain more than the basic 101 data points — over 10,000 data points are possible — save S-parameter data as Touchstone files for use in other programs, and make numerous other measurements that cannot be directly made or displayed with the NanoVNA alone. These include time-domain reflectometry measurements, data averaging, quality factor Q, inductance and capacitance measurements and filter parameter measurements. The software is available for Windows, Linux and Macintosh operating systems.

I selected the right-most peak of the imaginary component (**Figure 3**) as my selection criterion, and tested a handful of around 20 or so resonators from the batch of 500, selecting seven that were very close in value (483.46 kHz with a standard deviation of 0.15 kHz, or 0.03%). To obtain a fine resolution in selecting components, I calibrated the NanoVNA over the frequency range from 480 kHz to 530 kHz using 10 segments, or 1010 data points. Again, this cannot be done directly on the NanoVNA, but is readily accomplished with the *NanoVNA Saver* software.

SSB Filter Construction and Adjustment

I selected three of the matched components for use in my SSB filter. As ceramic resonators are generally operated in the parallel resonance mode, the filter design consists of the three ceramic resonators, operating in parallel, and loosely capacitively coupled to adjust the overall bandwidth. **Figure 4** shows the filter topology.

With a little experimentation, the coupling capacitors of 30 pF provided the lowest loss without over coupling the resonators. Capacitors C1, C2 and C3 should be in the range of a few dozen picofarads or so, just enough to slightly adjust the parallel resonant frequencies of the three ceramic devices. In my initial test configuration (see **Figure 5**), I used 1.8-15 pF variable capacitors for these capacitors. With the aid of the NanoVNA, and with the filter placed between ports CH0 and CH1 in order to measure the forward gain parameter S21, I adjusted the passband response for the best flatness.

The optimum values in my case are 12 pF for C1 and C3, and 8.2 pF for C2 as measured on a capacitance bridge. In the final implementation, these fixed-value capacitors replaced the variable capacitors. The final filter response is shown in **Figure 6**.

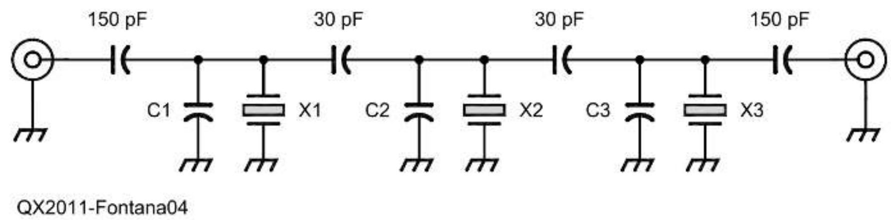

Figure 4 — Ceramic resonator SSB filter topology.

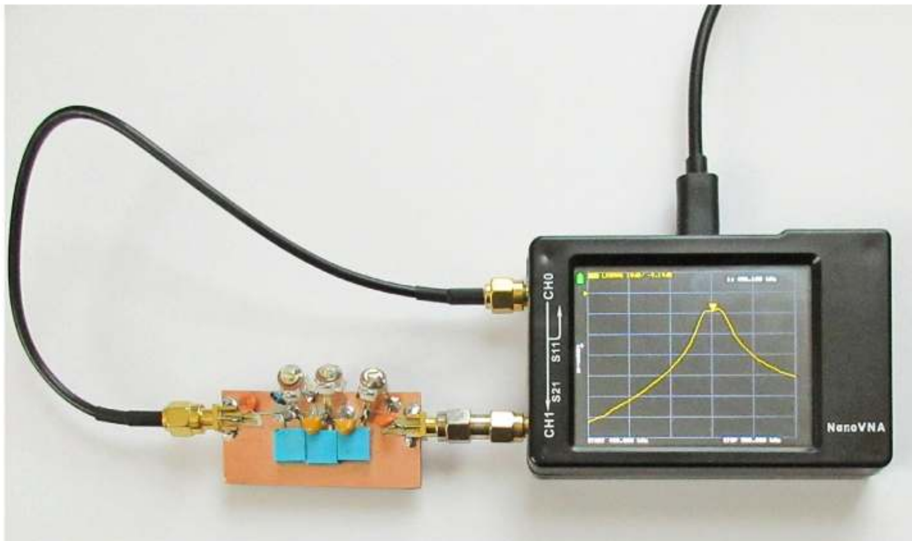

Figure 5 — Physical layout of filter test circuit.

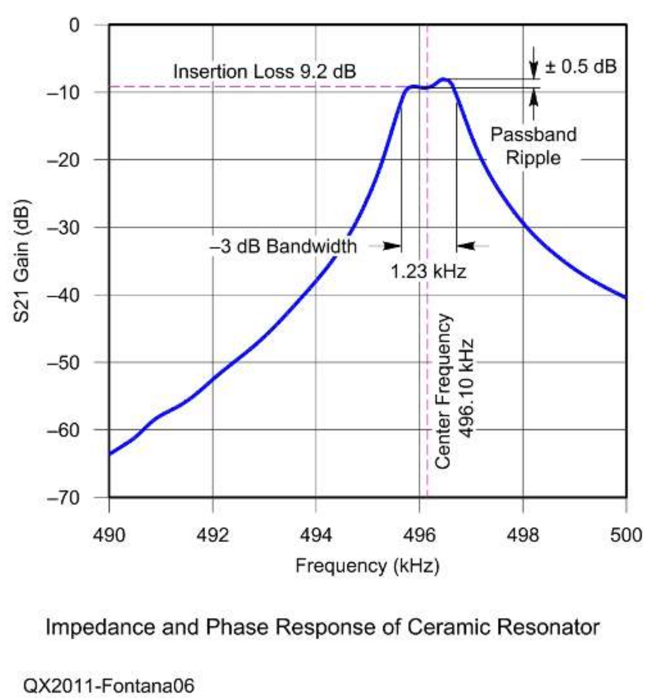

Figure 6 — Transfer characteristics (S21) of optimized SSB filter.

Table 1 - Characteristics of the filter designed for an FT8 waveform.

Center frequency	496.10 kHz
Insertion loss	9.2 dB
Passband ripple	±0.5 dB
3 dB bandwidth	1.23 kHz
LSB suppression	36.0 dB
2nd harmonic suppression	26.2 dB

The resulting filter had the characteristics shown in **Table 1**. This filter was designed as a transmit filter for FT8. With a nominal tone frequency of 1.5 kHz placed at the lower end of the filter passband, 495.78 kHz (using an IF frequency of 494.28 kHz), lower sideband suppression was better than 36 dB. In addition, the second and higher harmonics of the audio tone are suppressed by more than 26 dB. The higher harmonics of the FT8 audio waveform can give rise to spurious signals and, for this reason, WSJT-X provides a split mode for transceivers that can accommodate that function.

These are fairly impressive results for three cents worth of ceramic and a few capacitors! Note that my goal here was to build a transmit filter for use on FT8 that would provide good suppression of the lower-sideband component of the modulated waveform, and it is seen that it can perform that function quite well. It is a bit too narrow for use as an SSB filter for voice modulation. Such a design would benefit from the selection of a different set of ceramic resonator center frequencies, perhaps selecting two matched sets separated by 1 kHz or so.

NanoVNA and Touchstone Files – Smith Chart Presentation

As constructed, the filter fits nicely into a heterodyne design for my QRPp transmitter. The performance, even into 50 Ω as presented to the circuit by the NanoVNA ports, is more than adequate. However, it can be seen that the input impedance of the filter is far from 50 Ω, and it would be interesting to see if that impedance can be properly matched to 50 Ω for other applications. To determine the appropriate matching components, the *NanoVNA Saver* software is used to save the measured S11 parameters as a Touchstone file.

A Touchstone file was originally a proprietary file format named after the EESof linear circuit simulator. While the Touchstone simulator has long since been superseded, the file format lives on.

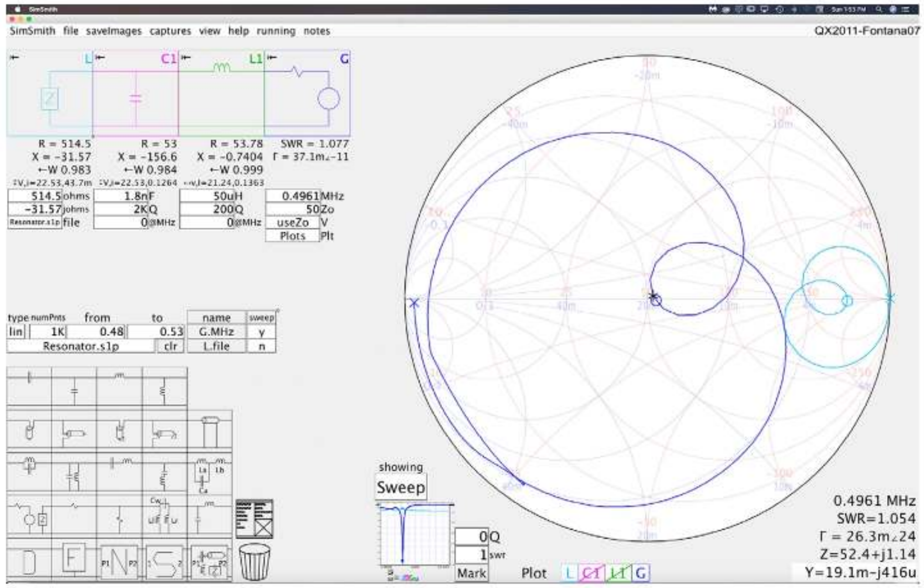

Figure 7 — *SimSmith* Optimization of filter matching network from S parameters.

Basically, a Touchstone file is an ASCII text file used for documenting the n-port network parameter data of linear active devices, passive filters, passive devices, or interconnect networks. It has become the *de facto* industry standard file format, not only for circuit simulators but also for measurement equipment such as the VNA.

NanoVNA Saver provides the option of saving all S-parameter data from the NanoVNA as Touchstone format files. This is particularly useful since there are a few excellent programs available that can further analyze these files. *SimSmith* **[6]** is one of those programs. Developed by Ward Harriman, AE6TY, *SimSmith* can import and export Touchstone files, display a Smith chart, SWR and other parameters, and allow the user to graphically connect a wide variety of passive devices (capacitors, inductors, transmission lines, microstrip, etc.) in an almost unlimited fashion, while observing their effects on the impedance seen by the circuit. Like *NanoVNA Saver*, *SimSmith* is also available for Windows, Linux and Mac OS operating systems.

In **Figure 7**, *SimSmith* was used to import the S11 parameters for the ceramic resonator filter from *NanoVNA Saver*. They were stored in file *Resonator.s1p*. The right most curve on the Smith chart is a representation of the original measured data. The curve near the center of the chart is from an L-C network match to the input impedance. The network used for matching is shown in the upper left hand corner, and the parameters can be easily varied with the UP/DOWN cursor while observing the performance on either the Smith chart, return loss or SWR charts, which are user selectable. Note that *SimSmith* allows the user to change the matching network at will by simply dragging circuit elements from the bottom left to the circuit diagram at the top.

In this case, a near perfect match at the ceramic filter center frequency is achieved with a series 50 µH coil and shunt 1,800 pF capacitor.

Conclusions

The VNA is an important tool for analyzing the performance and measuring the parameters of linear filters, discrete components, amplifiers, antennas, cables, mixers, and more. Until recently, these instruments were out of reach of most radio amateurs because of cost — often thousands to tens of thousands of dollars — and, as a consequence, few hams had the opportunity to use them in their design processes. The SWR or antenna analyzer, a low cost but very simplified version of the VNA, was the closest the ham came to using such an instrument to measure the performance of an antenna system.

At under $100, the NanoVNA is a game changer. Amateurs now have the ability to accurately measure most electrical properties of any network of components using S-parameters — that is, gain, return loss, SWR, reflection coefficients, and so on.

In this article, we used the NanoVNA for component selection, circuit tuning adjustment and, together with an interactive Smith chart application, network impedance matching. Our example used very inexpensive ceramic resonators to construct a single-sideband filter for use in a digital (FT8) QRP transmitter design.

To fully benefit from the NanoVNA, I highly recommend that the interested amateur develops a solid familiarity with S-parameters and the use of the Smith chart to display, analyze and modify circuits described in terms of these parameters. Rohde & Schwarz has excellent set of YouTube videos that introduce the basics **[7]**.

Dr. Robert J. Fontana, AK3Y, is a retired electrical engineer with a PhD from Stanford University. Prior to retirement, Bob was the founder, president and CEO of Multispectral Solutions, Inc. (MSSI), a small business that specialized in ultra-wideband (UWB) technology for communications, radar and tracking/positioning applications. Bob was elected a Fellow of the Institute of Electrical and Electronics Engineers in 2007 for his work with UWB technology. First licensed as a Novice in 1965, Bob holds an Extra Class license and enjoys ragchewing on 20 and 40 meter SSB as well as CW and digital modes of communications such as FT8.

References

[1] Phil Salas, AD5X, "NanoVNA Vector Network Analyzer," *QST* May 2020, pp. 39-43.

[2] Bob Fontana, AK3Y, "The Tuna Tin 'S': A Bare-Bones Synthesized QRPp Rig," to be published in *QST*.

[3] **https://www.goldmine-elec-products.com/prodinfo.asp?number=G24629**.

[4] Phil Elliott, "Surface Mount Ceramic Resonators," AVX Corporation Technical Information, **https://www.avx.com/docs/techinfo/Resonators/smceram.pdf**.

[5] **https://github.com/mihtjel/nanovna-saver**.

[6] **www.ae6ty.com**.

[7] **https://www.youtube.com/watch?v=rUDMo7hwihs**.

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Limitations of the Transmission Line Resonator Approach to Broad Banding 80 m Dipoles

Dipole height and inverted v angle affect the antenna input impedance of this often used matching technique.

A popular approach to increasing the bandwidth of 80 meter dipoles is the Transmission Line Resonator (TLR) approach described by Dave Leeson, W6NL, in November/December 2018 *QEX* **[1]**. The technique uses cascaded sections of multiples of a half wavelength of 50 Ω line followed by a quarter wavelength of 75 Ω, line as illustrated in **Figure 1** taken from Leeson's article. A doubling of the 2:1 SWR bandwidth is achieved, allowing coverage of the entire 80 m band. While the simplicity and superior performance of this technique makes it highly attractive, there are some little understood limitations.

Leeson in his article states that "If an inverted V is used, the angle must be kept shallow to keep the radiation resistance higher than the feed line characteristic impedance." While this is true, the effect of antenna height is of more interest to hams with modest stations. Proximity to ground affects the antenna feed-point impedance in two ways: the real part is lowered, and the Q of the antenna is increased resulting in a narrower bandwidth. It may be useful to think of the ground as an equivalent parallel reactance across with the feed-point. While this analysis utilizes the TLR approach that Leeson used, it is important to understand that the limitations imposed by the bandwidth of the antenna (load) apply to all matching topologies **[2]**, **[3]**.

Review of the Transmission Line Resonator Approach

The input impedance of an 80 m dipole is plotted on a Smith chart in **Figure 2A**. At resonance the real part is 79 Ω. Connecting a 50 Ω transmission line of 180° length at 3.75 MHz causes the ends of the impedance locus to rotate inward (**Figure 2B**). This is because the line is less than 180° long below 3.75 MHz and greater than 180° above 3.75 MHz.

A 90° length of 75 Ω line is added. Quarter wavelength transmission lines act as impedance inverters, transforming the impedance locus by the relation,

$$Z_{out} = Z_0^2 / Z_{in} .$$

In this case, the 75 Ω line will transform 112.5 Ω to 50 Ω.

For the dipole, the impedance locus at the end of the 180° line is roughly centered at 112.5 Ω (asterisk in **Figure 2B**). The 90°, 75 Ω section transforms the locus into an arc

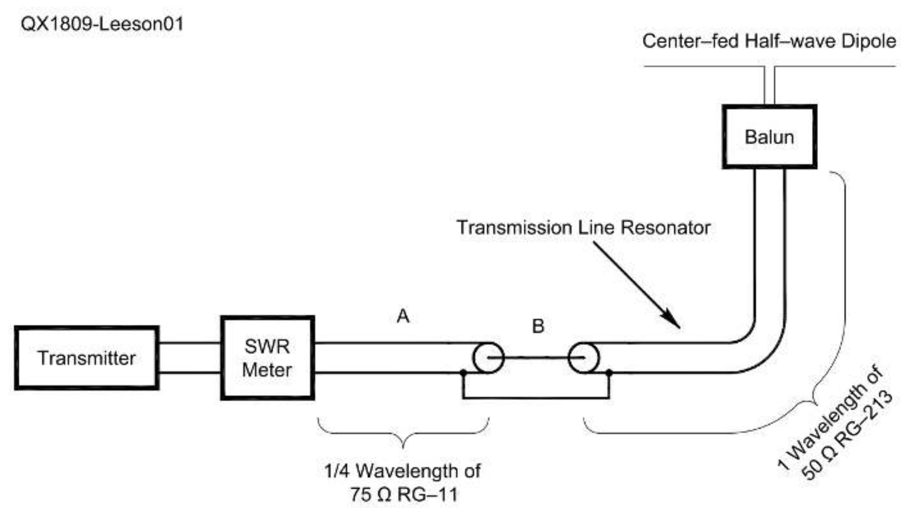

Figure 1 — Broadband feed-line match by Leeson, W6NL (originally from Witt, AI1H).

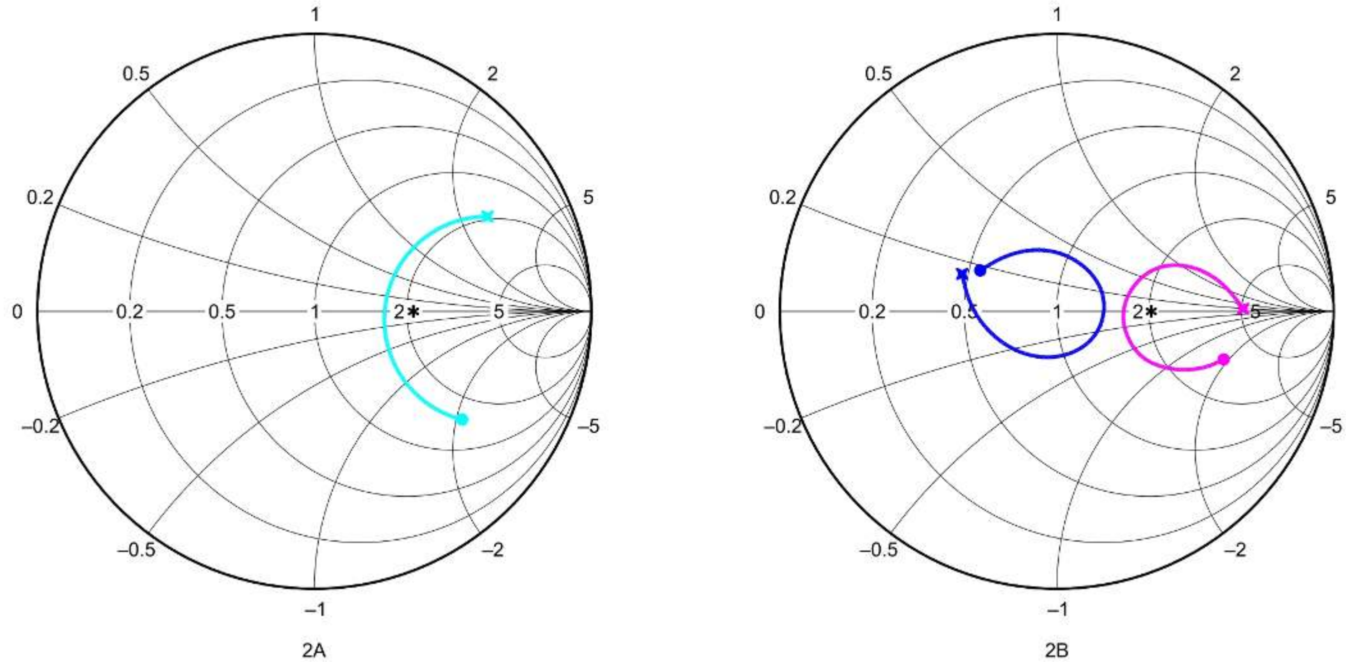

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Figure 2A — Impedance of the 80 m dipole at 75 ft. Figure 2B — Transformation of antenna impedance by a transmission line consisting of (left) 90°, 75 Ω and (right) by a 180°, 50 Ω line, both lines at 3.717 MHz.

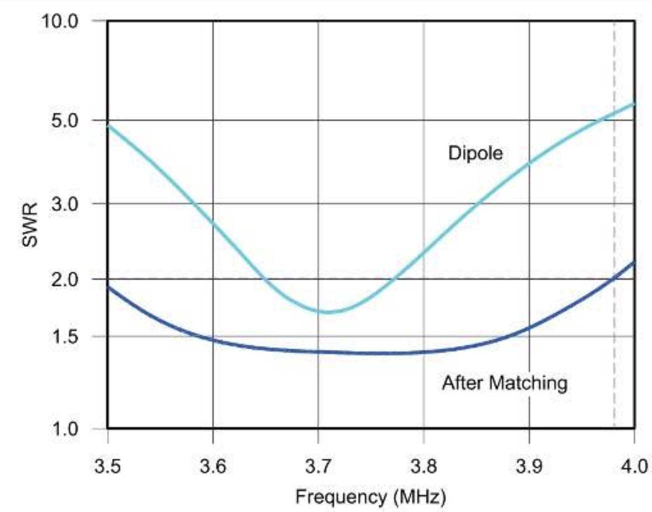

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Figure 3 — SWR for dipole (upper curve) and with broadband matching (lower curve).

Table 1

Measurements at W6AYC for matched inverted V dipole, 45 ft high at apex, 35 ft high at ends.

Frequency, MHz	*S_{11}, dB*	*SWR*
3.555	-10.09	1.91
3.699	-11.45	1.73
3.797	-10.00	1.92

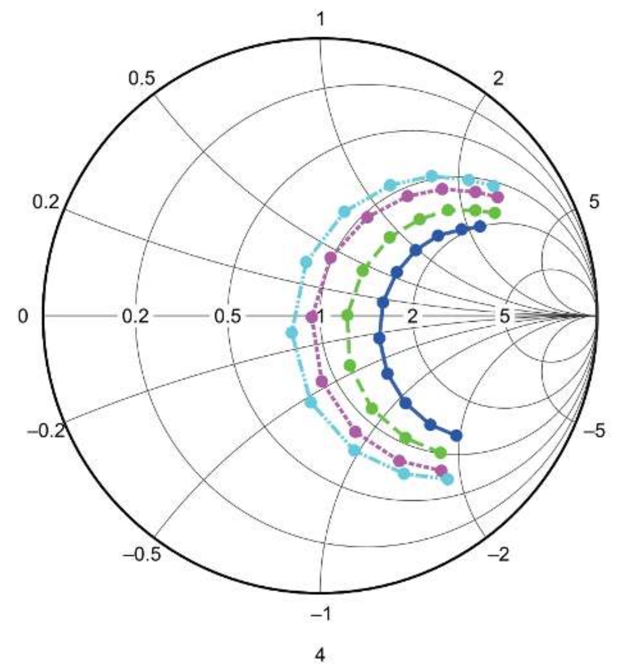

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Figure 4 — Impedance of an 80 m dipole at (right to left curves) 75 ft, 50 ft, 35 ft and 25 ft.

that is roughly centered on the Smith chart, **Figure 2B**. The result after matching is a nearly constant SWR over a broad bandwidth, **Figure 3**.

Effect of Dipole Height

EZNEC was used to calculate the input impedance of a dipole at various heights above average ground. **Figure 4** shows that the effect of ground proximity is significant. The real part decreases from 79 to 40 Ω as height decreases from 75 to 25 ft. The Q of the antenna also increases dramatically (the arc on the Smith Chart is extended). This effect is clearly illustrated in **Figure 5**. The bandwidth, normalized to the real part, decreases by a factor of two from 260 to 130 kHz.

Figure 4 shows the impedance of an 80 m dipole at (right to left curves) 75 ft, 50 ft, 35 ft and 25 ft. Clearly the TLR method will be less useful for lower dipoles. Two factors contribute: the shift to lower impedances, and the greater radius of the loci. The latter dominates. Basically, low dipoles are higher Q to begin with. The greater radius of the loci remains when transformed to the center of the Smith chart by the matching network. A dipole about 50 ft high approaches the lowest for which the TLR method is useful. Simulated SWR = 2 bandwidth is 450 kHz but minimum SWR is only 1.85:1, see **Figure 6**.

My own station approaches this condition. I recently installed an inverted V with a shallow apex angle. The apex is at 45 ft and ends are at 35 ft over poor soil. TLR matching resulted in a relatively flat 2:1 SWR over about 250 kHz, a significant improvement over the original 150 kHz bandwidth, see **Table 1**.

While the result may seem unimpressive, it is actually quite worthwhile as I am able to operate the entire band using the internal antenna tuner in the Elecraft KPA1500 amplifier.

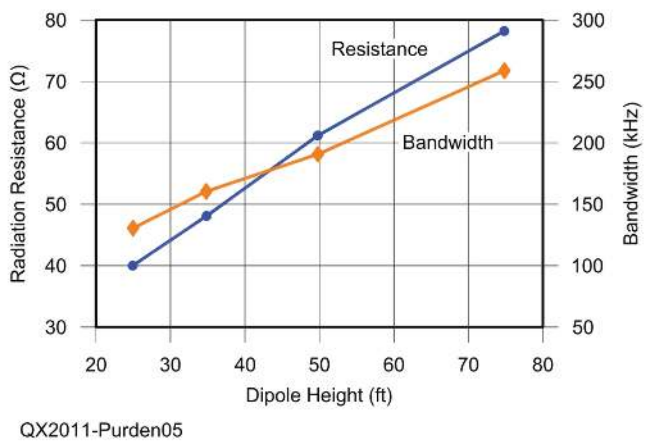

Figure 5 — Bandwidth and radiation resistance of 80 m dipole versus height.

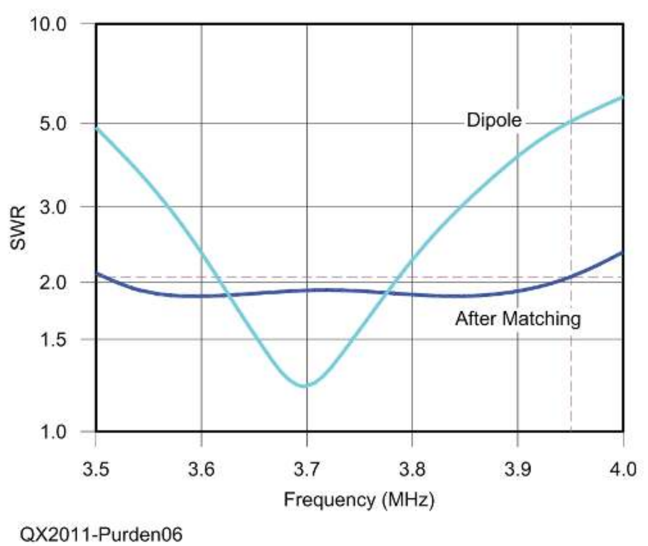

Figure 6 — SWR for dipole ("V-shaped" curve) and with broadband matching ("flat" curve) using the transmission line resonator approach for 50 ft high dipole.

Effect of Inverted V Apex Angle

Since most ham installations are closer to an inverted V than to a dipole, it is worth studying the effect of apex angle. We will look at two representative cases: apex heights of 75 ft and 50 ft.

Figure 7 shows the impedance of an inverted V with 75 ft apex and angles (left to right curves) of 90°, 105° and 120°. It is interesting to note that while the real part decreases at smaller angles as expected — from 63 to 48 Ω — the impedance arcs are similar; there is little effect on bandwidth.

The inverted V results are summarized in **Figure 8**. Both apex heights yield bandwidths of around 160 kHz, about two-thirds that of a high dipole. The radiation resistance is about 20% greater for the higher apex. These results are similar to, or worse than the 50 ft high dipole. Hence, we would expect TLR matching to be of marginal utility. This is confirmed by matching simulations showing 450 kHz bandwidth for SWR less than 2:1 for the 75 ft inverted V with the widest apex angle of 120°, see **Figure 9A**, and minimum SWR of 2.4:1 for the 75 ft high inverted V with 90° apex angle, see **Figure 9B**.

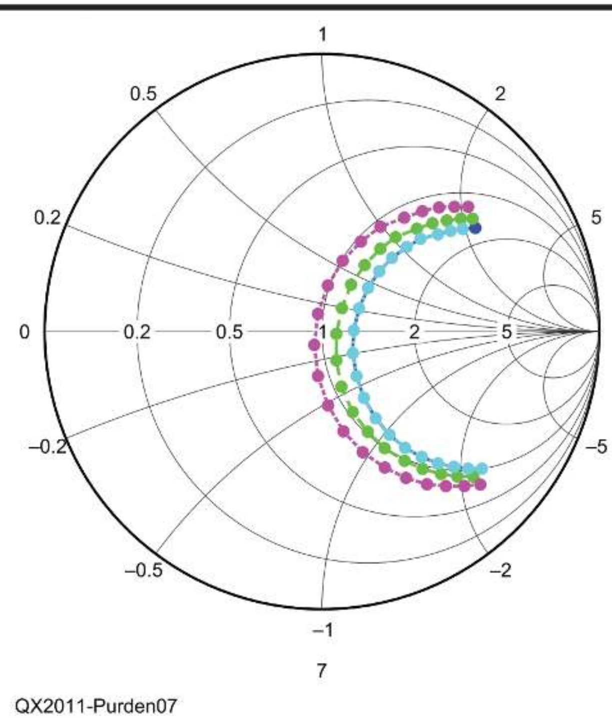

Figure 7 — Impedance of 80 m inverted V with apex at 75 ft and (right to left curves): and apex angle of 120°, 105° and 90°.

Note that the apex height for Lesson's installation was 120 ft. While this might not be a typical ham installation, it will yield excellent matching as his article shows.

Conclusion

The preceding analysis along with results at my own installation show that antenna height greatly affects the utility of the TLR matching technique used by Leeson **[1]**. While the bandwidth of low antennas can be significantly improved, the minimum SWR will be high, about 2:1 for a 50 ft high dipole. In my own case, this was adequate to cover the entire band using the internal tuner of my amplifier. The SWR limitation is primarily due to the decreased bandwidth (higher Q) of antennas less than a half wavelength high. I would like to note again that although this paper concentrated on a technique popularized by Leeson, the effect of height on antenna bandwidth will affect all matching techniques in the same way.

Joe Purden, W6AYC, was first licensed in 1968. His primary interests are antenna design and CW contesting. He earned a BSEE from the University of Cincinnati and MSEE from the University of Southern California. By profession he is a microwave design engineer. Joe designed microwave and millimeter wave transceivers for defense, commercial point-to-point and automotive radar applications. He retired in 2017. Joe's web pages, **w6ayc.com** *contain a number of antenna related presentations.*

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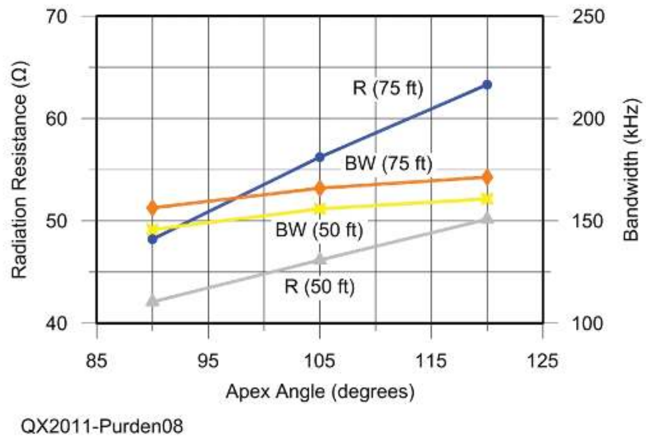

Figure 8 — Bandwidth and radiation resistance of 50 ft high and 75 ft high of inverted V dipoles versus apex angle.

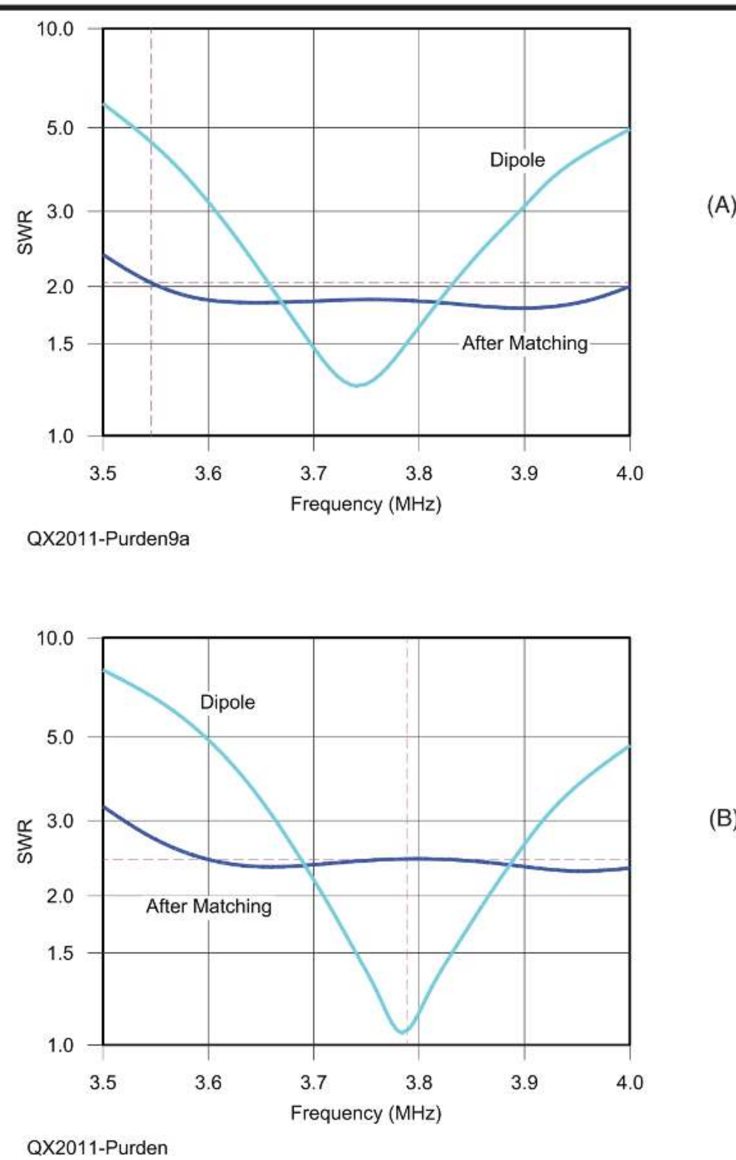

Figure 9A — The transmission line resonator (TLR) matching for an inverted V with 75 ft apex and 120° apex angle. Figure 9B — The transmission line resonator (TLR) matching for an inverted V with 75 ft apex and 90° apex angle.

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HOBBIES Software for Computational Electromagnetics

The latest in a series of software programs for electromagnetic analysis uses method-of-moments with higher-order basis functions.

Higher Order Basis Based Integral Equation Solver, called *HOBBIES*, is a computer program for the numerical analysis of general electromagnetic systems. *HOBBIES* capabilities include ac and RF systems. *HOBBIES* does not handle dc, electrostatic, or magnetostatic fields problems. *HOBBIES* is ideally suited for the modeling of antennas, arrays of antennas, coupled transmit and receive antennas, and scattering problems. The key features that distinguish *HOBBIES* from similar software tools lie in three areas: electromagnetic algorithms, the numerical algorithms for handling large matrices, and the computational architecture and implementation for efficient computation on small computers. As a result, *HOBBIES* can handle very large and complex models on a desktop or laptop computer, for which other software programs would require a supercomputer.

Versions

There are two versions of *HOBBIES* — Academic and Professional. The Academic version is a free download. Wiley provides a software registration code with the purchase of the *HOBBIES* software instruction book. The code can be used one time to obtain a software license that is locked to a user's disk drive. The Academic version handles problems of moderate complexity: 3,000 nodes, 15,000 unknowns, and 5,000 sample points for output responses.

The Professional version is sold by OHRN Enterprises. It costs several thousand dollars, far less than comparable professional software. The Professional version can handle large models. Both versions, Academic and Professional, have in-core and out-of-core solvers that use all of the available CPU cores. Small and medium problems run well on a laptop computer. Large models should be run on a multi-core desktop that has lots of memory and reliable fans as the fans may have to run for hours on large problems. The Professional version handles problems of large complexity: 70,000 unknowns in-core or 300,000 unknowns out-of-core, and 5,000 sample points for output responses.

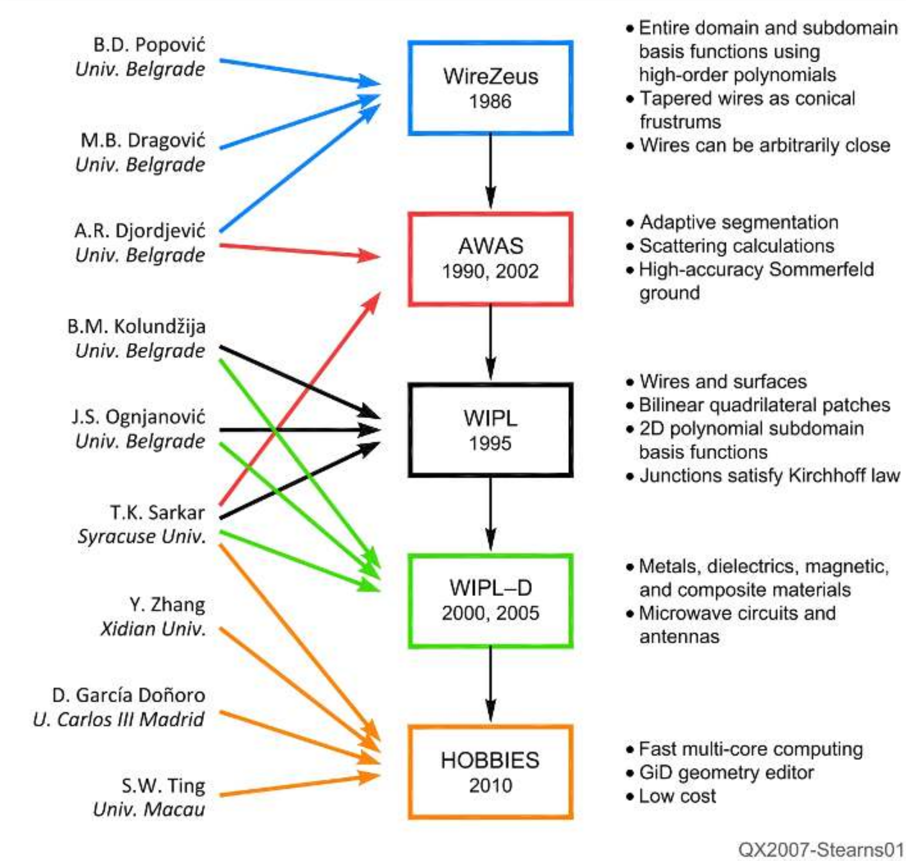

Figure 1 — Development history of *HOBBIES*.

The Shanghai Supercomputer Center reports obtaining stable convergent behavior when running *HOBBIES* with more than a million unknowns.

History

HOBBIES is the latest program in a series of software programs for electromagnetic analysis [1]. The programs in the series use method-of-moments with higher-order basis functions pioneered by Branko D. Popović in 1970 at University of Belgrade **[1]**, **[2]**. The programs in the series are *WireZeus* (1986), *AWAS* (1990), *AWAS 2.0* (2002) **[8]**, *WIPL* (1995), *WIPL-D* (2000), and *HOBBIES* (2010). Although *HOBBIES* relies on the work of researchers at several universities, the principal development was headed by T.K. Sarkar at Syracuse University and funded by the US government through government contracts to the university and OHRN Enterprises.

Figure 1 summarizes the development history. *WireZeus* **[4]** was a thin wire code roughly similar to *NEC* but which used polynomial basis functions on segments. *AWAS* provided for automatic setting of degree and segmentation, and added a numerically accurate Sommerfeld ground model. *WIPL* added surface modeling and meshing by quadrilateral patches. Patch shapes are bilinearly curved, not flat. *WIPL-D* added the capability to model objects made of homogeneous dielectric and magnetic materials. *HOBBIES* integrated the electromagnetic and computational software with the professional user interface *GiD*. The *GiD* interface allows for the easy import and export of standard geometry and mesh files, automatic meshing using user-defined rules, and post processing visualization graphics.

Capabilities

HOBBIES can analyze models made of wire and solid objects having arbitrary geometric shapes. Material properties are arbitrary and can be metals, dielectrics, magnetic materials or composite materials. Only materials that are linear, constant, homogeneous, and isotropic can be modeled. Materials that have a continuously varying or graded dielectric constant can be approximated by layers. So, for example, a graded-index Eaton lens or a planet with a molten iron core and an ionosphere are modeled by concentric spherical layers, each layer being homogeneous. *HOBBIES* does not have a Sommerfeld ground model. Ground is modeled in either of two ways. A complex reflection coefficient ground is provided. However, a reflection coefficient ground is not always accurate. A better way to model ground is as a dielectric surface. The ground is then meshed as part of an antenna or scatterer. This method allows the ground to have any shape; it need not be flat, horizontal, and smooth. The ground can be irregular. Topographic map data can be imported and used as ground if desired.

HOBBIES and *WIPL-D* both have thin wire codes and surface codes. The thin wire codes derive from *AWAS* and are asymptotically convergent in the limit of small spacing between wires. Consequently open wire transmission lines can be modeled physically. This is an improvement over codes like *NEC* which become inaccurate if wires are close to other wires or the ground. Coaxial structures can likewise be modeled and with dielectric fill.

HOBBIES allows one to define curved wires by parametric equations. Curved surfaces can also be defined by parametric equations. Moreover, the equations can be expressed in terms of variables, called Symbols. This allows the shape of a wire or surface to be tailored or optimized by varying the symbols of the defining equations.

HOBBIES handles both antenna and scattering calculations. It allows excitation by one or several source generators or by one or several incident plane waves. Source generators can be delta gap or magnetic frill types. The author's tests show the shunt capacitance error of the delta gap source model is smaller in *HOBBIES* than in *FEKO* or *NEC2/4*. Consequently resonant frequencies and characteristic modes are more accurately found.

The optimizer in *HOBBIES* offers three optimization engines: *Nelder-Mead*, *Gradient Descent*, and *Particle Swarm*. If good initial values for symbols are given, *Nelder-Mead* produces excellent results. If good initial conditions are unknown, *Particle Swarm* is recommended.

HOBBIES provides graphical output and numerical data. Output quantities computed by *HOBBIES* are currents, port parameters, far field patterns, and fields at finite locations. Port parameters are computed as *Y*, *Z*, and *S* matrix parameters. All computed output data are stored in text files and can be read or copied for external conversion to other file formats such as Touchstone *.sNp*. Fields are electric field **E**, magnetic field **H**, and Poynting vector **S**. Real and imaginary parts are computed and stored for each component of a vector. Graphs can additionally display magnitude and phase. *HOBBIES* can also make full-wave color videos of fields, which show how waves form and move through space.

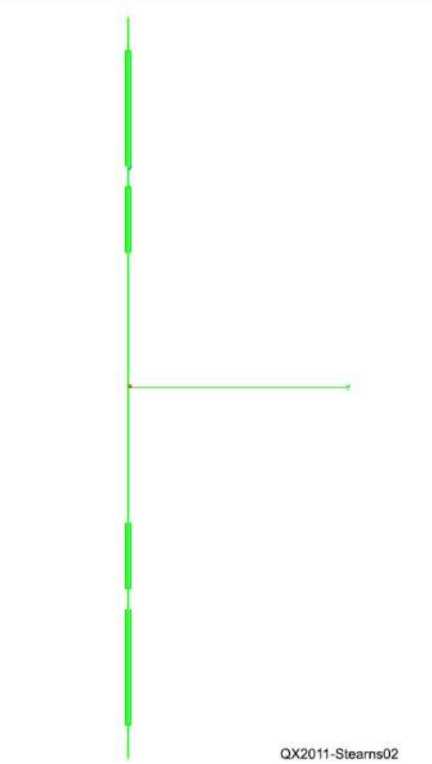

Figure 2 — A triband Extended Double Zepp (EDZ) antenna model.

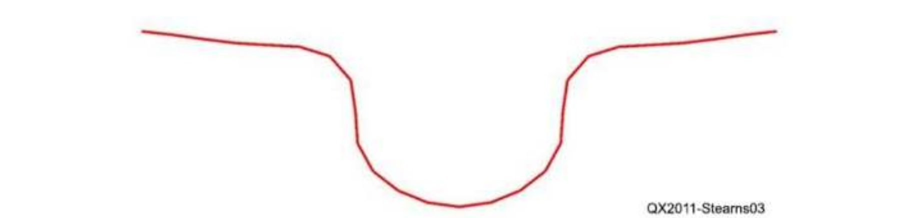

Figure 3 — Optimally curved shape for a very high gain Landstorfer-type antenna.

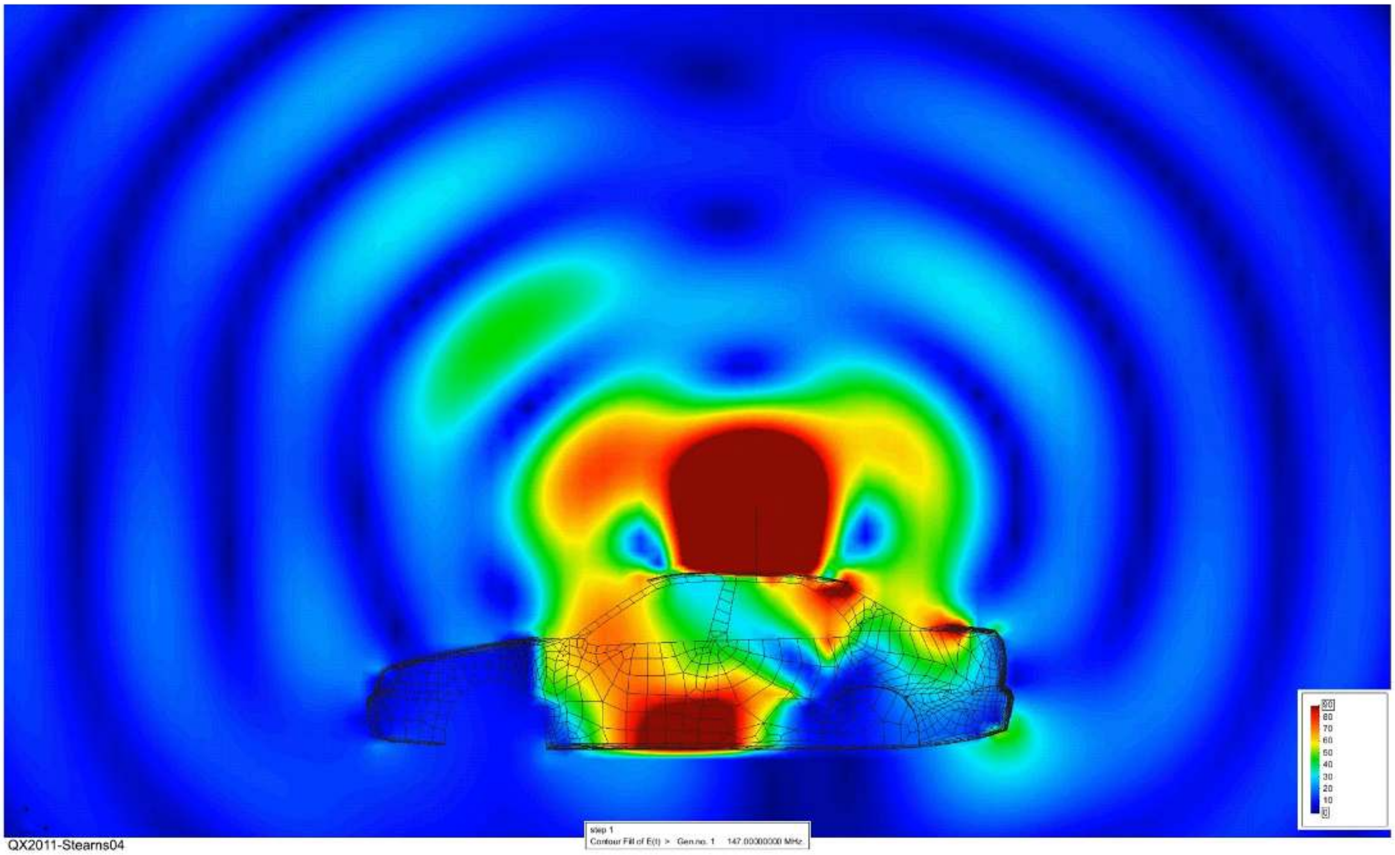

Figure 4 — Electric field inside an empty car at 147 MHz.

Examples

Five examples of models set up and analyzed in *HOBBIES* are shown below. It should be noted that these examples cannot be readily analyzed by *EZNEC* using either *NEC2* or *NEC4*. Full explanations and additional examples are in the author's tutorial presentations on computational electromagnetics and antenna modeling which are given annually at ARRL Pacificon **[12]**, **[13]**. Starting in 2019, a half-day short course is offered on advanced antenna modeling **[14]**.

Example 1

Figure 2 shows a model of a 2 meter, 1.25 meter, and 70 centimeter triband Extended Double Zepp (EDZ) with close-spaced transmission line cage traps. *HOBBIES* found the optimum dimensions of a slim vertical EDZ having gains close to 6 dBi on all bands. It can be re-optimized for conversion to coaxial end-feed.

Example 2

Figure 3 shows curved elements. *HOBBIES* found the optimum shape for a very high gain Landstorfer-type antenna.

Example 3

Figure 4 shows the fields inside a car with a monopole on roof radiating 75 W. *HOBBIES* was used by the author to confirm an article by KI6BDR in *QST*, October 2016. An independent calculation by AE7PD was published in RSGB *RadCom*, April 2020.

Example 4

Figure 5 shows a 160 m monopole with elevated radials surrounded by four short

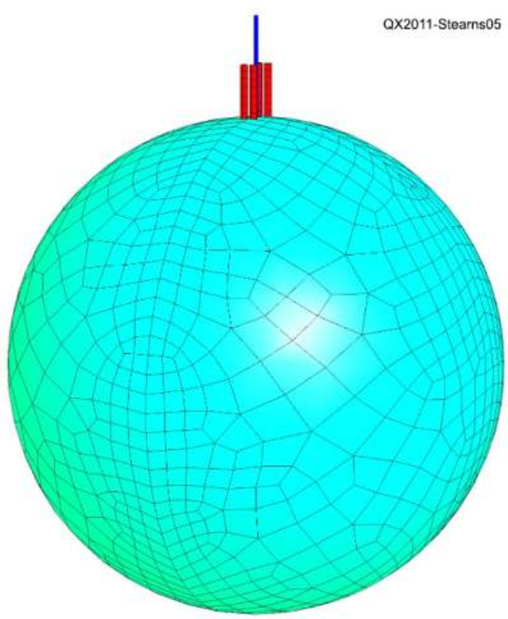

Figure 5 — Model of 160 m vertical antenna and trees on a dielectric planetoid.

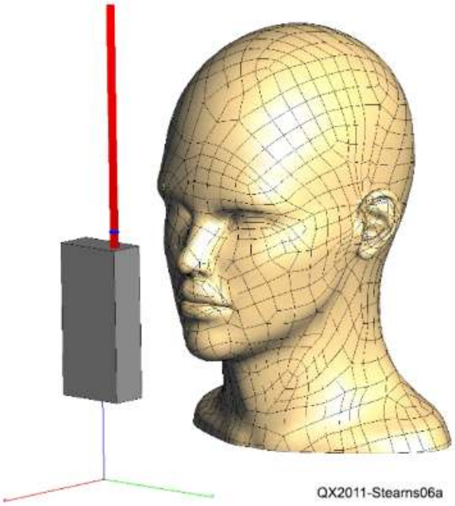

Figure 6A — Model of a head and hand-held radio.

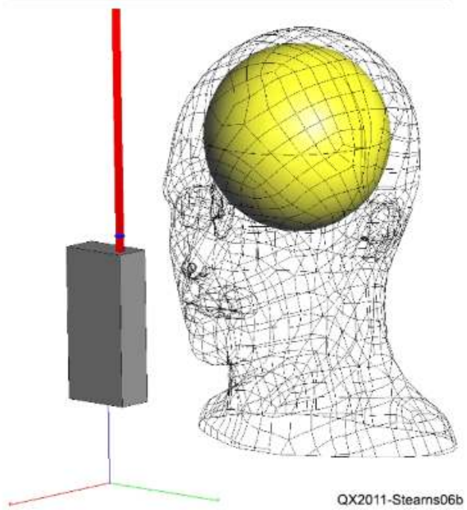

Figure 6B — Model of a transparent head showing a spherical brain.

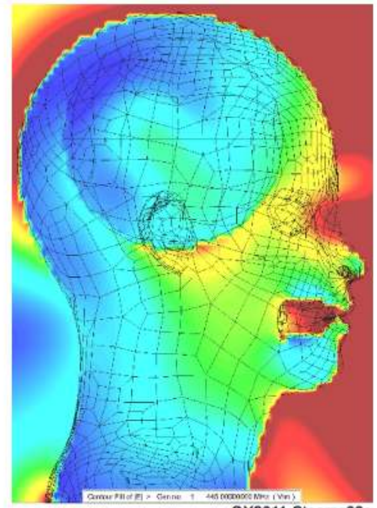

Figure 6C — Electric field strength in the central plane through the head.

trees on a spherical dielectric planetoid having an iron core. *HOBBIES* showed that a Sommerfeld infinite, flat-earth model gives different, inaccurate far field patterns.

Example 5

Figure 6A shows a human head with a handheld radio. **Figure 6B** shows a sphere brain with a handheld radio. **Figure 6C** shows the electric field strength in central plane through the head inside the brain computed by *HOBBIES*. Color scale (gray scale) can be adjusted or recalibrated to give specific absorption rate (SAR) directly for a specified tissue type.

Learning *HOBBIES*

A new user may find *HOBBIES* intimidating but no more so than other programs. *HOBBIES* is actually fun to learn. A new user should have two documents — the *HOBBIES* instruction book **[11]** and the *GiD* version 9 or 10 User Manual, a free download from the *GiD* support manual archive at **[16]**. The electromagnetic theory of the algorithms in *HOBBIES* is fully explained in **[3]** – **[7]** and summarized in **[9]** and **[11]**. A good way to learn *HOBBIES* is by watching the tutorial videos offered at *HOBBIES* support **[15]**, namely: (1) Dipole antenna; (2) Linear phased array of dipoles; (3) Square plate scatterer; (4) Cube scatterer; (5) Bowtie antenna; (6) Inhomogeneous dielectric cube scatterer; (7) Dielectric spherical radome; (8) Optimizer demo – optimizing the forward gain of a horn antenna; (9) Surface meshing.

If one's prior modeling background is *EZNEC*, a significant hurdle is to learn how to make and edit geometries, work with CAD files, convert a geometry to a mesh (meshing), and convert a mesh to a geometry. People who are familiar with 3D printing (artists, designers, makers, and mechanical engineers) will find such matters straightforward. A recommended adjunct to *HOBBIES* is the free software *FreeCAD* **[17]**. It is useful for editing geometry files and exporting them in formats that *HOBBIES* can import.

In addition to learning how to work with geometries, another useful skill is learning how to access computed data. *HOBBIES Post Processor* presents outputs as graphs. There are no front-panel controls or menu items for accessing computed data. All computed data exists in text files that are located in the *Post* folder inside a model's *.gid* project folder. The name extensions of the text files indicate what kind of data the file contains. There are four file types of interest identified by their file name extensions.

- *.ad1* files contain port admittance, impedance, and *S* parameter data.
- *.nf1* files contain field data for **E**, **H**, and the Poynting field vector in Cartesian component form.
- *.ra1* files contain far field radiation pattern data in spherical component form.
- *.cu1* files contain current data.

The user can open these files and copy and paste from them. Since data is arranged in tabular format, the files are easy to open in Microsoft Word and extract specific data by using Word's "text-to-table" and "table-to-text" commands.

Obtaining and Installing *HOBBIES*

Academic *HOBBIES* is obtained by downloading from the *HOBBIES* support web site **[15]**. A license is required to run the program. Every new copy of the instruction book **[11]** has a sealed envelope inside the back cover that contains a registration code. This code can be used one time only to obtain a license through the *HOBBIES* support web site. The online price of the book varies widely among sellers. When buying the book online the purchaser should confirm that the registration code is included and unused. It is recommended to buy only new copies from reputable sellers.

Two caveats are (1) *Academic HOBBIES* is supported by academics and only part time. The web site has a history of disappearing and reappearing. While the reasons are unknown, some theories are the server moved from one university to another and domain name registration expired and was later renewed. (2) It has been reported that Wiley did not put registration code envelopes in recent book runs. Purchasers report being able to get missing registration codes by complaining to Wiley Customer Service/Support through one or more levels of supervisors.

Professional HOBBIES is available for purchase from OHRN Enterprises. Contact Professor Tapan K. Sarkar at Syracuse University to purchase.

A last caveat is that *HOBBIES* is young software. As with any complex software, bugs are occasionally found as when commands or features don't work as expected. The program may halt, hang, or crash on occasion. It is recommended to make a backup copy of the installation file and a read-only copy of the license files. This enables one to uninstall and reinstall the program if necessary. If the program halts or hangs, it might be a memory or a Windows problem. Use Windows Task Manager to stop the program. Then restart it. Bugs should be reported to *HOBBIES* support, which may reply asking for the project files that elicit the bug in order to diagnose and provide a patch.

In summary, *HOBBIES* is an excellent tool, comparable to *FEKO* and *WIPL-D*, and far more capable than software based on *NEC*, *MiniNEC*, or *Matlab*. *HOBBIES* handles a larger class of problems. It is inexpensive. It runs on ordinary Windows laptop and desktop computers. However it does require patience when issues are encountered, and it is not recommended for neophytes who are learning antenna theory and modeling for the first time.

Steve Stearns, K6OIK, started in ham radio while in high school at the height of the Heathkit era. He holds an FCC Amateur Extra and a commercial General Radio Operator License with Ship Radar Endorsement. He previously held Novice, Technician, and First Class Radiotelephone Licenses. He studied electrical engineering at California State University Fullerton, the University of Southern California, and Stanford, specializing in electromagnetics, communication engineering and signal processing. Steve was a Technical Fellow of Northrop Grumman Corporation before retirement. He worked at Northrop Grumman's Electromagnetic Systems Laboratory in San Jose, California, where he led the development of advanced communication signal processing systems, circuits, antennas, and electromagnetic devices. Steve is Vice-President of the Foothills Amateur Radio Society, and served previously as Assistant Director of ARRL Pacific Division under Jim Maxwell, W6CF. He has over 80 professional publications and ten patents. Steve has received numerous awards for professional and community volunteer activities.

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[15] HOBBIES web site (not always reliable) **www.em-hobbies.com**.

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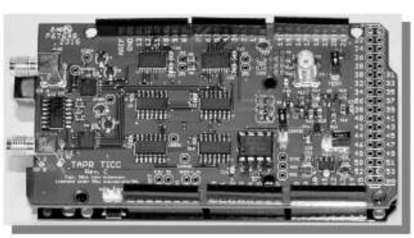
[17] FreeCAD web site **https://www.freecadweb.org**.



TICC

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UHF Quadrature Coupled Power Amplifier

Quadrature coupling of power amplifiers provides a level of redundancy in case of component failure.

I wanted to increase the power output of my DMR repeater from its current 20 W to something in the area of 80 to 100 W. I had previously run the repeater at about 40 W. It ran well for over a year then the final amplifier failed as they are known to do. Amateur radio repeaters can have a very high duty cycle especially on DMR where you may be hosting several talk groups. Most amplifiers in the 100 W category are not designed for repeater service and would eventually fail.

Searching the internet for UHF amplifiers, I discovered an amplifier rated for 80 to 100 W for about $150.00 from China. This little amplifier would not handle a high duty cycle at full power, but I thought two amplifiers in parallel — each one at about half power — might work out well. The amplifiers have a nice heat sink and two fans. I ordered two units, which arrived after two months.

Circuit Description

Figure 1 shows the schematic of the amplifier. The two amplifiers operate in a quadrature configuration where the input power is divided between the amplifiers by a 3 dB directional coupler used as a quadrature hybrid. The power is split evenly between the two output ports B and D with a 90° phase difference between the two outputs.

The input power is adjusted so that each amplifier module produces about 40 to 45 W. This power is recombined through the output 3 dB directional coupler. The phase relationship is such that the power from each of the two amplifiers is in phase at the output connector and 180° out of phase at the waste load connector.

Theory

The use of quadrature coupling is very common in amplifier design. It is often used in high power broadcast transmitters. This provides a level of redundancy. If one of the power amplifiers fails, the station does not go completely off the air. There will be however, a 6 dB loss of power — not the 3 dB you might expect. More on this later.

This configuration is also utilized at the other end of the power scale for receiver preamplifiers. This provides the same redundancy our friends in the broadcast business find attractive. If a single amplifier system fails, the broken amplifier typically will become a rather lossy attenuator and system performance will suffer greatly. Utilizing the quadrature configuration, if one of the amplifiers fails, the system loses only 6 dB of gain and can still provide some level of performance. Of course, receiver level systems will use amplifiers and couplers that are much smaller than those required for transmitters.

Directional Couplers

The system is based on two 90° directional couplers, part number 85-58-01-LT from TX RX Systems Inc. with a list price of $312.00. A directional coupler is simply two transmission lines in close proximity to each other. When power flows in one of the transmission lines some of that power will be coupled into the other transmission line. **Figure 2** shows a basic directional coupler with four ports labeled A, B, C and D. Inside the coupler, one of the transmission lines connects ports A and B and the other transmission line connects ports C and D. Each of the two lines is quarter wavelength at the operating frequency. This dimension is not extremely critical, and most couplers will operate across a relatively wide frequency range if we stay within the specified frequency band.

If power is applied to Port A it will travel down the transmission line to Port B. Depending upon the spacing between the two transmission lines, a percentage of that power will couple into the other line. Normally, Port C would be terminated with a 50 Ω load to properly terminate the line and absorb any reflected power that may be present. If the lines are properly spaced, one-half of the applied power will be coupled onto line C-D and will appear at port D. The remaining power will continue down line A-B and appear at Port B. In this case we now have a 3 dB or 50% power divider. If everything is properly matched to 50 Ω, very little power will be absorbed by the load on Port C.

If we measure the phase difference of the signals at Port B and Port D, we will find Port B lagging Port C by 90°. When used as the input coupler, it provides a 3 dB power split with a 90° phase difference in the power feeding the amplifiers.

Skipping the amplifiers for a moment and jumping over to the output coupler, **Figure 3**, we see that it is being used to combine the power from amplifiers #1 and #2. Power from amplifier #1 is applied to Port B and power from amplifier #2 is applied to Port D. A load is connected to Port A. We call this the waste or reject load.

If power is applied to Port D with no power applied to Port B, the power will be divided equally between ports A and C resulting in a 3 dB loss across the coupler with half the power appearing at Port A and absorbed by the waste load. The remaining power will appear at Port C and be sent to the duplexer and antenna. If power is applied to Port B with no power applied to Port D the power will again be divided between Ports A and C creating a 3 dB loss across the coupler.

Here is where the magic happens. If power is applied to both Ports B and D, and the amplitudes of both signals are exactly the same, and the phase of the signal at Port B lags the signal at Port D by 90°, the phase shift through the coupler will cause the two signals to be in phase at Port C and 180° out of phase at Port A. The result is the signals add at Port C and cancel at Port A. Very little power will be absorbed by the waste load on Port A, and all the power from both amplifiers will be present at Port C.

If one of the signals disappears, there will be no cancellation at Port A and the power present at Port A will be absorbed by the waste load. This results in a 6 dB loss of power rather than the 3 dB loss you might expect. The 6 dB loss is caused by two factors. One factor is the loss of one of the signals. This represents 3 dB loss in the total power output of the amplifiers. Second, the loss of the signal cancellation at the waste load port results in an additional 3 dB loss for the remaining signal. Both signals, with the correct phase and amplitude, are needed to keep the power going to the antenna and out of the waste load.

Construction

The layout of the amplifier is not critical. We built ours on an old rack shelf that measures about 17.5 inches by 8 inches. The directional couplers have two 10-32 tapped holes in the bottom for panel mounting. We duplicated the same mounting arrangement for the amplifiers by drilling and tapping two 10-32 holes in the bottom of their case. If you use these couplers remember that the screws are 10-32 not 10-24, a common mistake. Also do not use screws that are too long. If the screws that hold the couplers get too close to the transmission lines, they will upset the operation of the coupler.

The critical part of the construction of this amplifier is to make sure that the 90° phase shift between the two signals leaving the input coupler is maintained through the system until they reach the output coupler. The best way to do this is to make sure that the cables are exactly the same length. We usually make our cables a multiple of a half-wavelength from the ends of the connectors. Half-wavelength cables have a minimal transformer effect on the impedance match between the modules. Cables that are not a half-wavelength can cause a mismatch. Of course, if everything is close to 50 Ω non-reactive, this is not critical. At 440 MHz, for cable with a 66% velocity factor, 1 inch of cable introduces 20.1° of phase delay.

In my layout, half-wavelength cables were nearly a perfect fit. When making your cables, be sure to consider the velocity factor of the cable and the additional length added by the connectors. Again, the most critical part is to make sure that the total cable lengths through both signal paths from the input to the output coupler are exactly the same.

We don't know the phase shift through the amplifier modules, but considering that they are identical units, the phase shift

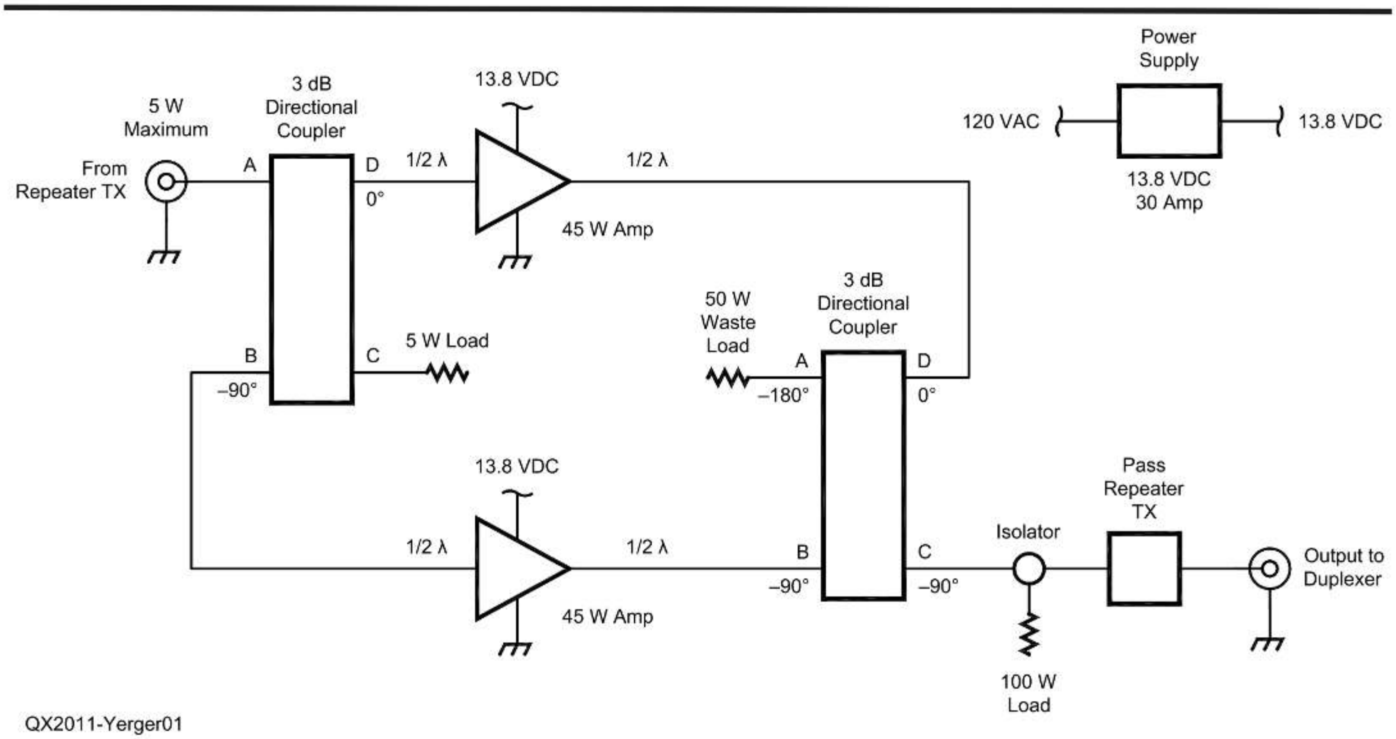

Figure 1 — Schematic diagram of the quadrature coupled amplifier.

through each amplifier is very likely the same within acceptable tolerances. You can construct this amplifier using different amplifier modules but remember, the two amplifier modules must be identical.

Final Checks and Adjustments

After the amplifier is completely wired and ready for testing, the first test should be a power-off test of the loss from the input connector to the antenna connector. The amplifiers were designed to be used in line with a transceiver, and they are bypassed when powered off. If everything is connected properly and the cables are all the correct length, the loss through the system with the power off should be limited to cable loss. In my case this was about 1.2 dB. If you terminate the antenna connector, the measured loss from the input connector to the waste load connector should be 20 to 30 dB.

If the loss between the input and the waste load is less than 20 dB, you probably have a mismatch in the cable lengths. Recheck your cable lengths and make sure you are connected to the correct ports on the couplers.

Return the cables and loads to their correct positions and power up the system. Connect a transmitter to the input connector and a wattmeter and dummy load to the antenna connector. Key the transmitter with low power, approximately 2 W or less. Both amplifiers should key up, and you should have about 40 W output power. Increasing the input power to 5 W should bring the output power up to about 100 W. Do not increase the drive power beyond 5 W, or at any level where the output power does not increase.

You should see very little power into the waste load with the amplifier producing maximum output. On a Bird Model 43 wattmeter with a 100 W element I could barely see the needle move. If you have more than about 1 W going into the waste load in this configuration, you probably have a cable length issue.

If you disconnect the power to one of the amplifiers you will see the output of the system drop by 6 dB to approximately 25 W. If you then measure the power going into the waste load in this configuration, you should see approximately 20 W. This higher power level when one amplifier has failed is why the waste load must be capable of dissipating at least 25 W; I would recommend 50 W in case a major failure results in higher power in the waste load.

The amplifier assembly requires only 5 W of drive or less. If your DMR repeater transmit power cannot be safely reduced to 5 W, then an attenuator will be necessary. In my case the repeater could be reduced to only about 18 W. A 6 dB high power attenuator was necessary to achieve about 85 W output power.

To minimize the possibility of creating interference to myself or others, we have also included an isolator and a band-pass cavity (Pass Repeater TX) between the amplifier and the duplexer as shown in **Figure 1**.

The fans are on a thermostat and will activate when the heat sink temperature rises. If you wish, you can short out the thermostat to allow the fans to run all the time, or add an external switch that shorts the thermostat allowing you to control the fan operation externally.

Coupler Alternatives

The directional couplers we used were purchased new from TX RX Systems Inc. There is an alternative coupler design that is less expensive. This design is called a hybrid or hybrid ring. This is a coaxial-based design that utilizes four sections of 75 Ω coax. The schematic of the hybrid is shown in **Figure 4**. Three of the sections are a quarter-wavelength and one section is three-quarter-wavelengths. They are joined

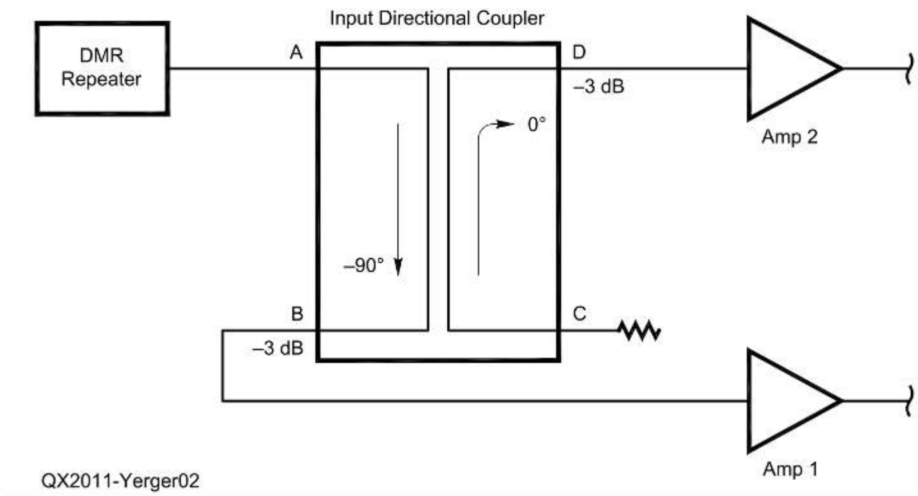

Figure 2 — The directional coupler with four ports, A, B, C and D, splits power between two amplifiers.

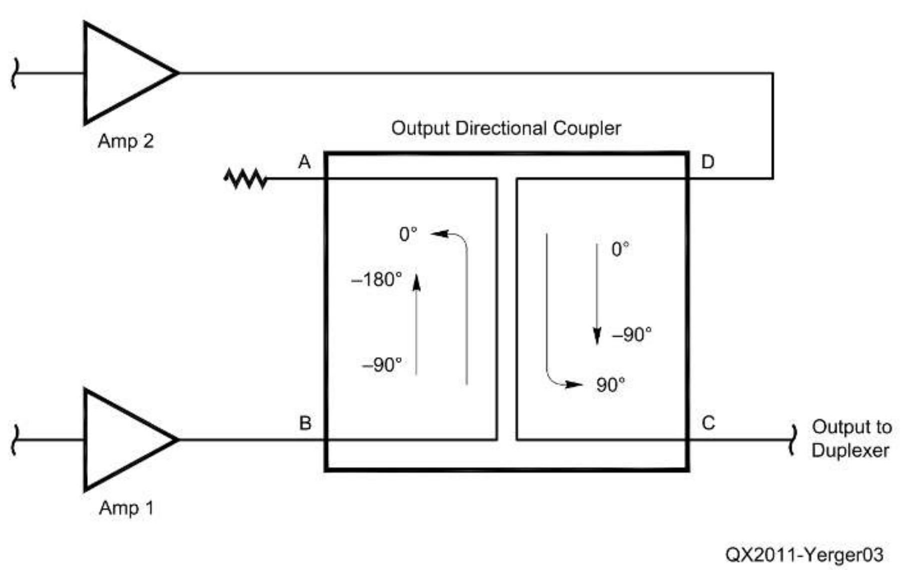

Figure 3 — Output directional coupler combines the power from the two amplifiers.

in a ring using four chassis-mount female connectors mounted on a chassis or panel in a square or diamond configuration. You can use UHF or N type (recommended) connectors. The cable lengths, and the connector spacing, are measured from center to center of the connectors. Don't forget to include the cable velocity factor in your calculations. The spacing between all four connectors is a quarter-wavelength. For the three-quarter-wavelength cable between connectors A and B, just loop the excess cable. At 440 MHz the length of the quarter wavelength cables is 4.47 inches for a cable with a velocity factor of 66%. The three-quarter wavelength cable is 13.41 inches long. Try to strip back as little of the shield as possible and connect the shield to one of the connector's mounting screws.

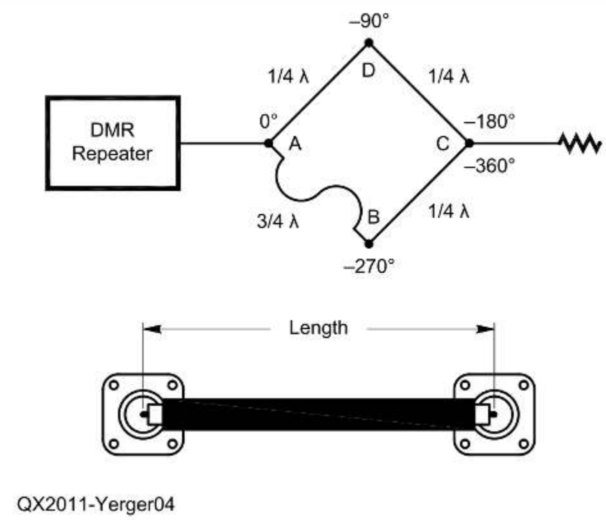

Figure 4 — Schematic of the hybrid coupler.

The major difference in this design is the amount of phase shift. If power is applied to Port A it will travel around both sides of the ring. When it meets at Port C, it will be 180° out of phase and cancel, creating a virtual short to ground. The power will then be reflected back to ports B and D. At Port B, the signal has traveled through 270° of transmission line and at Port D the signal has travelled through only 90° of transmission line. This causes the signal at Port B to lag the signal at Port D by 180° compared with the 90° we see with the directional coupler.

Reworking our design, **Figure 5**, we apply the input signal to Port A of the input coupler. This will result in the signal at Port B lagging Port D by 180°. Jumping over to the output coupler, the signal from amplifier #1 is applied to Port C and the signal from amplifier #2 to Port A. If we have maintained identical cable lengths through both paths, the signal at Port C will be lagging the signal at Port A by 180°. After passing through the hybrid, the two signals should be in phase at the output Port B, and 180° out of phase at the waste load Port D. This results all the power combining at Port B and very little power going into the waste load.

Note: I have not constructed this version

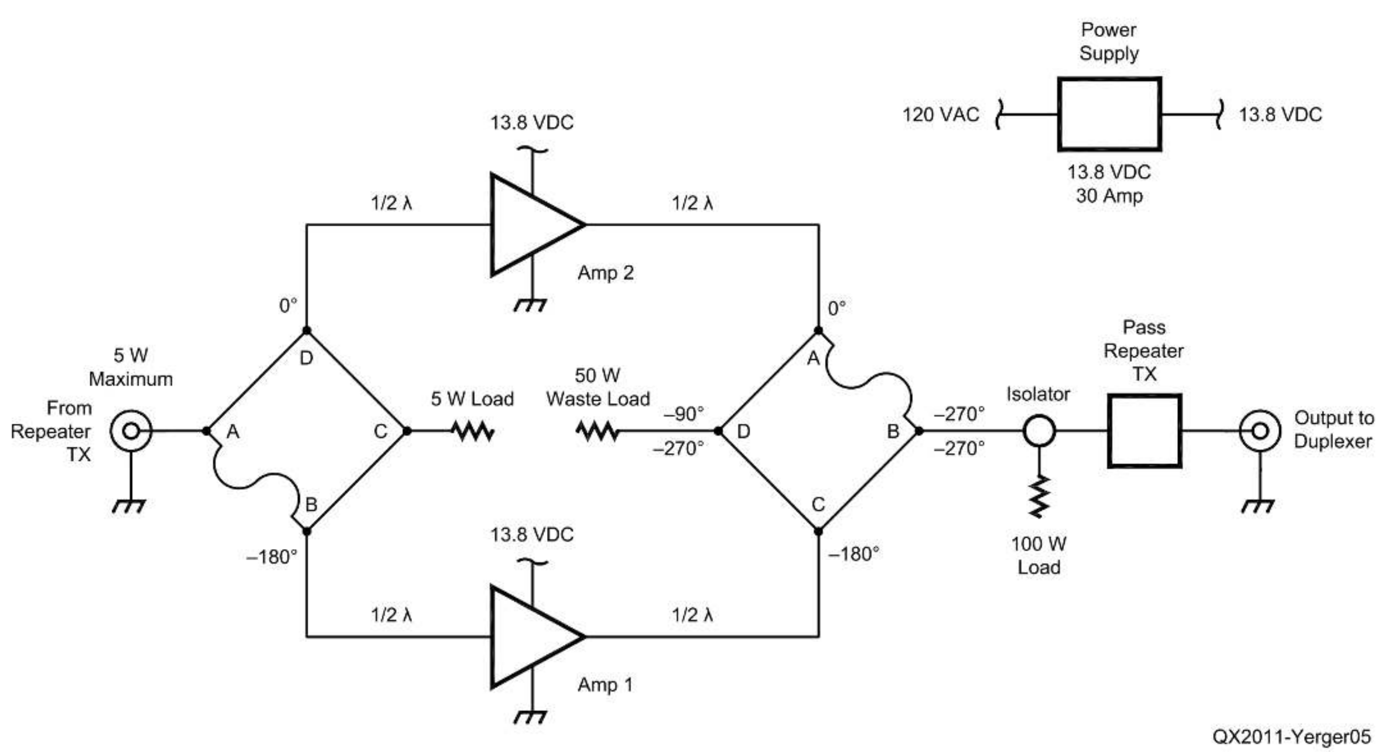

Figure 5 — Schematic diagram of an amplifier using hybrid couplers.

but if you are careful with the cable lengths it should work. The upside of this version is that it should be much less expensive than purchasing new directional couplers. The downside is that it will probably be significantly larger in size and require many more cables constructed to critical lengths.

Conclusion

Figure 6 shows a photo of the complete UHF quadrature coupled power amplifier. **Figure 7** shows the high power load on the bottom side of the amplifier chassis. I hope this article provides some insight into the operation and use of directional couplers and hybrids. There are more things that we can do with directional couplers and hybrids. Perhaps we can cover them in a future article.

ARRL Member and Amateur Extra class licensee Al Yerger, K2ATY was first licensed as WN2EHI in 1967 and held the call sign WA2EHI for 40 years. Previously with Motorola and then Bird Technologies, Al is now the senior field engineer for TX RX Systems Inc., specializing in interference mitigation and antenna site issues. He received an Associate in Applied Science degree from Orange County Community College in 1974 and held an FCC First Class Radio Telephone License until the FCC merged the commercial licenses into the General Radio Telephone License. Al is interested in many aspects of amateur radio. In addition to HF operation he currently operates a UHF DMR repeater as part of the DMR MARC network. He has previously published articles in QST, CQ Magazine *and in professional trade magazines. Al maintains a ham web page at* **www.qrz.com/db/k2aty**.

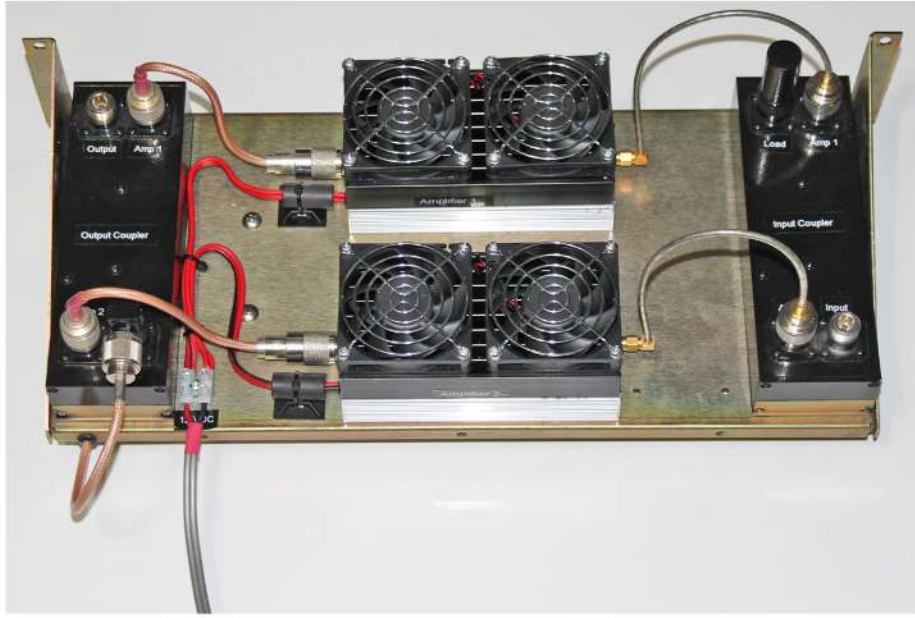

Figure 6 — Right to left: input coupler with load on the waste power port, two amplifiers each with two fans, output coupler. The cable on the lower left connects to the high power waste load bolted to the underneath of the assembly.

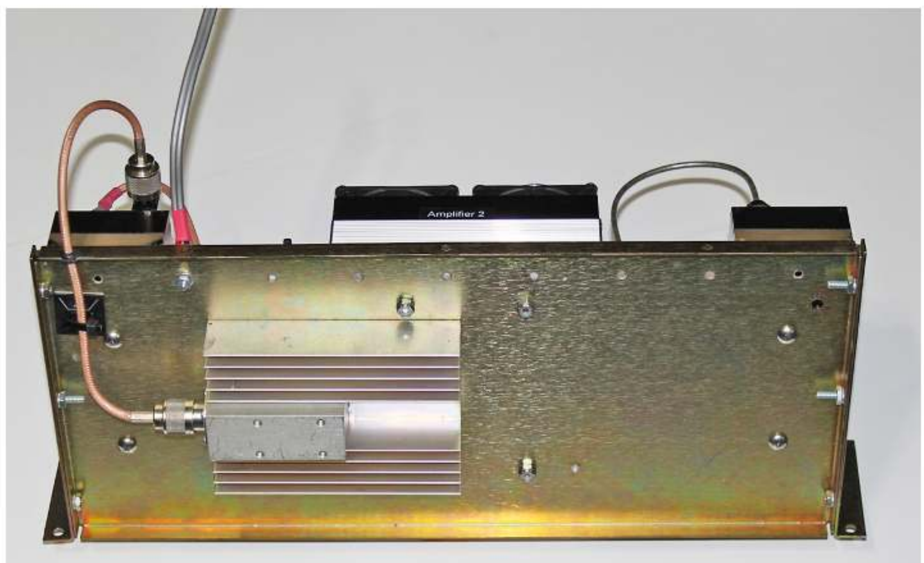

Figure 7 — The high power load is on the bottom side of the amplifier chassis.

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Self-Paced Essays — Electrical Engineering Lab

Essay 2: Setting up your home electrical engineering lab.

Introduction

Top quality test equipment has become so affordable that there is no excuse not to have a viable training lab in your ham shack or shop. We will present a shopping list for essential items for exploring EE topics.

Electrical Engineering is best learned with a 50/50 proportion of theory and practical lab work. You will want to assemble an electronics engineering laboratory as soon as possible in this course. And, never has it been simpler or more affordable to put together an excellent home EE lab. Astoundingly inexpensive electronics test gear and instrumentation has performance we only dreamed of a decade or two ago. There is no reason not to start accumulating some great equipment right away.

Absolute must is a good digital multimeter (DMM). Actually, I recommend getting *three* really cheap DMMs, which can be had for under $10 a piece, in addition to a *good* DMM. Having three of these is a great way to demonstrate Kirchhoff's Laws in real time, as we'll demonstrate soon. However, DO NOT use these cheap DMMs for any industrial measurement, such as checking out line voltage to your house! For any real electrical work you want an arc-flash protected meter, such as a good Fluke or equivalent, which is worth every dime of $250 or so. Use the "$10 specials" only for our low-voltage lab experiments, where the danger to life and limb is non-existent. Look up arc-flash — also called flashover — references on the Web. Fluke has a great video (**https://www.fluke.com/en-us/learn/blog/safety/electrical-safety-videos**) on the phenomenon and a compelling reason to have a good meter for electrician grade work.

Another extremely useful piece of test gear is a good adjustable low voltage power supply. You'll want one that can supply ±15 V dc, at 100 mA or so. Or, as an alternative, you can get an assortment of fixed voltage supplies. A +12 V supply, a +5 V supply, and a ±15 V supply will handle most of your needs for this course. Again, 100 mA for each of these is more than adequate.

You'll want an oscilloscope. A very serviceable new digital oscilloscope can be had for under $300, which has the same performance of top end analog scopes — for most purposes, anyway — at five times the price. Pretty decent older analog scopes can be picked up for under $100.

You'll want a few plug-in prototyping breadboards, along with a large assortment of jumper wires for the boards. You can make these yourself. You'll also want a big "bouquet" of alligator clip leads.

You'll want a good assortment of small components: resistors and capacitors, which come in presorted kits, very inexpensively. Another good thing to have is an assortment of ferrite toroidal cores for building inductors and transformers.

You'll want some op-amp chips, such as 741s. Be sure to get the through-hole versions, which will plug into the prototype boards. Also, get as many 2N2222 transistors as you can find.

A function generator is a great thing to have, and high quality units are available for about thirty dollars.

As we move into radio frequency design work, you'll want to get your hands on a grid-dip oscillator. This ancient device is incredibly versatile, and with some practice can do the tasks of a whole bench top of more modern equipment in less skilled hands.

Now, you don't need to acquire all of this at once. Get whatever your budget comfortably allows. Like most of us old-timers, we accumulated our test benches over years — or decades. But nowadays, you can start off with a far more complete lab than we could have in years past.

There is a vast amount of good used test equipment languishing in basements and attics, as well. Do check out local ham radio flea markets and the sheds of accommodating fellow radio amateurs or other electronics experimenters.

Nice to Have

While most of the above devices are fairly essential, there are a few items that you'll probably eventually want to have. But there's no hurry. Here are just a few.

(1) An RF spectrum analyzer.

These can range from a few hundred dollars to tens of thousands, when new. However, some top end RF gear has shown up on the used market for pennies on the dollar. A tracking generator is a great accessory to go with the spectrum analyzer, as well.

(2) A vector network analyzer.

Inexpensive VNAs are now available for well under 100 dollars, while top end units can run into the tens of thousands. Again, keep your eye out for good used higher-end units.

(3) An RF signal generator.

Most inexpensive function generators "top out" at 10 MHz or so. If you need to work with higher frequencies, or create cleaner modulation, you'll want a "real" RF signal generator or synthesizer.

(4) A lock-in amplifier.

For detecting extremely weak signals, no device can — or will EVER — be able to exceed the performance of the venerable lock-in amplifier. Although you can build one from scratch fairly easily, a good commercial grade lock-in is worth every dime. Lock-in technology is used in everything from medicine to metallurgy, but is almost unknown by the average EE.

(5) A GPS disciplined oscillator.

This has many uses for the radio experimenter, and is becoming quite affordable.

(6) A multi-channel data acquisition system.

Data Acquisition (DAQ) can be inexpensively implemented with Arduino and similar platforms, but a high precision DAQ system can be quite expensive. However for doing a lot of lab work, a lab grade DAQ system can be essential.

You'll need some soldering equipment, as well. While having a temperature controlled soldering station is nice to have, it certainly isn't necessary. I've done plenty of surface mount soldering with a simple low-wattage pencil iron. But if you can get a good soldering station, do so. I'm particularly fond of my Hakko soldering station, which I believe I like even more than the numerous, venerable Weller soldering stations I've had in the past.

For experimenting with radio frequency prototypes, especially at VHF and UHF frequencies, you'll want some PCB etching equipment. Plug-in breadboards are unacceptable for radio frequency work. Learning how to etch circuit boards is a valuable skill for RF prototyping and quite a bit of fun, as well. Most modern UHF circuitry uses etched strip-line circuitry and similar layouts.

Elbow Room

While it isn't always feasible, if possible you'll want a dedicated space for setting up your electronics lab. While I've spent countless hours in the past setting up temporary electronics labs on the kitchen table, it's absolutely wonderful to have a permanent and substantial work space. Some electronics projects can take weeks or months to complete, and it's really hard to do this if you have to intersperse it with the rest of your life. So, even if it's not pretty, do everything you can to establish a permanent lab space, even if it's just a corner of a garage or a broom closet. Be sure your space is well lit. Do make it as attractive as possible… at least to YOU…as you will hopefully be spending a lot of time in there!

You'll want space for some real genuine books in your lab, as well. While the trend is ever progressing toward e-books and related technology including this very course! — there is a lot to be said for a genuine physical library in your lab space. As unscientific as it may seem, I find my brain works better when surrounded by 'dead trees' and ink. I can almost guarantee yours will, also. Sure, you'll want a computer in your lab, but there's nothing to compare with an open book, or two, or three, on your lab bench.

I also have a number of antique radios around to enhance the ambiance…I can't overemphasize how this helps me maintain some sanity during our shelter-in-place status. Make your space as interesting and as scholarly as humanly possible. You'll be glad you did.

A Few Housekeeping Items

A substantial part of this self-paced course will involve practical labs. We will be supplying lab procedure sheets as we progress to record your lab results that will aid and abet the theory part of this course. While you will not be turning in your reports for a grade (although, perhaps in the future, we can figure out a way of doing this), we strongly encourage you to do the worksheets and keep detailed lab notes. Many of these lab procedurals will be based on my eight years' teaching electronics technology at the community college level. The procedurals all include discussion questions. We encourage you to share your discussion questions with us and other students. We will be developing some kind of forum for this. This will help us continually improve the labs. In addition, it provides a very Socratic model for learning, something that I strongly advocate Wikipedia (**https://en.wikipedia.org/wiki/Socratic_method**).

The **Socratic method** (also known as **method of Elenchus**, **elenctic method**, or **Socratic debate**), is a form of cooperative argumentative dialogue between individuals, based on asking and answering questions to stimulate critical thinking and to draw out ideas and underlying presuppositions. I believe the Socratic method is far superior to the instructor just standing at the front of the class and pontificating, and I believe you will too. As we've said earlier, we want this to be a highly interactive course, and we will take full advantage of the existing technology to make this happen.

Last but not least, you'll want a scientific calculator. While a "stand-alone" calculator is preferred, the virtual calculator included with Windows and other operating systems is fine. Just be sure to set it to the Scientific mode.

Some painless mathematics is coming up in the next installment. Until then, 73 and great success.

Eric P. Nichols, KL7AJ, is a two-time recipient of the William Orr, W6SAI, Technical Writing Award. He has written numerous articles for QST and QEX magazines as well as four ARRL books, the latest being "Receiving Antennas for the Radio Amateur." Eric's latest focus is on encouraging experimentation on our two new LF bands on 2200 meters and 630 meters, heroically attempting to make up for lost time in catching up with our LF brethren "across the pond."

Dr. Ulrich L. Rohde Receives 2020 IEEE Region 1 Technological Innovation Award

The IEEE Region 1 has selected Dr. Ulrich L. Rohde as the recipient of the 2020 IEEE Region 1 Technological Innovation (Industry or Government) Award. The selection was made by the Region 1 Awards and Recognition Committee and approved by the Region 1 Board of Governors. The award states "Technological Innovation Award – For pioneering research and leadership in signal processing." The Technological Innovation (Industry or Government) award is given for significant patents, discovery of new devices, development of applications or exemplary contributions to industry or government fitting Dr. Rohde's accomplishments in our industry.

Dr. Ulrich L. Rohde, N1UL, holds an Amateur Extra class license. He has been amateur radio operator since 1956, and also holds the call sign DJ2LR. He has also published extensively in the *QEX* and *QST*.