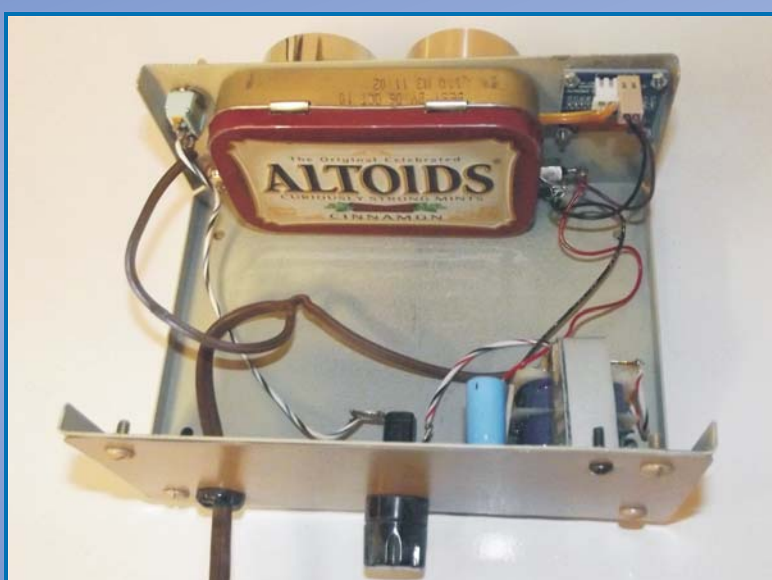
YOUR CONSTRUCTION AND OPERATING QRP SOURCEBOOK

Volume 65 Number 1
January 2024

QRP Quarterly

Journal of the QRP Amateur Radio Club International



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QRP ARCI℠ is a non-profit organization dedicated to increasing worldwide enjoyment of radio operation, experimentation and the formation and promotion of QRP clubs throughout the world.

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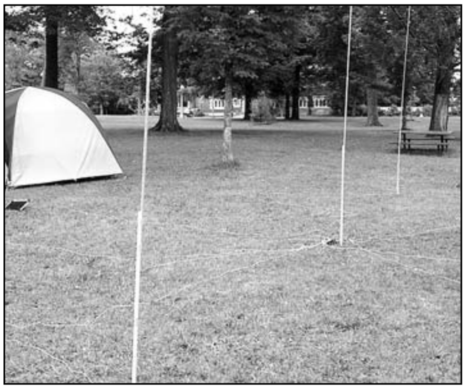

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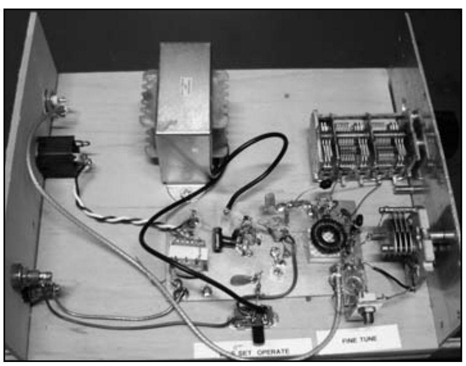

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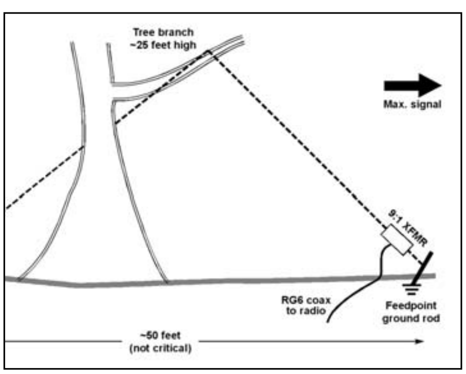

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Keep your QRP ARCI membership active!

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See the information on page 40, or at: www.qrparci.org

From the Editor

Mike Malone—KD5KFX editorqrparci@gmail.com

The holidays will have just ended by the time you are reading this, but as I write this, it is before Christmas and the New Year. I hope you have all had a good holiday season. It will be time to take down the festival pole and convert it to a vertical antenna.

As the year comes to a close, my thoughts always take me back to some of my fondest memories. Sixteen years old, I got my first HF rig... an HW 16. The only receiver I had to compare it to was an old Halicrafters, so it compared very favorably. My parents gave me a Hy-Gain vertical that year for my Christmas present along with a set of code practice tapes. The ARRL had a neat little book for Novices that included some great projects for Novice homebrewers, too.

I jump ahead a bit and remember taking my TenTec Century 21 (another novice rig) to my Mom's house with some wire and a tuner on a New Year's Eve for Straight Key night. There are lot's of fun memories that pop up and seem centered around the radio I was using at the time... more and more, I cherish those memories and the people that are included and associated with them.

It is funny how age blunts the blade of some of the bad times and highlights the good times. I am thankful for that. As the year comes to a close and a new one begins, thoughts turn to ideas for the future—may we all be propelled by something good and not chased by the bad.

72, Mike, KD5KXF

From the Desk of the President

David Cripe—NMØS president@qrparci.org

To my QRP Friends:

It's mid December as I write these words, and 2023 is rapidly drawing to a close. It's been a year of highlights, to be sure. Looking back, this was the first year that my XYL and I were able to make the drive up to Lobstercon. I can attest that this event lives up to its reputation—Rex and the gang throw quite the shindig! And it was great fun to get to hang out with the New England QRP bunch. And the lobsters were excellent! In retrospect, I regret that it took so long for me to make the journey up to Maine—and I resolve to travel more to attend more amateur radio events.

In the year 2024, I encourage you all to try to experience all that our hobby has to offer. Make the effort to participate in events and contests, build more, travel more, and share these experiences with those around you, and maybe write them up for *QRP Quarterly*!

Meanwhile, the plans for FDIM 2024 are coming together, and we have already lined up some excellent forum speakers. To all the members of QRP ARCI, I encourage you to make the trip to Fairborn to FDIM 2024. Bring your homebrew radios to show off, come to meet the other builders, experimenters and QRP fanatics. And invite some friends to come along! Enjoy a weekend with the greatest that ham radio has to offer! I can't wait to see you all there!

73 de NMØS/QRP
Dave Cripe, NMØS
President, QRP ARCI
nm0s@nm0s.com

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QRP ARCI News

FDIM 2024!

Four Days in May will once again be held in conjunction with the Dayton area (Xenia, OH) Hamvention©**.** The location is the Holiday Inn, Fairborn OH. Dates are May 16 through 19, with registration open the evening of May 15. Seminars are held on Thursday, May 16. Thursday evening is Vendor Night, with Homebrew and special contests featured on Friday night.

The Grand Banquet is Saturday evening, May 18. As in the past, there will be many door prizes at the banquet.

Please note that transportation to the Hamvention is not provided at the Holiday Inn. Parking and buses are available reasonably nearby—just a short drive.

Make your plans now! Registration will be available sometime in January, so check the club website for updates:

www.qrparci.org/fdim

ANNOUNCING —
The FDIM 2024 Logic IC Transmitter Power Challenge!

It was common in the early days of solid-state QRP to rig up a 7400 TTL chip as a crude QRP transmitter. With a crystal and a handful of parts, it was possible to put a few hundred milliwatts on the air for a couple bucks. While these simple IC-based transmit circuits have fallen out of favor, QRP ARCI is revisiting this bit of QRP history with the FDIM 2024 LOGIC IC TRANSMITTER POWER CHALLENGE!

The challenge is simple: Design and demonstrate a crystal-controlled 40M oscillator/PA to make the highest sustained power for a period of one minute using only a single 4000-series or 7400-series logic IC. This event will take place at 8:00 PM Friday, May 17 during FDIM, and the winner recognized at the QRP ARCI Banquet on Saturday, May 18, 2024.

The rules for the competition are simple, but we have to list every nit-picky detail to test your endurance anyway:

• The design is to utilize a single 4000 or 7400 series logic IC as the only active circuit element. There are no limits on the number of diodes, inductors, resistors, capacitors, or transformers, but a single IC may be the only active device.

• The PA must be crystal controlled within the 40M amateur band. One (or more) section of the IC must be a crystal oscillator to control the frequency of the transmitter and builders are encouraged to use their own crystals, though there will be 7030 kHz HC-49 crystals available at the competition. No external frequency source may be used.

• ICs to be used must be of the 4000-series or 7400-series. Different logic families of this type such as 74LSxx, 74HCxx, 54HCTxx etc. may be used.

• The circuit must fit inside a 12" × 12" × 12" volume. During the power test, the judges will cover the circuit with a blast shield to protect judges and contestants from flying bits!

• All circuit components are to be visible for inspection.

• A schematic of the circuit is to be provided with each entry.

• A zero-to-24v variable power supply, 40M band-pass filter, dummy load and power meter will be supplied by the judges.

The competition will have two rounds of trials to demonstrate power output of each circuit, with the best performance of each circuit being its final score. During each test, the builder will connect his circuit, set the power supply voltage and then announce to the judges when to begin measurement. During a period of one minute in which the builder may not touch the circuit or power supply, the RF power output at the end of one minute will be taken as the score for that trial. Failure of the circuit in that one minute test period results in a score of ZERO for that round!

The winner is the circuit generating the highest power score during either of his two rounds. If the circuit fails during the first test period, the builder will have five minutes in which to repair it before the second round trials. If your entry sets off the smoke detector in the Holiday Inn, you will be disqualified and may be subjected to rude laughter and finger pointing during the rest of FDIM!

The winner of the FDIM 2024 LOGIC IC TRANSMITTER POWER CHALLENGE! will be recognized at the QRP ARCI Banquet Saturday May 18, 2024.

Questions regarding the POWER CHALLENGE may be addressed to David Cripe NMØS, nm0s@nm0s.com.

Good luck and good building!

Four Days In May (FDIM) Speakers Have Been Announced

FDIM will be again held at the Holiday Inn, Fairborn Ohio, with the seminars on Thursday May 16, 2024. Speakers presently scheduled include:

Jack Purdum	W8TEE
Ashhar Farhan	VU2ESE
Cliff Batson	N4CCB
Hans Summers	GØUPL
Wayne Burdick	N6KR
Tom Witherspoon	K4SWL
Gregg Latta	AA8V
Ross Ballantyne	ZS1UN

Reminder! QRP ARCI Resources...

QRP ARCI is a club for low power enthusiasts worldwide.

We produce a professional quality magazine (*QRP Quarterly*), organize an annual conference at Dayton ("Four Days In May" — FDIM), and sponsor various QRP contests and awards. Our aim is to promote QRP and related activites.

Mail List

A Mail List is operated by QRP ARCI on the groups.io platform. This mail list is open to members and non-members alike for the discussion of QRP ARCI topics. QRP ARCI Staff handles the moderation of the list and you can gain access by sending an email to:

qrparci+subscribe@groups.io

and request to be added to the mail list. Be sure to include your callsign in the request. You can get your mail in digest form as well if you prefer it that way.

QRP Awards

QRP ARCI provides a number of awards, each of which encourages low power enthusiasts to accomplish a wide variety of goals. We invite you to review the various awards and to make a commitment toward earning your own special award (or several).

A number of applicants apply for several different awards at the same time, which is fine. We hope you will review your log and determine if you might be eligible for any awards at this time.

Please note that awards are free of charge for active members (maximum of 5 awards per year)—another significant benefit of active membership. Questions? Contact the Awards Manager.

Preston Buck, NØGLM
QRP ARCI Awards Manager
awards@qrparci.org

Contests

QRP ARCI sponsors these contests:

Spring QSO Party
Hoot Owl Sprint
Summer Homebrew Sprint
Fall QSO Party
Top Band Sprint
Holiday Spirits Sprint

https://qrpcontest.com handles contest logs, and includes lots of information for other QRP contests.

The Contest Manager can be contacted at: contest@qrparci.org

Membership

Join QRP ARCI by taking a subscription to *QRP Quarterly* magazine. A membership number will be issued after joining. Membership is for life.

A member with a current subscription to *QRP Quarterly* is an *active member*. An active member can apply for up to 5 QRP ARCI operating awards each year (issued free of charge) and has voting rights in QRP ARCI elections and polls.

An inactive member has let their *QQ* subscription lapse. The membership number is still valid for use in contests, but other benefits cease. Active membership can be restored by renewing your subscription to *QRP Quarterly* magazine.

All new subscriptions, and subscription renewals are for the next four issues of *QQ*. Subscriptions can be paid with Paypal. Our payment address is:

treasurer@qrparci.org

How Low Can You Go?

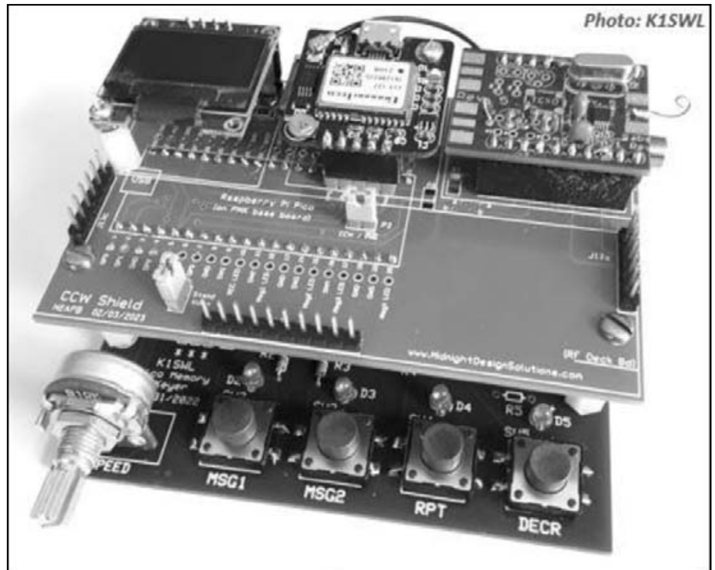
George Heron—N2APB and Peter Eaton— WB9FLW

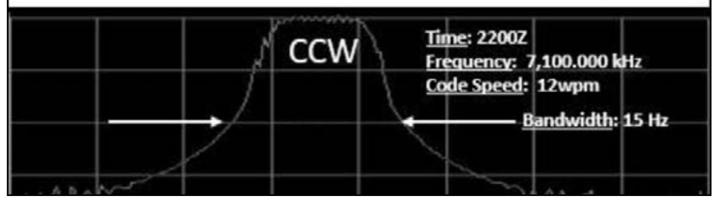
A Modern Coherent CW Transceiver for Weak Signal Communications

This article was one of the seminar presentations FDIM 2023.

Imagine how exciting it would be to copy a solid 599 signal when you hear nothing but the noise floor. This paper details a design of such a transceiver using an inexpensive Raspberry Pi Pico controller to achieve 20-30 dB signal path improvement over conventional CW rigs. Implementing techniques born almost 50 years ago one can turn a 5-watt QRP signal into the equivalent of more than 300 watts on the receive side with properly equipped stations.

This paper presents a brief background on the Coherent CW designs from the 1970s followed by a technical overview of our modern approach with the Pico processor including GPS-timed transmission and DSP processing of the received signal within precisely maintained windows corresponding to 12 wpm code speeds … and higher!





Introduction

More than two decades ago this paper's authors presented on the topic of "Coherent CW" (CCW) at the FDIM 1998 seminar (Dayton Hamvention), based on original groundbreaking experimentation done over twenty years prior to that by Ray Petit W7GHM, et al. During that 1998 seminar we even had a haphazard collection of circuits that demonstrated the CCW principles used back in circa 1980, as documented in the very early days of the ARRL *QEX* periodical.

Peter and I connected again last year and while reminiscing thought how intriguing it would be if one could utilize today's digital signal processing (DSP) technology to achieve the same performance improvements offered by the discrete logic implementations of CCW used almost half-century ago. Thus began our resurrection of understandings and the limitations of CCW. But who would possibly be interested in using Morse code at slow speeds like 12 words/minute in order to copy stations down so far "in the mud" that no other technologies today can achieve? Not even the extremely popular weak signal detection program WSJT-X has a mode for detecting or demodulating CW signals below the noise floor.

But we are getting ahead of ourselves! Most amateur radio operators do not even know what Coherent CW is; so before getting into the technical design story of the CCW transceiver itself, let's take a slight sidestep to bring readers up to speed on the amazing principles of signal "coherency" and how it can be the absolute best friend of low power CW operators.

Coherent CW — A Quick Technical Backgrounder

There is an age-old axiom popularized in detective stories: "The more we know about something we seek the easier it is to find." This can also apply very well to weak signal reception of Morse code. The things we need to know for schedules of course include the date and time, but equally important are three factors enabling coherent CW reception: the *frequency* to be used, the *timing* (wpm) of the CW signals being received, and the *phasing* of the signals or knowing precisely when to start looking for a dot or a dash. To paraphrase an aspect of the Shannon-Hartley [1] communications theorem,when we fit the narrowest bandwidth filter to the given information rate of a channel, the signal-to-noise ratio (SNR) skyrockets, which is a good thing because then only the 'marks' in the channel (i.e., the dits and dahs) are coming through while both the man-made band noise (QRM) and nature-made band noise (QRN) are vastly suppressed.

So in rather pseudo-technical terms, by knowing where to look, when to look and specifically how long to be looking — all with great stability and accuracy — we can create an extremely narrow (10 Hz!) bandpass filter for the Morse signals to yield a high SNR allowing the transmission to be easily decoded by human ear. Heretofore, if one were to try creating this extremely tight bandpass filter by using traditional techniques of analog filters or even digital/DSP filters, severe ringing and other artifacts would result,thus creating a very unpleasant and totally unusable listening experience. See Figures 1a and 1b.

Coming back to the genesis of coherent reception of CW, Ray Petit W7GHM published findings in the September 1975 issue of QST wherein in described how he designed integrate-and-dump circuitry to measure and determine whena mark (i.e., 800 Hz transmitted energy) was present at very specific time periods during a Morse code transmission (Figure 2). A very accurate 100-millisecond "timing frame" was used for the 12 wpm CW rate and WWV time-synchronization was requiredby the transmitting station to ensure that the frame being measured on the receive side was identical to the frame in which the mark was being sent.

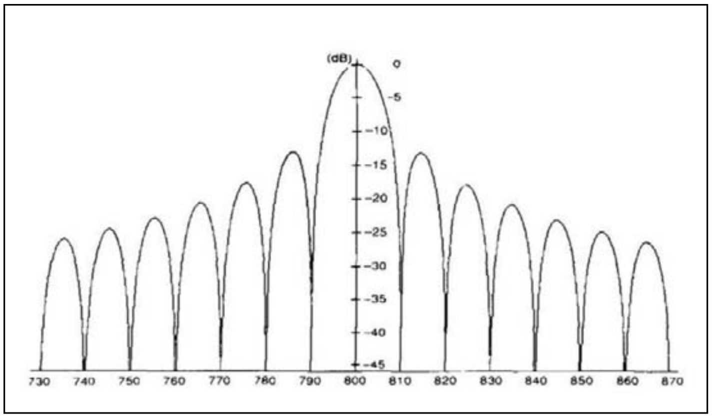


Figure 1a—10 Hz Sampling Spectrum.The characteristic response of a 10 Hz sampling filter shows notches occurring in the audio spectrum every 10 Hz.

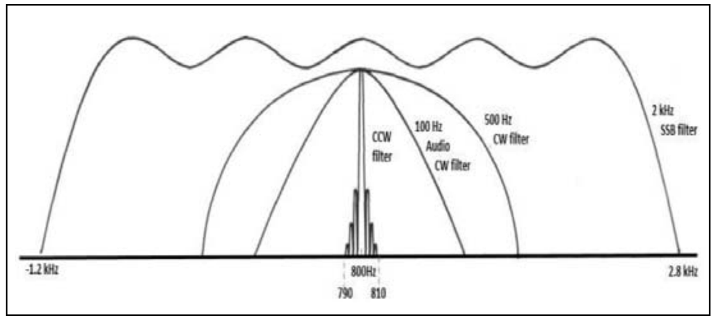


Figure 1b—CCW Bandwidth comparisons to traditional ham filters. The narrow 10 Hz CCW filter shown in the center is comparatively miniscule the traditional CW and SSB filters. One can envision the amount of QRM and QRN eliminated when using the CCW filter, and the correspondingly high signal-to-noise ratio for the precisely tuned signal being passed.

Of course this also meant that the transmitting station needed to ensure that the dots and dashes of were being sent precisely within those same 100-millisecond frames. Hence the sender also needed to have perfect time synchronization with WWV and very stable local oscillators of the transmitter itself.

The rest is an "exercise for the student", as they say. The integrate-and-dump circuitry would integrate the channel receive energy during the 100-ms frame period, then dump and measure it at the end to determine the state of that frame. Based on a given threshold level of the analog sample average, the state would either be a mark or a space. When a mark was determined to be present, a tone oscillator would be sounded and the operator would hear a clear and pure note, free of any band interference or noise — solid 599 CW reception of a signal that likely couldn't easily be heard through the receiver's speaker!

The "fly in the ointment" back in those early days was the difficulty in achieving and maintaining stability in the oscillators used for frequency transmission and time synchronization. Any drifting would cause the CCW system to quickly fail. Others came to the rescue, with some notable success. Bill de Carle (VE2IQ)

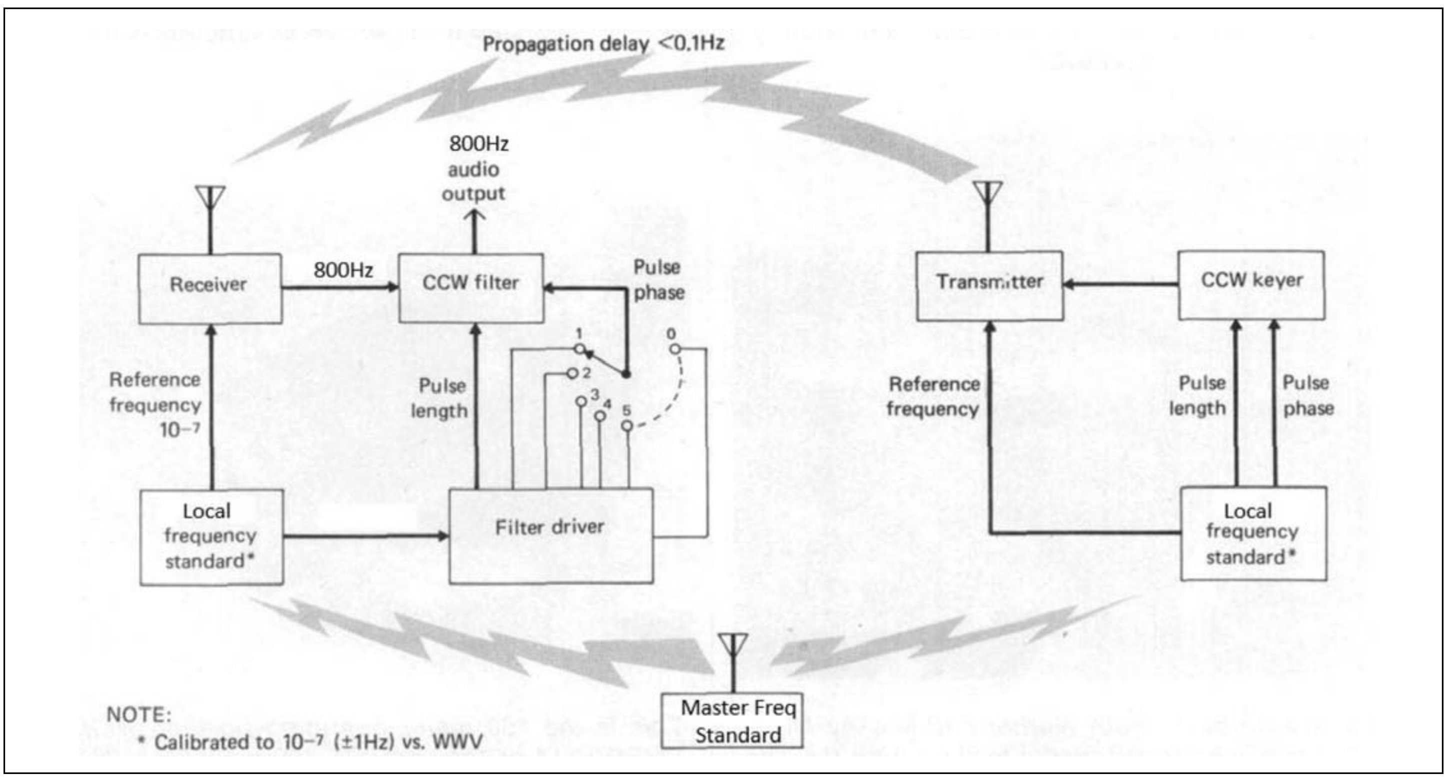


Figure 2—A CCW communications system.The three factors are illustrated that enable Coherent CW reception: known and accurate frequency, pulse length (wpm) and pulse phase (frame timing window). A system circa 1975 used WWV for the time sync, a local oscillator as the master frequency standard, and filter driver for the phase adjust. In the circa 2023 system we can depend on GPS for both time sync and (global) frequency standard, and digital signal processing for CCW filtering. [Graphic derived from *CQ Magazine* June 1977, Ade Weiss "Coherent C.W. — The C.W. Of The Future Part 1"]

developed on these early techniques to develop some of the first BPSK (Binary Phase Shift Keying) implementations, and technology advances brought along some early embeddable DSP solutions such as what Rick Campbell (KK7B) and Johan Forrer (KC7WW) achieved with the Motorola DSP56KEVM systems; but none really took steadfast hold within the Amateur Radio's community of CW operators.

After our initial CCW presentation at FDIM 1998 we established an online collection of all the published works we could locate concerning Coherent CW. The collection consists of over sixteen unique papers and a full collection of more than 100 issues of the *CCW Newsletter*, published from 1976 through 1994. To this day we continue refining the CCW Archives to provide a lasting picture of how this exciting technology evolved and the pioneers in our ham community who made it happen: Ray Petit W7GHM, Charles Woodson W6NEY, Bill de Carle VE2IQ, Peter Lumb G3IRM, Ade Weiss WØRSP, Stan Wilson AKØB, and Vic Black AB6SO. The address for the CCW Archives is indicated in the Bibliography and below [2]. Some really great reading material is in those Archives!

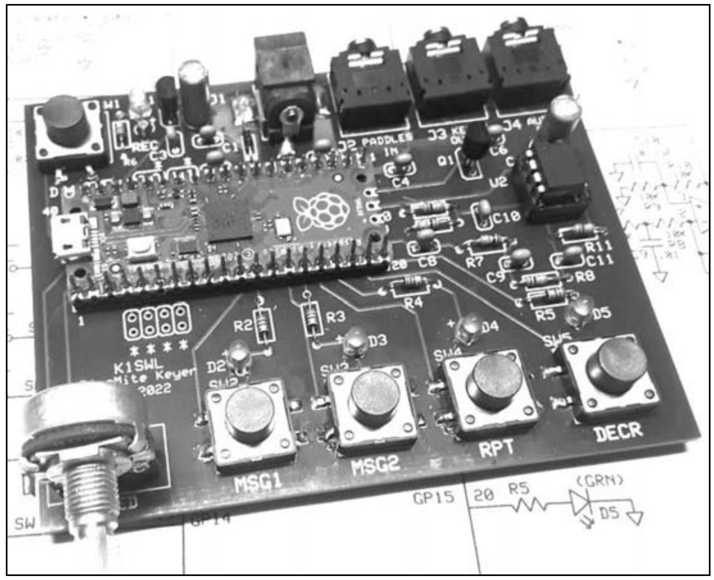


Figure 3—K1SWL's "PicoMite Memory Keyer".

CCW Operation —
A Little Deeper Dive

So now we've established the basics: CCW utilizes the notion that signals are sent at specific times and not at somewhat arbitrary times as in CW. All CCW dots, dashes and spaces are exact multiples of a basic time unit and occur within predictable time frames, including any pauses during transmission. When received, CCW signals should be like CW signals except that they are sent very precisely. As a result, very narrow filters can be used for reception. For example, if 12 wpm is used for sending, CCW receive filter bandwidths would be on the order of 10 Hz. A 1-watt signal copied through a 10 Hz filter is equivalent to a 50-watt signal heard through a 500 Hz filter and a 230-watt signal copied with a 2300 Hz filter. CCW indeed can offer quite an advantage for weak signal reception. This is all pretty great stuff … so how is it done?

The heartbeat of the modern CCW transceiver is provided by a small GPS receiver module configured to deliver a 10 Hz signal to a microcontroller that in turn is configured to interrupt the processor every 100 milliseconds, the Morse element timing frames for 12 wpm code speed. Within each of these frames,marks or spaces are transmittedas Morse code and then decoded as during receive.

The magic of CCW weak signal reception occurs on the receive side with precise timing of the 100 ms frames and FFT processing being performed within each of those frames to determine if a mark or a space is present. Data collection is begun at the start of each frame,followed by the FFT filtering by the processor resulting in a numeric value indicative of the presence (or not) of the 800 Hz [5] tone being transmitted by the sender. At the very end of each frame the processor determines if the threshold for a mark has been reached for the the 800 Hz receive tone; otherwise a space is assumed to be present.

Hardware Implementation of a "Modern CCW Transceiver"

Thus far, I've been describing Coherent CCW principles of operation from a higher-level perspective, which is good to establish an understanding of "The Big Picture". This also provides a good foundation for understanding the specific implementation taken for the "modern" CCW transceiver being presenting in this paper. The specific approach taken with this design was to utilize the K1SWL "PMK" (PicoMite Memory Keyer) both as a base computing platform as well a physical base hardware platform.

As a computing platform, the PMK uses the Raspberry Pi Pico as the microcontroller for all of Benson's Keyer software, yet it still has plenty of room and horsepower left over for additional capabilities such as CCW processing. The Pico processor is amazingly powerful for the price of about 5 dollars; and amazingly flexible with 26 multi-function I/O ports that can be programmed for special purposes such as interrupts, i2c/spi/rs232/usb communications, ADC, PWM, timers, accelerated on-chip floating point libraries, and more. The Pico also sports the popularRP2040 Arm Cortex M0+ processor operating at 255 MHz with two cores that may be independently programmed to work interactively on given software applications. It's no small wonder why K1SWL chose to experiment with this microcontroller when it was introduced some eighteen months ago. More about the Pi Pico can be found online (see References section).

As a base hardware platform, the PMK design was serendipitously timed with the genesis of ideas the authors had for developing a modern approach to a CCW transceiver. I had lightly collaborated with Dave during his own development of the PMK and it became evident to me that not only would the Pico microcontroller be "the one for me" too but his Keyer PCB would serve as a superb base computing and I/O platform for additional purposes. Since the 40-pin Pico device package has all signals readily available on its forty pins, a scathingly brilliant3 idea arose to develop a daughtercard, or "shield", to plug directly onto those pins, essentially extending the capabilities of the PMK base board. Further, the overall CCW 'system' then has full use of all the switches, LEDs and I/O jacks available on the baseboard. Such a deal!

Using this technique, I designed a generalpurpose PMK shield for hams containing an OLED display, a GPS receiver module and

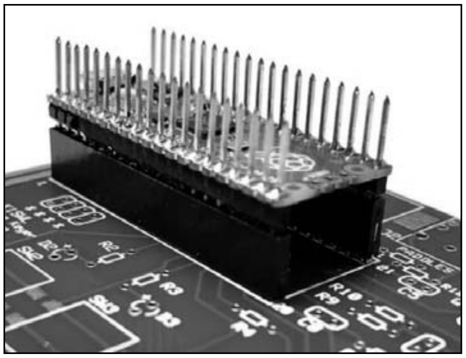


Figure 4a—Double-ended, long pin headers attach Pico to the PMK. These pin headers allows the Pico to plug into a set of SIP sockets on the PMK pcb. (It's a good practice to use sockets for programmable devices.)

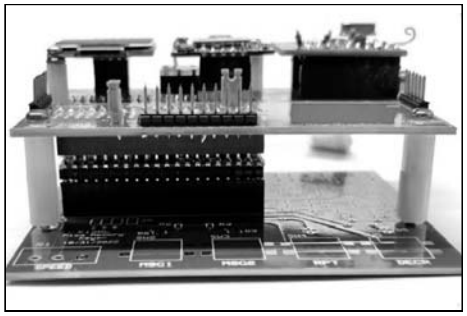


Figure 4b—Shield plugs onto the Pico's pin headers. Photo shows how the CCW Shield plugs onto the top of the Pico's long pin headers to form a compact and solid assembly, while also providing access to every signal that the Pico has to offer.

an Si5351 clock generator module that fits in place above the Pico using stackable pinheaders — double-ended long pinheaders on the Pico, which then (usually) plug into SIP sockets on the PMK board. Dual-20 pin SIP sockets are also soldered on the bottom of the Shield which allows it to plug onto the tall pinheaders extending up from the Pico. The illustration below should make this arrangement clearer!

To complete the hardware picture, Phase I of the CCW Transceiver interfaces with an external transceiver using the PMK's "Keyer Out" line to key the transceiver and an analog input from radio's audio for signal decoding.

This Shield may be used by anyone wishing to further extend the Pico or CCW capabilities, or even to develop custom projects based on this platform. Phase II of the CCW project adds the RF deck to the Shield, as covered in Part 2 of this article series, thus customizing it as a CCW Shield (or generally, a transceiver shield).

Two more notes about the hardware. The first is in regard to the schematic (see the Schematic at the end of the paper) — allcomponents on the lower half are on the completely unmodified PMK baseboard. Other than use of the stackable headers on the Pico processor, no hardware changes are required of the off-the-shelf Pico Memory Keyer kit.Further, the main interface between the baseboard and Shield is shown as a horizontal dashed line J5 between the two boards. This demarcation interface makes available all the Pico signals to the components on the shield board plugged into it, making it convenient for developers looking to extend/customize board capabilities.

So, the simplicity of the Shield is evident in the schematic … there's not much there! The OLED provides concise display of system function, the GPS module provides precise and accurate time for QSO synchronization, and the Si5351 clock module serves as the receiver local oscillator and main transmitter frequencies. Simple hardware modules … and the rest is "just" in the software.

The Software "Big Picture"

While the hardware was relatively simple and straightforward, the software design proved to be the largest challenge in this project. In retrospect, it's hard to believe that it's taken almost a year to get to this point of demonstrated "phase I" CCW capability; when writing this article it seems like the solutions were obvious all along. Perhaps it is often this way or maybe it just takes me a long time for me to wake-up [4]. [Also, being retired from the day job it's easier these days to stop to watch a movie, sleep in, and get distracted with myriad other shiny object projects along the way! Perhaps readers can identify with this syndrome.]

The software part of this Modern CCW Transceiver project consists of three main efforts:

1) GPS Time Synchronization
2) Paddle Detection and Time-sync'd Transmit of Dots & Dashes
3) Decoding the Received Bitstream

1) GPS Time Synchronization

At the heart of this, and earlier, CCW systems is a stable and accurate 10 Hz clock that provides 100-millisecond "frames" synchronizing both the transmit and receive stations. In the old days this way was accomplished as best as possible by carefully synchronizing to WWV for correct time (to seconds accuracy!) and using a very stable, low-drift local master oscillator derived from the radio being used. This sound complex — and it was indeed difficult to achieve the stability required for CCW use.

Today we have the luxury of having an elaborate network of GPS satellites orbiting the Earth, providing fairly accurate time and clock signals for all sorts of uses in daily life. In this project we make use of this by employing a small and inexpensive GPS receiver board that, once connected and "locked" with the satellite constellation, is able to provide both the absolute time and accurate, cesium-based clock signals. I used the uBlox u-Center application to pre-configure each GPS receiver card to provide a 10 Hz clock signal from its timepulse output pin, which connects to one of the input pins on the Pico.

This pin generates an interrupt every 100 ms (i.e., the period of a 10 Hz clock signal) which the CCW software uses to determine the "Start Of Frame". The ISR (Interrupt Service Routine) is pretty neat whereby all it does is quickly set a flag whenever the SoF is detected; and when the Pico is processing paddle inputs for transmit, or when it is looking to decode incoming data, the SoF flag is monitored and action is taken when it sees it change state. The use of this flag is integral to CCW operation and will be discussed in more detail shortly (see Figure 5).

2) Paddle Detection and Time-sync'd Transmit of Dots & Dashes

This is the biggie of the Software Big Picture. The CCW specification states that Morse code must be sent on explicit time boundaries so the receive side knows when to start and stop decoding for each possible code element being received. This is the phasing part of "knowing three things about the transmission", mentioned at the top of the paper. Those time boundaries are 100 ms periods (frames) set by the 10 Hz master GPS clock, and they define the Morse code speed of 12 wpm; so it is

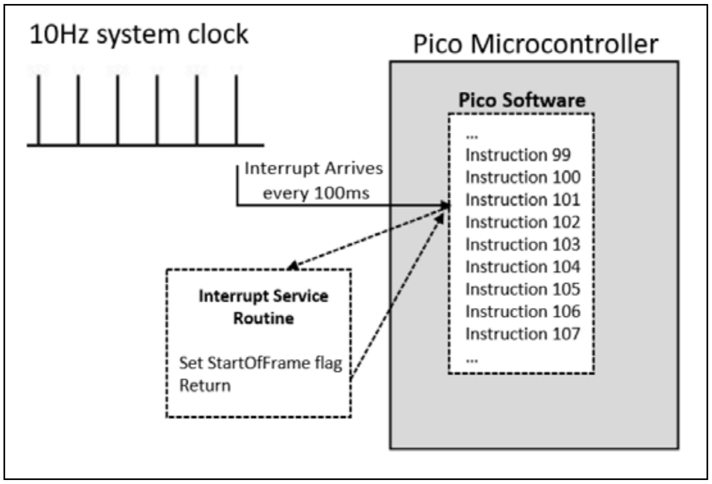


Figure 5—10 Hz clock interrupts the Pico every 100 ms. This is the main heartbeat of the CCW system.

imperative that the code being sent by hand be matched up to the precisely-defined 100 ms frames.

The challenge for this effort is that code sent by humans using paddles or a hand key is completely asynchronous in nature — code sent by the operator occurs at random times relative to GPS time, which is what CCW necessitates. It is nearly impossible to send perfectly-spaced code, even for the best of fists using the most accurate electronic keyer, because none is clocked by GPS-derived signals. Further "perfect" code — that which is sent with exact 3:1 dot-to-dash ratio — sounds quite boring and staccato-like, so most hams adjust the ratio weighting to give their fist a little personality. Hams using mechanical bugs personify this personality trait and certainly don't come close to CCW speed standards!

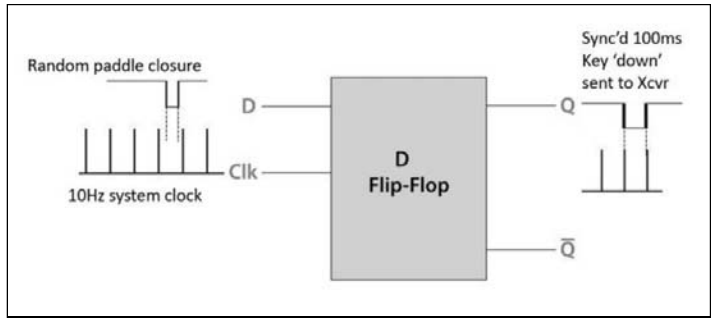


Figure 6—Simple representation of a D-flipflop.

The solution I selected was to use the time-tested D-flipflop logic element to sync an event to an external clock (Figure 6). The idea is that when an asynchronous event like a paddle contact closure occurs, the logic level is placed on a flipflop's input for Data and the logic block waits for a clock to come along pass it on through to the Q output. We can do this in software by hooking (intercepting) Dave's software when the DIT or DAH bit is set and then sit waiting for the next 100 ms frame to come along before acting on it.

Simple and elegant, right? Refer to Figure 7. Consider the following rather complex-looking illustration of a stream of 100 ms frames and the sample closure of first a dit (at 'A') and then a dah (at 'B'). First a dit occurs someplace in the middle of a 100 ms period and we need to remember it (with a D-flipflip flag called

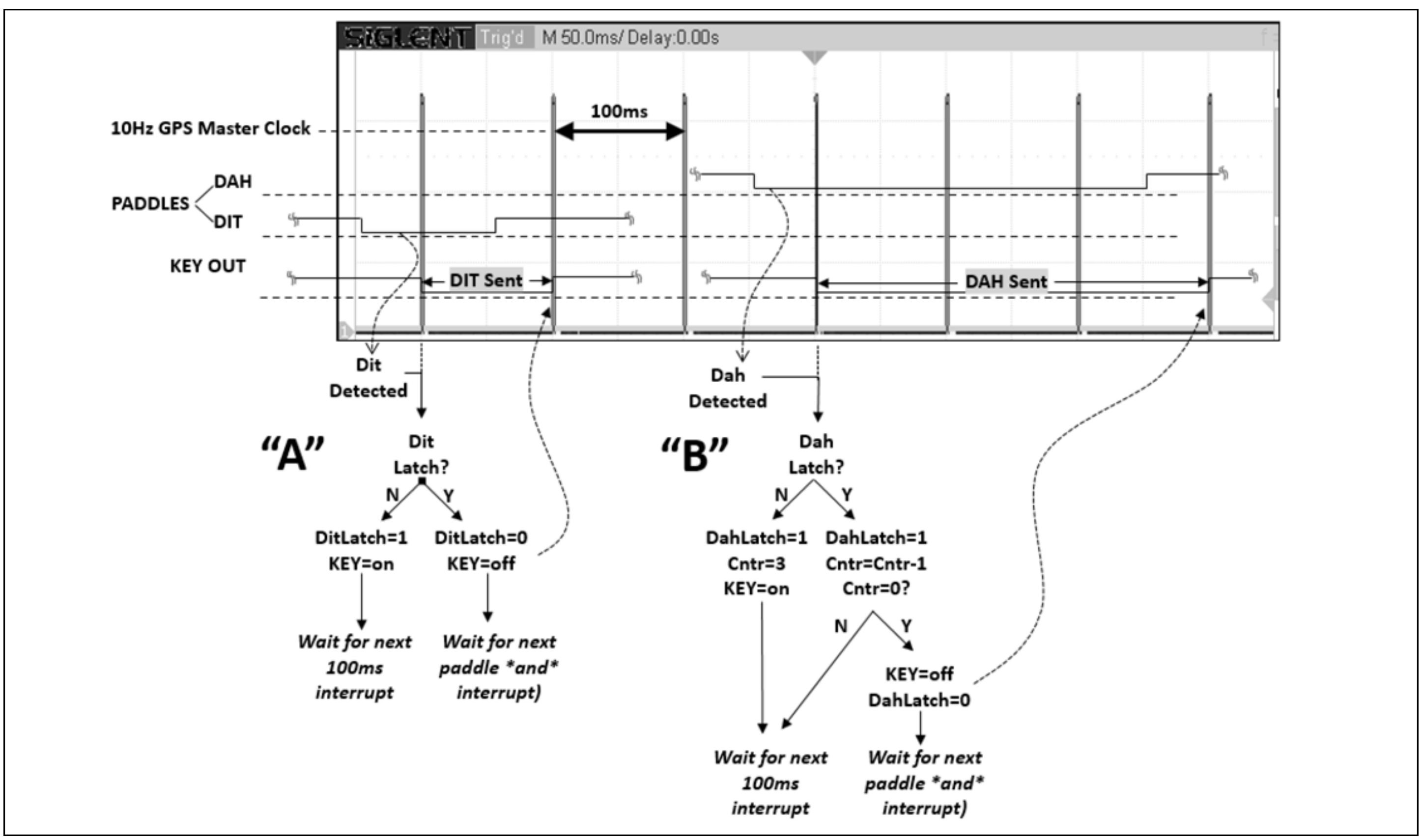


Figure 7—12 wpm synchronized transmit logic.

“DitLatch”) so we can key the transmitter at the start of the very next frame. We also must remember that the bit was set at the start of the next frame so we can turn off the key. Dit processing is pretty easy.

Handling the dahs is slightly more complicated. Recalling that dahs are three times longer than dits, we need to keep the transmitter keyed for three frames. So in addition to a DahLatch to tell us to go “key-down” at the start of the very next frame, we need a DahCntr to count how many frames to keep the key down. Still pretty easy.

The complexity lies in the fact that both the ‘A’ and ‘B’ processing scenarios occur at every single 100 ms frame boundary when the user is sending. Further, in Phase I of the software I am restricting paddle use to a single-lever version - not dual-lever “squeeze keying” type - in order to reduce probable complexities arising from the timing of two contact closures within the same window, or the logic labyrinth of more advanced keying styles (e.g., Iambic A/B, Ultimatic, et al).

3) Decoding the Received Bitstream

This last of the three main efforts in the project was the trickiest wherein DSP techniques were employed within each of the 100 ms frames to determine if an 800 Hz tone was being received, as sent by the CCW transmitting station. Yet curiously, this is the easiest effort to explain! I needed to study and experiment a lot to understand the sampling mechanism with the Pico’s Analog-to-Digital Converter (ADC), and especially for use of its accelerated Fast Fourier Transform (FFT) computations, but once I had this somewhat under my belt it was a straightforward move to implementation. A handful of charts and illustrations (Figures 8-11) tell the story better than words, so here we go. Please read the captions for each graphic in the order presented.

Sampling & FFT Information		
ADC depth	12	bits
Fs (max 500 kS/sec)	4000	Hz
Samples	255	
Bin Res (Fs/Samples)	15.69	Hz
Window (measured)	95	ms
Bin (of 800 Hz tone)	51.00	
FFT Magnitude	(See display & data tables)	

Figure 8— Sampling & FFT Information. The chart shows that with a sampling frequency of 4000 Hz (usable to only 2000 Hz before aliasing occurs) and 256 samples (127 samples are usable after the FFT is performed, in pairs), we end with having a “Frequency Resolution” (or filter bandwidth) of 15.7 Hz. This is not as narrow as the 10 Hz width of Petit’s original CCW system, but it’s pretty darned close, and still something far, far narrower than what could be achieved with electronics.

Two Final Notes

Not much has been mentioned yet about how the Date/Time reporting capabilities of the GPS receiver are used. Although somewhat obvious and relatively straightforward, they nonetheless play a very important role within the CCW system. I initially mentioned that three factors are required for successful CCW communications, and knowing exactly when to start the 100 ms framing windows is an essential one of the three. The CCW systems of the early days needed to adjust the phasing of the receive-side 10 Hz master clock relative to the timing of the incoming bit stream to peak reception signals. This was accomplished by sliding the local clock relative to the incoming data stream to maximize frame overlap and ensure synchronization. However in today’s system, with both the transmitter and receiver endpoints starting their respective 10 Hz clocks at the very same time, there is no need for sliding windows or phase adjustment! When a CCW station operator presses a button on the PMK to “Start CCW Transmit”, he/she can be assured that any other CCW station lis-

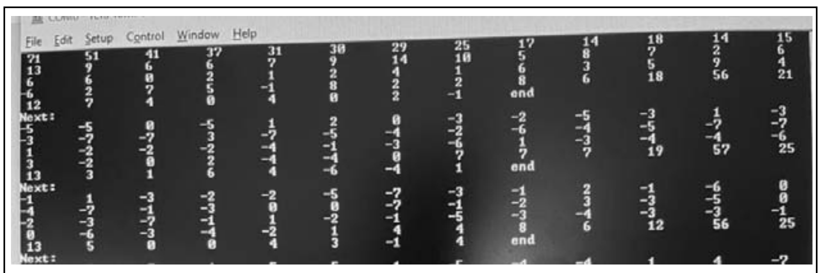


Figure 9a (Left)—FFT bin counts for bins 0-59. Screen shot of FFT results on actual data collected during reception. Note the “sweet spot” surrounding bin 51 representing 800 Hz. Note the big principleenabling sampling and successful representation of a single frequency: “Zero-bias for noise, Signal for a constant signal”. What this means is that the average signal in the presence of noise will tend toward a zero value, while that of a signal-of-interest (800 Hz in our case) will skyrocket out of the noise and be readily apparent to subsequent processing.

Figure 9b (right)—FFT bin counts for sweet-spot: bins 48-52. This screen shot shows that if we look at the bins in/around those for 800 Hz we see a clear and distinctive peak, so we can be relatively assured that a CCW signal is being received. This is why a CCW can be picked out of a “dead channel” as much as it is able to be spotted amongst a crowded band during CQWW contesting weekend or even in the FT8 band! Nobody but the CCW-transmitting station has the characteristic of sending the 800 Hz tones for properly formatted Morse code; hence only the CCW station will come through loud and clear. Man, what a filter!

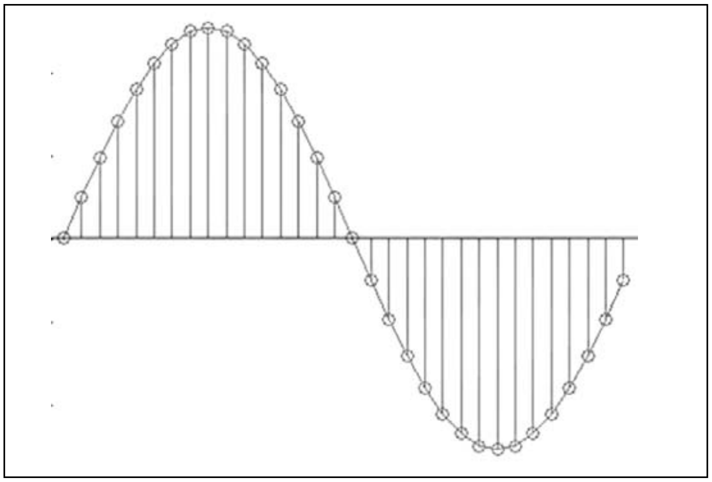


Figure 10a—Discrete sampling of a waveform performed by the Pico ADC. The software then takes the 255 samples and performs the FFT “in real time”, which all happens within a 945 ms window.

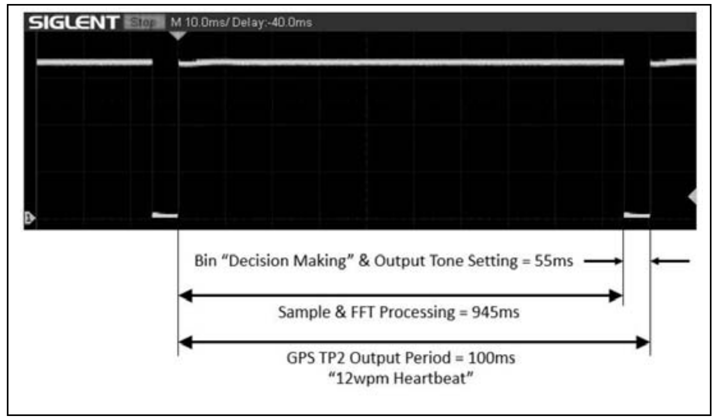


Figure 10b—55-milliseconds remain for mark/space decision making. The 945 ms sampling and FFT computation time is illustrated in this annotated oscilloscope trace. Note that the software has a whopping 55 ms remaining in the frame to make a decision of whether the received data is a mark or a space — Plenty of time!

tening on that exact frequency will be able to copy the Morse code transmission because of the common use of GPS timing. [Time will tell (ha ha) if something is yet needed to account for propagation path delays on longer-haul connections.]

Also not mentioned at all thus far is the software language used for developing this modern version of a CCW transceiver system. The Pi Pico proves to be an amazingly flexible platform by allowing developers to program in a number of different languages: Arduino C, C++, MicroPython, CircuitPython, Assembly Language, Scratch, HTML5, JavaScript, JQuery, Java, Perl, Erlang … and even in Basic! If your eyes have glossed over on this list of languages, you’re not alone, but this gives you some idea of the ubiquity of application that this marvel has. And in most cases all one needs to do is plug a brand new Pico into your computer’s USB port and drop a special file into the folder that appears in your finder window, essentially outfitting the Pico with the required drivers and native library calls for that language to operate the microcontroller. Pretty amazing all for $5.

So to answer the question of what language is being used for the PMK and the CCW project … <drumroll, please> … it’s done in Basic! “No way!” Yes way, and in fact the version of Basic Dave used for the PMK and that I also adopted for developing the CCW program is called MMBasic, optimized and enhancedfor the Pico by Geoff Graham. Take a look at the source code for both the PMK and the CCW project, located on the PMK web page — we think you’ll be impressed with the utility and performance of the Pico under control of this language of the past driving some projects of the future!

Next Time

In Part 2 of this epic article, we discuss our adventures with two-way CCW QSOs between principal parties: N2APB, WB9FLW and K1SWL. Also in process are refinements to the decoding algorithms, connectionand synchronization protocols, increases in keying speeds, and additional features for the user interface.

Lastly, an exciting parallel projectunder development will be presented: an RF deck that plugs directly onto the CCW Shield thus achieving the original goal of making this project a completely standalone CCW Transceiver.

The Authors

George Heron, N2APB: Licensed more than fifty years, George is now retired from EE and cyber security careers and is living in rural TN. Always involved in technology and homebrewing, he helped to form and lead the NJQRP, the AmQRP, and Chat With the Designers; he edited and published *QRP Homebrewer* and *Home-*

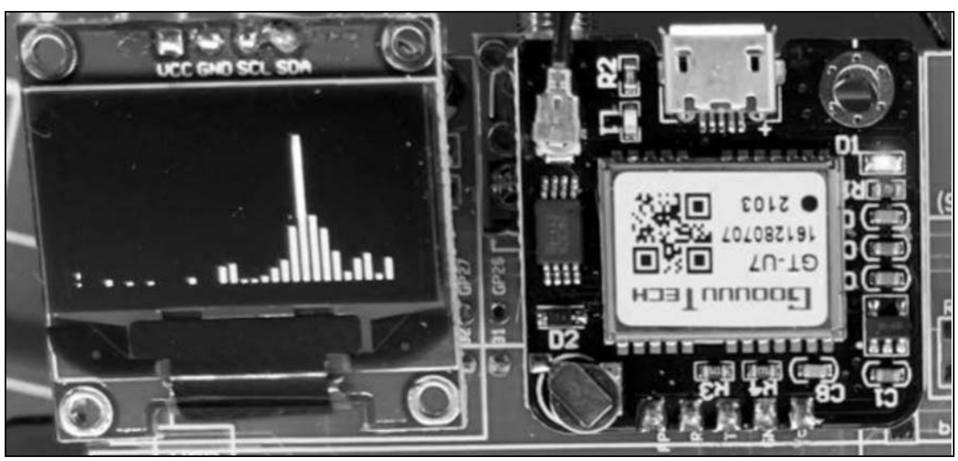


Figure 11—Frequency domain representation of the received signal after sampling and FFT processing.. Note thefrequency peaking at 800 Hz … How do we know the peak is at 800 Hz? It’s at the 51st bin, which at 15.7 Hz/bin yields the expected 800 Hz value, which is also the value of the receive tone coming from the speaker. (Using the SPOT pushbutton on the Elecraft K3 was a joy during development since it auto-adjusted the receiver dial to yield the 800 Hz receive tone!)

brewer magazines; and he co-designed numerous projects under the Midnight Design Solutions shingle including the SDR Cube and NUE-PSK transceivers, DDS-60 siggen, Midnight Ultimate Keyer and Precision Clock kits, and the Rainbow Tuner. George may be contacted at: n2apb@MidnightDesignSolutions.com.

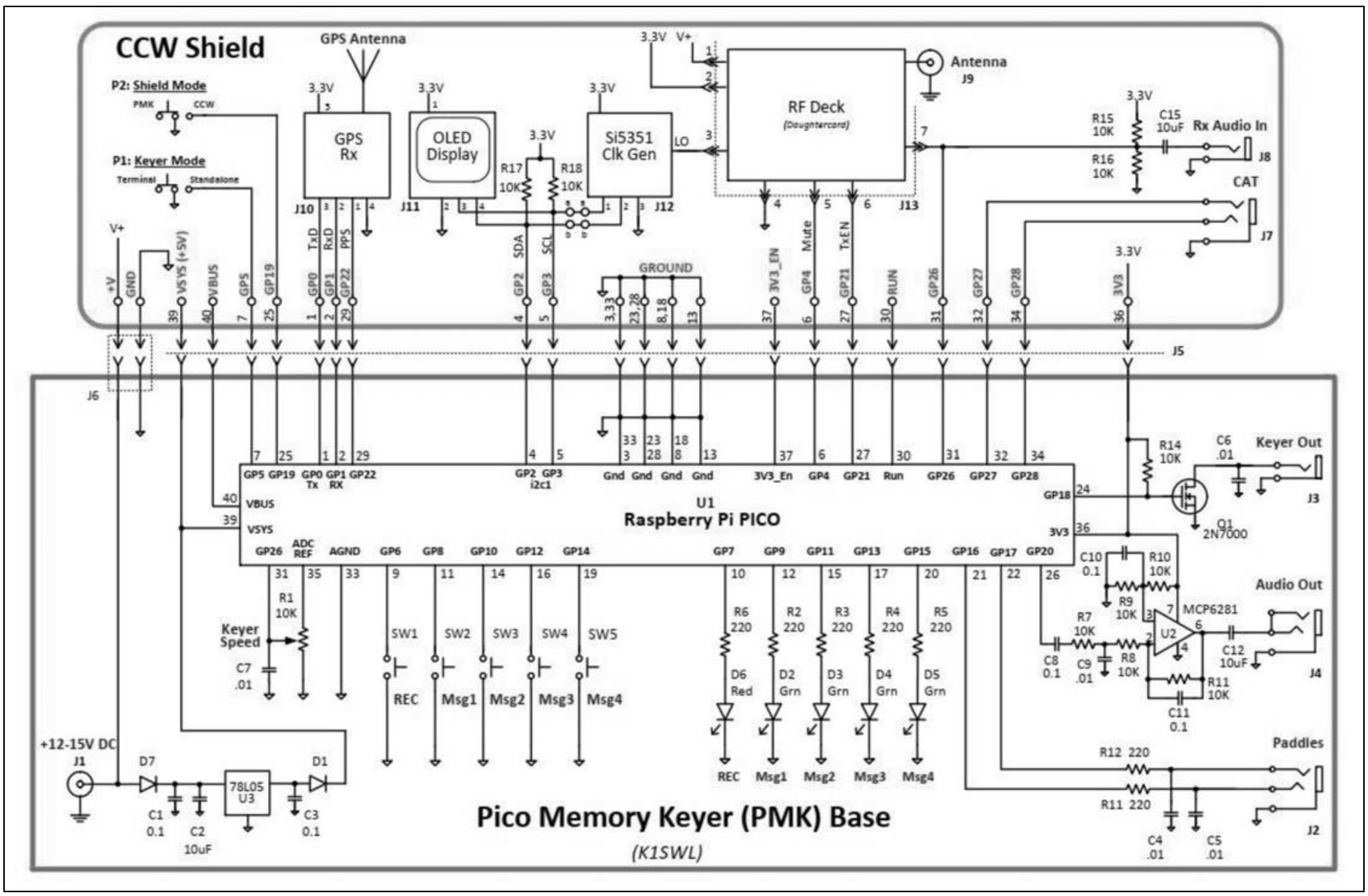
Peter Eaton, WB9FLW: Pete was first licensed as a Novice in 1963 (WN3EJB), then as a General (WA3KZA) and Advanced (WB9FLW and KA2PE) while stationed at Yokota AFB Japan. He was very active in TAPR during the early years and wore many different hats which included Executive Vice President, speaker on Packet Radio at many conventions, and was part of the Team that design three generations of Terminal Node Controllers. His current interests are Weak Signal Modes (thus CCW). Peter may be contacted at: zx97lite@yahoo.com.

Footnotes

1) https://en.wikipedia.org/wiki/Shannon%E2%80%93Hartley_theorem
2) The CCW Archives—https://midnightdesignsolutions.com/ccw
3) Spoken with a mock British accent, "Scathingly brilliant" was a term often used by my mentor Joe Everhart N2CX, as derived from the 1966 movie "The Trouble With Angels" starring Hayley Mills playing twins in an orphanage. https://www.imdb.com/title/tt0061122/characters/nm0001539
4) "Problems are nothing but wake-up calls for creativity" —Gerhard Gschwandtner
5) Most ham transceivers use an 800 Hz transmit or receive offset when in CW mode, thus delivering an audio tone of that frequency to the receiving station's speaker.

References:

1) PicoMite Memory Keyer, by Dave Benson K1SWL—https://www.midnightdesignsolutions.com/pmk/
2) Raspberry Pi Pico microcontroller—https://www.raspberrypi.com/documentation/microcontrollers/raspberry-pi-pico.html
3) Coherent CW Archives… Unofficial archive of the works from the early pioneers of Amateur Radio's digital communications era.https://midnightdesignsolutions.com/ccw
4) MMBasic... https://geoffg.net/MaximiteBasic.html



Schematic.

A 3-Element Vertical Array for 20M

Robert MacKenzie—VA3RKM, Pat Byers—VE3EUR and Michael Babineau—VE3WMB robert.mackenzie@rogers.com

A Temporary 3-element Parasitic Vertical Array for 20M

When I came back to ham radio in 2005 as a QRP operator, I worked for several years with a ground-mounted vertical for the 10, 15 and 20m bands in the backyard at VA3RKM. I had lots of fun, especially with contests. But it seemed that I was working the same stations year after year, with few new calls showing up in the log.

Adding some temporary 20m parasitic elements from time to time to the vertical made a welcome difference. Now I was hearing and being called by more ops in California in the QRP ARCI QSO parties and working more DX with 5 watts. It added variety to my operating, although it made more work for me having to answer those newly-found QRPers calling me with their tiny signals!

In this article we will look at the construction of a ground-mounted, temporary 3-element 20m parasitic vertical array that, with adjustment, can also be used on higher bands. It is a parasitic, as opposed to a phased vertical array, about which there are many more articles. The array is best described as a temporary antenna, since it is big and not very pretty. If you could afford the alimony, it could serve in your backyard as a permanent fixture. But it's more likely to be called upon for a limited time in contests, on Field Day and for occasional DXing. Two other Ottawa Valley QRP Society members contributed to the research. Pat Byers VE3EUR helped with the WSPR testing and Michael Babineau VE3WMB with technical matters. [1]

An array of this kind can be seen as a beam Yagi turned on its side. Like the common 3-el horizontal Yagi beam, it has a radiator that is the driven element, a reflector mounted behind it that is 4-5% longer, and a director in front of it, 4-5% shorter. Spacing between elements is often in the range of 0.20 or 0.25 wavelengths. The big difference is that the horizontal Yagi has elements that are about 1/2-wavelength long, whereas the usual vertical (also termed a monopole) array's elements are 1/4-wavelength, with the ground system serving as the other half of the "dipole." Being ground-mounted, ground losses greatly reduce the gain of the vertical array as compared with a horizontal Yagi that is elevated by 1/2 wavelength or more. But the vertical array still has some gain compared with a single-element vertical, and a potentially useful front-to-back ratio. [2]

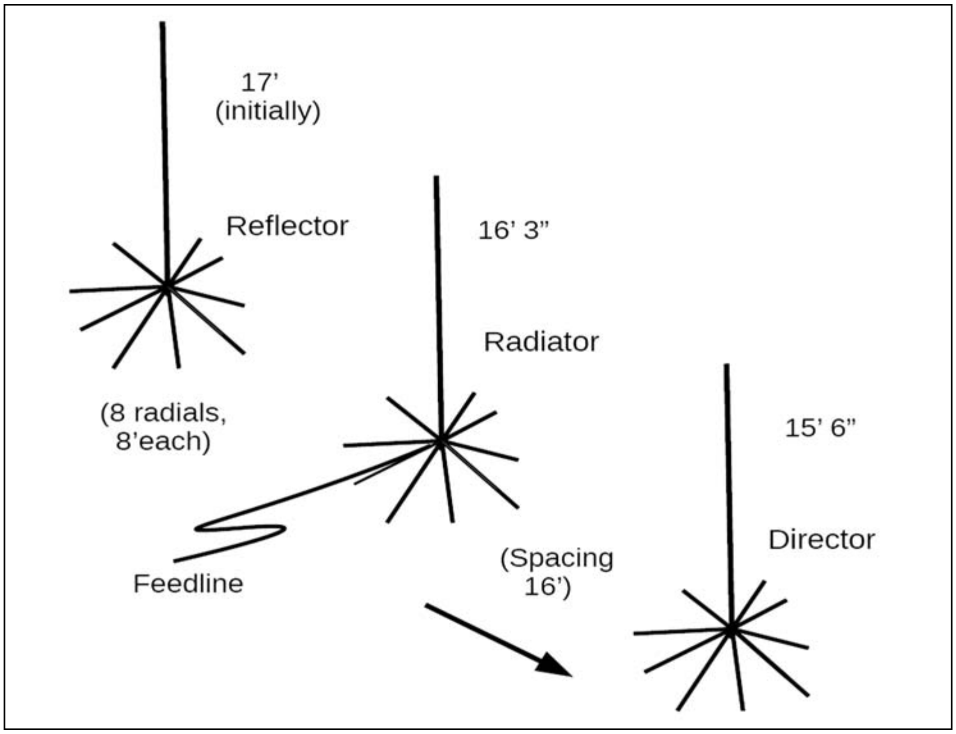


Figure 1—Basic layout of the vertical array.

My first parasitic elements consisted of 14ga insulated wire from Home Depot taped to long Shakespeare fishing poles. They worked fine, capitalizing on the effect that their being slightly off resonance, relative to the driven element, caused cancelling and strengthening of RF fields. That interaction afforded the array gain and directivity. Portable operating needs, especially on Field Day, led me to buy more durable 6' aluminum tubing to constitute the array's elements. This tubing (0.058" thin-wall 6061-T6) telescopes nicely, with a 0.625"O.D. section serving as a 20m element's bottom portion, 0.500" the middle, and 0.375" the top. Buying 3 more 0.500" pieces to set aside as 15m sections will avoid you having to adjust the 20m elements' lengths in the field when changing bands. The 15m sections can quickly be interchanged with the top sections used for 20m.

As a start to construction, clean the overlapping areas of the tubing and coat them with anti-oxidant such as Ox-Gard. Then fit small stainless steel (to reduce corrosion) hose clamps to the top two sections to prevent them from collapsing into one another. The clamps can later be loosened and shifted to make the final length adjustments to an element. Putting a dab of the same coloured paint on each section of a given element helps with quick assembly in the field.

Set the driven element's length to 16' 3" (4.95m) initially, the reflector 9" (23 cm) longer to 17' (5.18m), and the director 9" shorter to 15' 6" (4.57m). These dimensions are shorter than the theoretical free-space lengths due to the capacitive effect of the ground, which, for a ground-mounted vertical, depends to a large degree on the conductivity of the ground where it is erected and on the number of radials employed. If you have extra tubing for 15m elements, use the hose clamps to set this top section of the radiator to 5'

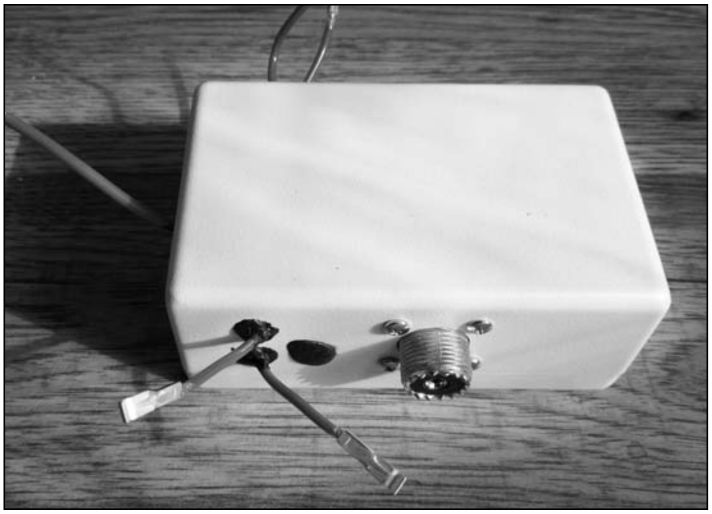


Figure 2—Junction box used at the feedpoint.

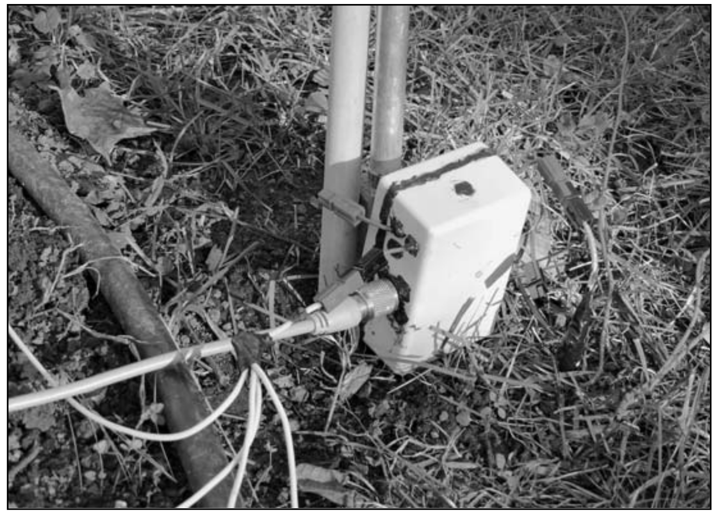


Figure 3—Junction box placed at the bottom of the element.

(1.5m) to add to the 6' bottom element, and the parasitics 6" (15cm) longer and shorter. After the array is erected, review the SWR and radiation resistance with an analyzer and adjust the elements as needed.

The elements in the array can be placed about 16' (about 5m, or 0.25 wavelengths) apart for 20m, or 11' (3.4m) for 15m). Decide in advance in which direction you want the row of elements to point, using a great circle map. When desired, the top two sections on 20m (one section on 15m) can be quickly be switched manually from reflector to director and vice versa, reversing the direction of the beam.

Hardwood dowels (3/4" in 4-foot lengths, available at Home Depot) serve well as support stakes for the elements. Usually they are not difficult to pound into the ground with a hammer. But if the ground is dry and hard one can start a hole for them with a large metal screwdriver or other tool and pour some water into the hole to soften the earth somewhat. If penetrating the ground sufficiently deep to hold the stakes is too difficult, thin Dacron rope attached with hose clamps to the elements to guy them can support them. The guys can be held held tight by thin metal tent pegs driven (if possible) into the ground. Frozen ground in winter would require some sort of stand to hold up the elements. Use several wide Velcro tape or ties to fasten the tubular elements to the stakes, with a few turns of green painter's tape around each stake and element to snug things up.

Over the years, for radials, I have come to use spools of 16 ga or 18 ga insulated wire bought on sale at an auto supply store. It is more durable than smaller-gauge wire and I find that it does not tangle as much. According to several well-regarded articles, the radials for ground-mounted (as opposed to elevated) verticals need not be 1/4-wavelength; they can be much shorter when 8 or 16 are employed. The *ARRL Handbook* recommends 0.1-wavelength (about 7' or 2m) radials when 16 are employed, and others opt for 0.125-wavelengths (about 8' or 2.5m). [3] Greater lengths do not contribute to the effectiveness of the vertical. A 100' (30m) spool of wire will provide a dozen 8' (2.5m) radials. Personally, I like to make a number of assemblies of 4 radials each that are 16' (about 5m) long so that I can deploy them with both 40m and 20m verticals.

The array will work (poorly) with 4 radials per element over urban soil, but 8 or more is much better. My RigExpert analyzer showed large losses with just 4 radials, requiring the driven element to be shortened to only 15' 3" in order to provide a reasonable SWR. Adding 4 more radials per element yielded better element element dimensions and lower losses. To make the radials, I usually solder 4 wires together to a short pigtail terminated in a PowerPole. That PP that attaches to a matching one on a pigtail coming from the element. You may want to use another kind of connector for the radial assemblies, such as auto electrical bullets or ring terminals.

The solder joint for the wires in the assembly will be brittle. This makes it a mechanical weak spot, and it is prudent to cover the soldered area in Coax Seal and then to wrap the first few inches of the assembly in electrical tape to ensure that any bending and flexing occurs further down than at the joint.

To connect the parasitic elements to the radials, you could drill a small hole in the element at its base to accommodate a stainless bolt and wing-nut. It will hold in place a short jumper with one or more PPs on one end and a ring terminal on the other to be fastened to the element. You will need a PP (or other connector) on the jumper for each 4-wire radial assembly to be used. Or to avoid drilling, you could employ the hose clamps from DX Engineering that have a threaded 10-24 stud welded to them. Another option is a metal connection plate (commercially available) that is fitted with bolts and wing-nuts with which to connect the radial wires. It would be set at the base of an element and joined to it by a ring terminal pigtail. I place a small block of wood under each element of the array to act as an insulator and to provide ready access to the wire connections.

For the driven element's feedline connection, I chose to mount an SO-239 connector onto a small plastic junction box to be placed at the base of the element. A short pigtail with a PP is soldered to the SO-239's centre pin and run out of the box. Several wire pigtails attached to the SO-239's mounting bolts and terminated in Powerpoles also run out from box through separate holes to connect to the radials .

The holes and seams are sealed with Coax Seal. Other ways to mount an SO-239 connector are possible, of course. For example, DX Engineering sells a pre-drilled, right-angle metal mounting brack-

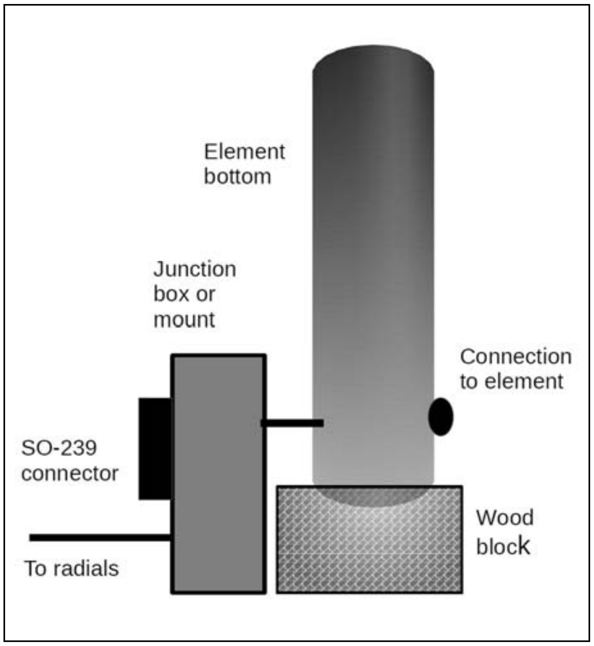


Figure 4—Connection diagram.

Figure 5—The vertical array deployed and ready for operation.

et. As an alternative to employing an SO-239, a PP or auto connector pigtail can be soldered directly to the inner conductor of the coax feedline and another pigtail to the braid (with as many PPs or connectors on it as are needed for radial assemblies). Use a hose clamp and pigtail or a bolt and wing-nut and ring terminal to provide a connection from the element to the PP.

Make sure that wires of pigtails are very short and that any junction box or mount for an SO-239 connector is as close as possible to the driven element. Otherwise, the wires and the mount can form part of the radiator, making tuning more difficult.

In summary, in the field the first thing to do is to pound in 3 dowel stakes 16' feet apart, aligned in the desired direction. Then assemble the elements and Velcro and tape them to the stakes. A small block of wood or other insulator can be used to raise each element off the ground. Lay out the radial assemblies. Connect the coax to the mounted SO-239 that is hooked up to the driven element. Then connect the radial assemblies to all of their respective elements (Figure 4). Check the SWR and adjust the length of the elements as needed, keeping the 20m parasitic elements about 9" different in length from that of the driven element (6" on 15m).

You should be set to go (Figure 5).The direction of beaming can be reversed by switching the top 2 sections of each parasitic element for 20m and the single top section for 15m. If you are really keen, you can drive in two more stakes perpendicular to the array's axis. That would allow you to readily move the parasitic elements and their radials to beam to any of the 4 corners of the world!

Computer models of vertical parasitic antennas (facing page) in general show gain in one direction and an increased front-to-back ratio compared with single-element vertical [4]. Concurrent on-air testing of the array and a single vertical antenna in a nearby park using two of SOTA's WSPR Lite beacons running together bore this out (spots are gathered on Dxplorer.net, with premium-level service). Consecutive testing at home with a single WSPR Lite, taking in turn the average of 10 spots for several callsigns with 1 vertical element then with 3, also indicated gain. For consecutive testing, it takes about 45 minutes to collect 10 spots with a 40% transmission cycle, at which time the number of elements can be changed.

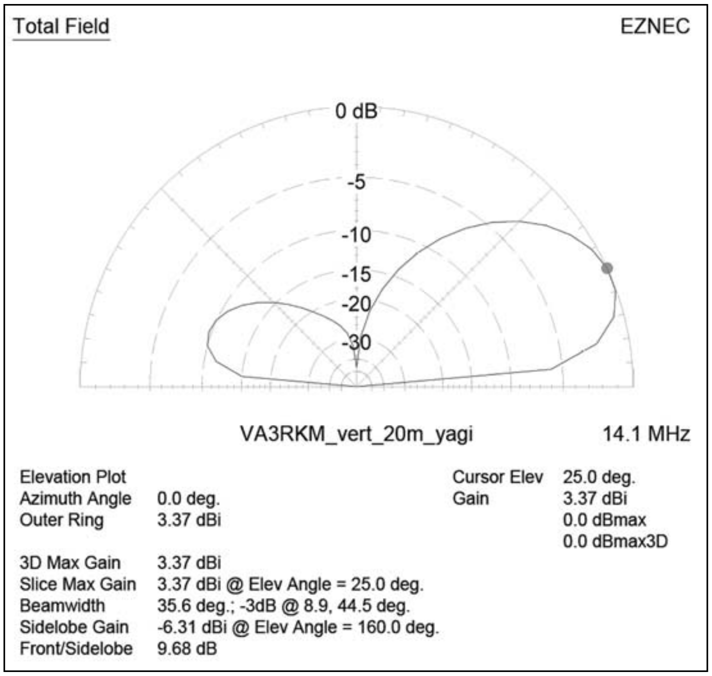
Based on my operating experience, I would say that the array is a better DX antenna than a simple vertical and also allows me to work more stations in North America. This will not be the case for everyone, however. The effectiveness of verticals depends on the type of soil and ground that surrounds it out to many wavelengths. If this reflection zone is not suitable, a raised horizontal antenna that is not as dependent on the ground would work better, even if its radiation angle is higher. [5] But if you think that your soil will work well enough, the array may be a fun thing with which to operate and to experiment.

From Editor VE3IPS — I can confirm that the JP1QEC antenna does what is designed for to offer improved directivity in QRP operations but this design offers an additional element to improve on forward and F/B gain. No coils improves on ensuring as much as signal gets radiated at lower power levels and not dissipated into coils. I think having the poles in big box store buckets could prove useful in paved areas for emcomm or ARES ops.

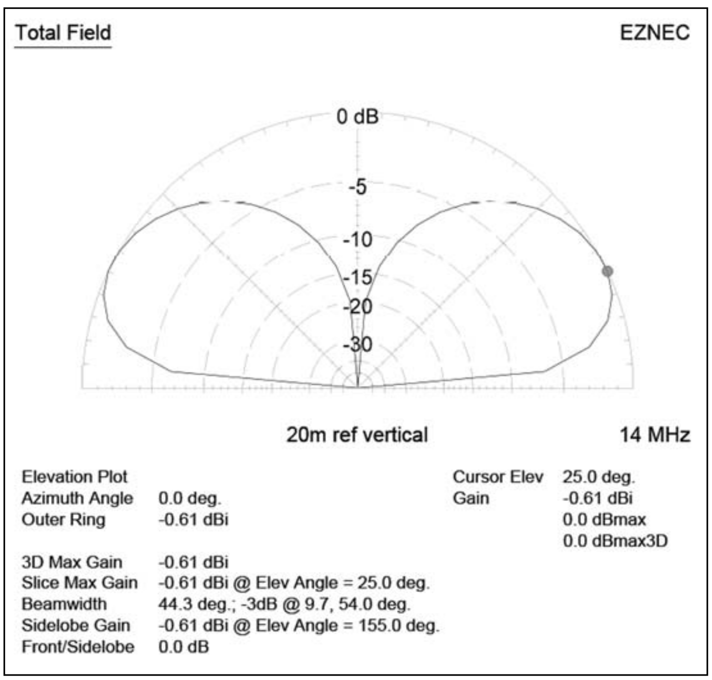
Footnotes

[1] Two articles on temporary and portable verticals that appeared in recent years in *QRP Quarterly* contain helpful material: L.B. Cebik W4RNL, "Some Techniques for Building a QRP Vertical," April 2016 issue, reprinted from April 2002; and Akira Motohashi JP1QEC, "The QEC Antenna: a New Design," January 2017 issue.

[2] The well-written chapter 9 about verticals in ON4UN's *Low-Band DXing*, 5th edition (ARRL, 2010) by John Devoldere ON4UN provides more than enough theoretical and practical information for amateurs like us. Well worth the price!



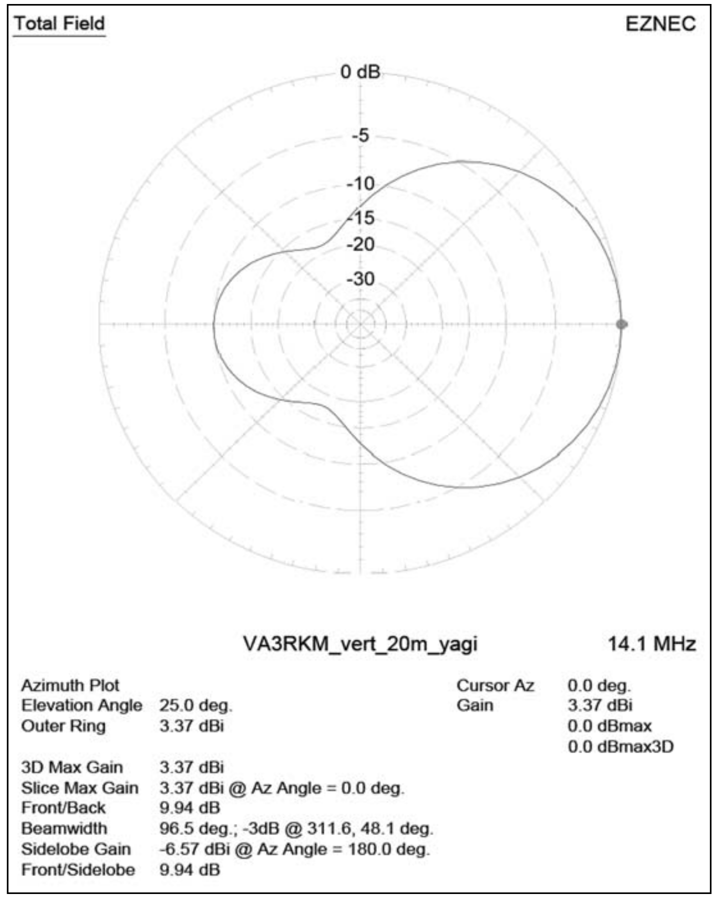
Plot 1—Elevation pattern.



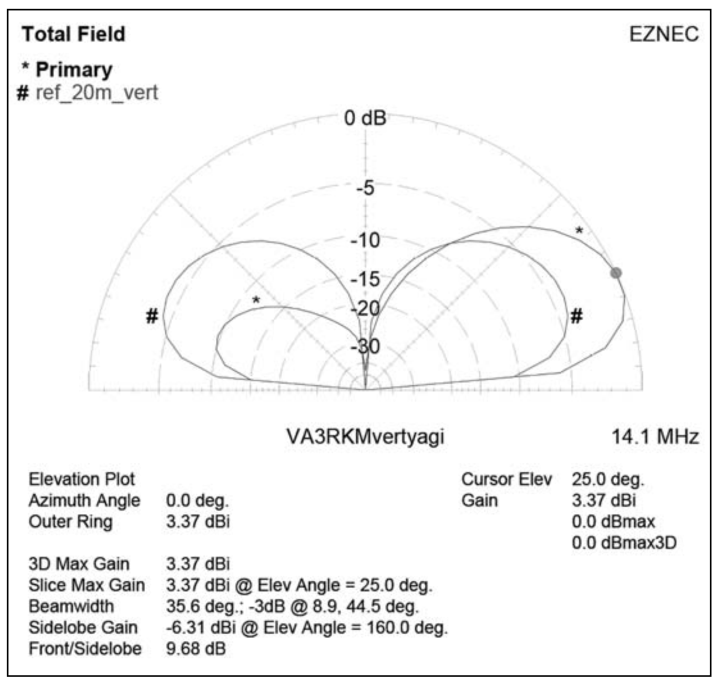
Plot 3—Reference elevation pattern of a single element.

[3] The *ARRL Handbook* 2021, section 21.3, reproducing a table by John Stanley K4ERO/HC1 from the December 1976 *QST*. Two other helpful articles discussing radials for ground-mounted verticals are: Brian Edward N2MF, in the June 1985 *QST*; and Rudy Severns N6LF, in the March 2010 *QST*. All three of these articles can be downloaded by ARRL members from the League's website.

[4] Computer models show a -0.61 dBi gain at 25 degrees elevation for a single vertical and +3.37 for the array, for a difference of about 4 dBi. Azimuthal beamwidth for the array at 3 dBi is 97 degrees, and front to back ratio 10 dBi.



Plot 2—Azimuth pattern.



Plot 4—Comparison of the array and a single vertical.

[5] ON4UN's *Low-Band DXing*, chapter 9, section 4.4 notes the experience of two well-known hams who found the performance of sophisticated verticals over poorly-conducting soil to be disappointing. ●●

The EZGen3

Don Cantrell—ND6T nd6t@velotech.net

The emergence of inexpensive microcontroller boards, like the Arduino series, and signal synthesizers, like the Si5351 and AD9850, prewired and mounted as modules makes for easy construction of relatively complex projects. Display modules, complete with their controllers, are also available cheaply. This makes it a simple matter to just wire them together for easy construction of otherwise complex projects.

The completed EZGen3.

For those experimenting with or repairing communication devices signal generators are essential. Building them can save money and allow customization. You can build test equipment to exactly suit your needs. Not to mention that you will learn a few things. Most importantly, you will be able to repair it if it breaks. When you don't need it any more, you can use the parts for something else entirely!

My first such generator project in this series was the Easy Signal Generator, http://www.nd6t.com/test/EasySignalGenerator.htm, my "EZGen1". Just a Direct Digital Signal (DDS) board plugged into an Arduino Uno and controlled through the USB port by a computer. You had to have a computer connected to change frequency. A fixed output level was all that was available. Still a great tool for generating low distortion audio down to ridiculously low frequencies.

My next effort was to use a smaller controller board (the Arduino Nano) and small OLED display to control an Si5351 breakout board. I called this the EZGenII, http://www.nd6t.com/test/EZGen2.htm or "EZGen2". This has proven to be a very useful addition to the bench but required external attenuation for any level below the 2 milliwatts (+3 dBm across 50 ohms) that it produces at its lowest drive level (default) setting. I still use it a lot for prototyping generation and for a portable sta-

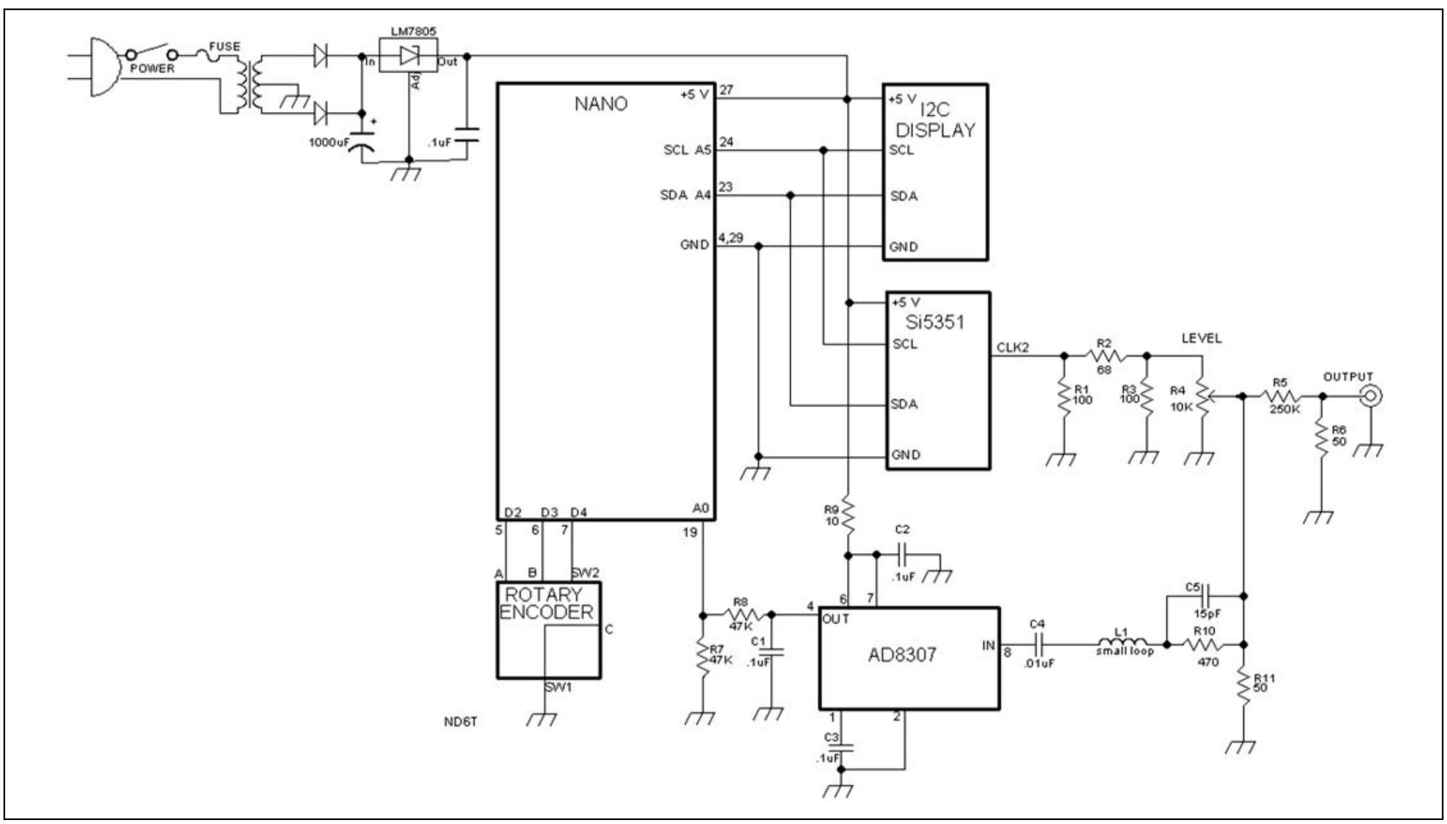


Figure 1—Schematic of the EZGen3. Note the attenuator circuit at the output.

ble signal source, e.g. for projects like calibrating Doppler RDF systems.

Attenuation control

I often need a very low level signal to evaluate a receiver. Usually below -73 dBm (50 microvolts, the standard for S9 meter readings). Ideally the level should be able to be reduced to well below any receiver's detection capability (like -150 dBm). Lofty goals, indeed, since it is quite difficult to provide shielding good enough to reduce the signal to less than a billionth of the original without significant leakage.

For this project I chose to try a simple potentiometer as an attenuation control. I used a 10 dB resistive network to isolate the Si5351 from varying loads, and followed the potentiometer with another resistive network for the bulk of the attenuation. Figure 1 is the schematic.

Rather than attempting to calibrate the attenuator knob, I chose to use an AD8307 logarithmic detector to measure the RF level at the wiper of the potentiometer. I had used this device earlier when building a power meter, had purchased several chips, and had made up a few modules for future projects like this one. The circuit that I used was the one that Wes Hayward and Bob Larkin published in the June 2001 issue of *QST*. It is has a very wide frequency range and develops a DC voltage that accurately tracks the logarithmic level of the RF signal to be measured.

The Nano reads this voltage, calculates the level that will be delivered at the EZGen3 output BNC, and displays the result, in both microvolts and dBm, on the SSD1306 OLED display.

The resistive network between the potentiometer and the output connector sets the overall attenuation to the proper range and provides a constant match. The values shown in the schematic set my range from -85 dBm (12.8 microvolts) down to -129 dBm (0.08 microvolts). That range was decided mostly by the 44 dB range that my potentiometer allowed.

Since I only wanted this to be a test bench instrument I included a 120 VAC to 5 VDC power supply. This was built from a salvaged "wall wart" mostly. I removed it from the plastic shell and plug and then strapped it into the (salvaged) aluminum case with a strip of aluminum flashing. I added a line fuse, too. Wall warts often use the transformer primary as a fuse. Ugh!

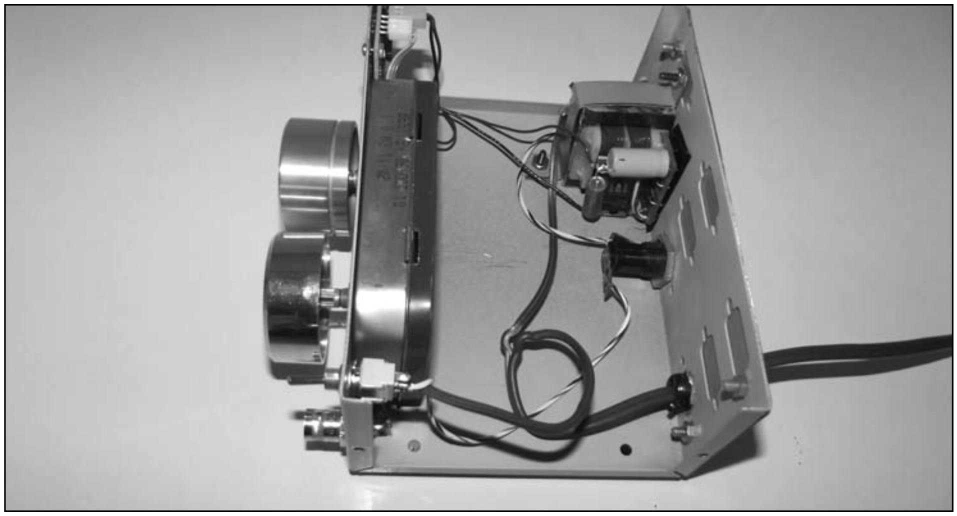


Figure 2—The generator is built into a repurposed data switch box.

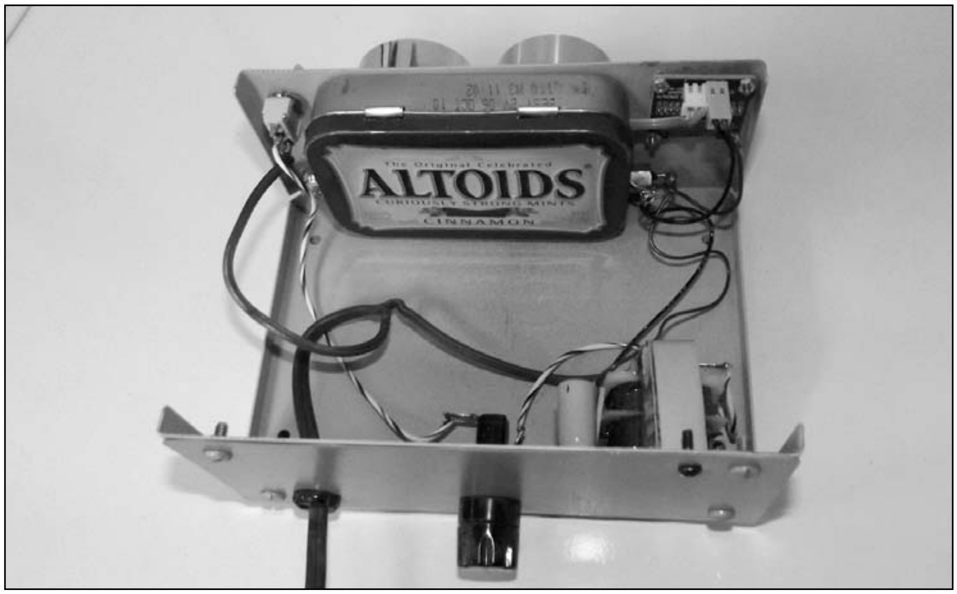


Figure 3—An Altoids box provides shielding for nearly all the working electronics.

Construction

For this project I used a junked data switch found at a second-hand shop (Figure 2). After removing everything from the cabinet I cut a piece of scrap aluminum from a spare dishwasher decorative panel and covered the rear of the cabinet. I didn't need all of those holes.

For quick-and-easy shielding I chose an Altoids tin to contain the Nano, the rotary encoder, the potentiometer, the SI5351, the AD8307,and most of the resistive networks. See Figure 3. The encoder and the potentiometer shafts protrude through the bottom of the tin and through the front panel of the cabinet, mounting the assembly to the cabinet. The Nano is mounted on the back of the encoder, the Si5351 is mounted on a block of double-sided foam tape in addition to the solder connections to the Nano, and the AD8307 module is glued to the back of the potentiometer. A view inside the shielded box is shown in Figure 4.

The 5 volt power is fed through a feed-through capacitor into the shielded area. The USB port of the Nano is accessible if the Altoids tin lid is lifted, thus programming in place is easy. R5 exits the shield so that half is inside, half outside the shield, and R6 is across the BNC output connector. All RF leads are as short as possible.

Firmware

The firmware is an Arduino "sketch". You can download the latest version at

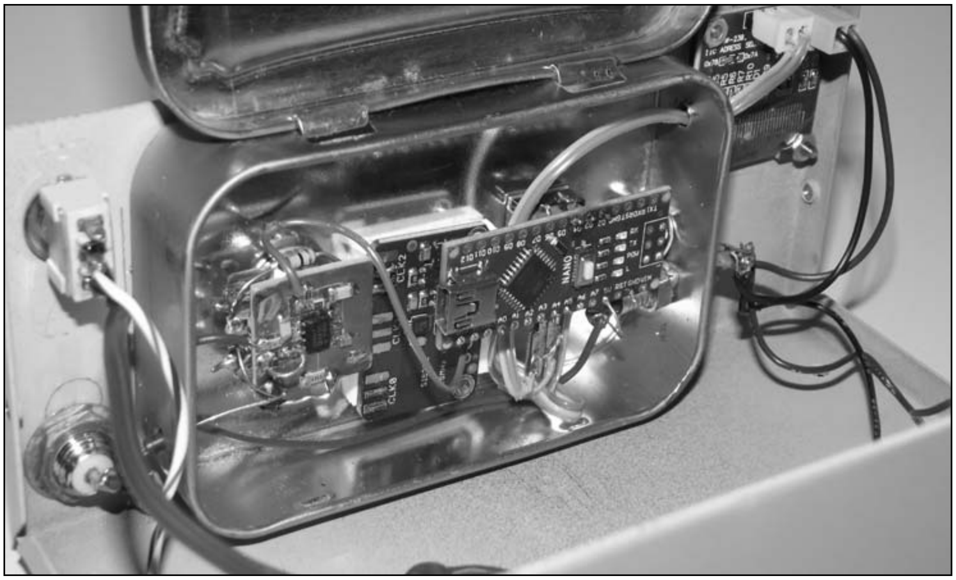


Figure 4—DDS, controller, encoder and attenuator all fit into the Altoids box.

http://www.nd6t.com/test/Software/EZGen3.ino Tuning is handled by interrupts so is effective immediately whenever the frequency knob is turned. Otherwise the only things for the Nano to do is just read the level and feed the display. Level reading is done by averaging a thousand measurements at a time. Doing that calms the display to a comfortable rate and makes it as accurate as possible.

To tune the frequency, press the knob and turn to move the underline cursor to the position to change and then release it. Turn the knob either way to change the frequency by that increment. For example: Moving the cursor to the one kilohertz position allows you to change frequency in 1 kHz steps. Moving it to the MHz position tunes in 1 MHz steps.

The level control knob is a single 270 degree control and a simple twist of the knob changes the output level quickly. A big knob makes precise level adjustment easier. I've had no issue getting the exact level set immediately.

At the time that I built it, January 2020, the total cost was under $10 USD. That didn't include the stuff that came from my junk pile like the wall wart, cord, knobs, and such. The electronics costs have probably doubled in the last 4 years, too. So call it about $25 now? Still, I learned a lot and I have been enjoying the generator more than I had imagined. Great for checking and tuning up my various receivers. Fast, too! ●●

FDIM 2024!

Four Days in May will once again be held in conjunction with the Dayton area (Xenia, OH) Hamvention©**.** The location is the Holiday Inn, Fairborn OH. Dates are May 16 through 19, with registration open the evening of May 15. Seminars are held on Thursday, May 16. Thursday evening is Vendor Night, with Homebrew and special contests featured on Friday night.

The Grand Banquet is Saturday evening, May 18. As in the past, there will be many door prizes at the banquet.

Please note that transportation to the Hamvention is not provided at the Holiday Inn. Parking and buses are available reasonably nearby—just a short drive.

Make your plans now! Registration will be available sometime in January, so check the club website for updates: www.qrparci.org/fdim

FDIM Speakers Have Been Announced

FDIM seminars will be held on Thursday May 16, 2024. Speakers presently scheduled include:

Jack Purdum	W8TEE
Ashhar Farhan	VU2ESE
Cliff Batson	N4CCB
Hans Summers	GØUPL
Wayne Burdick	N6KR
Tom Witherspoon	K4SWL
Gregg Latta	AA8V
Ross Ballantyne	ZS1UN

2nd Place FDIM Design Challenge

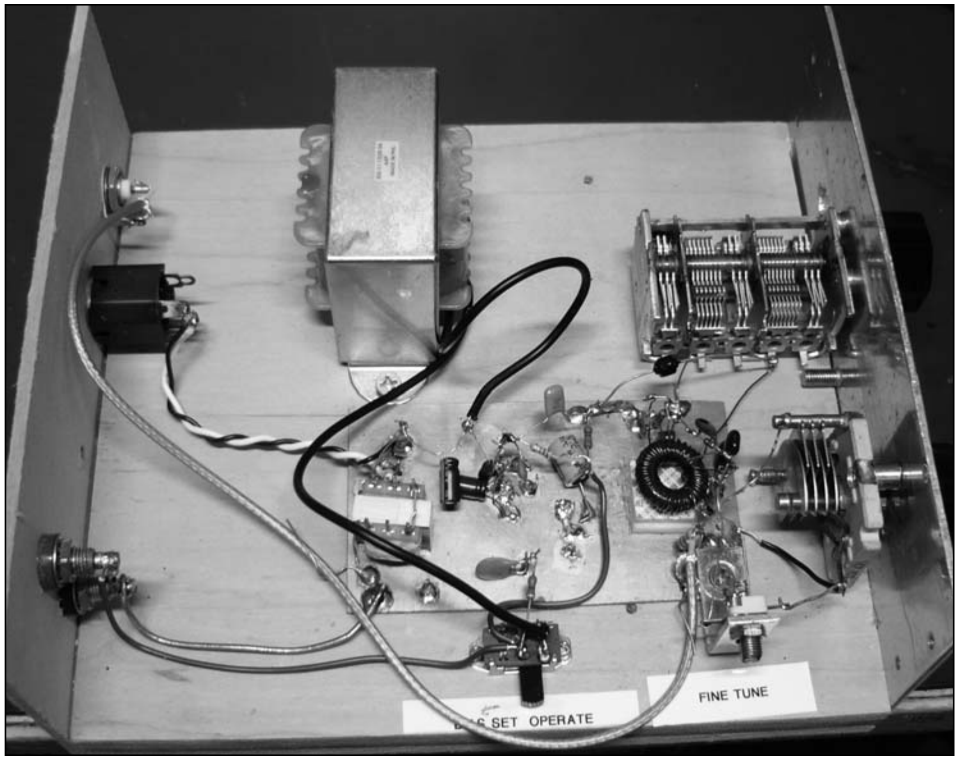
Harold Smith—KE6TI
ke6ti.homebrew@gmail.com

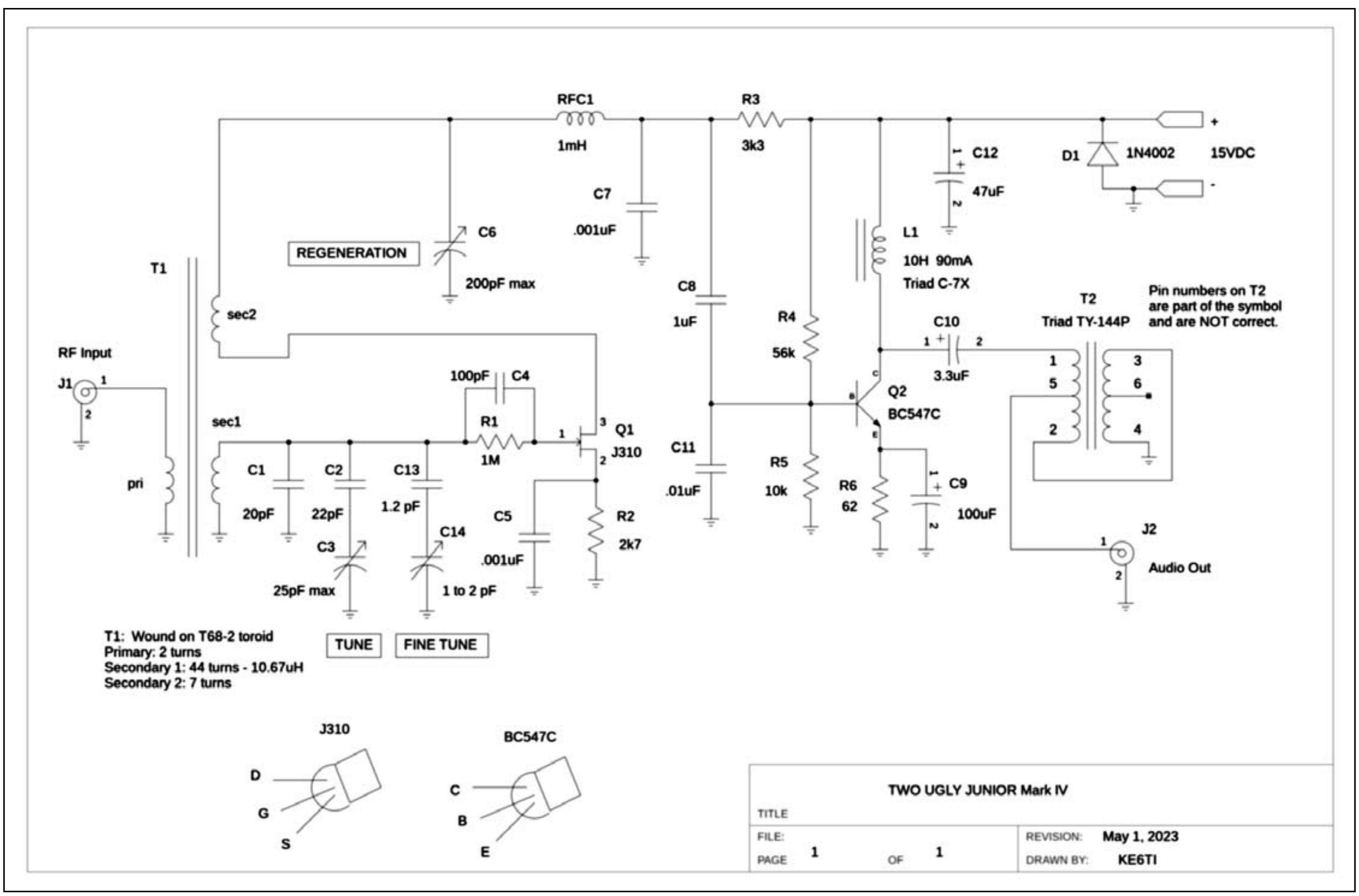
Second Place Receiver in the 2023 FDIM Design Challenge...

OK, this is not an article, just a picture and the schematic of the second place receiver I entered in the last FDIM (2023) Design Challenge. A couple of folks have asked to see this, and I thought *QQ* readers might also be interested.

The only additional info I can add is that the BC547C was selected from those I had on hand for the highest Beta, approximately 550; and the slide switch at the bottom of the photo is not part of this version of the receiver—it is left over from an earlier version. (There were about six versions in all...)

—de KE6TI, Harold Smith





A No-Trap Multi-Band Vertical for 60-10 Meters

Denton Bramwell—W7DB denton@dmbramwell.com

The Point of the Exercise

I live in a suburb, with multiple trees and not much room for antennas. The problem I set out to solve was the creation of an effective antenna that favors DX, that fits in a small area, and that is affordable. Along the way, the idea was to have some fun and to learn something new. And that is how it turned out.

The First Attempt, EZNEC

I started out with quarter wave vertical elements for 40, 30, 20 and 17 meters, joined at the base working against six 16-1/2 foot radials, with the base of the antenna 18 feet above ground. You don't see that design in many antenna books. There is a reason for that, which I will explain in the Summary.

Using EZNEC, I found a design that adjusted the lengths of the vertical elements to work with each other and with six 16.5 foot radials with the feed point 18 feet above ground. Why six radials? It's what I started with, and by the time I questioned whether 4 would be enough, the antenna was ready to put up.

Figure 1—With a quarter scale model, even the top of the 40 meter element is accessible from an eight foot stepladder, provided one or two sections of the mast are collapsed.

I built the antenna on a Spiderbeam 18 meter telescoping pole, using 12 gauge insulated wire taped to the pole with outdoor grade duct tape. A little knot in the end of each wire prevents it from slipping out from under the tape. The feedline is equipped with coax choke baluns at both ends, to prevent it from trying to be a radial.

Blaine, KC7ZQS, Rick, KK7ASA, and Roger showed up to help me erect the mast. That done, I eagerly headed for the ham shack to check the results. Each band showed some very acceptable SWR points, but well outside the bands. The one exception was 17 meters, which was off, but within the range of my transceiver's built-in tuner. The details are in Table 1.

Somewhere along the way, I offended the basic assumptions of EZNEC. But at least I had 17 meters, which was a step forward.

Another Approach to Modeling

Hauling the mast up and down for a few rounds of cut and try is fairly laborious. My long-suffering friends volunteered to help me take it down for adjustments, but asking them to do that three or four times is really a bit much. So, what to do?

Antennas scale linearly with frequency with one exception that is not important in simple wire antennas. With the advent of antenna analyzers and VNAs, it's easier to scale the antenna, make adjustments on the model, then scale the results to the working frequency. I opted to scale 4 × frequency, or 1/4 size.

The vertical elements interact; the length of the radials influences both the resonant length of the vertical elements and the feed point resistance at resonance. I count 13 frequencies where the antenna is resonant, i.e., has zero reactance. I had unwittingly wandered into a swamp of interactions and multiple resonances, and quickly began to understand why multi-band verticals of this type were seldom attempted before VNAs were available. Also, some simplifications were in order.

I opted for an automatic tuner at the feed point, and eliminated the 14.1 MHz vertical element. Of course, with a tuner it's possible to have just one vertical element, but that encourages unwanted high angle lobes on the higher bands, plus having multiple elements reduces the impedance excursions. With the vertical elements shown, the maximum resistive component of impedance within the 5-29 MHz range is 430 ohms, and the maximum reactive component is 196 ohms.

SWR is such that I can transmit directly on the 40 and 17 meter FT8 frequencies. Reactance is zero at 9.56 MHz, but the resistance (at the end of the feedline) is ~12 ohms, giving a high SWR. I suspect that the element is about the right length, but having a single set of 16.5 foot radials produces the odd feed point resistance. In any case, the tuner covers a multitude of sins, and expands coverage to all of 60-10 meters.

Summary

Table 1 shows the design process, from the first EZNEC model, to the 1/4-scale model, then a revised length estimate..

The antenna has provided contacts with Asia, Australia and eastern Canada with my FT-817. At 100 watts, Africa, Europe, Asia, South America, Antarctica, Australia and Oceania have all provided contacts with very good signal reports, including two 40 meter contacts with Africa. The antenna performs quite well with DX, and well enough with local stations. Of course, vertical antennas tend to have about 3 dB more noise than their horizontal cousins, but that hasn't seemed to be a problem.

Besides the Fun, Did We Learn Something?

Yes we did:

1. If your feed point is well elevated, you do not need quarter wave radials for each band. 1/8 wave at the lowest frequency, to 1/2 wave at the highest can be efficient and effective. However...
2. Resonance may occur with an element length different from the one predicted by the usual formula, and
3. At resonance, your feedpoint resistance may be quite different from 50 ohms, or from the 36 ohms you'd expect with a conventional vertical antenna. ●●

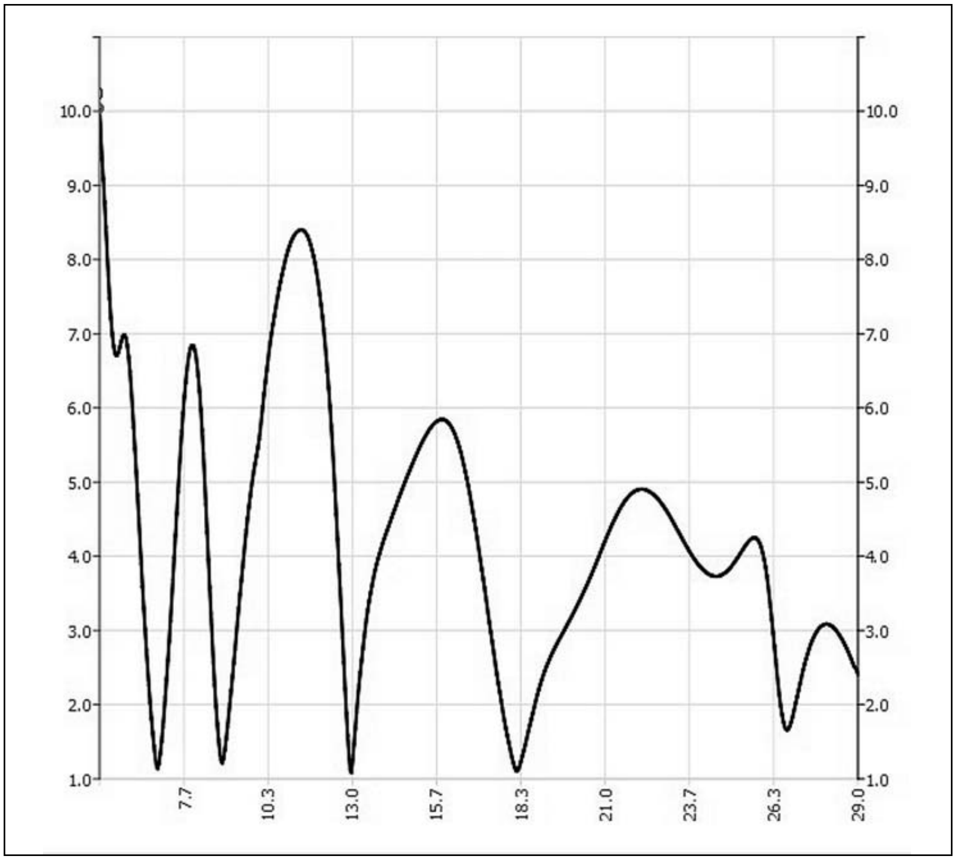


Figure 2—SWR sweep of the antenna, via about 50 feet of cable, from 5 to 29 MHz.

		EZNEC First Antenna		From 1/4 Scale Model		Revised Estimate
Design Frequency, MHz	Feet per Formula, 234/f	Length, Ft	Actual Resonance, MHz	Length, Ft	Actual Resonance, MHz	Length, Ft.
7.1	33.0	38.1	6.47	35.36	6.9	34.40
10.125	23.1	25.3	8.57	22.68	9.56?	?
14.1	16.6	17.65	11.91	X	X	X
18.1	12.9	14.05	17.38	13.42	18.45	13.67

Table 1—These are the element lengths and resonant frequencies for the antennas designed with EZNEC and derived from the 1/4 scale model. The Revised Estimate column shows the approximate length needed to bring resonance to the design frequency.

Start planning now for FDIM 2024! (May 16-19, 2024)

Antennas 101: A Collection of Ideas

Gary Breed—K9AY k9ay@k9ay.com

Here are a number of hints, kinks and observations regarding the design and construction of antennas. Some are from my own experience, others are ideas from friends. And a couple “Gee, that might be interesting!” items, as well. Here we go...

MATERIALS

QRPers are homebrewers — we build things! And much of the fun in building things is finding bargains and acquiring interesting “stuff” for our projects. Then we use these things to make antennas that do what we want—good performance at home, convenience for portable operation, multi-band coverage, or stealth.

Shopping at Surplus Outlets

I have searched for antenna-related naterials at surplus yards since about 1970. My first significant discovery was some 12-foot lengths of aluminum tubing, a few each 1-3/4” and 1-1/8” I never knew the alloy and temper, but they were reasonably strong and stiff. The larger tubing was used as a 40M vertical, and later as a mast reaching 36’ above my back porch roof to hold various wire antennas.

One use of the smaller tubing was a 15M ground plane attached to the chimney, with wire radials running down the roof valleys. Although it was 50 years ago (!), I remember it well because it was a terrific DX antenna.

My latest interesting surplus acquisition was some structural fiberglass tubing in 8 ft and 10 ft lengths, with 4”×5” rectangular cross section and about 3/8” wall. One is serving as my mailbox post. Others became piers supporting a new deck. Figure 1 shows a post securely installed with the top 7 ft above ground. This post has supported a multiband vertical and a loop receiving antenna. Next will be a 40 meter ground plane for the upcoming ARRL DX Contest (CW). Sure, I could use a 4x4, but these were a bargain, won’t warp or rot, and are VERY strong.

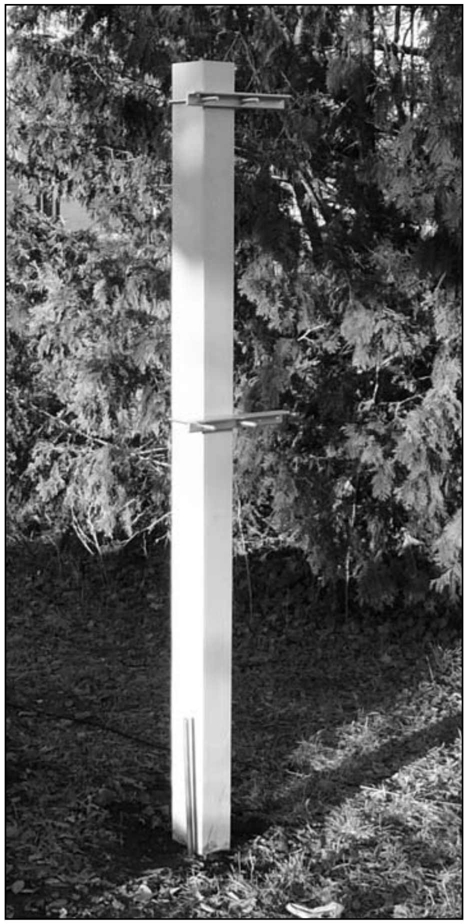


Figure 1—A surplus find: 4×5 inch structural fiberglass post, ready to support whatever new antenna I have under consdtruction.

Hardware Stores and Home Centers

Any antenna builder needs tools, nuts & bolts, hose clamps, PVC or ABS plastic pipe and fittings, and other hardware items. You also may need concrete mix, silicone adhesive, electrical supplies, and so on. In particular, I like to know which stores have the best supply of stainless steel hardware.

Neighborhood hardware stores tend to have higher prices, so I mostly shop at big box home centers and those big “farm stores”. One word of advice is to check out more than one store. I have found that different stores have different brands, product selection and prices.

Don’t forget sporting goods stores, too. Or the sports department in a big box store. A long time ago, I found my first telescoping fiberglass pole (16 ft) in a fishing shop in northern Wisconsin lake country, and a heavier 20 ft pole a bit later at a well-known outdoor sports mega-store.

These same stores have provided galvanized fittings (boat and dock hardware), as well as a good quality slingshot that easily launches a fishing line attached to a 1/2” bolt over the 50+ foot top limb of the only big tree in my yard.

Online Shopping

There are quite a few online sellers of ham radio equipment, including antennas, hardware and accessories. MFJ, DX Engineering, Ham Radio Outlet, and few others are among the largest, but with some searching and feedback on the ham reflectors, you can easily find a pretty long list of dealers who may have what you need. Local swap lists are not so productive, but occasionally have interesting items for your experiments. I once found a brand new bundle of 6063-T832 aluminum angle on Craigslist.

I won’t even try to make a list of online sources — there are many, and I’m not really up-to-date!

ANTENNA DESIGN

I am always working on antenna projects! Some of them actually get built...

Since moving into a new QTH in 2021, I have been operating with antennas that are built and installed a lot like Field Day—as noted above in my comment about the slingshot.

I am now planning for a real “antenna farm” that will let me walk into the shack and operate without needing to hoist wires into trees. Here some notes on matters that have arisen along the way:

1) Like they say in real estate—location, location, location. After 25 years with hilltop acreage, my new place is in the middle of a village, with significant terrain limitations in some directions. It is only 1/3 acre, but I get some benefit from adjacent railroad right-of-way and two walking trails. Mostly, this means fewer close neighbors and a low level of man-made noise (most of the time...).

OK, the QTH is adequate, but not ideal for ham radio—but there are those walking trails, and a nearby Class A trout stream!

2) Height is important! It largely controls the takeoff angle, but you also need

enough height to get an antenna above nearby clutter. This can be difficult in town, so use what you can—a tall tree, slender neighbor-friendly masts, and when possible, a tower compliant with local ordinances. I'm planning on a tilt-over, crankup tower of modest height.

3) With any limitations, you end up needing priorities. What bands are most important? Are you operating all QRP, or a range of power levels? Do you want enough performance to enjoy contest operating or DXing?

My favorite bands are 40M and 160M. I have enough room for an elevated ground plane on 40M. It won't be a beam like I've had at past QTHs, but I already know it will do OK. In the 2023 ARRL DX Contest, I used a wire vertical with the top at 50' in my tree. It worked well.

160M is a challenge, but my buffer zone of open space makes it possible on a small lot. An inverted-L is an efficient transmit antenna on 160 (and also 80), as long as there is a good radial system. I borrow a bit of the adjacent land to extend some of my radials. It all works well enough to enjoy this unique band.

Low band receive antennas can be a challenge, mostly to keep them from coupling to the TX antenna and the radial field—far enough away, or disconnected with a relay when transmitting. This winter I've been pleased with the simple RX antenna shown in Figures 2, 3 and 4. Located about 20 feet beyond the end of TX antenna radials, it works as expected.

4) The high bands tend to be less of a problem. A multiband vertical can work well, especially if it is elevated enough to reduce the effects of ground clutter and interaction with nearby structures.

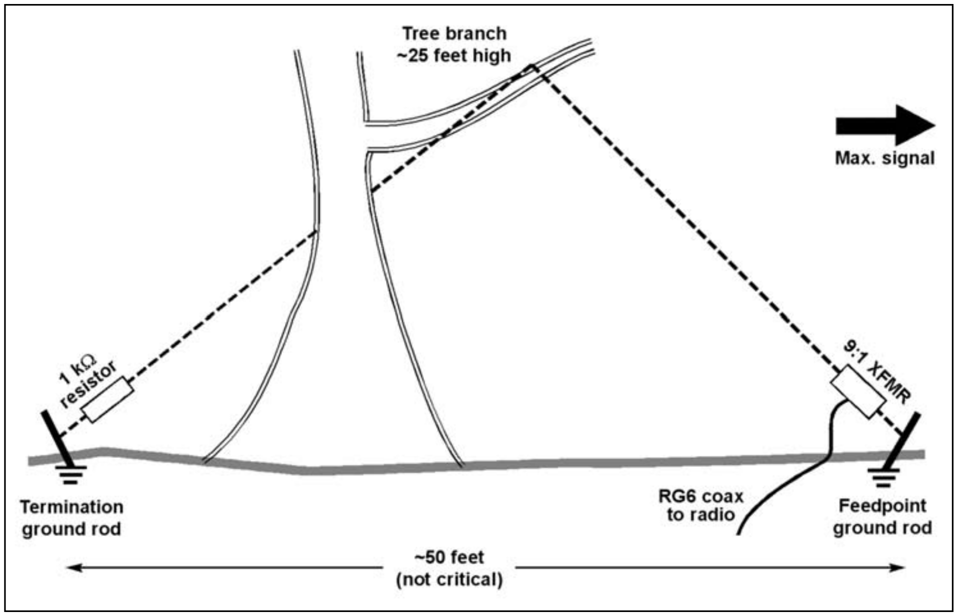


Figure 2—This may be the simplest receive antenna I have ever built. It's a modified "EWE" with an inverted-vee shape instead of the original rectangle shape of a wire strung between two posts or masts. Also see Figs. 3 and 4. *[Ref: F. Koontz, WA2WVL, "Is This EWE for You?," QST, Feb. 1995.]*

The height (in wavelength) is realistic for a useful takeoff angle. Ideally, horizontal antennas should be at least a half wave high. For 20M that's 35 feet, which is practical for most hams. Just remember: higher is better! Often a lot better.

Also, for the next couple years, an active sun will help your signal carry a long distance. Enjoy it while you can!

5) Finally, use the resources available to you for planning and building antennas. Books, magazine articles and online info are plentiful. Although knowledge keeps growing, don't toss the old books and magazines! I have a number of reference books from the 1920s through 1950s that contain theory, design, and measurement data that is no longer included in modern texts. This vintage info can provide the germ of an idea for something new!

To Wrap Up...

I had originally planned a more academic article, but quickly realized that "storytelling" was the path I was taking. Hopefully my rambling commentary has provided some encouragement as you plan your own antenna farm.

So get creative, learn as much as you can, then plan and build the antennas that work at *your* QTH! ●●

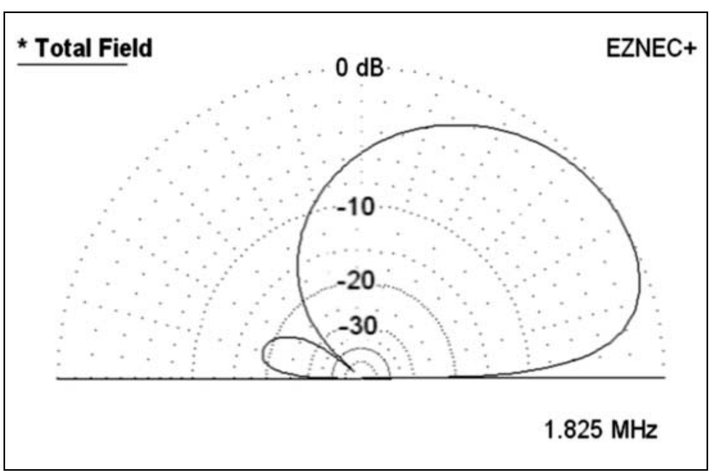


Figure 3—The pattern plot of the simple EWE of Figure 2. The rear null was verified by listening to AM radio stations.

Figure 4—Photo of the feedpoint. At the other end, there is a 1000 Ω terminating resistor between the wire and ground.

Evolution in Radio Design: Building the Next ...

Hans Summers—GØUPL/AF7BF

Here is an edited version of GØUPL's presentation at FDIM 2023. The talk included a substantial review of the history of QRP Labs, as background leading up to the development of the QMX. We have included the entire QMX description, but first, here is brief overview of the historical notes: —editor.

Introduction

I studied physics at university. I'm not an RF engineer, not an electronic engineer, not any kind of an engineer. Yet here I am, somehow ended up earning a living designing QRP Labs radio kits for QRPers. I've been thinking about all this lately. So in this seminar, I'm going to talk briefly about the QRP Labs story, from simple beginnings to significant complexity, one step at a time. Then some details about designing the next product in the QRP Labs lineup, with the simple aim: to create one of the greatest QRP transceivers in amateur radio history.

QRP Labs kits

Back in May 2010, I presented a Dayton FDIM seminar for the first time, on the topic of QRSS (weak signal) modes. I excluded WSPR which was at that time still quite a new mode and was outside my personal experience.

The previous summer (July 2009) I had been on a two week vacation to Grenada, Caribbean. My wife and I aren't particularly quick at packing and it wasn't until 3 am that we were finally finished, only two hours remained for sleeping before we had to get up and leave for the flight from London's Heathrow airport. Two hours? At that point—I just thought well, why bother to sleep at all, I'll build a QRSS beacon transmitter to take with me! I already had a 30m LPF from a former project, and some code on an ATtiny13 8-pin microcontroller to produce the letters "UPL" over and over in slow Morse. Two hours was enough to build a crystal oscillator, a 100 mW amplifier, assemble it all in a tiny mint tin, test and adjust it, and have it ready with some antenna wire and a cellphone charger, in an ice cream box stuffed into the suitcase.

The screenshot (right) is a reception report by MØPUB on the opposite side of

the Atlantic, showing the "PL" part of the "UPL" transmission. Weak Signal "ARGO" software (spectrum analysis) is used on a PC to display the transmission which can then be decoded visually. I used a 10.140 MHz crystal oscillator with a 5mm red LED used as a varactor diode to apply a small shift of a few Hz (typically 5 Hz) to the transmission on the Morse key-downs.

When I was invited to speak at Dayton FDIM 2010, my good friend Steve GØXAR and I had the idea that we could between us produce a QRSS kit to accompany the event. It was a great success and we decided to keep producing them after the event.

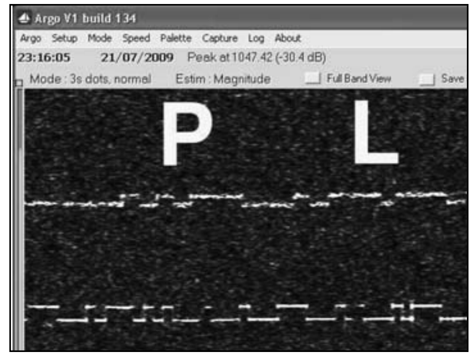
So begins a story of continuous evolution. Every QRP Labs kit was built on the lessons and elements of its predecessor(s). As my knowledge and experience grew, the complexity and quality of the kits grew with it, along with the worldwide popularity of these kits.

A Progression of Kit Developments

The first QRSS kit was followed by the :Ultimate2: QRSS/WSPR kit, then the Ultimate3 less than a year later. These first kits were the starting point for learning how to design—plug-in boards, writing code, selecting the right components and modules, pcb layout, finding reliable suppliers... then getting the kits ready for market!

The first few kits were sold at FDIM 2010, and the improved and enhanced versions were developed over the next few years. In 2016, Hans left his "regular job" to pursue QRP Labs full-time, and quickly added some frequency control and PA modules to the catalog.

The first transceiver was the QCX,



which has proved to be very popular. The QCX+ addressed mechanical and packaging issues, and the QCX-mini is a smaller rig for portable operation.

The next effort, QSX, was a challenge that was never quite solved. However, some of its new circuits have been used in other products, such as the U4B balloon tracker, the later QCX versions, and the QDX digital transceiver.

The 5-band QDX XCVR for digital modes is popular. It's two-year development time paid off in a quality SDR multi-band digi-mode rig.

As mentioned earlier, the all-mode, all-band QSX has not yet seen the light of day, to the disappointment of many. But at the same time, many elements of QSX have been developed and proven. Several smart observers have commented on this. Each of these brings closer the final day when QSX is ready at last.

Evolution, not big bang!

I hope you can see the way the QRP Labs kit range evolved over the years since the humble beginnings in May 2010. How each kit uses concepts, ideas, circuit blocks, mechanical designs, and firmware code modules developed for the earlier kits.

QSX was a too ambitious, too large step. I now realize that evolving gradually step by step, and keeping my big mouth shut, would have been a much better, less stressful, more efficient strategy. The famous QCX monoband analog CW transceiver didn't come about, big bang style, in 2010. It came at the end of a string of predecessor kits, building on their successes.

...so what's next???

Building the next: QMX

Now we come to the design of what might become, perhaps, the final step on the way to the QSX. And along the way, perhaps become one of the greatest portable QRP rigs yet seen.

QMX. The M is for Marriage. Magnificent. Merger. Marvelous, many things like that. It's what you get when you marry the mechanical and conceptual design of QCX-mini, with the SDR, multi-band digital implementation of QDX. Simply: QDX + QCX-mini = QMX.

This part of the story details some of the decisions in the development of QMX.

Why QMX?

Because it provides another stepping stone on the way to QSX. It seems a logical progression. And because there's a need for a high performance, inexpensive, small. portable multi-band, multi-mode transceiver. Many people have things like an Elecraft KX3, Yaesu FT817 etc. But if you take this with you into the wild, if it gets stolen, broken, damaged somehow, that's quite a hole in your pocket. Some people prefer something less expensive for their portable operations. The popular LNR Precision mountain toppers are one option but $370 is hardly all that inexpensive, and it's limited to CW only. Performance isn't stellar, band switching is clumsy and the design is a bit cheesy in my opinion. The uSDX series fit the "inexpensive" requirement but you suffer a not inconsiderable performance penalty, in addition to the 3D printed plastic enclosure which doesn't shout "quality" at you. Neither have big-easy-to-read-outdoors displays either.

(Photos below from the respective websites).

Lots of people have asked me for a multi-band QCX CW transceiver. But it's inherently difficult to change this mono-band design into a multi-band transceiver. The Class-E output stage isn't easily mutli-band-able as it is a tuned resonant load circuit by definition. There certainly isn't space in a QCX-mini for band switching. The firmware of the ATmega328 chip already fills up the 32K Flash memory space of the processor chip entirely. Switching to a higher AVR chip is possible but this would mean a SMD package, which makes plugging in a firmware chip to upgrade the firmware impossible; so it means a lot of new development for a bootloader to allow firmware updates. There are a host of issues with trying to multi-band a QCX—the Low Pass Filters, Band Pass Filters, and Class-E resonant load circuits are all band-dependent and in need of switching.

Lots of other people asked if QDX (5-band Digi modes transceiver) can do CW, or could be made to do CW. The reason QDX can't do CW is that a design choice (for simplicity and low cost) was to not include any RF envelope shaping. That is (reasonably) fine for digi modes where you have an FSK signal and the only sharp on/off RF carrier transition is at the beginning and end of the transmission where it is relatively harmless. But if If you transmit CW—which is inherently an on/off keyed mode—without envelope shaping, you generate wideband clicks that will annoy people on nearby frequencies, even if you are only using 5 watts QRP. So you need envelope shaping for CW. It could be implemented in QDX without too much trouble. But you'd still need to type your CW message on a PC and have the PC send it to QDX as audio. The majority of CW operators will want the full CW experience, keying properly on a straight key or paddle. So why not do it properly? Hence QMX.

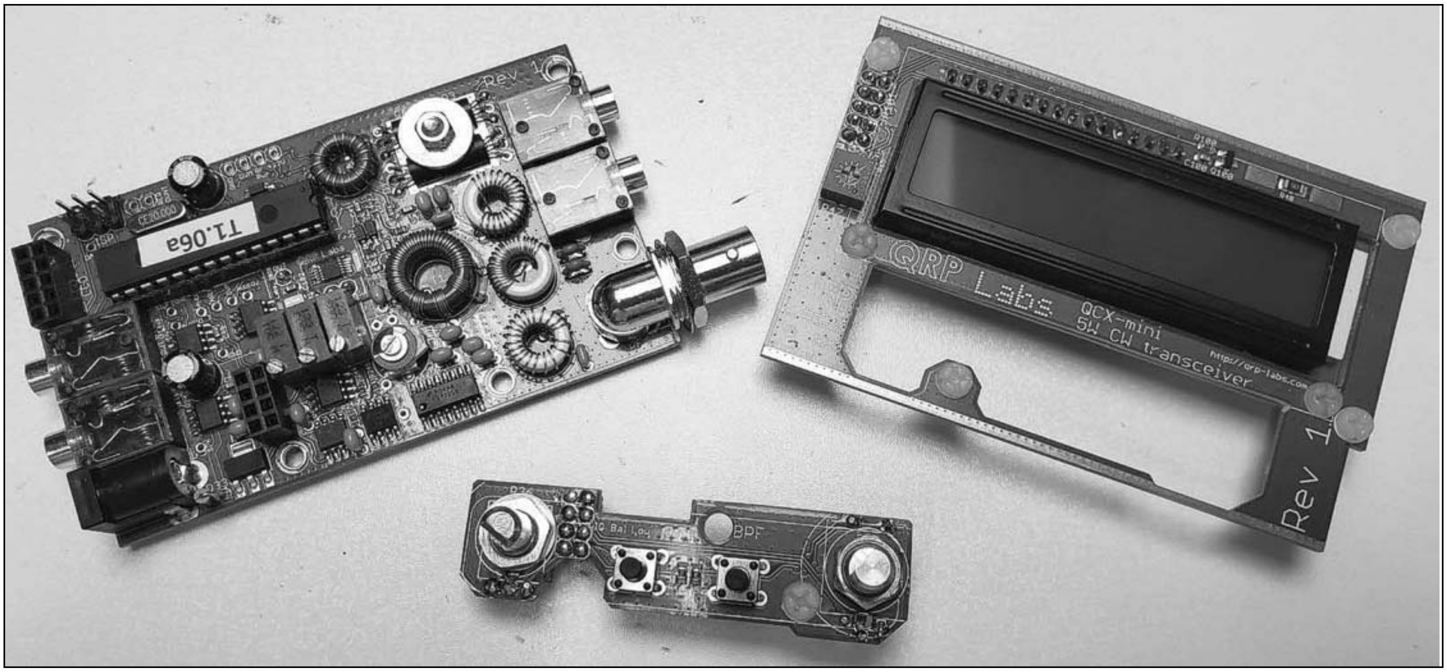
Features

I'd like to incorporate all the standalone user interface features of QCX-mini (no host computer necessary), with all the embedded SDR, DSP filtering and digital features of QDX, available to an optional host computer if required. I'd also like to include several stretch goals, including the potential of SSB (more on that later). Some of the stretch goals are so so stretchy I won't even dare mention them right now.

Low receive current is a parameter many people have their eye on for portable operation. DSP means a powerful CPU and that gobbles power. It's an area where an analog design has an advantage. Because of this I'd like to include switched mode DC-DC converters for the internal power supply rails for 3.3V and 5V supplies, so as to make the power supplies as efficient as possible. Yet these switching converters mustn't create RF noise that interferes with the performance of the receiver.

A new feature I want to include, is inline SWR metering. It's another oft-received request, particularly for portable operations where the QMX will often be used, and antennas are likely to be more variable than at a fixed home location. A criticism of QDX and QCX-mini could be the vulnerability and lack of protection against bad SWR situations. So let's try and address that here from the outset, by including SWR measurement and metering, even protection features in the firmware.

I'd like to take several more steps



toward QSX too, as mentioned earlier, and this will influence the design process, particularly on the software side of the design.

Mechanical design

The QCX-mini is a quite nice mechanical design which I'm rather proud of. The enclosure is extruded aluminium, 3.7" wide by 2.5" deep and 1.0" high (plus control knobs). Inside is a display board which slides into the rails in the walls of the enclosure extrusion; the main board plugs onto that from behind and is slightly smaller so doesn't use the enclosure rails. There is a small plug-in board holding the gain control and buttons, that breaks out of the LCD cut-out of the display board. It all fits together and is bolted using some nylon spacers and nylon screws. The aluminium end plates (left and right) are screwed in their corners, to holes in the aluminium extrusions. No other mounting screws are required, to hold the QCX-mini boards to their enclosure. The 16 x 2 yellow/green LCD is dated (OK very dated, HD44780 displays go back to the mid 80s) but still ideal for a portable rig for many reasons: sunlight readable, big, easy to read characters, low cost, and low current consumption (under 1 mA when the backlight is off). This picture above shows the QCX-mini boards:

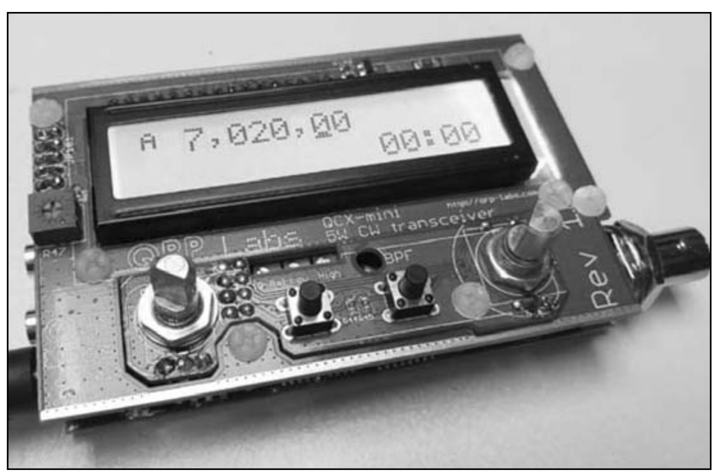
Here's how the boards stack up (right):

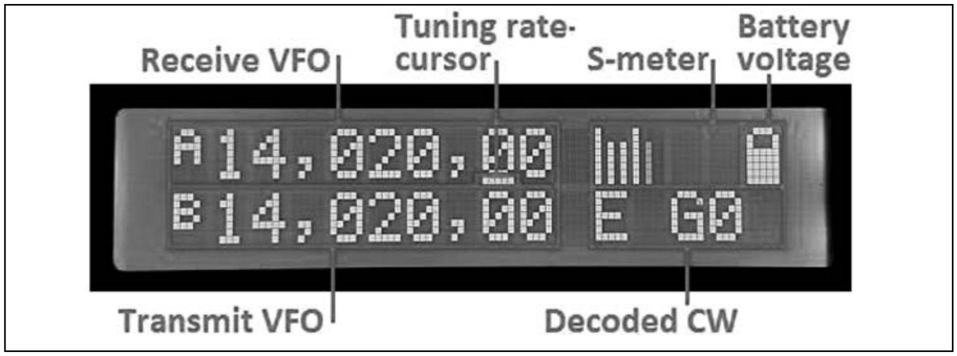
QMX has a lot more components to squeeze inside. But for reasons of pride and challenge, I don't accept making the enclosure larger. So that'll be a significant design challenge. I want to keep the enclosure visually almost identical to QCX-mini.

So QMX has the same connectors on left and right, as the QCX-mini. DC power, audio out, and paddle input on the left. RF (BNC), PTT output, and serial on the right. But the QCX-mini "serial" is a 38,400 baud serial connection on a 3.5mm stereo jack. Whereas for QMX we need a USB connector for the USB 48 ksps stereo 24-bit sound card and the Virtual COM Serial ports.

Which USB connector? Well USB-micro? I'm sorry, yuck. It's flimsy in my experience. Who had an Android phone in the USB-micro days, and after a while the cable connection got intermittent? Or worse, the problem was on the phone side, much harder to deal with than a new cable. I used USB-micro on the first batch of U4B trackers and there were connection problems; I have to use it on the ProgRock2 module which is tiny by design, but at least the USB connection is likely temporary. But I'd prefer NOT to use it here in a design which is to be used portable and needs to be robust. USB-mini was nice, but never as common. USB-B (full size USB) as often used on printers, is robust, hardly ever fails, and is what I love to use in QDX. But it's big, it's TOO big, it won't fit on the QMX PCB in the available height under the LCD module. So we're left with USB-C, the modern popular implementation of USB which can deliver power at lots of different voltages, can be plugged in either way, and is hopefully mechanically more robust than USB-micro was. In QMX we won't use the power delivery funkiness, we'll just stick to plain old USB connections. Furthermore, to reduce the risk of connection problems in the field - and since this is a critical component—we'll choose a high quality USB-C connector from Digikey, having through-hole pin connections rather than SMD.

Other than the change in the host computer connector, to USB-C, and the labeling on the front panel, the rest of QMX will look very similar to the QCX-mini and be difficult to tell apart. QCX-mini is a well-loved, insanely cute transceiver implementation so

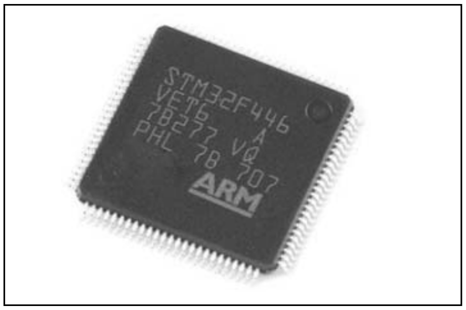




it makes all the sense in the world to re-use the mechanical design here; and a nice challenge to try not to increase its size (such as, make the enclosure wider).

Microcontroller

We will of course, in keeping with the step-by-step evolutionary approach, stick with the STM32 series. QDX has a 64-pin microcontroller. For QMX, we want to



incorporate more features, more I/O is needed, and more peripherals, more Flash and RAM, as I will have a number of things I want to try out on the step by step path to the QSX all-mode all-band 10W HF transceiver. Hence QMX needs a step up in the processor family, to a 100-pin microcontroller, probably the STM32F446VET6. Not entirely coincidentally, you will note that STM32F446 is the same family member used in the QSX so far (YOTA 2018 builds).

User Interface

The QCX two-button and rotary encoder interface is intuitive and we have 6 years of dealing with it; it itself evolved from the earlier menu and control systems used on the Ultimate-series beacon kits described earlier, and the VFO/SigGen kit (rotary encoder handling code). So let's build on the same user interface used in the QCX, which uses the same 16 x 2 LCD. The same menu system can be used, of course with modifications for the enhanced functionality in QMX.

People are familiar with the QCX-series user interface. Many QMX owner operators will be previous QCX-series owner operators. This is another reason for keeping the user interface similar.

A third, more pragmatic reason, is not re-designing a whole new user interface! The whole 2023 theme for me is about re-use, step by step evolution. So that's it—let's keep the user interface as similar as possible to the QCX-series and in particular, the QCX-mini!

The exception is the gain control. QCX, being an analog design, has a potentiometer as the gain control. QMX is a digital design, the internal electronic design of QMX is much closer to QDX than QCX. So why make an analog audio output stage with an analog potentiometer like the old days? Furthermore, people may not know: the analog potentiometers used in QCX-mini and in QCX+, are custom-components custom-manufactured for QRP Labs. It's always cheaper, faster, and less vulnerable to supply chain issues, when you can source off-the-shelf standard components rather than use specially manufactured custom ones.

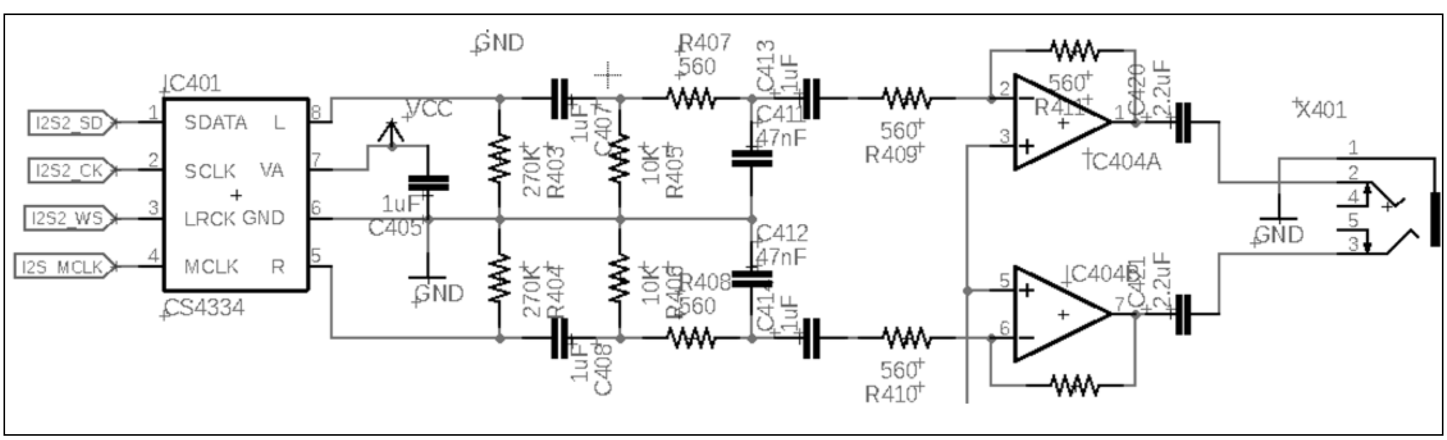
So for QMX the audio output is a 24-bit stereo DAC, this gives sufficient dynamic range to implement the audio output level control entirely digitally (also just like in QSX—spot a pattern here?). A rotary encoder can therefore be used, just as in the right hand knob of QCX-mini. This additionally gives us one more button for free, which we can use for things such as, ah, I don't know, well, changing the mode, band, and a soft power switch!

The audio output uses the same I2S 24-bit DAC chip, CS4334, as the QSX design. There are no accidents. The left and right channels separately drive two halves on an op-amp that drives the earphones. Keeping the channels separate will in future, allow things like gain adjustment to balance left and right channels for people with hearing defects, or in future, binaural reception. See the circuit diagram below.

Transceiver Design

The design of the actual transceiver closely mirrors the QDX 5-band Digi modes transceiver with a few additions. What we are basically doing is taking a QDX, adding RF envelope shaping, a user interface and a couple of other new things, and putting it into a QCX-mini enclosure.

The design closely follows the block diagram for QDX shown previously. I don't intend to cover the entire QDX design in great detail, which was the topic of last year's seminar and is documented extensively elsewhere. I'll summarize it



then let's talk about what's new in QMX.

The receiver has a double balanced Quadrature Sampling Detector (QSD, a.k.a. Tayloe detector) converting RF to I and Q baseband signals. These are amplified, sampled at 48 ksps by a 24-bit ADC chip with very high performance, and the rest of the demodulation is done digitally in an embedded SDR on a 32-bit STM32F4 ARM processor, that implements a superhet receiver with 12 kHz Intermediate Frequency. Ahead of the QSD is a simple series resonant tuned circuit as band pass filter, with capacitors and inductor taps selected by a CMOS switch under processor control. The transmit/receive switch can be simple and the Low Pass Filtering is shared between transmitter and receiver sections.

The transmitter uses a push-pull power amplifier with two BS170's on each side. This has the advantage of very low even-order harmonic content, simplifying the LPF design. There are three LPFs, each of which contains two toroidal inductors and four NP0 capacitors. These LPFs are PIN diode switched under control of the processor to select the band.

The synthesized oscillator is our good old friend, the Si5351A; which in the transmit mode outputs 180-degree out of phase signals, and during receive provides quadrature output suitable for driving the QSD directly with no need for the old divide-by-4 circuit. This was a trick I developed in 2017 for the QCX, it reduces parts count and has high performance.

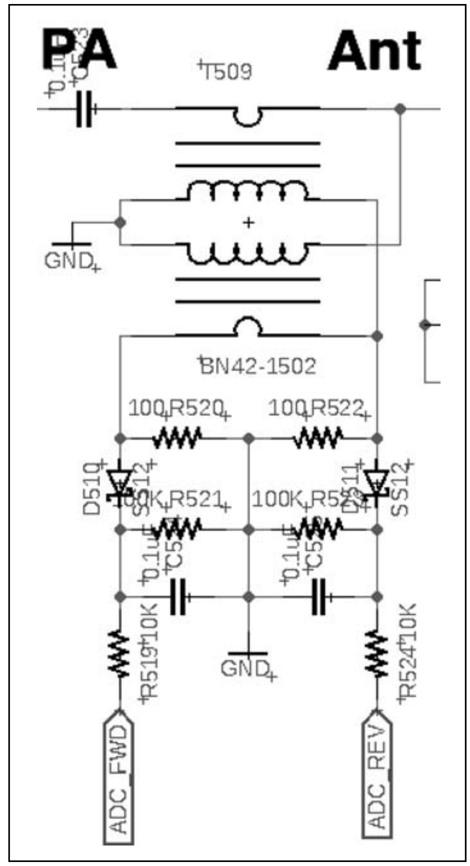
Several key differences between QDX and QMX need discussion in greater detail:

- User interface (LCD, buttons and connectors discussed already)
- SWR measurement
- RF envelope shaping
- Power supplies

SWR Measurement

A very standard SWR bridge is used (right), which samples forward and reverse power. It remains always inline between the PA and Antenna. The output voltages are measured by microcontroller ADC inputs. This circuit or variants of it are seen in many transceivers and standalone power meters.

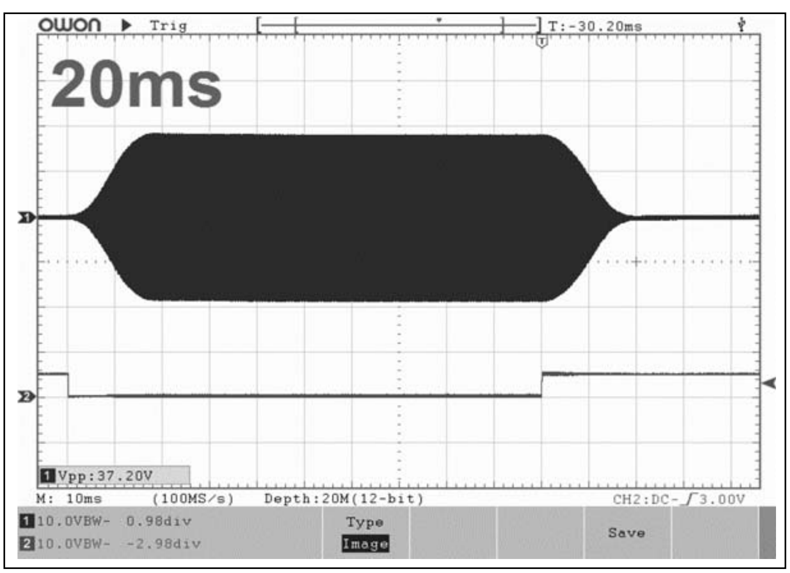
Note that the two transformers are often implemented on ferrite toroids such as FT50-43 toroids. Here we use a more compact method, a binocular core. The two transformers are each wound in the two separate holes. As far as the binocular core is concerned, what happens on one side is electrically invisible from what happens on the other. So the use of a single binocular core instead of two toroids is a parts count reduction benefit and also in our case, crucially, helps reduce the space required, which in QMX is at a premium.

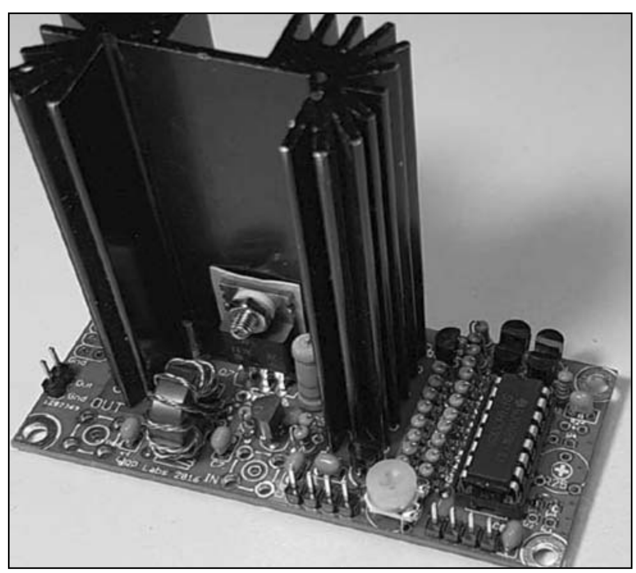


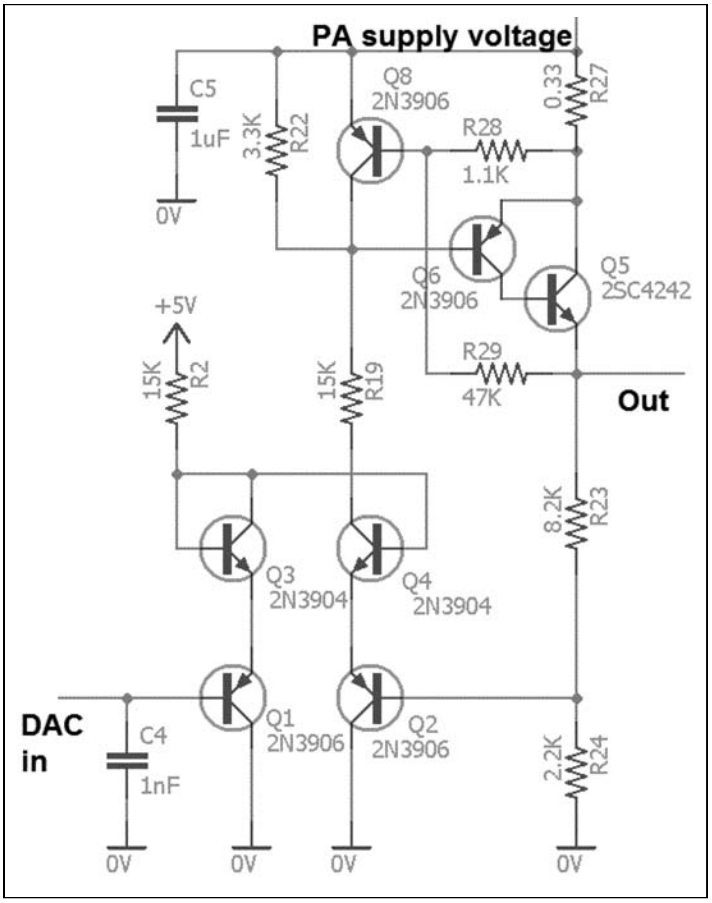
RF Envelope Shaping

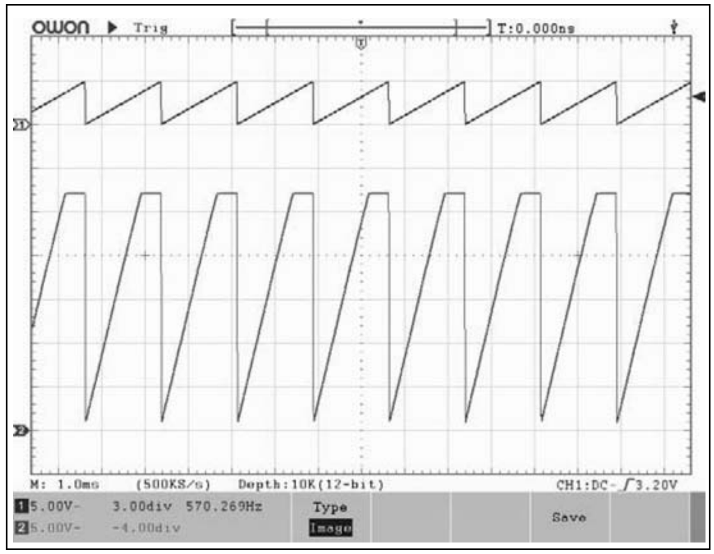
The QCX CW transceiver design uses a simple PNP transistor to provide a kind of trapezoidal approximation leading and trailing edge shaping. It's not an ideal raised cosine shape, but it's close enough to provide very good no-click performance.

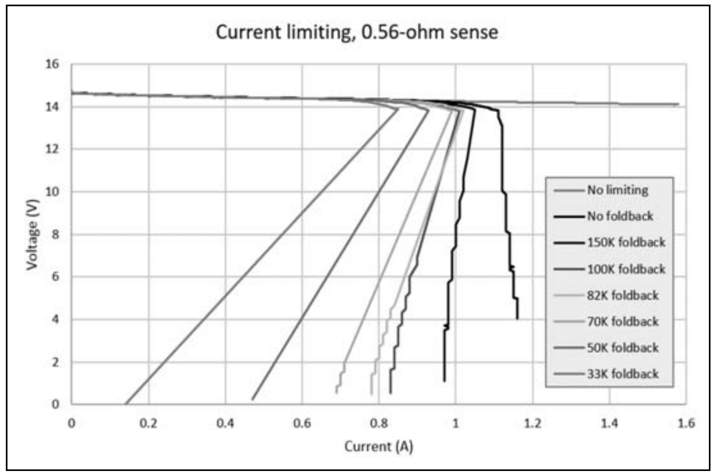
A problem is that the rise and fall times are heavily influenced by variations in component tolerance, particularly the hFE parameter of the PNP transistor, and these can be highly variable even between devices in the same batch. We aim for a 5ms rise and fall time, but the actual variation from one QCX to another is quite considerable. It would also be nice if the rise/fall times could be adjusted depending on the operators' preference, or automatically depending on keying speed, etc. For the SSB stretch goal, it would be excellent to have fine control over the envelope shaping (effectively, amplitude modulation). More on this later.











So for QMX I've gone back to the design developed together with Alan G8LCO for the 5W PA kit designed for the Ultimate3/3S QRSS/WSPR kits. The circuit may be considered as a variable voltage regulator whose output voltage is set by a control voltage which may be provided from a Digital to Analog Converter (DAC) under microcontroller control. In our QMX case now, the chosen STM32 microcontroller has internal fast accurate 12-bit DACs so this is even easier.

You might even consider this as a sort of power operational amplifier! The schematic fragment reproduced above is taken from the 5W PA manual. In QMX the same layout is used but of course the transistors are replaced by appropriate miniature SMD ones. The voltage at the DAC control input will be in the range 0-3.3V, in 4096 little steps (12-bit). The output voltage is simply this control voltage multiplied by the ratio created by the potential divider R23/R24. In testing of the 5W PA this circuit was found to be very linear and fast-operating.

In the next 'scope screenshot the triangular waveform ramp frequency is 570 Hz. The control voltage ramp is shown at the top trace (blue) and the output voltage is the bottom trace (brown). This circuit will hopefully be plenty fast and accurate enough in this application too. The 'scope screenshot also shows what happens if the "gain" (R23/R24 potential divider ratio) is too high - just like any op-amp, the output is limited to the supply rail voltage. So it's necessary to take care, particularly when the supply voltage to the transceiver can itself have a variable range. But the microcontroller in QMX can also measure that supply voltage so will be able to predict what the maximum DAC control voltage can be for any given supply voltage to avoid clipping.

An additional benefit of this shaping circuit is the foldback current limiting feature. In the event of a current threshold being breached, the circuit automatically and immediately shuts down. So if there was a short circuit, or even a too high current condition caused by a bad SWR mismatch, the PA would automatically shut down to avoid the high current condition. This is quite a useful additional feature to avoid PA damage in abusive situations!

Power Supplies

This is a really key problem area. You can insult the poor strong signal intermodulation performance of a cold-war era SA602 superhet receiver design such as used in the Mountain Topper radios (for example) as much as you like. But people will always pop up, and rightly so, to tell you: "ah yes, but it has very low receive current consumption! When I'm on top of a mountain, it's more important to me that the rig doesn't drain my battery quickly, rather than the finer details of its dynamic range!". Yes!

Unfortunately low receive current is the enemy of a high performance embedded SDR receiver architecture. The Si5351A synthesizer by itself consumes 25-30 mA of current. The microcontroller running at 72 MHz (QDX) or more, sucks current quite thirstily too. High performance and low noise is correlated to higher current consumption in operational amplifiers—and we must have four high performance low noise operational amplifiers in the pre-amplifiers to the ADC on the I and Q baseband channels, since this critical point determines the sensitivity and dynamic range of the whole radio. The ADC chip takes quite some current too. To put some ballpark figures on this, QDX consumes around 150 mA on receive. On QMX we add the audio output and LCD module (with disable-able backlight). Current consumption can only go in one direction.

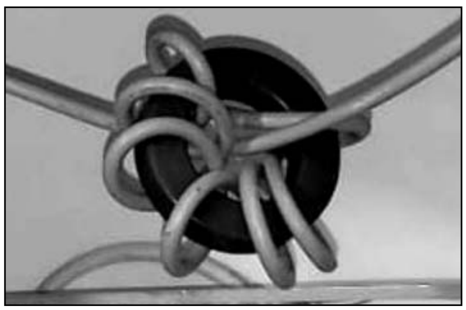
We need both 3.3V and 5V supplies, as well as a transmit-only forward bias current supply for the PIN diodes. If the total current draw on these supplies is somewhere in the range 150-200 mA, then at 12V supply to the radio, the receive current draw will also be the same—IF we are using linear voltage regulators.

It's a whole other story if we are using switched mode voltage regulators (DC to DC converters)! Now we have a much higher conversion efficiency, we don't waste so much energy as heat. If the current consumption on a 3.3V bus for example is 100 mA, then if the converter was 100% efficient, at 12V supply the current consumption would be only 27.5 mA. Quite a significant improvement! In practice we never achieve 100% conversion efficiency of course, but the improvements are still major and worthwhile.

Having decided we need switched mode voltage regulators, the next issue we are faced with is NOISE. Switching regulators have a reputation for being RF noise generators!

Here's an example of switching mode regulator noise (below). This graph was a record of me a couple of years ago, trying various tests to improve my station receiver (QCX) performance in the face of interference from my new PC's switched mode power supply. It turns out to be hard to buy a PC these days that doesn't come in an enclosure with at least one tempered glass wall, and full of all kinds of pointless coloured LED lighting (below right). Faraday would be turning in his grave. You can see on the graph, the huge noise peaks which come and go every couple of minutes as the noise drifts past the operating frequency (horizontal axis is time in seconds).

All the details are a long story in their own right. To summarize, I had to search for an "all-metal" case; which when it arrived, turned out to have a plastic front. My Mother-in-law had recently donated an old cable TV tuner box whose steel lid could be cut to size and inserted inside the plastic front of the new PC. That got me a Faraday cage. Part of the problem was also common mode feedline current on the antenna coax (also another whole topic), the solution to that was 10 turns of RG58 coax around an FT240-43 ferrite. With all



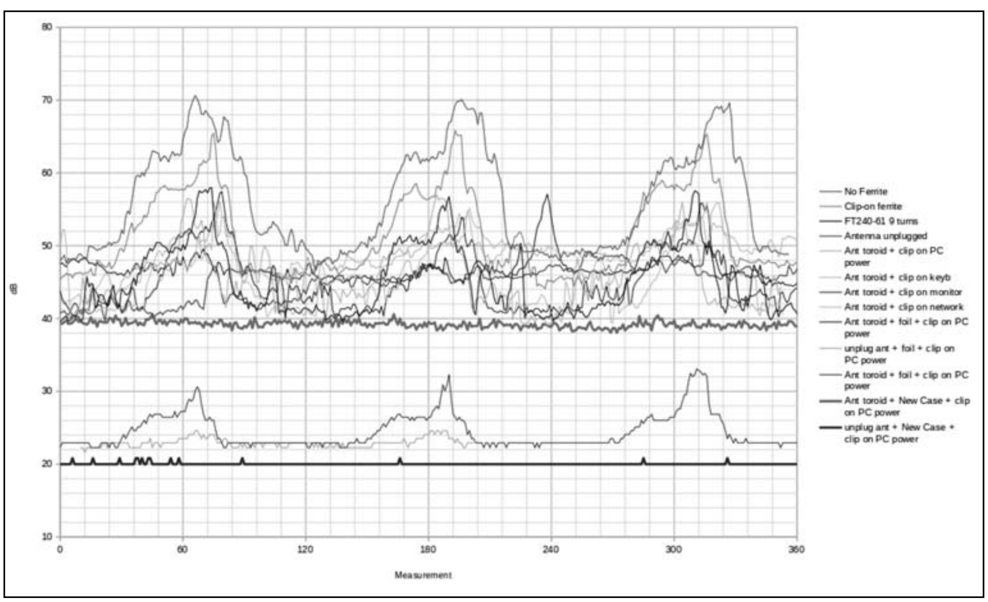
these measures in place, the noise from the PC power supply noise went from 30+ dB over the antenna band noise, to completely undetectable.

The trouble with switched mode power supplies is that the current is in principle switched hard on/off, typically at 50 kHz or more. After this switching comes an inductor and capacitor smoothing circuit whose effect is to average out the spikes to give you your desired output voltage; a control circuit manages the necessary pulse width modulation (PWM) and/or frequency control to regulate the output voltage to the correct target voltage.

The hard switching generates harmonics well up into the RF spectrum. One problem is that of course these supplies are supposed to be as cheap and nasty as possible, who cares about radio frequency interference. They typically use simple resistor-capacitor oscillators which are drifty and have very bad phase noise performance. Therefore you usually get a band of noise which drifts up and down; on HF it sounds like a horrible raspy S9+ noise that is several kHz wide, drifts up and down slowly, and if you tune up and down the band, appears to repeat itself every 50 kHz or so.

My idea with QMX is to design switching converters which solve these problems as follows:

1. Produce the PWM frequency from the microcontroller, so it is crystal referenced (good narrow low phase noise performance)—any interference should be constrained to a narrow band or birdie.
2. Control the frequency at which the switching occurs; the microcontroller knows what frequency the radio is operating on and should be able to predict where the harmonics will land; it



Four Days in May — FDIM 2024!

Fairborn, OH — May 16-19, 2024

Four Days in May will once again be held in conjunction with the Dayton area (Xenia, OH) Hamvention©**.** The location is the Holiday Inn, Fairborn OH. Dates are May 16 through 19, with registration open the evening of May 15. Seminars are held on Thursday, May 16. Thursday evening is Vendor Night, with Homebrew and special contests featured on Friday night.

The Grand Banquet is Saturday evening, May 18. As in the past, there will be many door prizes at the banquet.

Registration will be available sometime in January, so check the club website for updates: www.qrparci.org/fdim

ANNOUNCING — The FDIM 2024 Logic IC Transmitter Power Challenge!

The challenge is simple: Design and demonstrate a crystal-controlled 40M oscillator/PA to make the highest sustained power for a period of one minute using only a single 4000-series or 7400-series logic IC. More detailed information can be found on the club website. This event will take place at 8:00 PM Friday, May 17 during FDIM, and the winner recognized at the QRP ARCI Banquet on Saturday, May 18, 2024.

Four Days In May (FDIM) Speakers

FDIM seminars are on Thursday May 16, 2024. Speakers presently scheduled include:

Jack Purdum	W8TEE
Ashhar Farhan	VU2ESE
Cliff Batson	N4CCB
Hans Summers	GØUPL
Wayne Burdick	N6KR
Tom Witherspoon	K4SWL
Gregg Latta	AA8V
Ross Ballantyne	ZS1UN

Club Night, Show & Tell, and Homebrew Competitions

Friday night is a special time for QRP enthusiasts! All events take place in The Ballroom starting at 8.00 pm. People setting up club tables or Homebrew Competition entries can enter earlier.

This is a social event where QRP clubs and groups set up their own tables to publicize their activities and generally have some fun. Tables are free of charge.

Please note that transportation to the Hamvention is not provided at the Holiday Inn. Parking and buses are available reasonably close—just a short drive.

Visiting FDIM for the first time ?

Here's a guide so you know what to expect

Location

The venue is the Holiday Inn, Fairborn OH. It's a pleasant and safe area to visit. The hotel has plenty of parking available. Facilities include a restaurant, bar, gym and indoor swimming pool. Ground floor rooms are available for disabled guests. Free WiFi is available throughout the hotel. There are plenty of restaurants within easy walking distance.

Wednesday Evening

Registration opens at 7.30 pm (as you enter the hotel, turn right and walk to the end of the corridor).

There are likely to be two lines—one for pre-registered and another for those who need to pay. Please follow directions from the volunteers. If you pre-registered then your badge will be available for collection and should be laid out on a table in order of Last Name. For those that are not pre-registered, you will need to pay for your tickets and wait while badges are prepared.

Thursday Daytime

Registration (for those who did not register on Wednesday evening) is available starting at 7.30am. You will find the Registration Tables right outside the main entrance to The Ballroom.

The seminars start with an opening address at 8.50am. Attendees sit at a table and are given a set of FDIM Proceedings. Snacks are provided at breaks.

Thursday Evening

At 8.00 pm we hold a Vendor Evening in The Ballroom. Vendors can set up their tables from 7.00 pm. Please wait outside the entrance if you do not have a reserved Vendor Table.

Friday Evening

All events take place in The Ballroom starting at 8.00 pm. People setting up club tables or Homebrew Competition entries can enter earlier.

Everyone attending is highly encouraged to bring a Show & Tell item for display on a table

Saturday Evening—
The Grand Banquet

The banquet is held in The Ballroom with entry at 7.30pm. Dress code is smart casual. No need for penguin suits!

The meal is served buffet style and guests will be invited to attend the buffet by hotel staff.

More information, including registration availability can be found at:
www.qrparci.org/fdim

can therefore make adjustments to the switching frequency in order to move the inevitable birdies away to a harmless place far from the operating frequency.
3. Put the DC converters on their own separate PCBs to try and shield the rest of the circuit. OK part of the reason for this is also that the main PCB is full…

The circuit fragment shown here is the 5V regulator. The circuit is the same as the one I developed for the PIN diode forward bias current in the QDX PCB Rev 4, that provided a great improvement in efficiency and removed three quarters of a watt of unnecessary heat generation from the enclosure during transmit.

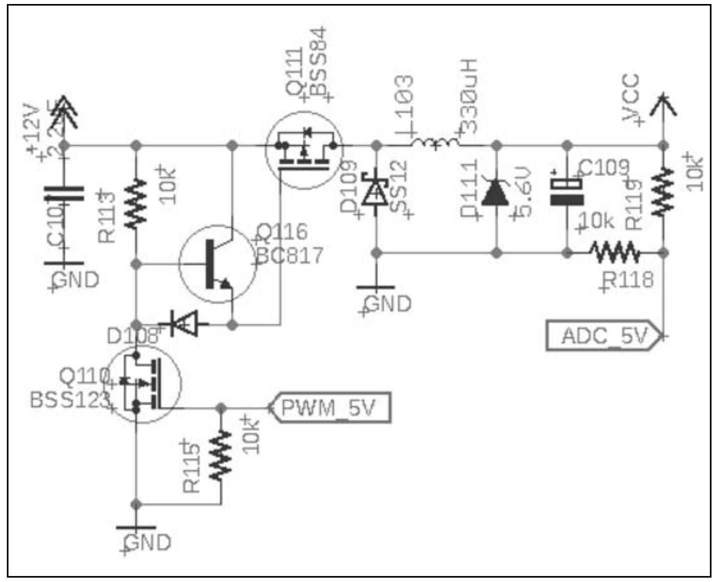
There's a P-channel MOSFET which is switched by a PWM signal from the microcontroller. The microcontroller also monitors the output voltage using an ADC input, and has a control loop implemented in firmware. NPN transistor Q116 provides an improvement in efficiency by ensuring a fast discharge of the Q111 gate charge, in other words a quick turn-off. More details are in the QDX manual. Note that here I also added a 5.6V zener diode as protection at the output. Because who wouldn't be nervous that something somehow could go wrong and pffff all the 5V circuits would be fried by too high supply voltage?

Very similar discrete component buck converter circuits are used for the 3.3V rail and the PIN diode forward bias current (as on QDX).

On the 3.3V line there's a little complication. The microcontroller is the control loop for the three buck converters. But the microcontroller needs 3.3V to operate. How can it get 3.3V to operate its control loop, if the voltage regulator which supplies it, is itself controlled by the microcontroller? It's a classic chicken and egg situation.

The solution is to include a 78M33 linear voltage regulator. At power up, the Q106 and Q107 switching circuits will ensure that the 78M33 linear voltage regulator is active. Then the microcontroller can boot up and sort itself out, and when it feels ready it can switch over to the efficient buck regulator by pulling the LIN_REG_EN signal low.

The circuit below also does much more than this, because it has an AOD403 as reverse polarity voltage protection, and also a soft power switch, that is connected to the button of the left rotary

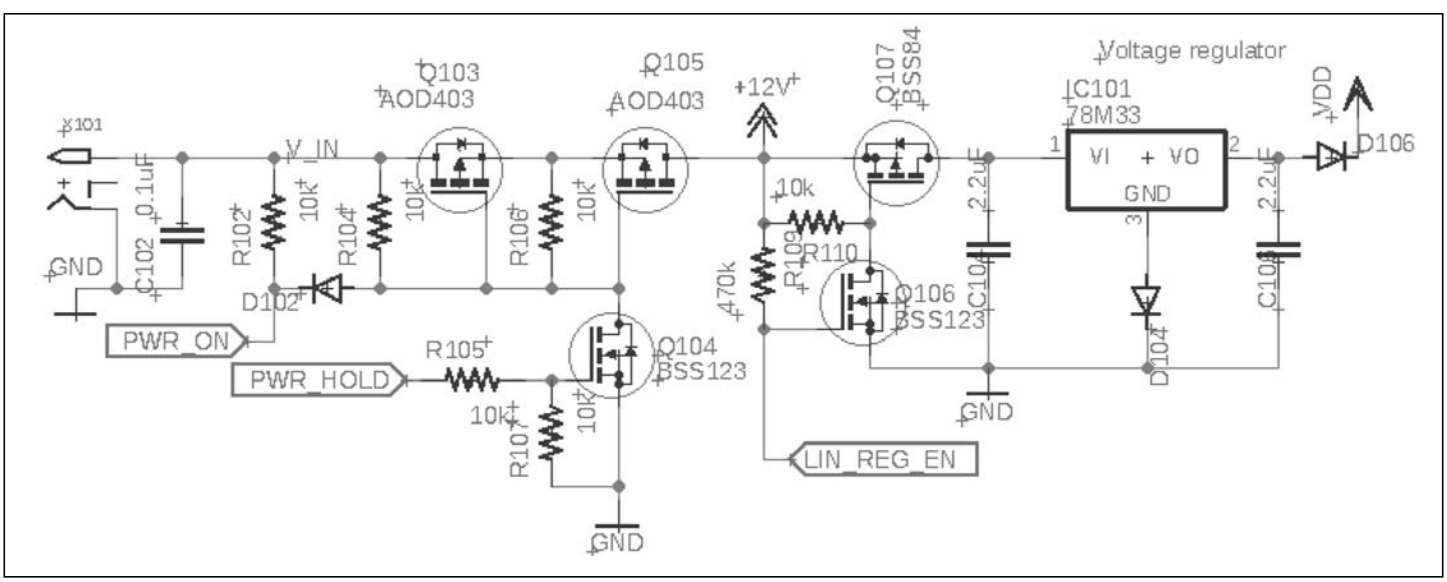


encoder. This effectively gives QMX an On/Off power switch so that it may be permanently connected to batteries for example. Press the button to switch on QMX. Once done, the microcontroller applies a 3.3V logic "high" signal at PWR_HOLD which keeps the power switched on though the button is released (and the button may then be used normally for other purposes). When the QMX is switched off, then it releases PWR_HOLD and the P-Channel MOSFET switches off, cutting power to the circuit. An additional advantage of this is that QMX is able to save its state (operating frequency, volume, mode, etc) before shutting down - so that when you next power up, it comes on in exactly the same state you left it.

PCB Design

The QCX-mini enclosure is really tiny. Quite a bit of board area is consumed by the connectors. Smaller connectors could be found, such as for the 3.5mm connectors… but these work and we have long experience with them (QCX, QCX+, QCX-mini)—any change is risk. A smaller connector might have shorter life or reliability issues; who knows until you have thousands of radios out in the field and the problems start!

Making the enclosure larger would solve a lot of my



headaches but I had already set my challenge and there it is. QMX has to fit the QCX-mini enclosure, period. The photo (next page) shows the prototype PCB.

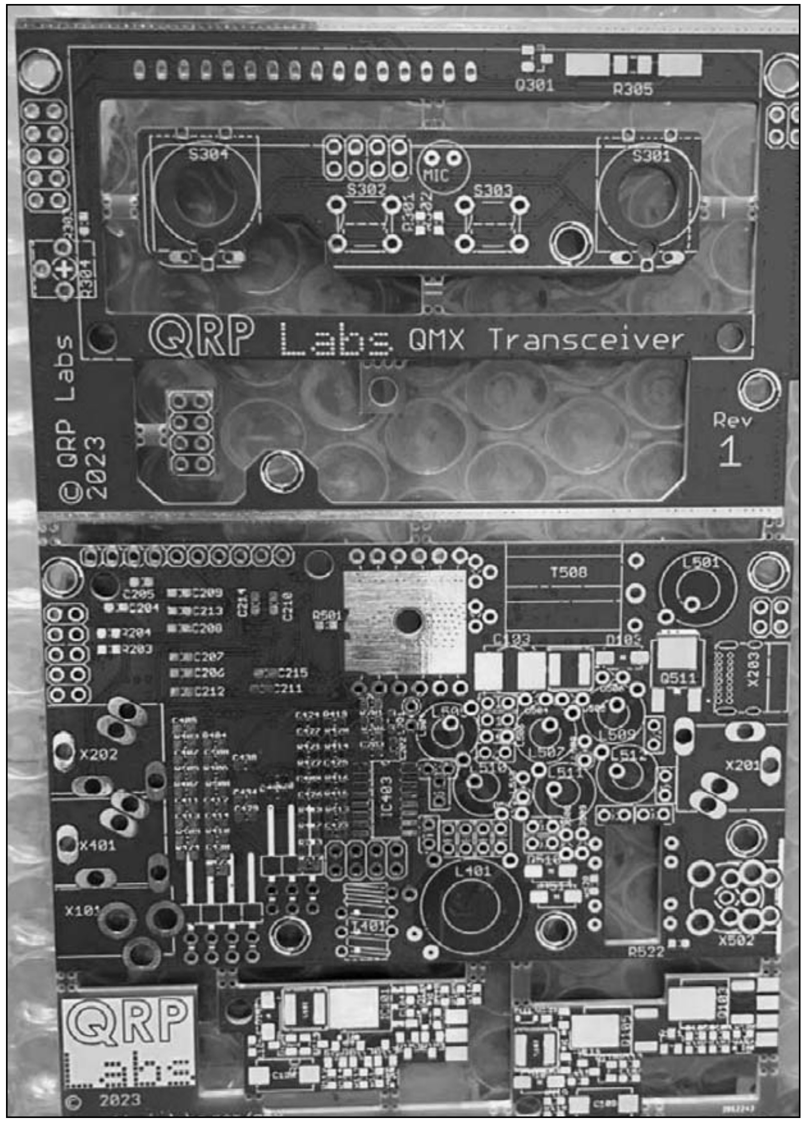
There is naturally some similarity to QCX-mini. QCX-mini has two PCBs, a main PCB and a display PCB; the display PCB further pops out a small board which holds the buttons and controls, and a couple of tiny spacing boards to get the height of the control board correct.

For QMX it was all done on one single board, sized 3.6 x 5.5 inches. This contains snap-off boards, so it all breaks apart into:

- Display board (top)
- Main board (bottom)
- Controls board
- Two small power supply boards
- Spacer boards for the control board mounting

The five boards all have connections to the main PCB using inexpensive pin header connectors.

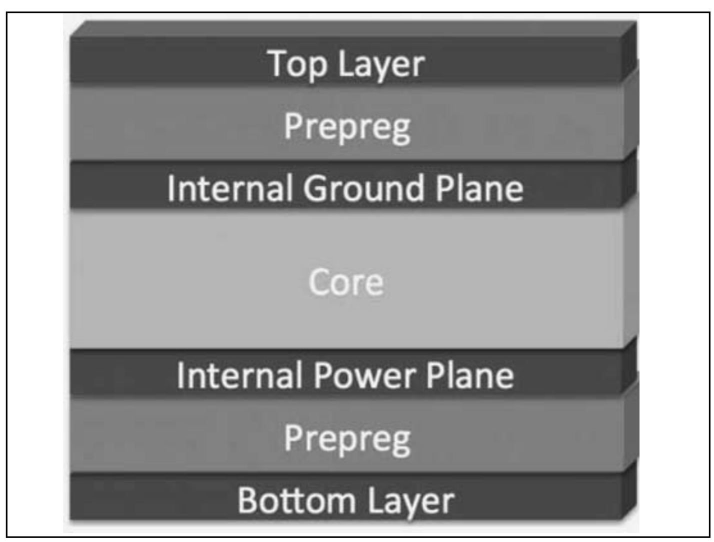
The big problem I had was that the large number of necessary SMD components, which must be on both sides of the main PCB, meant that there was simply not enough space to route the necessary interconnection signals between them on the top and bottom layers. Let alone provide any remnants of a nice groundplane to look after the noise performance. For the switched mode buck regulator boards, for reasons of available space, I had to have components only on the top side; and for wishing to avoid noise interference, I wanted the bottom side of those boards to be only groundplane. So again had nowhere to route traces.

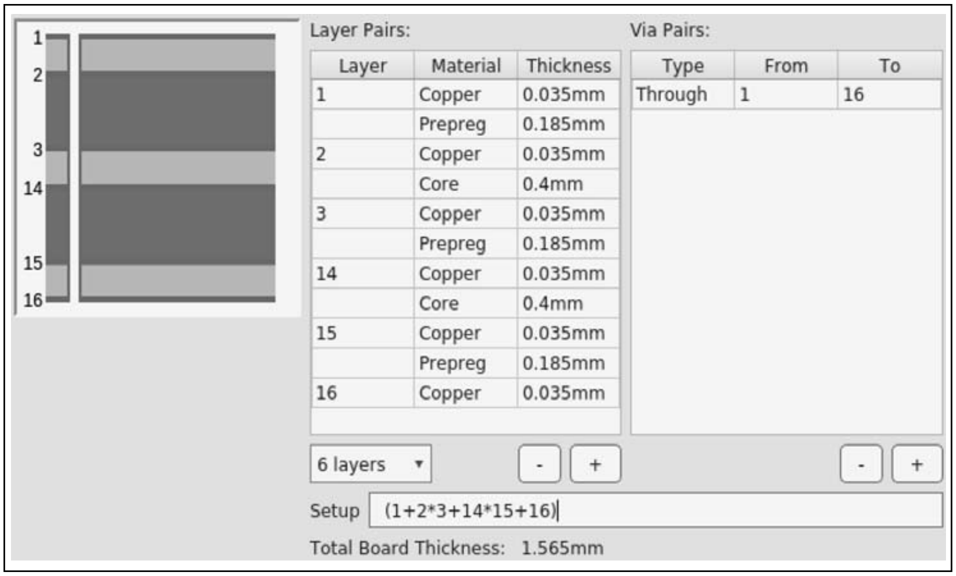


Accordingly I had to resign myself to designing my first ever, multi-layer board, which sounded very scary indeed. But in the end it's not so difficult, and in many ways is actually easier than struggling with so many signals and maintaining ground plane integrity on a normal 2-layer board (top and bottom copper). There are YouTube videos and websites. These days all the information in the world is instantly at your fingertips and you can learn anything you need to know.

Some people might not like the idea of a multi-layer board. Some want to see every trace. Well OK, I'll give you a large diagram so you can see where all the traces go. Others worry: how will they repair a broken trace that's inaccessible inside the board? I'm sorry, you won't. I'd like to ask, how are you planning to damage that internal trace hidden inside, in the first place? "Well what if I drill into it?"… WHY would you want to drill into a PCB, specifically a multi-layer PCB… If you do, all bets are off.

One interesting YouTube video talked about the mistake of the most common 4-layer board stack-up which has signals on the top and bottom layers, a ground plane on one inside layer and a supply plane on another. It was very well explained. A "via" is a plated hole drilled through the board to transition or connect a signal from the top layer to the bottom layer. The video pointed out that a return current flows on the ground plane under any signal. At the point the signal transitions through the board from the top side to the bottom side, the ground plane return current now has to flow on the supply voltage plane (which is also assumed to be RF ground). The problem is that now you have two unconnected return ground return signals, moving away from that layer transitioning via, and you just created a little dipole antenna which can radiate any signal on the trace, or indeed pick up noise. To solve that, you need to arrange a low impedance connection between the





two grounds (in this case, ground plane and power supply plane).

The video explained that the only way to do this, because they are at different DC potentials, is now to put a capacitor between them. Yes the layers themselves act like a capacitor but it's not a particularly large, useful or low impedance one. So you would ideally now need a capacitor next to every via transitioning signal from one layer to another. Of course this capacitor has to sit on one layer or the other, and have its own via connecting one side to the opposite layer. Nothing is as good or low impedance as a simple via connecting the two ground planes. So the best thing to do is forget about the power supply plane, and make both internal planes ground. The video pointed out that even an 8 mil trace can handle over an amp of current - so massive thick traces or power planes aren't necessary for current handling purposes in most applications (unless you're designing some kind of industrial high power electronics for example).

I was all ready to start designing my 4-layer board, having two ground planes in the middle, but I realized that even 4 layers wasn't going to be enough, if I wanted to have good ground planes everywhere. Which I do—because it's quite important on a board which mixes high performance sensitive analog electronics with potentially noisy digital electronics like a fast microcontroller.

I even got fancy and included lots of blind vias. Blind and buried vias are ones that don't go all the way through the PCB (see diagram). A blind via starts or finishes at one surface of the PCB and goes part way through only; a buried via exists only on the inside.

They're useful because if you're stuck in a tight spot to route a signal, and you can't put a via in right there because there's an SMD component on the bottom side of the PCB under that location, for example—you can still connect a signal on the top layer of the PCB to an inside layer, by using a blind via. It doesn't go all the way though and contact with the SMD component on the bottom side. They're also useful when it comes to more groundplane stitching because again, you can do it underneath SMD components.

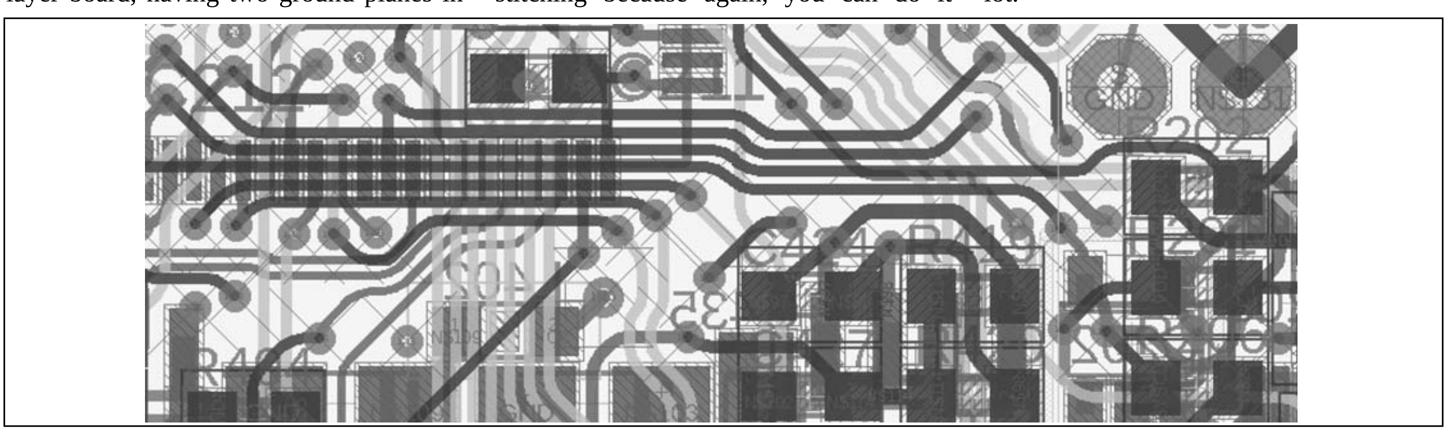
The image above shows how the layers stack up in Eagle CAD which I use for all my PCB design. It uses 6 of Eagle's available 16 layers.

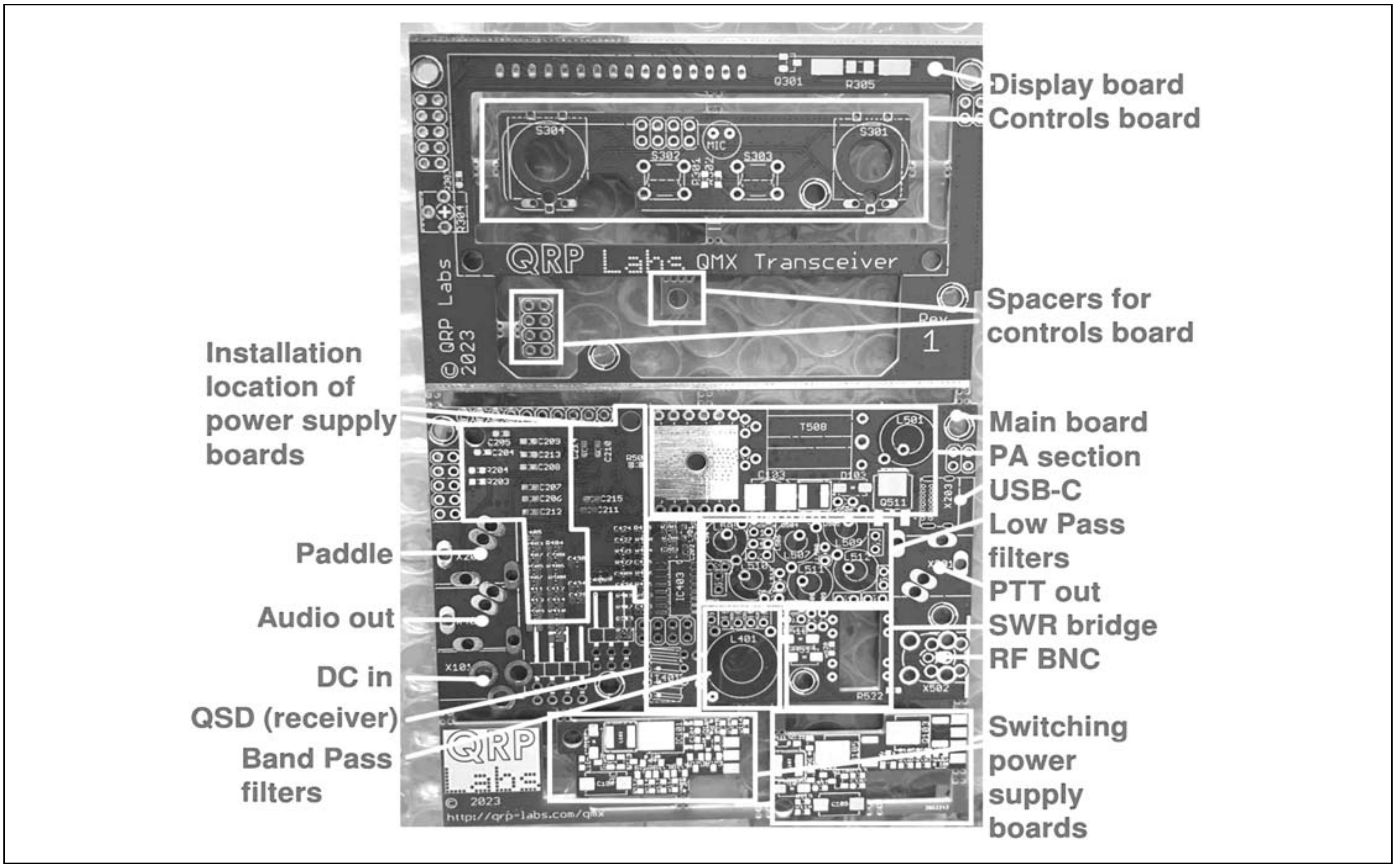
1: Top layer (SMD components)
2: Strictly groundplane only
3: Signal interconnect
4: Mostly power connections
5: Strictly groundplane only
6: Bottom layer (SMD components)

I kept two layers for purely ground plane, with no exceptions. Layer 4 has mainly power connections with a few signal interconnects where I could not manage it any other way; but mostly ground plane.

On all 6 layers, any unused areas are copper-pour groundplane. There are vias stitching the groundplanes together as close as possible to every signal via, and at intervals of not more than 0.1-inches in any open areas. Stitching groundplanes together is important. It ensures ground return currents always have the best possible lowest impedance path to "ground", minimizing the opportunity for noise-pickup ground loops. Since the inside of the PCB could also be considered a microwave cavity, by stitching together the groundplane frequently you break up the cavities into much smaller ones, which have far higher resonant frequency where they will be less and less troublesome.

The first nasty surprise came when I ordered 5 (minimum order quantity) prototype PCBs. $117 (23.something each), quite a jump from the usual few dollars per PCB we'd expect, even for a larger PCB like this one! Wow, making it 6-layer really bites. Hopefully when it comes to volume production, the price comes down a lot.





Not long after I'd got over that and paid… I had an email from the PCB manufacturer, oh, after the PCB audit we now have to tell you, the actual cost is going to be $1,519! To say I fell off my chair would be an understatement. For five boards! It turned out that blind and buried vias make things more expensive. A lot more expensive. So you think you're clever with all those blind and buried vias only to discover ooops, manufacturing those is not so easy nor inexpensive.

Back to the drawing board—I spent another few days repairing my 6-layer PCB layout to remove all the blind and buried vias! 6-layers is really not as hard as it seems and I really think I spent less time on the QMX layout than I did on the QCX-mini.

Physical Layout—Squeezing it all in

Getting all the required components to fit inside such a small enclosure was a major challenge. I used SMD components wherever possible. But that still leaves the larger components, like the connectors, toroids, controls, LCD.

There wasn't enough board area to fit all the SMD components so I had to design two little plug-in boards for the buck converter switching regulators, 3.3V and 5V. The PIN diode forward bias converter is on the main PCB near the output transformer.

The vertical space between the bottom surface of the LCD PCB and the top surface of the main PCB is 11mm. However the LCD module PCB itself deletes 1.6mm of that and there are further protrusions such as the epoxy blobs containing the LCD module ICs and the metal tabs which tighten the LCD module sandwich together. So it's necessary to design the component layout with all this in mind, so that nothing gets in the way of anything else!

- The position of connectors on the left and right main board edges is pretty much the same as for QCX-mini, except for the new USB-C connector for serial data. Which also makes space for four more pin header connections between main and LCD board.
- The controls board pin header connections were moved to make space for the pin header connectors under it on the main board, for the plug-in buck converter boards.
- Almost all the toroids have to lie down flat on the board! The only exception to this was the FT37-43 trifilar transmission line transformer which is part of the double balanced QSD in the receiver circuit - there's space for that standing up under the middle of the controls PCB.
- Smaller T30-6 toroids are used for the Low Pass Filter inductors, so that there is (hopefully) enough space to squeeze in the diodes, radial chokes and NP0 capacitors of the LPF and switching circuits!
- All ICs under the position of the switching power supply plug-in boards are restricted to being on the lower side of the PCB, with only resistors and capacitors on the top side—because these are very low profile, less than 1mm.
- The switching power supply plug-in boards only have components on the top side. Low profile tantalum capacitors had to be used instead of electrolytics, just because electrolytic capacitors are too tall to fit!
- For the SWR bridge, I believe based on my analysis a smaller binocular toroid can be used than the BN43-202 in the output transformer—I chose a BN43-1502 for this. It's the same cross-section as the BN43-202 but half the length.
- Even so—that smaller BN43-1502 in no way fits in the available height between

the bottom of the rotary encoder on the controls board, and the main PCB top surface. Due to this, I had to cut out a rectangle which you can see at the bottom right of the main board, for the binocular core to sit in.

Stretch goals: SSB

SSB is the only stretch goal I'm going to talk about. The others are my secret, for now.

SSB capability is not only important for the sake of being able to transmit actual SSB, but also because some digital modes such as PSK31 or WinLink which involve either phase shift modulation or multiple concurrent tones, don't work on QDX with its non-linear exciter and power amplifier. The use of the push-pull switching amplifier in QDX and its unique method of audio frequency measurement and direct synthesis of the RF has plenty of advantages as discussed earlier, not least of which is the great circuit simplification of not needing a SSB exciter, and linear driver and power amplifier, all of which would make a design more complex.

SSB reception is no issue, and QDX does that already, indeed, very well… many people have commented that the QDX receiver outperforms their Yaesu, Kenwood, Icom etc. The problem area is SSB transmission.

The uSDX tranceiver project originally was based on the QCX Classic, with some hardware modifications and a totally new firmware written by Guido PE1NNZ on the ATmega328 microcontroller chip. Later, Manuel DL2MAN did a lot of work on improving the Class-E power amplifier and producing a slick implementation no longer based on the QCX. There are now several Far East uSDX productions and an "official" uSDX implementation called (tr)uSDX which is approved and supported by PE1NNZ and DL2MAN.

The uSDX transceiver uses the existing QSD baseband I & Q signals of the QCX receiver section, and implements an SDR on that low resource microcontroller chip sampling the I and Q channels with the 10-bit multiplexed ADC of the ATmega328. It uses PWM for its audio output.

On transmit, uSDX implements a version of Class-E Envelope Restoration (EER). The SSB signal is split into Phase and Amplitude components, which can then be transmitted using the radio's Class-E power amplifier. The phase component modulation is implemented by rapid frequency change transmissions to the Si5351A which are equivalent to phase modulating the oscillator signal to the power amplifier. The amplitude component was originally implemented on uSDX by a PWM signal connected to the RF envelope shaping circuit. However the current designs use a DC blocking capacitor between the logic gate driver circuit, and the gate of the PA MOSFETs, then apply a variable DC bias to the MOSFET gates. The DC bias is derived from a PWM output of the processor.

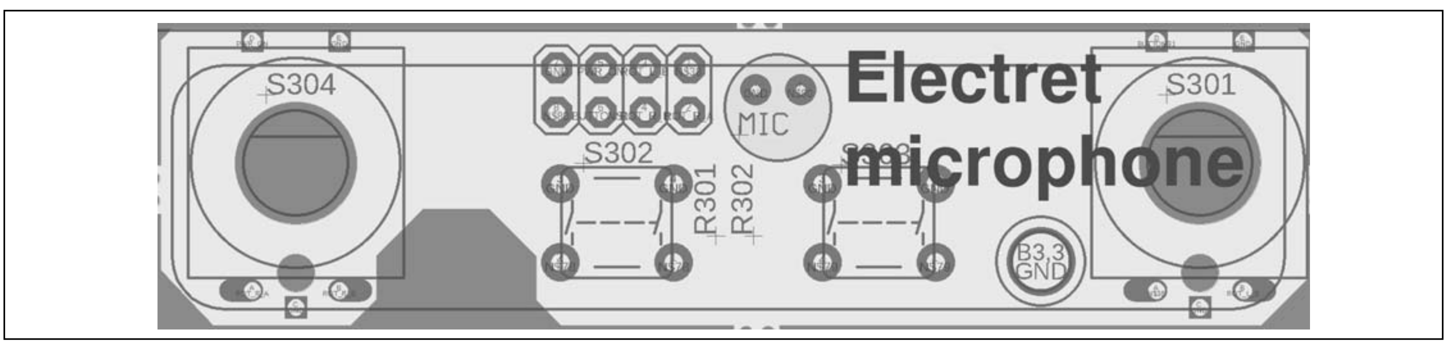
Overall uSDX is a very clever design, and it is amazing that a multi-band multi-mode radio transceiver can be designed around such limited hardware! But it is not, in my view, a sufficiently high performance transceiver.

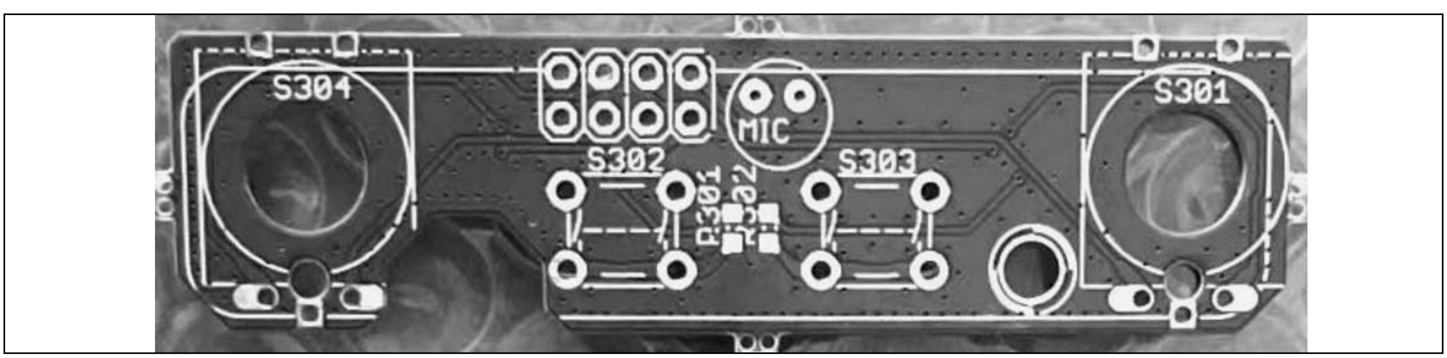
On receive, the performance is quite severely (in my view) limited by the hardware constraints. Dynamic range of an ADC is determined by the number of bits, at a rate of 6 dB per bit. This is a theoretical maximum, the actual delivered performance is always worse than 6 dB multiplied by the ADC bit depth, because it is also determined by the noise floor of the ADC chip being used. Furthermore, uSDX manages all that DSP on a dated 8-bit microcontroller running at 20 MHz.

On transmit, the limitations of modulating amplitude by a low resolution processor PWM output, and the small control range (I measure 10 dB or so) of amplitude control afforded by the DC bias at the BS170 MOSFET gates, along with its non-linearity and again the severe limitations imposed by such a low end (by modern standards) 8-bit 20 MHz microcontroller, all combine to impact on the quality of transmit signal it can produce.

QMX, on the other hand, has several advantages:

- Fast 180 MHz 32-bit ARM Cortex M4 microcontroller with DSP and Floating Point units





- High performance 48 ksps 24-bit stereo ADC on receive, which results in a truly excellent performance SSB receiver (already in production in QDX for 18 months)—and should provide much improved performance on transmit
- 12-bit DAC controlled AM power modulator

This is why the little control PCB of the QMX design has space for a small electret microphone!

Two ADC inputs to the microcontroller are connected to the internal microphone connection to the controls board, as well as to the IAMBIC Paddle jack—which can then be used to plug in an external microphone and PTT switch if desired.

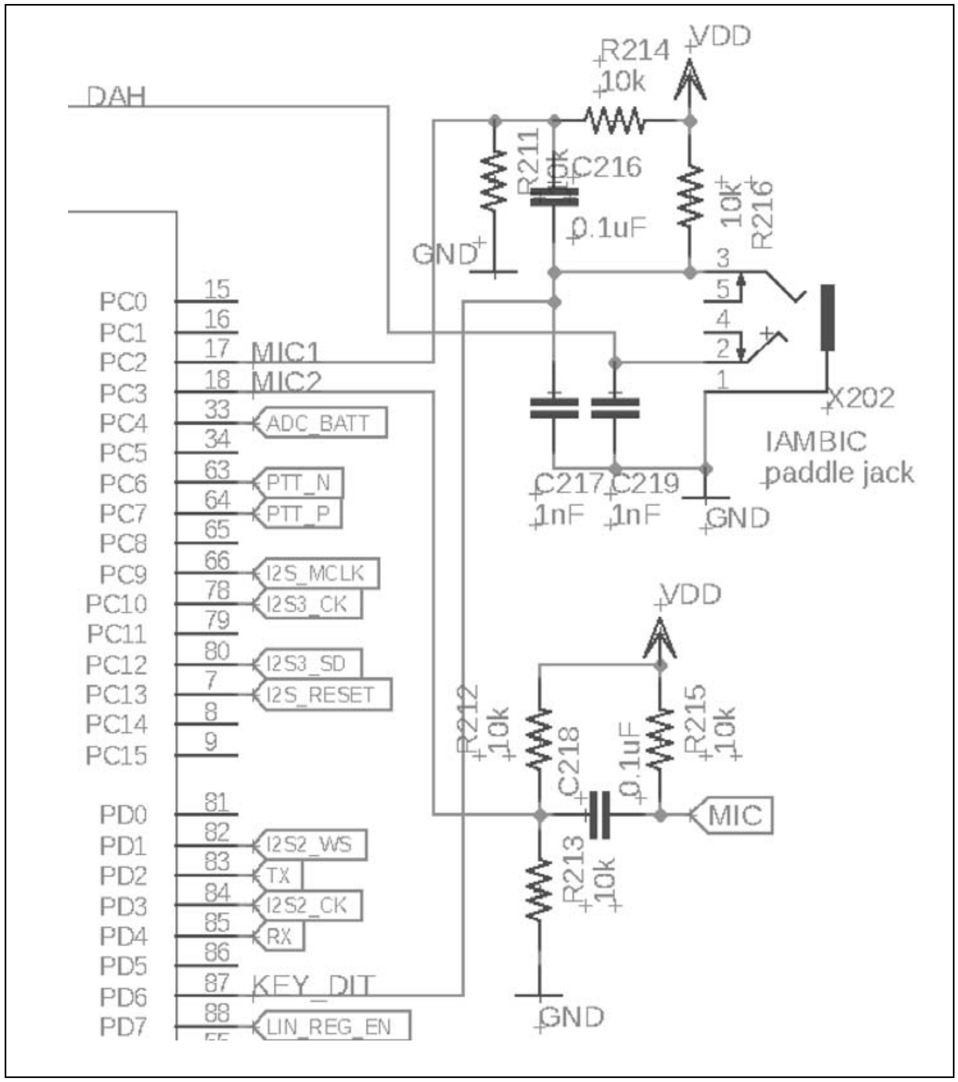
Only time and testing will reveal whether the stretch goal of including SSB transmission is feasible or not. I suspect it will be; but whether or not it works well enough (good enough performance) to own up to on the official list of supported modes and features, that's the real question.

Conclusion

I hope this article has been interesting and that you can understand a bit more about the evolution of QRP Labs kits; and I hope the new QMX design sounds as exciting to you as it does to me! I think it's a rig full of potential for further development, as well as an amazing combination of performance and features in a small package at such a low price. And most importantly of all: being one more stepping stone on the path of QRP Labs kit evolution!

More: http://qrp-labs.com/qmx

—73, happy homebrewing
and happy QRP!



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QRP Quarterly (ISSN #1551-1537, USPS #022-276) is published quarterly in January, April, July and October by AY Technologies LLC, 301 Crescent Street, Mazomanie, WI 53560. Periodical postage paid at Mazomanie, WI and at additional mailing offices.

POSTMASTER: Send address corrections to QRP Quarterly, 301 Crescent Street, Mazomanie, WI 53560-9668. Subscription information: (608) 215-9779.

Subscription prices (all in U.S. dollars): Domestic one year $25, two years $50; Canada and elsewhere one year $28, two years $56.

QRP Quarterly is the official publication of the QRP Amateur Radio Club International (QRP ARCI), which is responsible for all editorial content. Editorial submissions should be sent to the Editor or an Associate Editor. See the staff listing on page 3 of each issue. Membership/subscription inquiries should be sent by e-mail to: membership@qrparci.org, or by mail to the club Treasurer.

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