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Automation Options for the CTR2 HMI

This comprehensive station control system supports several switching options that can be added at any time and in any order.

The September/October 2021 issue of *QEX* presented Control the Radio 2 (CTR2), a multi-radio Human-Machine-Interface (HMI) capable of controlling multiple radios. At each radio, an I/O module collects audio, CAT control, and keying signals and transports them to the HMI using CAT5 cable. In its simplest form a single radio I/O module connects directly to the HMI. The system can be expanded using manual RJ45 switches (not Ethernet switches) to connect any number of radios to the HMI.

Routing radio I/O to the HMI is only part of the challenge when controlling multiple radios. The antenna distribution system must also be considered. Antenna selection and routing to the operating radio can be done using a patch panel or manual antenna switches. As the number of radios and antennas increases these methods quickly become cumbersome.

To fully realize a comprehensive station control system, three switching options are supported by the CTR2 HMI. These options can be added individually at any time and in any order. This allows you to build the station controller to suit your needs today and in the future.

Switching options include:

• An ASC (Antenna Switch Controller) and it's associated remote antenna switch to route up to 8 antennas in any combination to a common antenna port.

• An RASC (Radio Antenna Switch Controller) together with up to two 8-port remote antenna switches route the common antenna port from the ASC switch to one of sixteen radios.

• An RJ45 switch that synchronizes with the RASC to route the selected radio's audio, CAT, and key control to the HMI.

Both antenna switch controllers are designed to control either a homebrew remote switch like the 8-channel remote control antenna selector presented by Michael Dzado, ACØHB, in the March/April 2014 issue of *QEX*, or a commercial antenna switch such as the DX Engineering RR8B-HP. See the **Sidebar – Antenna Switches**. Options are provided to source +12 V dc, sink ground, or use an external power source to control the switches of your choice.

Antenna Switches

A word about antenna switches.

When it comes to switching a common antenna between two or more radios, go for the most isolation you can afford. Dzado's March/April 2014 *QEX*, article goes into great detail on what it takes to design a proper antenna switch with high port isolation. If you run at legal power limits you'll need a minimum of 70 dB isolation. 60 dB is sufficient for 100 W. Resist the temptation to buy inexpensive antenna switches from internet merchants, especially if they don't list or guarantee the port isolation of their switch. Many inexpensive switches have less than 30 dB of isolation. Excessive RF coupling can easily damage your expensive offline receivers. Isolation requirements are not quite as critical for switching multiple antennas. However, using an antenna switch with low port isolation here will degrade your antenna system's performance.

CTR2 System Build-Out

Figure 1 shows the functional drawing of a fully built-out CTR2 system using the automated switches described in this article. The antenna switch routes one or more of the available antennas to a common port. This switch is controlled by the CTR2 ASC. The switch itself is usually mounted outside, and the 9-wire shielded control cable and common antenna coax run back to the station. Once in the station, the coax can be connected to an optional antenna tuner then to the common port of one or two 8-port radio antenna switches under control of the CTR2 RASC. Individual coax runs from these switches then feed each radio.

The RJ45 switch consists of one to four 4-port RJ45 switch boards. The RASC and the RJ45 switch work together to route the antenna to the selected radio and the I/O from that radio to the HMI. The ASC works independently and can be configured in the HMI to switch antennas based on radio and band selection. It also allows two or more antennas to be selected at the same time if you use phased arrays.

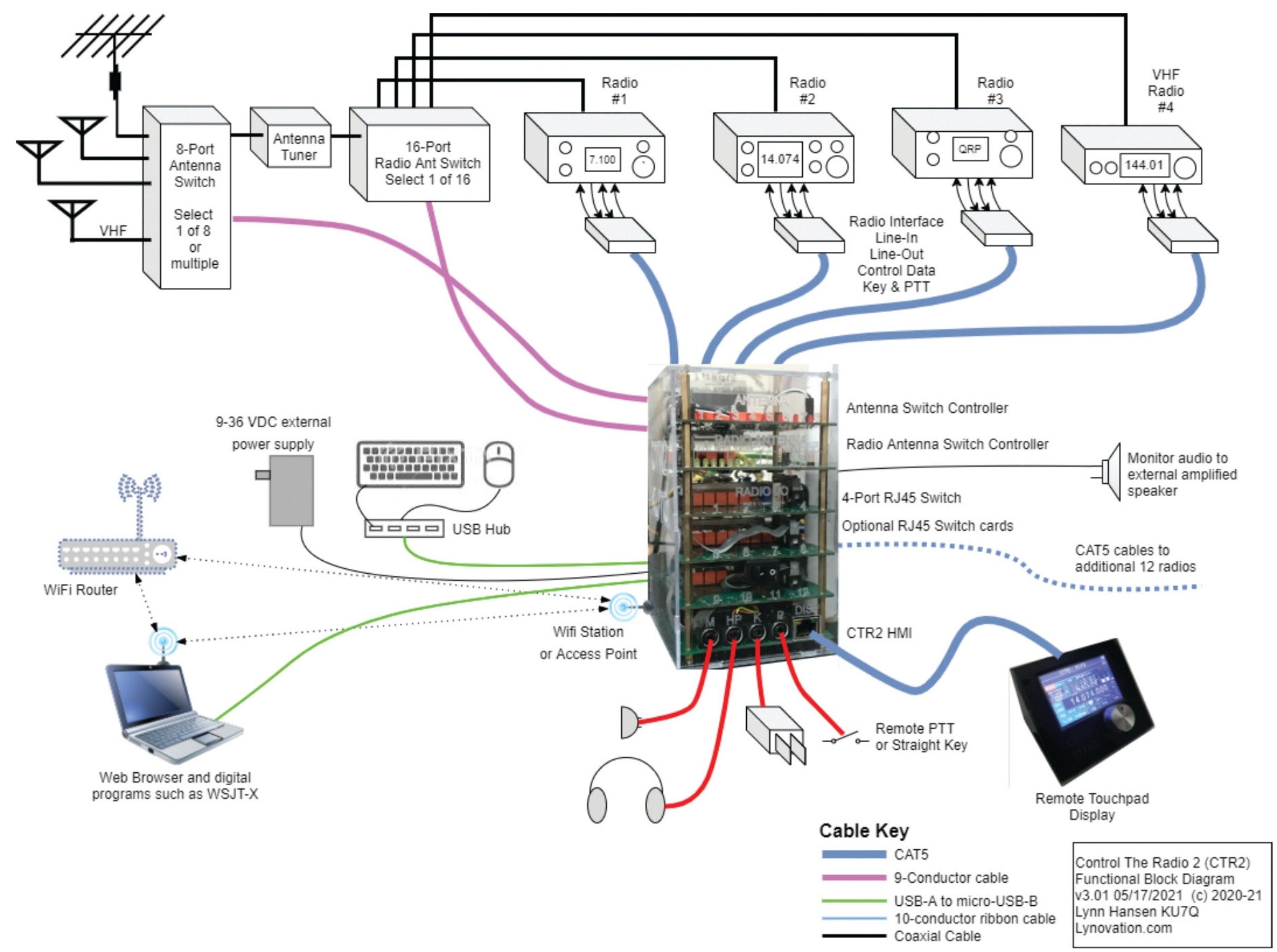

Figure 1 — Functional drawing of the fully built-out CTR2 system.

Logic Circuit Description

The same basic logic circuit is used for all three switch controllers. Referring to the logic section schematic, **Figure 2**, the heart of the circuit is IC1, a CD4514 CMOS 4-Bit Latch/4-to-16 Line Decoder chip. This chip takes a 4-bit address (Data 1, 2, 3, and 4) and decodes the binary value to drive one of 16 outputs. A **STROBE** signal is driven **HIGH** to **LOW** to latch the address into the decoder. Once this is done the **INHIBIT** signal is driven **LOW** to force the selected output pin **HIGH**. Low pass filters are installed on all signal lines for RF isolation.

The output pins of the CD4514 decoder are routed to two ULN2803 Darlington transistor arrays, IC2 and IC3. These devices each provide 8 Darlington transistor pairs and are designed to drive relays and stepper motors from TTL or CMOS inputs. They can sink up to 50 V at 500 mA and have integrated clamping diodes to shunt the inductive kickback when operating inductive loads such as relays. They are inverters so, a **HIGH** input level causes the output to go **LOW**.

Full schematics and bill of materials for each board can be found on my web site, **https://ctr2.lynovation.com/**.

Antenna Switch Controller (ASC) Circuit Description

The CTR2 ASC operates independently from the other two switches in that it can select up to 8 relays in any combination. To do this, 12 V latching relays are employed.

To operate a relay the HMI sends a **SET** or **RESET** address to U1. Addresses 0 to 7 operate the **SET** relay in K1 to K8 and addresses 8 to 15 operate the **RESET** relay in K1 to K8. Power to the coil can be removed once the position is latched into the relay.

On U1 the **INHIBIT** input is connected to the **STROBE** input through an RC delay circuit. The **STROBE** and **INHIBIT** inputs are normally kept **HIGH**, disabling all outputs. To operate a relay its address is asserted on the **DATA** lines then the **STROBE/INHIBIT** line is driven **LOW** to latch the address and drive the selected output of U1 **HIGH**. The Darlington driver output on U2 or U3 then goes **LOW** which latches the selected state (**SET** or **RESET**) in the relay. After 10 ms the **STROBE/INHIBIT** is driven **HIGH** again disabling all outputs from U1 and deactivating the selected relay coil. A small time delay RC network (R9 and C22) delays the **INHIBIT** signal for a short time to allow the decoder time to decode the address.

The **Antenna Selection** page, **Figure 3**, in the HMI visually displays the antenna switch configuration and controls the ASC. There are options to allow single or multiple antenna selections, select antennas based on the selected band, tag each antenna with a name, and reset all settings back to default.

The **[Save]** button saves new settings to the radio's database.

TB1 is used to connect the ASC to the antenna switch. Both +12 V dc and ground are available on this terminal block to provide the required return path. A 9-conductor wire is needed to control the 8 relays on the switch. MOVs are provided to suppress any induced voltages from the field since the switch will generally be mounted outside.

There are several options to provide power to the ASC and RASC boards and their associated remote switches. These options are described on the Lynovation web site.

Radio Antenna Switch Controller (RASC) Circuit Description

The RASC operates in sync with the RJ45 switch. Its job is to control up to two 8-port remote antenna switches to route the common antenna port from the ASC controlled antenna switch to one of 16 radios.

This board uses the same addressing logic as the ASC with the exception that the **STROBE** and **INHIBIT** inputs to U1 are controlled separately and momentary relays are used. Once one of the 16 relays is selected, the **INHIBIT** input is pulled **LOW** to keep the selected relay activated. This ensures that one, and only one, relay can be active at a time.

TB1 and TB2 are used to connect the antenna switches. TB1 controls switches 1 to 8. TB2 controls switches 9 to 16. Both +12 V dc and ground are available on these terminal blocks. MOVs are not provided on this controller since these antenna switches will generally be located inside near the radios.

Like the ACS, this board has multiple options to provide power to the external antenna switches.

RJ45 Switch Circuit Description

Figure 4 is a block diagram of the 16-port RJ45 switch. The system is comprised of a main switch board and up to three expansion boards. **Figure 5** is a close-up of the main switch board.

The main switch board interfaces to the HMI with two 10-conductor ribbon cables that connect to the RJ45 Switch Control and Radio I/O ports on the HMI. The main switch board routes radio I/O for ports 1 through 4. Additional 4-port expansion boards can be added to the system by connecting the Expansion Port (J3) on each expansion card to the 'Ports xx-xx' connector (J4, J5, or J6) on the main board and daisy-chaining the Radio I/O port to each board.

Decoding logic is the same as used on the RASC board. The Darlington drivers control four DPDT relays for each port. These relays route the eight wires from the HMI's Radio I/O port to the selected RJ45 port on the rear of the board. DPDT relays were chosen over 4PDT or 8PDT relays solely based on cost. Four DPDT relays cost around $7.00 while 4PDT and 8PDT relays are priced in the hundreds of dollars. Additionally, relays were chosen over

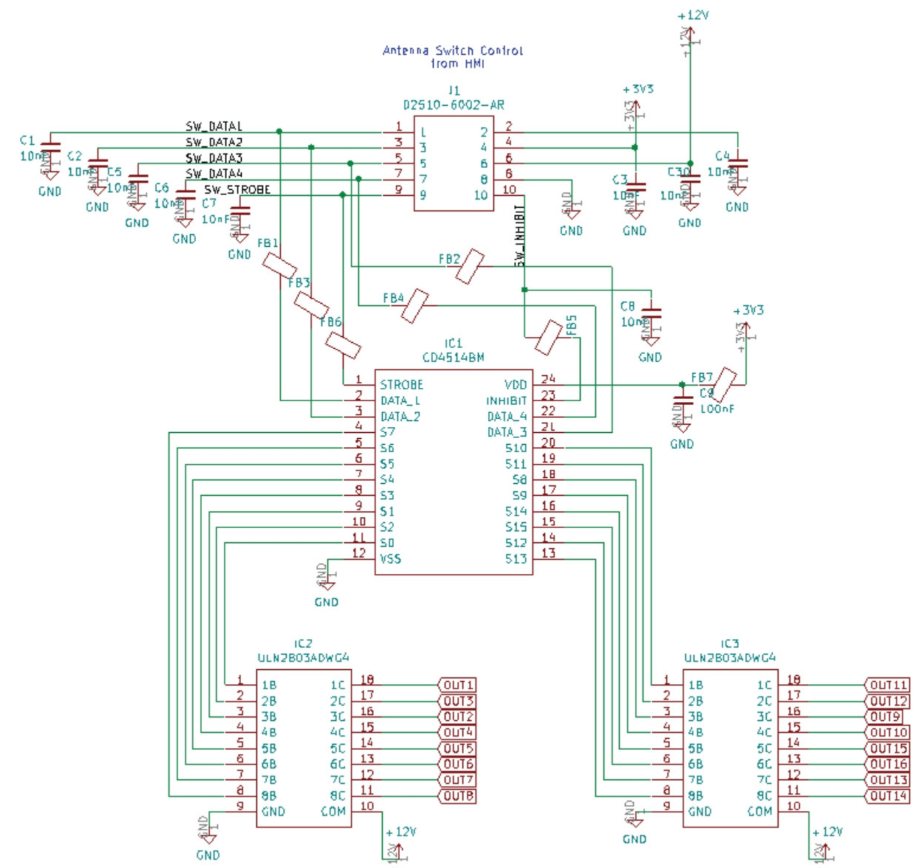

Figure 2 — Decoding logic circuit common to all switches.

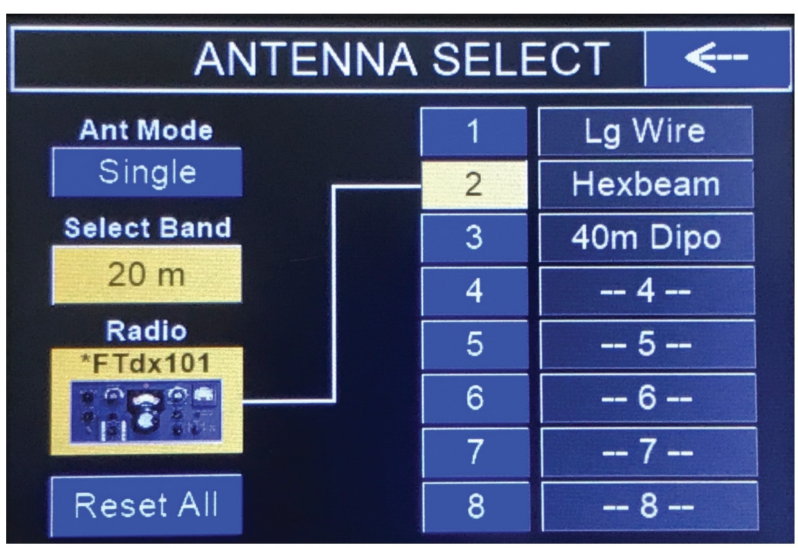

Figure 3 — Screen shot of the HMI Antenna Selection page.

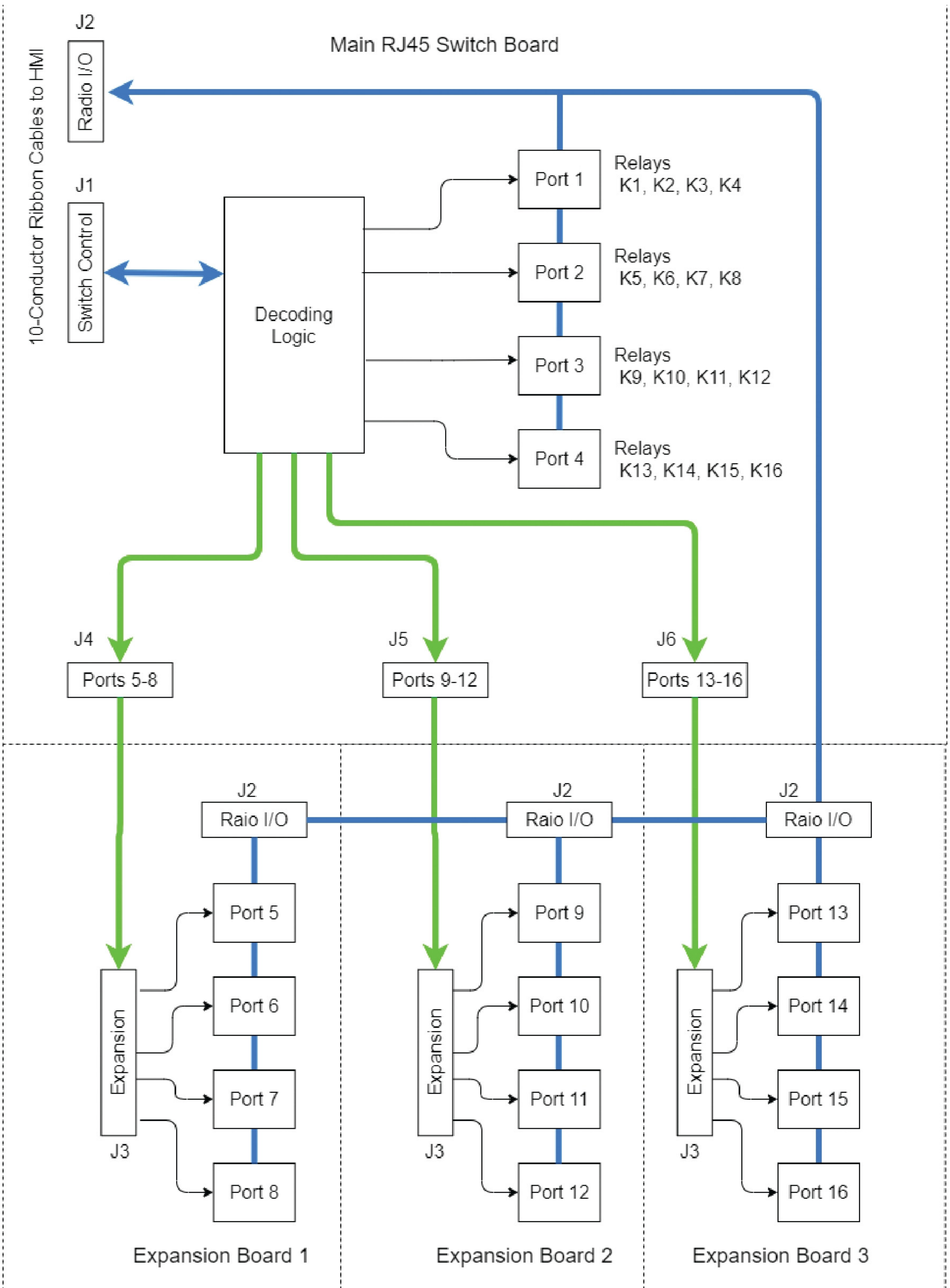

Figure 4 — Block diagram of the 16-port RJ45 switch.

solid-state switches or digital multiplexing because of cost and simplicity.

The data lines that drive the decoder are bi-directional and are also used to detect installed boards. This allows the HMI to "know" which expansion boards are installed. Sensing resistor R6 is connected to Data 1 and always pulls this line low (2.2 kΩ to ground) when it's not being used to set the decoder. Sensing resistors R5, R4, and R3 connect to Data 2, Data 3, and Data 4 respectively, and are pulled low when expansion boards 1, 2 or 3 are installed. To detect the installed boards the CPU momentarily switches the switch address output lines to input mode with "weak" pull-ups (around 20 kΩ to 3.3 V) then reads the values on these lines. Inputs connected to installed boards will be read as **LOW** when sampled.

The +5 V dc power is supplied by the CTR2 HMI and 5 V momentary relays are used throughout. A +3.3 V dc regulator on the main switch board provides power for the decoding logic.

Optional continuous or offline receiver monitoring for one radio on each board is provided for in this design. J10, J11, J12, and J13 tap both continuous and offline Rx audio from the four radio I/O interfaces. Pins 1-2 provide continuous Rx audio and pins 2-3 only sample Rx audio when the radio is offline (not selected in the HMI). Pins 1-2 or 2-3 are then connected to J8, the input of isolation transformer T1. A 3.5 mm phone jack can be connected to J9, the output of T1, to provide a connection to an external amplified speaker for monitoring Rx audio from this radio. Note that the monitored receiver must be connected to a separate antenna. I use this option with a PCR1000 wideband receiver to monitor activity on other bands.

Let's Build It

PCBs are required to build these boards because the connectors are not perf-board friendly. PCBs with all the SMD components pre-installed are available at **https://ctr2.lynovation.com/**.

Automated Bill of Material (BOM) files, as described in the September / October *QEX* article, are available for each board in the CTR2 series at my Lynovation web site. These files run in your browser and list the part numbers and dynamically show the part placement as you click on each part.

The RJ45 switch main and expansion boards are built using the same PCB. The main board requires all parts except the

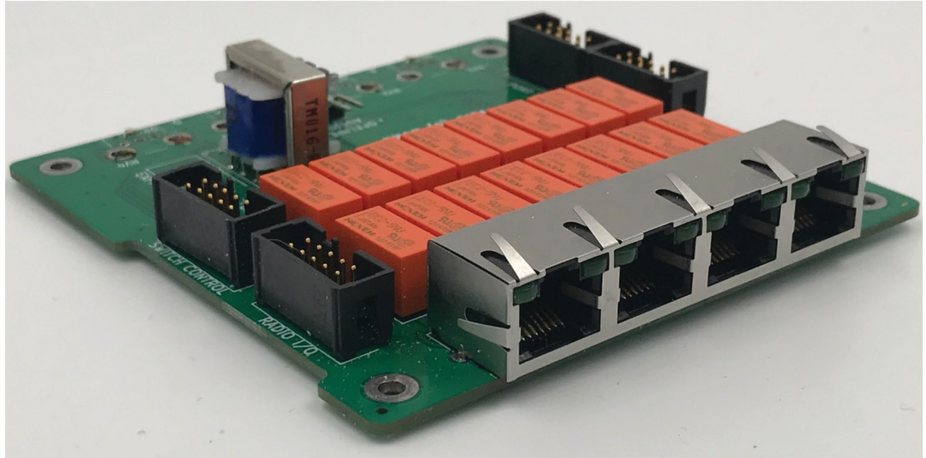

Figure 5 — Close-up of the main 4-port RJ45 switch board.

Figure 6 — CTR2 stack with HMI, three RJ45 switch boards, the ASC and the RASC.

Expansion Port (J3) to be installed. You can also leave off connectors for J4, J5, and/or J6 if you're not going to use those expansion boards. The Rx Audio monitor hardware is optional.

On the RJ45 expansion boards, install Expansion Port J3, the 16 relays, the 4-port RJ45 jack, LEDs D2 to D5, LED current limiting resistors R7 to R14, and RF bypass capacitors C9 to C12.

Let's Package It

As seen in **Figure 6,** CTR2 option boards are designed to stack on the HMI board. Start the stack using M3 6 mm male/female threaded standoffs on the bottom of the HMI board then add four M3 25 mm for each board, screwing each standoff into the one below the board. Each board adds 26.6 mm (a little over 1") to the stack so the HMI with four 4-port RJ45 switch board, an ASC and an RASC forms a stack 110 mm (approximately 4.25") square and 204 mm (8") high.

The assembly is self-supporting and can be left "open-frame" if you prefer. It can stand vertically or horizontally to fit your needs. If you have access to a CNC mill you can cut an interlocking enclosure for it from the dimensions supplied in the documentation on my web page. I can supply a limited number of pre-cut acrylic enclosures for this project. A 3D-printed enclosure is certainly possible but I haven't explored that option.

All boards connect to the HMI using 10-conductor ribbon cable and IDC connectors. Be sure to verify pin 1 is correctly oriented on each end of the cable and the cable is long enough *after you fold the cable back through the strain relief clamp* before you crimp the connector! There is a small arrow on the #1 pin side of the connector for reference as shown in **Figure 7**.

The Radio I/O cable will require additional connectors installed "mid-stream" if using RJ45 expansion boards. A 16 port switch requires 5 connectors on this cable. Space each connector so the finished distance between connectors is about 40 mm. I recommend purchasing extra IDC connectors and ribbon cable as they are easily broken or misaligned during installation. The cable must be precisely aligned in the connector before squeezing it together. A misaligned cable can cause short-circuits between the wires. Expansion pliers or a vise can be used to squeeze the connectors onto the ribbon cable, but an IDC installation tool makes the job much easier. Once the connector has been set, fold the ribbon cable over the top and install the strain relief clip. Before using them it's a good idea to check the continuity on each pin and verify that they are not shorted to adjacent pins.

Using the CTR2 System

Connect the CAT5 cables from the radio I/O modules to the RJ45 jacks on the back of the RJ45 switch, taking note of which radio is on each port. Power up the HMI and it will select the last radio port used. The LED of the active port on the front of the RJ45 switch lights as will the green LED on the active RJ45 connector on the back. If using the RASC the same # LED will light on it showing the common antenna port is connected to that radio. If using the ASC, the LED (or LEDs if more than one antenna is selected), will also light. If you are using CAT control, change the frequency on the HMI and verify the correct radio responds. On the HMI's **Home** page, **Figure 8** the **[R3:A2]** button indicates that radio #3 and antenna #2 are selected. Touch this button to open the **Radio Select** page, **Figure 9**. The selected port is highlighted in orange. If you have one or more expansion boards installed, as in this case, the background surrounding their ports will be orange also. In this example the main switch board and

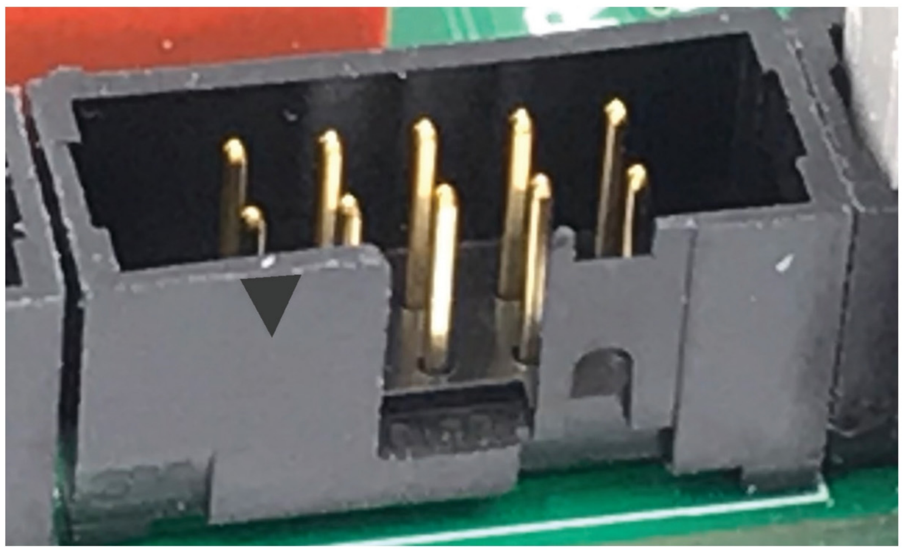

Figure 7 — Close up of the #1 pin mark on the 10-pin IDC connector.

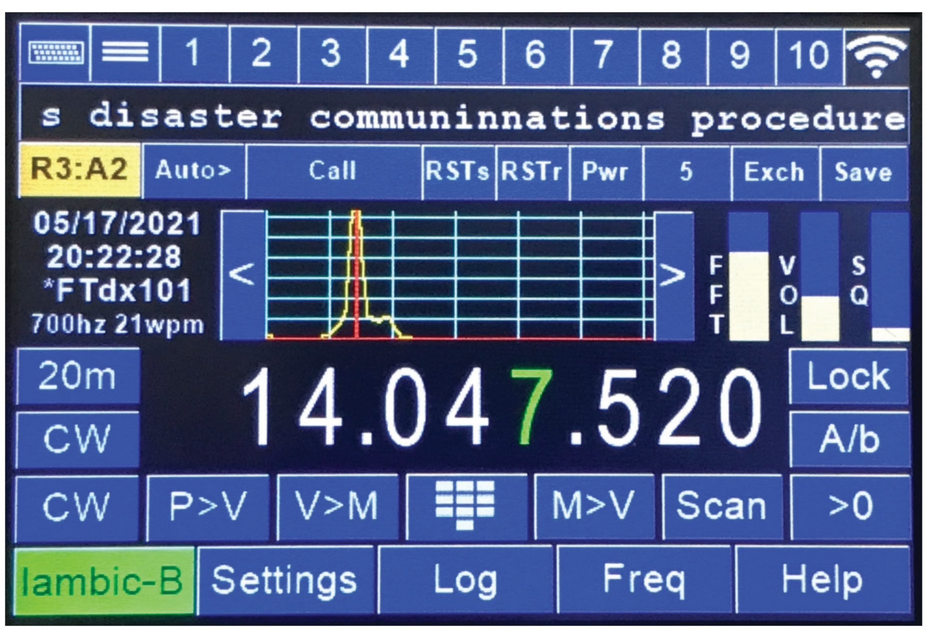

Figure 8 — Screen shot of the HMI Home page.

one 4-port extension board is installed and Port 3 is selected (my FTdx101). To select another radio just touch the numbered blue button below its caption.

To edit the caption for each port touch the black area above the numbered blue select button. This caption will be displayed on the **Home** page just below the date and time. It is also displayed when loading the radio files and when connecting to the HMI via its web server. On the **Radio Select** page you can also copy or erase a port's settings.

• Touch **[Copy]** then select one of the other ports to copy the current settings to.

• Touch **[Erase]** to erase the currently selected port.

Ports can share a common database by touching the **[SharedDB]** button. This allows every radio sharing the common database to have the same favorite frequency list, transmit buffers, band registers, and antenna settings. Changes made while the common database is selected will appear on all of the radios sharing this database. The **[R#:A#]** button on the **Home** page will be red when the common database is selected and orange when it is not.

To select antennas, touch the **[R#:A#]** or **[Band]** button on the **Home** page then touch the **[Set Ant]** button at the top of the page. The **Antenna Selection** page will open **Figure 3**. The default is to assign a single antenna for all bands. Touching the **[Band Select]** button takes you to the **Band** page **Figure 10**. This page shows the assigned antenna for each band in the small black box on each button. Selecting a band here returns you to the **[Set Ant]** page where you select the antenna for it. Continue this back and forth process until all bands have been mapped to an antenna. The HMI will now automatically switch to the selected antenna as you change bands. These settings are saved in the radio's database or the common database if you have **[ShareDB]** selected.

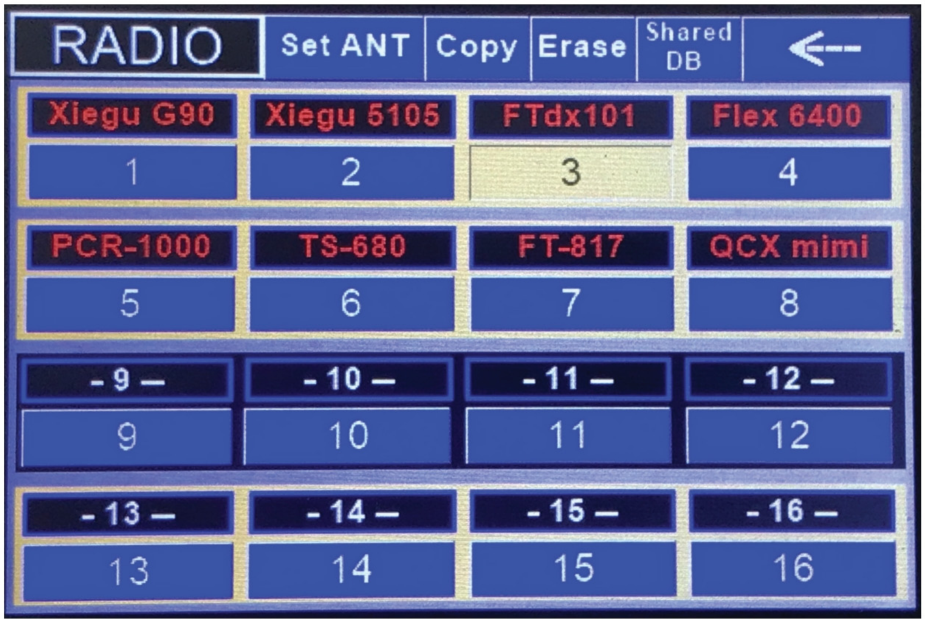

Figure 9 — Screen shot of the HMI Radio Select page.

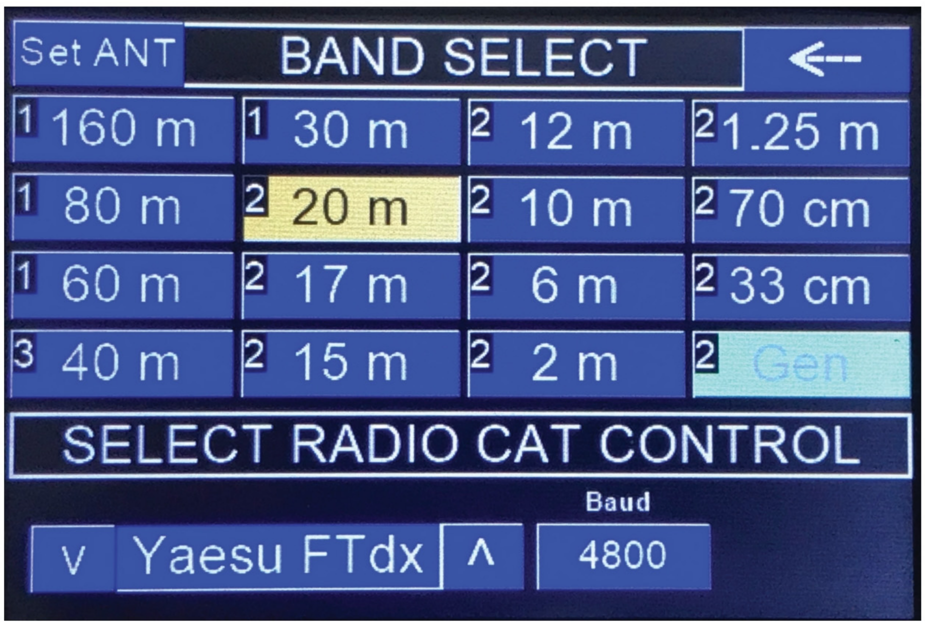

Figure 10 — Screen shot of the HMI Band page.

Wrapping It Up

You might be wondering if there is a real need for such a switching mechanism when it's relatively easy to just move your headphones, paddles, mic, remote PTT switch, antenna, and PC to the radio you want to operate. After all, you've probably been doing that for years. This is especially true if you rarely operate multiple radios. In my case I have acquired many radios during the years I've spent in this hobby and plan on acquiring a few more! I tend to keep my radios instead of selling them to buy the next flavor of the month and I still enjoy using the old ones on occasion. But technology has spoiled me. I like a lot of the features in the new radios like touch tuning, voice keying, etc., and decided to create a system that provides as many of these features as possible for my older radios.

Is CTR2 and its automation options overkill? Sure it is. But for me it's part of the fun of ham radio. It might not be for you and that's okay. I do hope that you have found something useful or inspiring in these projects. For me, DSP is no longer in the realm of magic. The **PJRC.com** Teensy ecosystem has placed DSP in the hands of us mere mortals. Use your imagination and learn how to create something that works for you.

If you manage a club station you might consider building a station controller as a club project. CTR2 board assemblies can be constructed by club members with varying skill levels. The HMI board requires the most skill whereas the switch boards are mostly mounting relays and connectors. Since every club has one or more software gurus, let them customize the HMI software to fit your needs.

The latest updates on this project including firmware, source code, and PCB/enclosure ordering information can be found on my website, **https://ctr2.lynovation.com/**. I'll also be posting features and how-to videos to my YouTube channel. Search for Lynovation.

[Photos by the author].

ARRL member Lynn Hansen, KU7Q, was first licensed in 1971 as WN7QYG at the age of 14. He achieved the Amateur Extra class level and became KU7Q in 1981 while studying for his Commercial Radio Telephone license. His amateur radio experience, several Cleveland Institute of Electronics (CIE) home-study courses, and an innate desire to learn something new every day provided a career in electronics and communications as a utility communications technician, an engineering assistant, and finally as the operations manager over a large multi-state utility communications network. Now retired, he continues to learn and apply new technologies and has time to follow his passions. This project is one of many.

Errata

QEX Nov./Dec. 2021

In George R. Steber, WB9LVI, "*NanoSSB RX – An Ultra Low Cost SSB Multiband Receiver,*" *QEX* Nov./Dec. 2021, **Figure 3**, each of the two boxes to the right of the DSP should be labeled "DAC." Thanks to Wes Plouff, AC8JF, who spotted the error.

QEX Sep./Oct. 2021

In Luiz Duarte Lopes, CT1EOJ, "*Designing an Impedance Matching Network with a Drafting Ruler and Triangle,*" *QEX* Sep./Oct. 2021, the vector **BE** in **Figure 3** lags the vector **AD**, so it is an inductor. The vector **FD** should be **DF** with the arrow pointing to **F**. This component is a capacitor. In **Figure 2** reverse the position of the components *C* and *L*. In the *Final Calculations*,

$$X_L = V_a / I_L = 122.5 / 3.62 = 33.84$$

$$X_C = V_C / I_0 = 100 / 1.414 = 70.72$$

$$L = \frac{X_L}{2\pi f} = \frac{33.84}{2\pi \times 14.215} = 0.38\ \mu\text{H}$$

$$C = \frac{1}{2\pi f X_C} = \frac{10^6}{2\pi \times 14.215 \times 70.72} = 158\ \text{pF}.$$

Finally, delete **Figure 4** and delete the section *Confirmation* and everything under it, including **Table 1**, except the last paragraph. Thanks to Frank Fusari, W8KA, who called attention to the problem.

QEX Jan./Feb. 2021

In Eric P. Nichols, KL7AJ, "*Self-Paced Essays — #3 EE Math the Easy Way,*" *QEX* Sep./Oct. 2021, p. 19, we should have referred to Beverly Dudley as Mr. Dudley. We regret the error. Thanks to Richard Clark, WQ9T, who called attention to the problem.

QEX Jul./Aug. 2016

In Gene Hinkle, K5PA, "*Radio Frequency (RF) Surge Suppressor Ratings for Transmissions into Reactive Loads*," *QEX* Jul./Aug. 2016, the missing reference is:

[8] *The Antenna Handbook*, 23rd Edition, pp. 23-13, [Eq. 18].

Thanks to Mike Zydiak, W2MJZ, for calling the omission to our attention.