

# The “At Last!” Radio TR Sequencer

*Finally, a computerized version of a radio transmit-receive sequencer you can put together.*

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One possible evolution path for any active Amateur Radio operator is to get into communications that are more demanding on equipment. Whether you get into satellite communications, or weak signal VHF and UHF communication or even dare to try earth-moon-earth (EME or moonbounce), you will undoubtedly consider equipping your radio setup with a transmit-receive (TR) sequencer.

## Why a TR Sequencer?

A TR sequencer turns radio equipment on and off in a defined sequence when going from receive to transmit mode. The sequence is reversed when going back to receive mode. A good example of this is shown in Figure 1. This setup has a receive preamplifier and bypass relays mounted at the antenna, a transverter (transmit and receive converter), an RF amplifier and an HF transceiver used as an IF subsystem. A typical receive to transmit sequence involves the following steps.

- Sequencer OUTPUT-1 switches the relays, taking the preamplifier out of the link.
- After a predetermined delay, the RF amplifier gets energized via a switch on OUTPUT-2.
- Again following a delay, the transverter gets the signal to switch from receive to transmit mode.
- Finally, once again after a delay, the IF transceiver’s PTT line is asserted, effectively sending RF up the chain, and out to the antenna.

After the transmission is over, the user releases the sequencer PTT line. This causes the sequencer to switch the radio equipment back to the receive mode, following a reverse-ordered sequence. The key point here is that the receive preamplifier must be taken out of the chain *before* transmit RF is applied and kept out until there is no RF coming from the transmitter; otherwise it may be destroyed.

A TR sequencer became a must for me after repeatedly burning out the RF transistor in my satellite VHF antenna preamplifier. While looking around on the Internet for existing designs, it became clear to me that most documented circuits are too application-specific or not versatile enough to operate in

other people’s station configurations. Some published designs have been around for quite a while and base their timing on an analog resistor-capacitor (RC) discharge circuit — not precise enough to suit me. I thought I could do better than that. If you can’t find it, design it!

## Features of the “At Last” TR Sequencer

I decided to design and build the “at last” TR sequencer in order to meet both current and future requirements. Figure 2 shows a block diagram of the system. Here is a list of its key features:

- It is a microcontroller-based approach, which brings a lot of features and flexibility into the unit. The device can easily be reconfigured as the radio setup evolves.
- The sequencer controls up to six outputs; they can be individually configured as either normally open or normally closed, or they can be disabled.
- All outputs are switched through solid-state

relays; no mechanical relays are used. Currents up to 2.5 A can be handled, depending on the solid-state relays used.

- The outputs can switch ac or dc loads of up to 30 V.
- Switching detection is fed back to the microcontroller for confirmation purposes. A timeout feature will abort the sequence if switching feedback on an output is not detected within a predefined delay.
- The sequencer Push-To-Talk (PTT) logic can be configured for either current keyed or no current keyed.
- User set delays are inserted between any two output state changes. Delays are set for both the receive to transmit and the transmit to receive sequences independently.
- While under operation, all sequencer connections to the radio equipment are isolated from the microcontroller side by the use of optical couplers.
- The sequencer provides a visual indication of each output’s state via a series of bi-color LEDs.

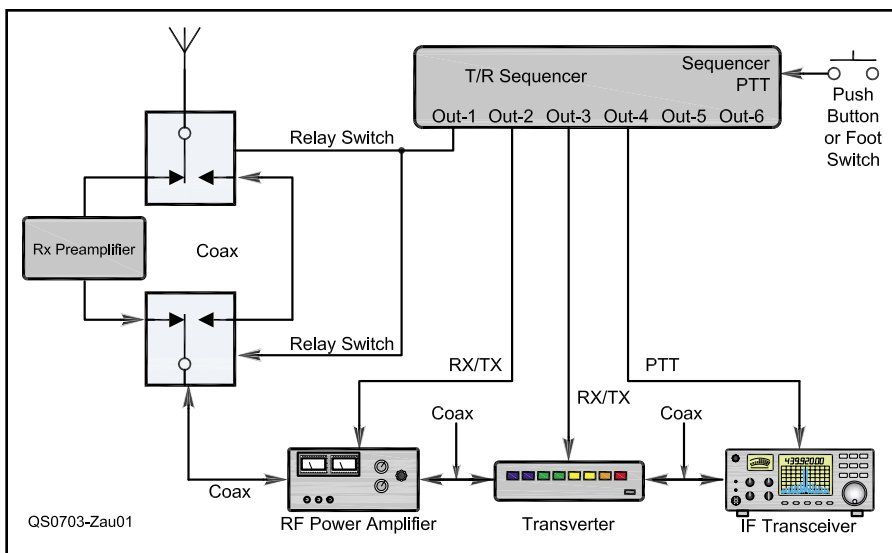


Figure 1 — A typical Amateur Radio setup requiring a TR sequencer.

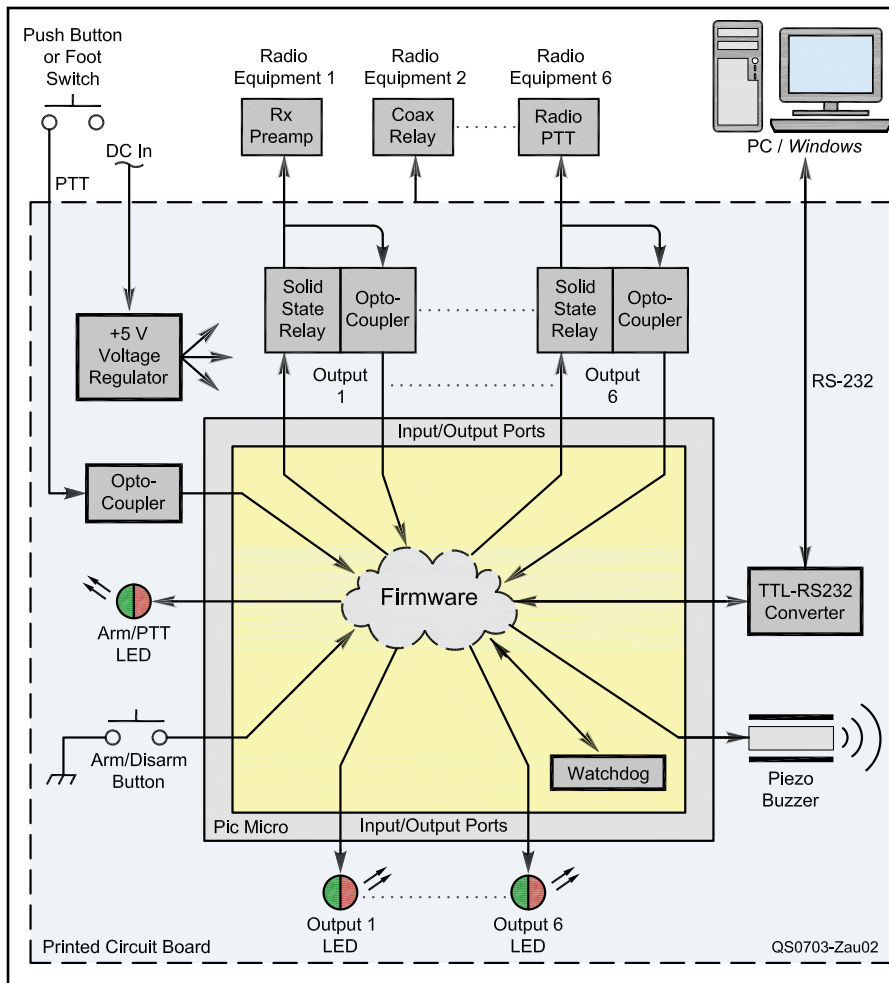


Figure 2 — Block diagram of the “At Last!” radio TR sequencer.

- It also emits various tones via a piezo sounding device at switch completion. This provides confirmation of completion, a feedback alarm and a transmit timeout alarm (more on these below).
- A hardware watchdog ensures that the outputs get promptly released if the firmware fails.
- All the electronics are integrated onto a small double-sided printed circuit board (PCB).
- A *Windows*-based software tool allows the user to configure the sequencer in a matter of minutes via an RS-232 serial link. After configuration, the personal computer (PC) is disconnected. All settings are saved in nonvolatile flash memory.

I could go on with the list of features, but instead let me explain how the sequencer hardware works.

## System Description

Figure 3 shows the system’s circuit schematic. The circuit is quite simple and easy to describe. U2, the microcontroller, does almost everything in this system. It senses the sequencer PTT line via optical coupler U1. There are six identical output and feedback circuits connected to the microcontroller. Six

bi-color LEDs indicate the six output states. A piezo sounding device, BZ1, emits various informative tones. An ARM/DISARM push button (S1) enables and disables the sequencer. Bi-color LED D14 indicates the PTT status of the sequencer system. RS-232 chip U3 does the transistor-transistor logic level (TTL) to RS-232 level conversion for PC connectivity. That is it! No RC circuits, operational amplifiers, potentiometers or mechanical relays are required.

## Outputs and Feedback

Outputs are switched using solid state relays. These are MOSFET-based “glorified” optical couplers. Their on-state insertion resistance is quite small. The output transistor arrangement allows switching ac or dc loads equally well. Since they are polarity-independent, you can switch dc loads on the high side or on the low side. Panasonic makes a series of pin-compatible AQV-2xx devices with various voltage and current handling ratings.<sup>1</sup> One of their solid state relays will switch a current up to 2.5 A and has an on-state insertion resistance of 0.1  $\Omega$ . The price range for the series is between \$2 and \$5 each, depending on the

<sup>1</sup>Notes appear on page 37.

handling limits chosen. This compares favorably with mechanical relays.

In order to detect that a switch actually occurs at an output, a switching detection (feedback) circuit is also implemented. Though optional, it is quite useful to detect a malfunction on one of the outputs. The detection device is a separate optical coupler with its input pins connected in parallel with the relay’s output pins through a current-limiting resistor. Under an open-circuit state, the load, while not switched on, still provides enough current (1 mA minimum) to turn on the feedback optical coupler. This signals to the microcontroller that the output is open. When the solid-state relay is switched to a closed-circuit state, the voltage developed across the solid state relay becomes insufficient to turn on the detection optical coupler. The microcontroller detects this change of state. Two output checks are performed — prior to switching and after switching. If either of the two checks fails to match the expected state, the sequencer will declare a fault on that output and stop processing any sequence until the system is disarmed. This protects the radio equipment from any violation of sequencing order.

Note that the sequencer PCB can be populated with fewer than six outputs. The unpopulated output(s) are disabled using the *Windows* setup tool. In any case, the user will populate output solid-state relays and corresponding optical couplers starting with output-1 and then incrementing up to the last desired output.

## Output and Status LEDs

Since the number of pins on the microcontroller is limited, I had to find a way to control the bi-color LEDs with only one output pin per LED. The classic approach would have been to use a resistive voltage divider to set one pin of the LED at midpoint between 0 V and +5 V. The other LED pin could be toggled between high and low via the microcontroller to set the color. Resistive voltage dividers always pass current, wasting energy as heat. I have come up with a neater way of doing this. I use two reverse biased Zener diodes. The Zener voltage of two of these diodes in series (6.6 V) is higher than the 5 V bias across them. This means that in an idle condition, the diodes only partially conduct. This saves power. When the microcontroller pin is set high or low, only one of the two Zener diodes will conduct, setting a 3.3 V reference for the LED to operate. In total, seven LEDs are controlled with this approach.

## Piezoelectric Sounding Device

Provision is made for a piezo sounding device (BZ1), also called a transducer. Although not essential, this is a useful addition to the sequencer since it provides a few status and alarm tones (see the Operation section for more detail). The sounding device

**Table 1**

**Parts List for “At Last” Sequencer**

Digikey ([www.digikey.com](http://www.digikey.com)) catalog numbers are shown unless otherwise noted.

BZ1 — CEM-1206S piezo transducer (102-1155-ND).

C1-C3, C10, C11 — 0.1  $\mu$ F, 25 V or higher, radial (478-3187-ND or equivalent).

C4-C7 — 1  $\mu$ F, 16 V or higher, electrolytic, radial (P1196-ND or equivalent).

C8 — 10  $\mu$ F, 25 V or higher, electrolytic, radial (P1176-ND or equivalent).

C9 — 0.01  $\mu$ F, 25 V or higher, radial (478-3179-ND or equivalent).

D1, D2, D4, D5, D7 D8, D10, D11, D13, D15-D17, D19, D20 — 1N5226B, 3.3 V Zener diode, DO-35 package (1N5226B-TPCT-ND or equivalent).

D3, D6, D9, D12, D14, D18, D21 — Bi-color (green-red) LED, two leads. (160-1058-ND or equivalent).

JP1 — Terminal block, 6-position screw-in type, 5 mm pitch (ED2223-ND or equivalent).

JP2 — Terminal block, 12-position screw-in type, 5 mm pitch (ED2226-ND or equivalent).

R1, R13, R14, R17, R18, R21, R22 — 4.7 k $\Omega$ , 1/4 W, axial (P4.7KBACT-ND or equivalent).

R2 — 47 k $\Omega$ , 1/4 W, axial (P47KBACT-ND or equivalent).

R3-R8, R10 — 68  $\Omega$ , 1/4 W, axial (P68BACT-ND or equivalent).

R11, R12, R15, R16, R19, R20 — 470  $\Omega$ , 1/4 W, axial (P470BACT-ND or equivalent).

R9 — 100  $\Omega$ , 1/4 W, axial (P100BACT-ND or equivalent).

S1 — Momentary push-button, SPST, normally open (450-1109-ND or equivalent).

U1, U6, U7, U10, U11, U14, U15 — Lumen OCP-PCT124 opto-coupler, DIP-4 package (67-1564-5-ND).

U2 — Microchip PIC18F2220 microcontroller, DIP-28/0.3 inch package, programmed part (PIC18F2220-I/SP-ND). See Notes 3 and 4.

U3 — MAX232 conversion chip, DIP-16 package (296-1402-5-ND).

U4, U5, U8, U9, U12, U13 — Panasonic AQV-2xx family solid state relay, DIP-6 package. See text and footnote 2. (255-1418-5-ND or 255-1791-5-ND).

VR1 — 7805 Voltage Regulator, TO-220 package (LM7805CT-ND or equivalent).

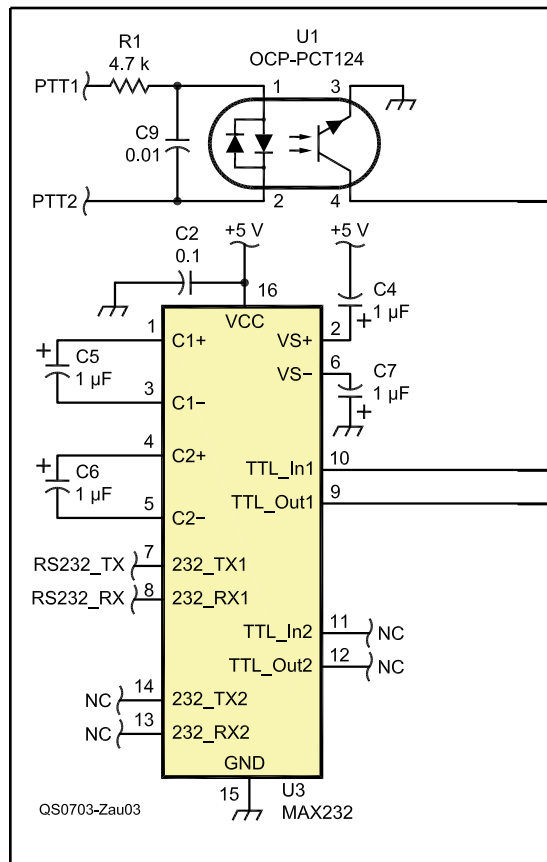
Socket for U2 — IC Socket, 28-pin, 0.3 inch spacing, low profile, recommended (ED3128-ND or equivalent).

Socket for U3 — IC Socket, 16-pin, 0.3 inch spacing, low profile, optional (ED3116-ND or equivalent).

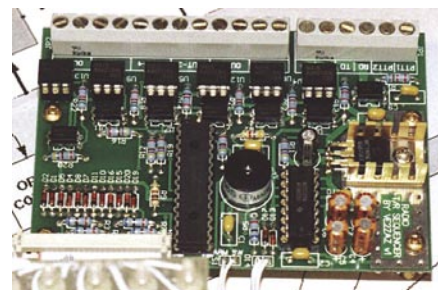
Sockets for U1, U6, U7, U10, U11, U14, U15 — IC socket, 4-pin, 0.3 inch spacing, low profile, optional (ED3108-ND or equivalent. Shorten socket with heated hobby knife blade).

Sockets for U4, U5, U8, U9, U12, U13 — IC socket, 6-pin, 0.3 inch spacing, low profile, recommended (ED3108-ND or equivalent. Shorten socket with heated hobby knife blade).

Heatsink for VR1 — TO-220 compact heatsink, recommended (HS107-ND or equivalent).



**Figure 3 — Circuit schematic of the “At Last!” radio TR sequencer.**



**Figure 4 — The assembled “At Last!” TR sequencer board ready to be installed in an enclosure.**

is excited by the microcontroller pulse width modulated (PWM) output through a current-limiting resistor.

**Serial Port**

A serial port is also implemented to configure the TR sequencer using a Windows-based PC. The serial port will connect directly to a PC’s RS-232 port. A MAX232 chip solution (U3) is used in the system. The RS-232 provided is of the three-wire transmit data (TXD), receive data (RXD) and ground (GND) configuration.

**Voltage Regulator**

In order to guarantee a more stable and cleaner voltage supply to the circuitry, a +5 V dc fixed voltage on-board regulator, VR1, is included. A small heat sink is recommended on the regulator since the board could potentially draw over 100 mA when all outputs are closed. This could make the regulator become quite hot if no heat sink is used.

**Printed Circuit Board**

I designed a double-sided PCB to integrate the hardware.<sup>2</sup> Its dimensions are 2.7

× 3.9 inches. Integrated circuit (IC) sockets are optional, but recommended. This is especially applicable to the microcontroller and the output solid-state relays. A fine tip soldering iron should be used for all components except terminal blocks JP1 and JP2, which require more heat.

The user may elect to build the circuit using other techniques, such as breadboard and point to point wiring. The layout is not critical since there are no high-speed signals. Care should be taken in proper dc supply decoupling near the ICs. Wire gauge for the solid-state relays should be selected to carry the current required by the outputs.

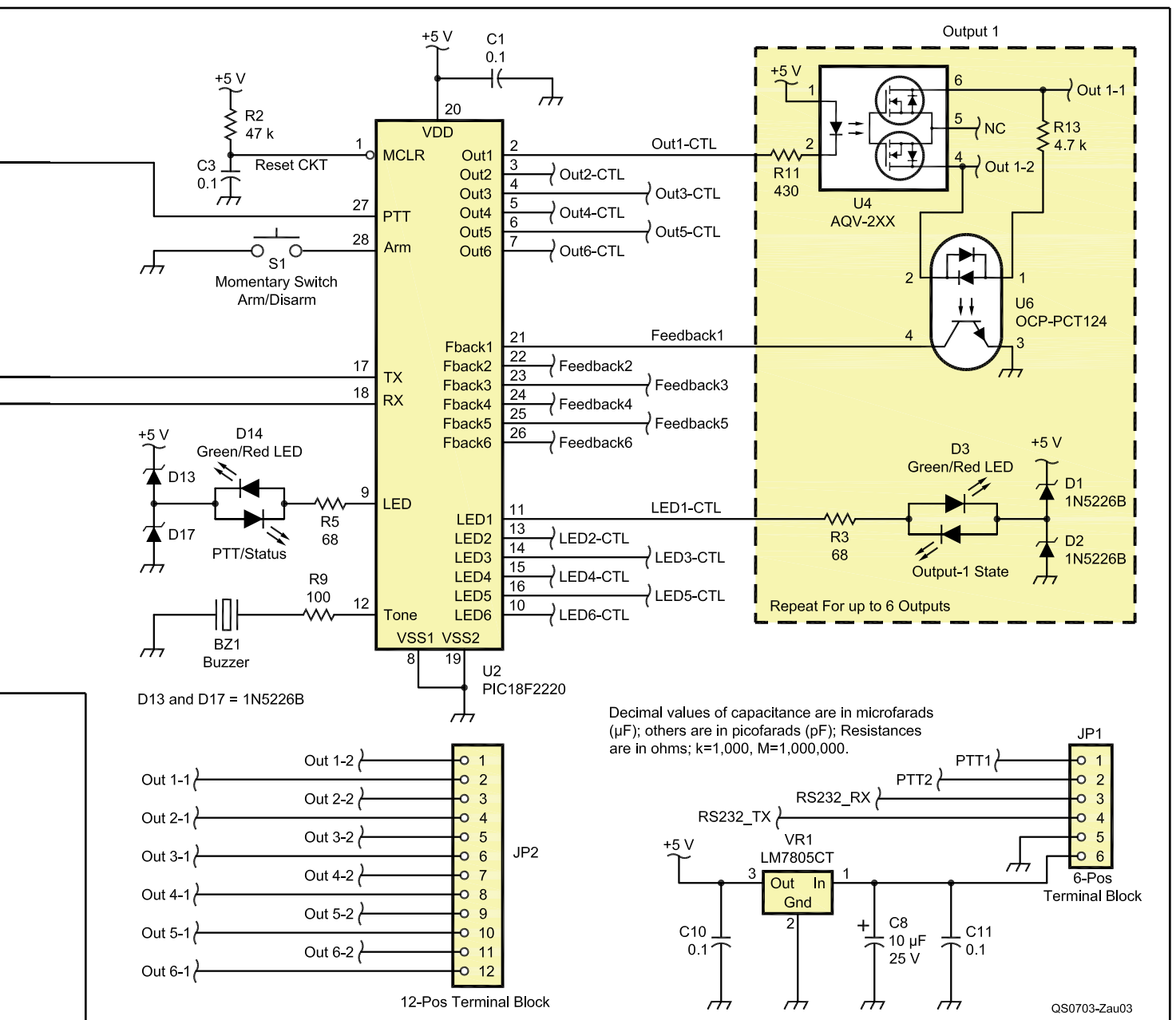
Figure 4 shows the assembled sequencer board. The unit is now ready to be installed into an enclosure.

**Enclosure**

The lead photo shows how I enclosed my sequencer board. I used a recycled Ethernet hub enclosure. Since we are dealing with RF energy in the shack (alas, sometimes too much!), there is always a risk of excessive RF current disturbing electronics. Despite the fact that inputs and outputs are opti-

cally isolated, which reduces the amount of RF current flowing on the sequencer board, remember that nothing is totally immune to high levels of RF energy. Thus the following recommendations apply:

- Consider mounting the PCB in a metallic enclosure. This should suit most applications anyway. Note that the PCB terminal strips are designed to protrude outside of the enclosure through a thin slot.
- Another precaution is to use a separate floating dc supply for the sequencer. A wall cube with appropriate rating will be fine.
- Some other filtering techniques (ferrite cores, feedthrough capacitors, etc) could also be implemented here but this applies



to any high RF energy environment and is beyond the scope of this article.

## Firmware

The firmware (embedded software) running on the PIC microcontroller was written in assembly language. It is well documented in the source code file. Both the firmware source code and the assembled hex code can be downloaded from my Web site or the ARRLWeb.<sup>3,4</sup> Once assembled, the hex code takes about 2 kB of flash memory space.

## Hardware Setup Sequencer PTT Line

For the sequencer PTT line, the idea is to pass a dc current of at least 1 mA between the PTT1 and PTT2 terminals. This current will

turn on the optical coupler and transition the sequencer to the alternate (transmit or receive) mode. As with any PTT line, this current must be maintained in order to keep the sequencer in the same mode. The direction of that current does not matter, as seen in Figure 5A and B. An on-board resistor will limit the current in such a way that any dc voltage between 5 V and 30 V will trigger the sequencer PTT line.

## Output Wiring

Wiring the output terminals is not complicated either. Referring to Figure 5C, D and E, we notice that an output is wired in the same way as a mechanical relay, in series with the signal to control. Once again, the direction of the current does not matter. Even an ac load can be handled. I will warn you, though, not to switch a 120 V ac line. The PCB is not

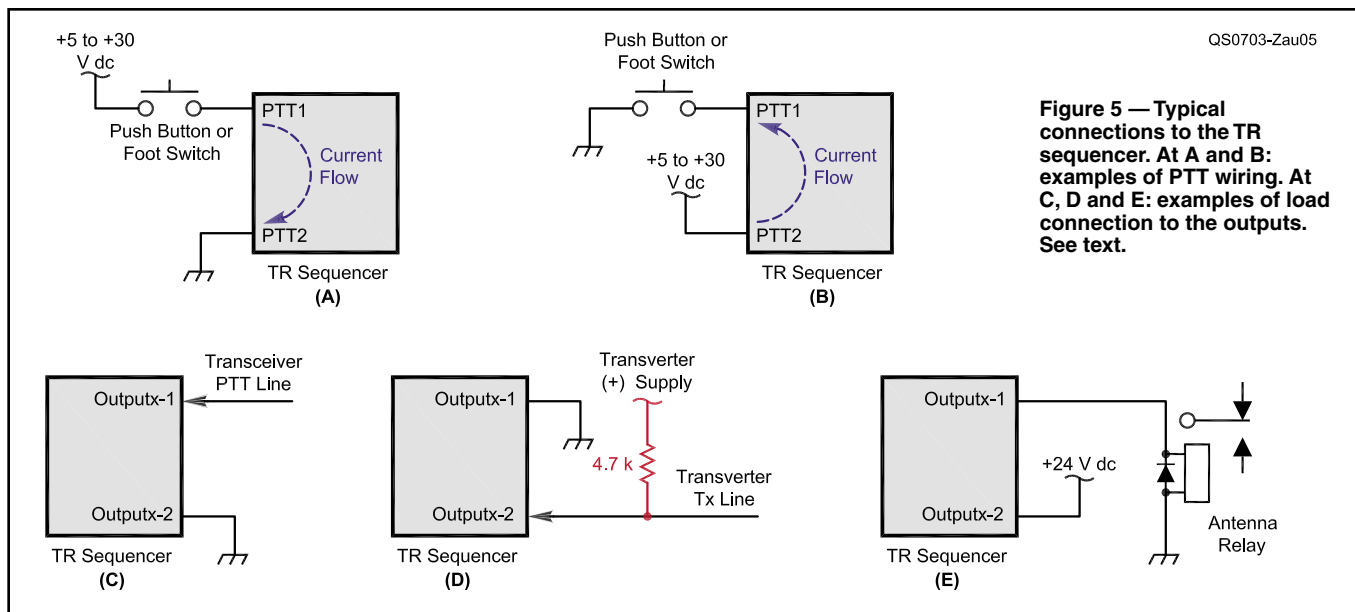
designed to be capable of switching that.

Obviously, you will want to make sure that the solid-state relay populated on an output has the proper current and voltage ratings for the load connected to it.<sup>5</sup>

Some controlled signals may have a very high impedance. This would be the case with a FET transistor gate input. As a result, these signals may not be able to provide the 1 mA required to operate the switching feedback circuit. An external resistor can be added in parallel with the load to provide a current path for the sensing optical coupler, as shown in Figure 5D.

## Direct Current Supply

As mentioned above, to benefit from total dc isolation, a separate dc power line to the sequencer board must be used. A wall cube



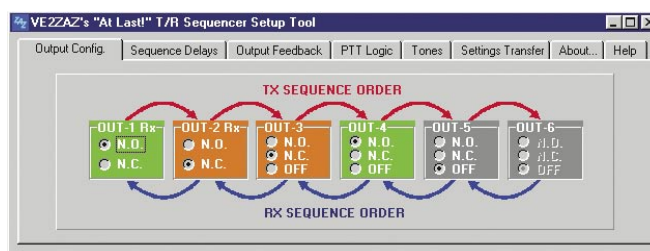
**Figure 5 — Typical connections to the TR sequencer. At A and B: examples of PTT wiring. At C, D and E: examples of load connection to the outputs. See text.**

with an output from +8 to +20 V dc and able to provide at least 200 mA will be fine for this application.

### Firmware Configuration

In order to make the man-machine interface more friendly, I have created a *Windows* program to configure the TR sequencer. The compiled *Windows* software is available for download from my Web site. This is a non-contaminating program; no DLLs are added and no *Windows* registry changes are made at installation time. A snapshot of the software window is shown as Figure 6. As seen in the figure, the tool is tab-based with features distributed over several tabs.

- The first tab provides the ability to set the number of output channels to control and to set the default output states in receive mode, either normally open or normally closed.
- The next tab sets the time delay between two output switches, with independent delays for the receive to transmit and transmit to receive sequences. Delays can be set from 20 ms to 1 s each.
- Another tab allows the user to enable or disable the switching feedback feature for each output.
- A tab provides control over the PTT logic that triggers a transition from receive to transmit modes between current keyed and not current keyed.
- The final setup tab deals with the various tones that the sequencer can produce. The user can enable or disable the switching tones, the switching feedback alarm tone and the timeout tone. The timeout tone feature also has a timeout delay setting with ranges from 30 s to 10 minutes, in increments of 30 s.
- There is a settings transfer tab from which



**Figure 6 — The “At Last!” TR sequencer configuration software window.**

you will be able to read the current settings from the sequencer or write new settings to it.

After selecting the PC COM port, reading from or writing to the sequencer is just a matter of pressing a button. A progress bar informs you of the status of the transfer. Everything completes in a matter of a few seconds. When reading settings from the sequencer, all fields in the various tabs get updated with the current sequencer settings. This means that a change to only one setting involves a read-modify-write process. There is nothing special to perform in order to save the data to non-volatile memory. A WRITE SETTINGS command will permanently save the data inside the microcontroller. After configuration is complete, the user will want to disconnect the cable; this is important to preserve the dc isolation feature of the sequencer since the RS-232 line offers no galvanic isolation.

### Operation Power-Up State

Upon power up, all outputs default to a floating state (normally open). They will remain in that state until the sequencer is armed by the user. All LEDs are dimmed indicating that the sequencer is disarmed. The output LEDs show two colors — green for outputs

configured in normally open state and amber for outputs configured in normally closed state. Since the outputs are still floating at this point, this gives the user a chance to review the current sequencer configuration before operating the outputs. Also to be noted is that the LEDs assigned to the unused outputs are turned off and they will remain off at all times. The PTT status LED (D14) is also dimmed. Its color shows green since we are in receive mode. If the user triggers the sequencer PTT while in disarmed state, the status LED will turn amber (transmit mode) and the output LEDs will simulate the sequence; LEDs transition from green to amber or from amber to green following an OUTPUT-1 to OUTPUT-6 order, with the proper delays inserted between the outputs. The sequence simulation reverses when the sequencer PTT is released.

### Arming Process

The next action for the user is to depress the ARM/DISARM button once. This signals the sequencer to transition to an armed state. The arming process enables the outputs in a reverse sequence order, OUTPUT-6 first, OUTPUT-1 last. User-defined delays are inserted also during the arming process. When all output LEDs turn to full brightness, the sequencer is armed. The output states will have adopted the user configuration and

will match LED colors, once again, green for outputs configured in normally open state and amber for outputs configured in normally closed state. Note that the arming process is denied unless the sequencer is in receive mode.

### Output Sequencing

From that point on, feeding a current into the sequencer PTT will initiate a receive to transmit sequence. Outputs will switch states starting with OUTPUT-1 and ending with the last enabled output. User-defined delays are inserted between switches during the sequence. Releasing the sequencer PTT will initiate a transmit to receive sequence. Outputs will switch back to receive state starting with the last enabled output and ending with OUTPUT-1. Note that if the sequencer PTT is released before the transmit sequence is over, the system will simply transition to a receive sequence, starting with the output where the transmit sequence aborted. Once again, user defined delays are inserted between switches during the sequence.

### Switching Feedback

One key feature is output switching detection (feedback). In a nutshell, the sequencer will not process the next output until the switch has been detected on the current output. The sequencer will wait for switch detection a maximum of 200 ms, after which it will abort the sequence and turn the corresponding channel LED red. The sequencer will not proceed to the next output until the problem is resolved. This switching feedback works in both the receive to transmit and transmit to receive sequences. A high pitch alarm tone will also sound to signal the alarmed state.

Switching feedback can be enabled or disabled on a per output basis by the user via the *Windows* setup tool.

### Switching Tones

Another useful feature is the generation of tones (beeps) that provide an audible confirmation that output switching actually occurs. The sequencer generates 10 ms beeps of increasing pitch after each output is switched. When the sequence is over, a 40 ms tone is emitted to tell the user that she can start sending information (voice, CW, etc). Note that if switching feedback is enabled for an output, the tone will sound only after feedback is detected for that output.

The switching tone feature can be enabled or disabled by the user via the *Windows* setup tool.

### Feedback Alarm Tone

This feature will sound a 2400 Hz tone of approximately 1 s duration whenever switching detection (feedback) fails on one of the outputs. Again, the feature can be enabled

or disabled by the user via the *Windows* setup tool.

### Timeout Tone

One nice feature is the timeout timer with tone alert. You can enable a timer that will increment whenever the sequencer is in transmit mode. After a user defined delay, the timeout tone will sound. This feature has a few applications. For example, some people do not want to extend their transmission for more than a certain amount of time, so this feature will let them know that the transmission time is expired. Another use of the timeout tone would be to alert the user if the system is inadvertently put in transmit mode. I have personally experienced that. Was the linear amplifier heat sink hot? I'll say!

### Disarming Process

When the sequencer is armed, depressing the ARM/DISARM button once will signal the TR sequencer to transition to disarmed state. Disarming is performed in a reversed fashion from the arming process. This means that OUTPUT-1 will be the first one to go floating, and so on. Note that disarming can be invoked in any condition, and even if the sequencer is in transmit mode. Once the sequencer is disarmed, all LEDs turn dimmed.

### Some Caution Required

In spite of all the care put into the sequencer, overall system robustness is highly dependent on how the communication system is wired and sequenced. I strongly recommend that you implement the following rules:

Use current keyed PTT (applying a current at the sequencer PTT triggers a transition to the transmit mode). Even though I provide the ability to configure the PTT to no current keyed, I do not recommend it. Any PTT failure or power loss would put the system in transmit mode — bad!

Control any RF generating device with normally open output logic. Do not use normally-closed logic with such devices. In an incorrect setup, a transceiver will go in transmit mode if the assigned sequencer output is in open state. To figure the risk, think about what will happen if you turn off the sequencer! Use normally closed output logic for receiving devices only (preamplifiers, antenna relays energized in receive mode, etc).

Use long enough delays between output switches. Don't try to tweak it down to the last millisecond in the sequence. Remember that some devices don't always take the same amount of time to switch. Give yourself plenty of margin.

Be very careful as some radio equipment (transceivers, transverters, amplifiers) briefly transmit RF when turned on or when transitioning to the transmit mode.

The bottom line rule of thumb is that

the system should be fully idle when the sequencer is disarmed or turned off. By fully idle, I mean no active source of RF energy, preamplifier bypassed, etc. Failure to meet this rule could have destructive consequences on sensitive devices such as preamps or receive converters. Another impact of not meeting this rule is the risk of interfering with other ham contacts due to unintentional transmissions, should any part of the control system fail.

### Conclusion

This TR sequencer is quite an improvement over earlier RC driven analog designs. It is easy to (re)configure and fun to operate. Finally, you can build a processor based unit that is reliable, truly universal and versatile enough to be used in almost any Amateur Radio application.

Assuming a reasonably stuffed junk box, you will be able to assemble and own the TR sequencer for around \$75. And no longer will you be scared of blowing up your tower-mounted preamp or receive converter!

### Notes


<sup>1</sup>Panasonic's Aqv-2xx devices offer various voltage and current handling ratings. A suggested device for currents of less than 130 mA is Aqv-210HL. Use Aqv-252G for currents up to 2.5 A. The user can substitute any of the Aqv-2xx series devices since they are pin-compatible.

<sup>2</sup>I distribute high quality, fully etched plated-through bare PCBs for this project. Please contact me via e-mail if you are interested in obtaining a PCB. I am also making the PCB layout files available in .pdf form on my Web site. Printing them in a 1:1 scale will give accurate printouts.

<sup>3</sup>I maintain a Web site where I provide updates to this project, source files and additional comments. Please visit [www3.sympatico.ca/b.zauhar](http://www3.sympatico.ca/b.zauhar) for more detail. A copy of all software and firmware is also available at [www.arri.org/files/qst-binaries/zauhar0307.zip](http://www.arri.org/files/qst-binaries/zauhar0307.zip).

<sup>4</sup>For those of you who cannot program Microchip PIC18F series microcontrollers, I have made pre-programmed PIC microcontrollers available for purchase. Please contact me via e-mail for more detail.

<sup>5</sup>See Note 1.

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