An Even More Fool-Resistant Conditional Sequencer

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I've started building some new microwave transverters and find that I have all the pieces except for the sequencers. Back in 1997, I designed the "Fool-Resistant Sequencer[1]," built a bunch of them, and have been using them successfully since in various transverters. In that time, I have only had one preamp failure, and that wasn't while operating. But I have run out of the boards, so I must do something for more sequencers.

Since the original design was rather cramped and difficult to build, it was time to finally update the design and add some improvements. When I started thinking about this project a couple of years ago, I had also asked for suggestions on the microwave reflector and have incorporated some of those ideas.

This certainly isn't the only sequencer design available – a number have been published. However, I believe there is still a need – there seem to be blown preamps on the EME reflector nearly every activity period. And particularly a need for one that is fool-proof. However, nothing is fool-proof – there is always a more clever fool – so we can only try to make it more fool-resistant.

Design

The function of a sequencer is to operate things in a particular order, so that nothing blows up. Most important is that a power amplifier should not be activated until the TR switch, usually a coax relay or waveguide switch, has completed operation and connected the amplifier to the antenna. Not only does this prevent damage to the amplifer from high VSWR, it also protects the relay and the receive preamp. Most relays can only handle a small amount of power during switching, and isolation is much lower while switching, even for waveguide switches.

This design is called a conditional sequencer because it does not just proceed sequentially, but requires that appropriate conditions are met before moving to the next action – a sequential state machine. For instance, many coaxial relays have auxiliary contacts which can be used to sense that the relay has operated successfully. This sequencer may be configured to wait until the auxiliary contacts have closed before applying power to the power amplifier, thus eliminating any possibility that the PA sees a load other than the antenna. Provisions for other conditions are also included.

One feature that makes this design fool-resistant is that it incorporates an IF interface and PIN-diode switch which not only reduces transmit power as needed, but also absorbs all RF power until the switching sequence is complete, so that neither the receive nor the transmit sections of a transverter see any unwanted RF. RF sensing assures that the PIN switch absorbs unwanted power at any time.

Another fool-resistant provision is that all external connections are made through optoisolators. If wired correctly, these can provide several KV of isolation – enough to prevent damage from most mistakes.

Finally, I put a good deal of effort into making this unit easier to build, since I will probably build a number of them for myself. Components have old-fashioned leads, and are arranged in a regular pattern on the PC board with silk-screen labels so they are easily located. The RF switch part of the IF interface is spaced away from the logic and control section – the board could easily be cut in two and the sections separated. Some applications might not need the RF switch section.

The desired switching sequence is shown in Figure 1, with nominal delays. The delay times may be extended if waiting for a conditional input; if the condition is satisfied before the delay is completed, then only the nominal delay will happen.

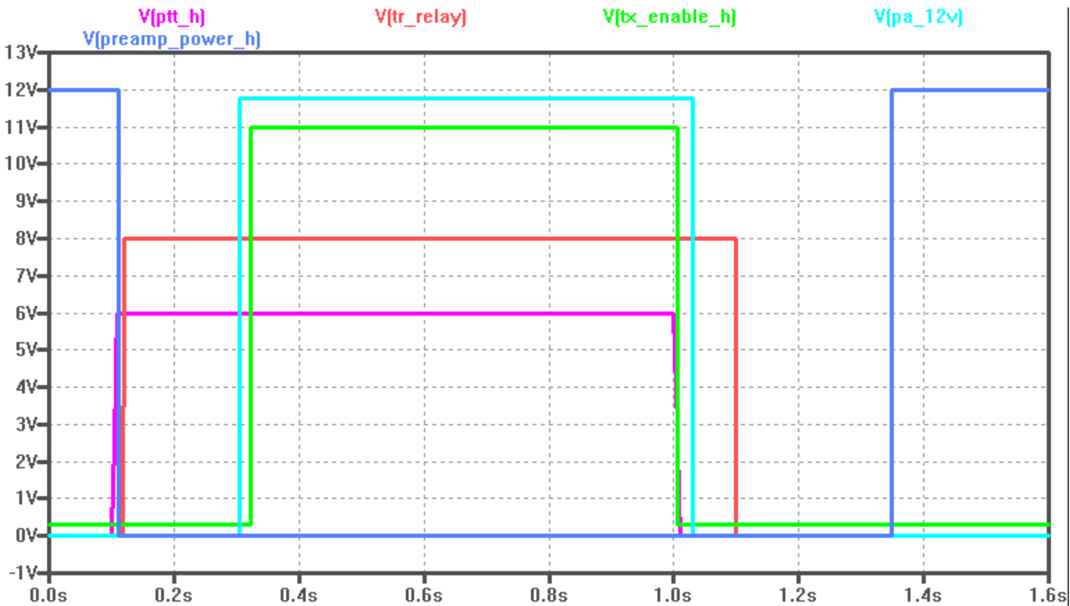

Figure 1 - Sequencer Timing

What we see in the waveforms:

1. PTT is actuated. Preamp power is removed and the PIN switch immediately disables the receive path so that any RF power from the IF transceiver is dumped into a load.

2. After a few milliseconds, switching of the TR relay is initiated.

3. Wait for TR relay to operate (nominal 250 ms), and for two conditional inputs: AUXILIARY CONTACTS (**TRC)** and AMPLIFIER READY (**AMP**). Then PA power is turned on. **EXT** output is also enabled, for TWT amplifiers that require a more complicated sequence.

4. Wait for PA power to stabilize (nominal 100 ms for solid-state), and for conditional input **EXT READY** (high power amps may require more time). Then Transmit is Enabled in the PIN switch and the **INHIBIT** output is released.

NOTE: Failure to hold the PTT will terminate this sequence before transmitting.

5. After making a transmission, the PTT is released. The PIN switch immediately disables the transmit path, dumping any residual RF, and actuates the **INHIBIT** output.

6. After a few milliseconds, PA power is removed and **EXT** output is disabled.

7. Wait for PA power to drop (nominal 50 ms), then initiate switching of TR relay.

8. Wait for TR relay to operate (nominal 250 ms). Then preamp power is applied and the PIN switch enables receive.

The important things are that while the TR relay is switching, no RF is passed to the transverter and neither the preamp nor the power amplifier are powered.

Technology

The tendency today is to computerize everything – small processor chips are amazingly inexpensive. They can be programmed to perform nearly any desired function. They appear to be an attractive possibility, if one meets my requirements.

My goals included:

1. Parts readily available everywhere, and will be for at least another ten years.
2. RF resistant – will operate in a high-RF environment.
3. Easy to assemble.
4. Inexpensive.
5. Flexible – easily configured as desired.
6. Rugged, tolerant of abuse.
7. Design can be simulated, proven, and tweaked before building.

Many of the latest chips seem to become obsolete or hard to find rather quickly. Some of them come in tiny packages that can be difficult to work with, and they use transistors with modern geometries that respond at hundreds or thousands of MHz. So, I chose to use traditional technologies that met my objectives better.

In the original fool-resistant sequencer, I used CMOS logic and discrete transistors. Both of these are used in many applications, so they promise to be available for some time, although availability of the CMOS logic is becoming more limited. Another problem is that I relied on the CMOS gate threshold to control delay times, but the threshold voltage is not tightly controlled and may be temperature-sensitive.

Since then, I have found that integrated-circuit comparators with a good reference voltage will switch consistently, so that they can be used to generate a predictable time delay. Even better, a comparator with an open-collector output can also replace some of the discrete transistors. Finally, a full set of logic functions, needed for the conditional sequencer, can be implemented by adding diode logic.

The most common comparator with an open-collector output, the LM339 (quad) or LM393 (dual), has been around for at least 30 years and is used in myriad applications. It is still manufactured in volumes high enough to be profitable for several manufacturers, and should continue to be for at least 10 or 20 years. The old IC geometry will only operate at relatively low frequencies, so they are pretty RF resistant. Other traditional components: resistors, capacitors, diodes, and transistors, will also be available for a long time. The only slightly unique part, PIN diodes, will be needed for RF switching in many "wireless" applications; however, they are already becoming hard to find with leads, so we may need to use surface-mount packages, which are readily available. All of these parts are also really cheap, and are available almost anywhere, certainly anywhere with postal service.

What we give up with this traditional approach is the easy programmability of a microprocessor – if you have that capability. Many hams don't, and would be limited to buying pre-programmed chips. And someone would have to program and distribute them.

The PC board approach with discrete components has some flexibility and programmability. I have planned for some options, and others can be added with a soldering iron and perhaps an X-Acto knife. And it isn't any bigger than a PC board using a microprocessor – most of the board area and periphery is used for external connections, through optoisolators, and connectors

Finally, a circuit with discrete parts is easy to simulate. Draw the schematic using LTSpice software (free at www.linear.com) and then use the software to simulate operation. For this circuit, you can simply download my schematic and run it. I used LTSpice to trim the delay times, to check voltages and currents, and to make some improvements. If you have an idea for a modification, you can test it quickly before hacking up hardware.

Features

Fool-resistance:

- RF absorbing PIN-diode IF switch absorbs all IF power until switching sequence is complete and transmit is enabled.
- Conditional sequencer waits for external inputs to be ready before continuing.
- External inputs and outputs isolated by optoisolators
- Inhibit output to control IF transceiver output
- Idiot diode on DC power input.

Conditional sequencer:

- Basic timing plus conditional inputs
- Amplifier Ready input (**AMP)**
- TR relay auxiliary contacts (**TRC**)
- External sequence start output (**EXT**), ready input (**EXT RDY)**
- all conditions optional, more can be added.

IF interface:

- Attenuates transmit power, amplifies on receive to make up for attenuation, absorbs all IF power until switching sequence is complete and transmit is enabled.
- Works with many IF rigs and frequencies, configurable for different power levels from <100 mW to 10 watts.
- Configurable for single or combined transmit and receive on both IF and transverter side.
- **INHIBIT** output to control IF transceiver output

Outputs:

- RF at mixer level to transverter
- TR relay driver
- +12V switched for power amplifier
- +12V for preamp
- DPDT relay contacts uncommitted and available
- **INHIBIT** output to control IF transceiver output

Flexibility:

- PTT level can be either GND to XMIT (**L**) or +V to XMIT (**H**)
- PTT through IF coax, selectable polarity
- TR relay can be active on either transmit or receive
- Transfer relay option for bi-directional amplifier
- Uncommitted DPDT relay available for any function, any timing.
- Conditional sequencer inputs may have other functions
- External sequence start output, ready input
- Works with many IF rigs and frequencies, configurable for different power levels from <100 mW to 10 watts.
- Configurable for single or combined transmit and receive on both IF and transverter side.

RF sensing

- Can use RF sensing for TR switching – no PTT required
- Can be used as fail-safe only – no transmit without PTT

PC board: Components placed in regular pattern and identified with silk screen.

Connectors: All connections can use low-cost connectors or be wired directly.

Low cost: All parts cheap, total parts ~$20

Circuit

The schematic diagram is shown in Figure 2. I've tried to identify functional blocks.

The sequencer uses a number of comparator ICs. A comparator compares the two inputs and switches the output accordingly – if the + input is more positive than the – input, then the output is high. Otherwise, if the + input is less positive than the – input, then the output is low. If both outputs are the same, the high gain of the comparator will find some noise and switch back and forth, appearing to be oscillating.

The LM393 dual comparator has open-collector outputs – it only pulls the output low, and releases it high, so a load resistor is needed to pull the output up. If we put a capacitor in parallel with the load resistor, it will slow the risetime of the output by the RC time constant (Rohms * Cfarads), which is the time for the voltage to reach 63% of the final value.

In the sequencer, the comparators have a reference voltage of 2.5 volts on one input, so they switch when the voltage on the other input exceeds 2.5 volts. Since the supply voltage on the RC load is 6 volts, the voltage only need reach 2.5/6 = 41% of the final value before the comparator switches. This only takes 54% of the RC time constant, R*C. If you must work it out for yourself:

$$V(t)=1-e^{t/RC}$$

Example: 10,000Ω * 22μF = 220 milliseconds. Switching time = 220 * .54 = 119 msec.

Transmit

The first comparator, U1b, detects the PTT, switching when either the PTT_L input goes below about 1 volts, or the PTT_H goes above about 3 volts. With no input, pullup and pulldown resistors hold the comparator off.

The output of U1b, named **TX_sense_L** (the L indicates that the signal is TRUE when low), drives comparator U2b, which provides hysteresis to reduce switching chatter. The comparator with hysteresis does not switch on and off at the same voltage – a higher voltage is needed to switch on than to switch off, so that the PTT must be definitely held before the sequencer starts to operate. If jumper J6 is closed, then RF switching by the RF sense circuit is also enabled.

The RF sense circuit steals a little of the transmit power from the IF through C17, then rectifies it with D6 and D7 to turn on transistor Q5. Capacitor C19 provides some hold time to prevent chatter on SSB; it might need to be larger for slow CW.

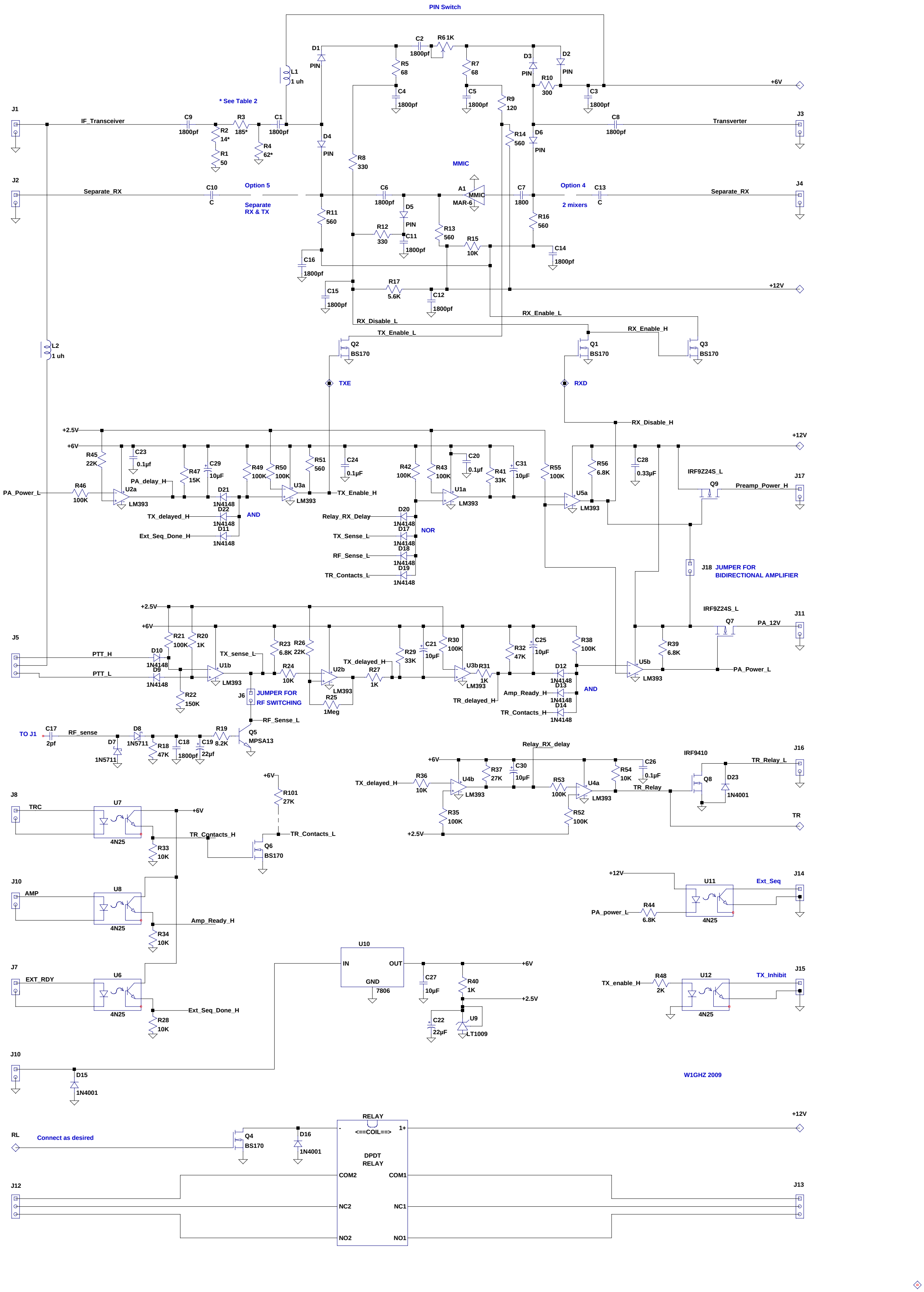

Figure 2 - Schematic Diagram

Either the output of U1b, **TX_sense_L**, or the output of the RF sense circuit, **RF_Sense_L**, whichever occurs first, also drive comparator U1a through a diode NOR gate. U1a in turn drives comparator U5a which activates the **RX _Disable** section of the PIN diode switch and turns off FET Q9, removing power from the receive amplifiers.

The output of U2b is delayed for a short time by R29 and C21 to allow the **RX_disable** to complete before starting the TR relay. The delayed signal, **TX_delayed_H,** drives U4b which drives U4a which turns on FET Q8 to activate the **TR_relay**.

TX_delayed_H also drives U3b, whose output is delayed by R32 and C25. This delay is longer than the estimated time for the TR relay to complete switching, so that PA power is not applied until the TR relay is ready. The delayed output is combined in a diode AND gate with conditional inputs from the TR contacts (**TRC**) and AMP ready (**AMP**). When all three inputs to the gate are TRUE (unused conditional inputs are always TRUE), then U5b is driven to turn on FET Q7 and apply +12V for PA power.

The output of U5b, **PA_power_L**, drives U2a. The output of U2a, **PA_delay_H**, is delayed by R47 and C29 to give the PA time to power up and stabilize. **PA_delay_H** is combined in another diode AND gate with conditional signal **Ext_Seq_Done_H**, if used, and with **TX_delay_H**, to make sure the PTT is still active. If all three inputs to the gate are TRUE, U3a is driven, which drives **TX_Enable_H**, turning on the transmit section of the PIN diode switch and sending the output from the IF transceiver to the transmit mixer. **TX_Enable_H** also drives optoisolator U12, turning off the INHIBIT signal to the transceiver.

Receive

When PTT is released and no RF is sensed, U1b, U2b, and U3b turn off. When U2b turns off, signal **TX_delayed_H** is FALSE, so U3a is turned off by the diode AND gate and **TX_enable_H** becomes FALSE, turning off the transmit section of the PIN diode switch as well as optoisolator U12, sending INHIBIT to the transmitter. At this point, no RF can go out.

The output of U3B is delayed for a short time by R31 and C25, after which U5b turns off. This turns off FET Q7, removing **PA_power**.

When **TX_enable_H** becomes FALSE, U4b turns off. The output of U4b, **Relay_RX_delay_H**, is delayed by R37 and C30 to allow time for the PA to power down completely, then U4a turns off, turning off FET Q8 which removes power from the TR relay, causing it to start switching to the receive state. [NOTE: If we have chosen Option 7 below, powering the TR relay on receive, then the relay will be powered on at this time.]

When **Relay_RX_delay_H** becomes TRUE and the TR relay contacts (**TRC**) open, then the diode NOR gate driving U1a allows the comparator to turn on. The output of U1a is delayed by R41 and C31 to allow time for the TR relay to finish switching to the receive state, then U5a is driven, turning on FET Q9 to power the receive amplifiers.

The timing table, Table 1, summarizes all the timing delays in the sequencer.

FROM	TO	Delay	C	R
PTT	TR relay start	20 ms	C21 10uF	R29 4.7K
PTT	PA power on	250 ms	C25 22uF	R32 47K
PA power	TX enable	50 ms	C29 10uF	R47 10K
PTT off	PA power off	25 ms	C25 22uF	R31 1K
PTT off	TR relay deactivate	100 ms	C30 10uF	R37 27K
TR relay deactivate	Preamp power	250 ms	C31 22uF	R41 27K

PIN Diode Switch

The PIN diode switch has three states: receive, transmit, and failsafe. The failsafe state absorbs all RF power while switching between transmit and receive, thus protecting the PA, the TR relay, and the preamp from stray RF while the relay is switching. This third state is not possible with a single relay, which is why I have chosen the added complexity of the PIN diode switch.

A PIN diode has an intrinsic (I) layer, neither P nor N, between the normal P and N layers. This makes it operate very slowly, so that it will rectify only at very low frequencies. At high frequencies, the electrons can't get across the intrinsic layer fast enough, so it looks like an open circuit, with some capacitance, of course. However, if we put some DC current (electrons) through the diode, then the high frequency electrons can travel with the DC electrons, just modulating the DC current. So to make an RF switch, we apply more DC current than the peak RF current to turn it on, and remove the current to turn it off. Adding reverse bias in the off condition reduces the capacitance and improves the isolation. In the PIN diode switch, each diode has one end at 6 volts and the other end is switched between 12 volts and ground to turn on and off, through resistors to set the DC current

In the receive state, PIN diode D6 is on and D1 is off, connecting the mixer to the MMIC amplifier. At the other end, D1 and D5 are off, and D4 is on, connecting the output of the MMIC to the IF through a fixed attenuator. There is a small net gain between the MMIC amplifier and the attenuator.

In the transmit state, the PIN diode switch must attenuate the RF output from the IF transverter down to the level required by the mixer, usually less than one milliwatt. PIN diode D1 is on and D4 is off, connecting the IF input to the attenuator. At the other end, D3 is on and D6 is off, connecting the output of the attenuator to the transmit mixer. Finally, D5 is on to protect the receive MMIC amplifier from any transmit leakage.

For the failsafe state, D1 is on and D4 is off, connecting the IF input to the attenuator, but D3 and D6 are both off, so neither side is connected to a mixer. Instead, D2 is on, shorting out the output of the attenuator to ground. This reflects the signal back into the attenuator. However, the total attenuation is more than 25 dB, so the return loss from this reflection is more than 50 dB – absorbing all the power for practical purposes.

Attenuator table

The input attenuator may be configured for different power levels and attenuations. This is done in two parts: a fixed input attenuator to absorb most of the power and keep power levels in the PIN diodes to less than 50 mW (+17 dBm) to minimize IMD, and an adjustable attenuator which is switched out on receive. Thus, a 1-watt input attenuator would need to have at least 13 dB of attenuation, while a 10-watt one would require at least 23 dB of attenuation. Then the PIN diode switch includes an adjustable attenuator with about 20 dB of adjustment to set the desired output level for the mixer, usually less than one milliwatt. The limiting factor for the input attenuator is that it is also in the receive path (if all else fails, it limits power going this way to 50 mW also). To recover the loss in the receive path, there is a MMIC amplifier which provides about 20 dB of gain to compensate for the fixed attenuator, and to act as a cheap fuse if some fool were to set his IF transceiver to 100 watts.

So why not just use a low power transceiver for the IF? In most cases, this would require modifying the transceiver to reduce output power, so that it would be unique to the transverter. This limits interchangeability, and things do fail – but only at inopportune times! Another strategy would be to use a low power setting on a transceiver like the FT-817, which has provision for different power levels. However, Leif, SM5BSZ, has tested many rigs for output cleanliness[2], and found that the FT-817 emits spurious garbage when operated at less than 2.5 watts, particularly on CW. N1EKV investigated further and found that the ALC circuit, used to set the power level, oscillates at low power settings.
He also found a simple fix, by changing one resistor, but complete disassembly is required to get at the small surface-mount resistor on the bottom of the board. I decided that it is preferable to operate at 2.5 watts and be compatible with all my other IF rigs.

Since the input attenuator must absorb nearly all of the IF power, it is designed so that a large proportion of that power is dissipated in a hefty 50-ohm power resistor that may be bolted to a heat sink. The rest of the attenuator consists of parallel ¼-watt resistors to make up the desired attenuation while absorbing some portion of the power. The resistor values for the various power levels are shown in Table 2:

IF POWER	**10 watts**	**6 watts**	**3 watts** 1/2 to 3	**100 mw** <250 mw
First attenuator	23 dB	20 dB	18 dB	6 dB
R1	50 @ 8W	50 @ 4W	50 @ 2W	50
R2	27 * 4	43 * 4	56 * 4	100
R3	1.5K * 4	1K * 4	560 * 3 750 * 4	39
R4	56	62	62	150

NOTE: 56 * 4 means four 56 ohm resistor in parallel

My prototype used the 3-watt attenuator and a single mixer output, which gave the results shown in Table 3 below. Min and max are the settings of the variable attenuator, which adjusts the transmit drive level to the mixer. At 28 and 144 MHz, the SAFE state reduces the unwanted transmit level by more than 20 dB. The sequencer must be mounted on a metal ground plane with standoffs for the PIN switch to work well. At 432 MHz, it probably needs to be inside an enclosure for better performance.

Table 3: PIN Switch - 3 watt Attenuator

State	**28**	**144**	**432**	MHz
RX	0	0	-2.5	dB
SAFE (max)	-50	-48	-38	dB
TX (max)	-23	-25	-28	dB
TX (min)	-50	-45	-40	dB

Optoisolators

Optoisolators are used to isolate external connections from the circuitry, preventing stray transients and RF from upsetting operation or damaging components. Used properly, these inexpensive parts can provide several KV of isolation.

This type of optoisolator contains an LED and a phototransistor. When the LED is lit, it turns on the phototransistor. More accurately, the phototransistor will conduct roughly as much current as passes through the LED to light it, even though there is no electrical connection.

The important point is that there is no electrical connection – for isolation, we must keep the two sides separated. As an output driving an external circuit, we drive current through the LED to light it; the phototransistor then conducts current between collector (positive) and emitter (negative), *neither of which is otherwise connected to the sequencer*. The current must come from an external source, which senses the current flow or the reduced voltage drop across the phototransistor. Note that this is not a power transistor – it won't drive a relay directly.

As an input, an external source, with no other connections to the sequencer, must provide enough current to light the LED – a couple of milliamps. This causes the phototransistor to conduct current into a resistor between the emitter and ground. The internal signal is the voltage across this resistor – with no current, the voltage is zero, and enough current raises the voltage higher than the comparator reference voltage.

By maintaining complete isolation, we are able to make remote connections without fear of high voltages or ground loops. We can sense relay contact closure at the top of a tower, or sense operating voltage in a power amplifier.

Options

I don't ever expect to use all the options in any one system, but expect to find a use for each of them at some time. Most of them can have components left out, or be populated and ignored if not needed, but a few must be removed if not used. It's probably easier to choose the options before assembly.

1. **PTT** – the basic switch that initiates operation. Could come from the mike switch, or a foot switch, or a computer. Selectable either LOW (= ground to transmit) or HIGH (> ~4 volts to transmit). Can be delivered through the IF coax J1(recommended for portable operation), or through a separate connector. J5 has three pins: one for PTT-L, one for PTT-H, and the center pin is the DC connection (through an RF Choke) to the IF coax. For IF coax operation, simply put a jumper on J5 to the appropriate side.

2. **RF sense –** detects RF at the IF input and puts the sequencer into the SAFE state, turning off the preamp and dumping any RF, until the switching sequence

initiated by PTT is complete. Can also be used for RF switched operation by adding a jumper at J6. I configure my portable transverters with the jumper, so that they can operate with RF switching with any available IF rig or even a handy-talky in a pinch. The PTT still takes precedence and overrides the RF sense.

3. **PIN switch –** the PIN switch switches the RF power from the IF transceiver between transmit and receive, and absorbs any RF power during the switching sequence to prevent damage or spurious output. The transmit path includes a power attenuator configurable for the IF transceiver power level (see Attenuator Table). The receive path includes a MMIC amplifier to overcome loss in the common section of the attenuator. The PIN switch may be configured for a transverter with a single mixer or one with separate TX and RX mixers (*option 4*). Similarly, it may be configured for an unmodified IF transceiver with a single coax connection, or one with separate IF ports for TX and RX (*option 5*). There are systems, particularly with separate IF ports, where the PIN switch may not be needed and that section of the PC board may be cut off (*option 6*). And a few folks may not trust them, but prefer a relay.

4. **Separate mixers for Transmit and Receive –** the TX mixer connects to J3 and the RX mixer to J4. D6 and R16 must be removed, and C13 added.

5. **Separate IF ports for Transmit and Receive –** the IF transmitter connects to J1 and the IF receiver to J2. D4 and R11 must be removed, and C10 added. Since the receive path does not go through the input attenuator, the MMIC gain may be too high. Consider a MMIC with lower gain.

6. **Remote PIN switch** – the PC board is arranged with the PIN switch at one end (left in Figure 3 and 4) and the control circuitry on the rest of the board, with enough separation so that they may be cut apart and used for remote operation, at least over a short distance like different parts of a cabinet. There is a silk-screen line across the board indicating where to cut. Then a few wires are needed to make the needed connections: **RXD**, **TXE**, **+12V**, **+6V**, and possibly **PTT**, if it is coming up the IF coax.

7. **TR Relay direction** – conventional usage has the TR Relay off during receive, and powered for transmit. This minimizes power consumption, always important for portable operation. However, some think it is more fail-safe to have the TR Relay powered to receive, and off to transmit. Both directions are options, selected by placement of R52 and R53. The positions nearer U4, lined up with other resistors, selects the power-to-transmit option, while the alternate placement, shifted away from U4 toward J16, selects the power-to-receive option.

8. **TR Contacts input** (**TRC**) **–** this optoisolator input at J8 detects closure of the TR relay auxiliary contacts in the transmit position (most relays have SPDT contacts so can be used either way). When the contacts close, they should pass current (2 to 5 ma) from some external source through the optoisolator. The

square pad of J8 is the + side. A current limiting resistor in series is highly recommended. When the contacts close, the sequencer continues applying PA power, then TX enable. When the contacts open again, the sequencer removes power from the PA, waits a delay time for the relay to operate, then applies preamp power. If not used, R34 must be unpopulated to allow the sequencer to operate with time delay only. The optoisolator U7 as well as Q6 may also be omitted if not used.

9. **AMP ready input –** this optoisolator input at J9 detects that an amplifer is ready, allowing for warm-up delay or amplifiers with separate power supply. It requires current (2 to 5 ma) from some external source to pass through the optoisolator. The square pad of J9 is the + side. A current limiting resistor in series is highly recommended. One example would be to provide the current through a 10K resistor from the 24 volt power for a solid-state amplifier – if the 24V is not available, the amplifier isn't ready. The return side should be isolated and go back to the negative side of the 24V supply. If not used, R33 must be unpopulated to allow the sequencer to operate with time delay only. The optoisolator U8 may also be omitted if not used.

10. **External sequencer –** this optoisolator output, **EXT** at J14, and input, **EXT RDY** at J7, allow the addition of an external sequencer. For example, some high power TWT amplifiers require several different voltages to be applied in sequence. The **EXT** optoisolator turns on (transistor conducts) when the TR relay has completed and the PA may be powered. Our sequencer then waits for the amplifier to turn on the **EXT_RDY** optoisolator by providing an external current before TX is enabled. If the external sequencer is to be fully isolated (a good idea with high voltage), all four connections should be isolated from our sequencer and only connect to the optoisolators. The square pads of J7 and J14 are the positive sides. If not used, R28 must be unpopulated to allow the sequencer to operate with time delay only. The optoisolators U6 and U11 as well as R44 may also be omitted if not used.

11. **Transceiver inhibit (INH) –** this optoisolator output at J15 is intended to drive the inhibit pin on an FT-817, and probably some other rigs. The FT-817 RF output is inhibited if the inhibit pin on the ACC connector is less than 1.0 volts, and allowed if the voltage is greater or the pin is floating. When the optoisolator is off, the pin is floating; when it is on, the pin is pulled to FT-817 ground (which could be electrically isolated, but is probably connected to the sequencer by the IF coax shield anyway). The square pad goes to the FT-817 inhibit pin and the round pad to FT-817 ground. The optoisolator U12 as well as R48 may be omitted if not used.

12. **Relay –** a small DPDT relay has two sets of contacts floating and available for any use on J12 and J13 (no marking on PC board). The relay is driven by Q4 but otherwise unconfigured. Putting a high signal on the input to Q4 at pad "**RL**" will turn on the relay, so it may be used for any desired part of the timing sequence:

a. PA power
b. TR relay
c. TX enable
d. Preamp power

These small DPDT relays have decent performance up to 2 meters, so the relay could even be used as a bandswitch between two transverters, with an external switch driving pad "**RL**". If the relay is not used, it may be omitted as well as Q4.

13. **Bidirectional amplifier –** in some simple transverters, a single amplifier is used on both transmit and receive, with the direction reversed by a 4-port transfer relay. We would like the amplifier powered for both transmit and receive, but not powered while the relay is switching. This is accomplished by a wired-OR connection of the drivers for the receive power FET Q9 and the PA power FET Q7, so both will be turned on for both transmit and receive, by a jumper wire on J18. Either power FET can be used, and the other unpopulated.

14. **Receive Power –** if all the receive amplifiers are left on during transmit, there may be enough total gain to form an oscillating loop. Common wisdom is that the preamp should remain powered to make it less susceptible to damage, but other RX stages should be powered down. FET Q9 switches receive 12V power

Construction

The printed circuit board layout was planned with a regular pattern which can be seen in Figure 3, and a photo of an assembled sequencer is shown in Figure 4. The sequencer ICs and associated components run down the middle of the board, with all inputs on the lower side and outputs on the top and right sides. The IF interface and PIN diode switch is at the left end; like all RF circuitry, lengths are kept short so layout is less regular in this area. A photo of the bottom of the board is shown in Figure 5, and a closeup of the PIN diode switch, with chip capacitors and surface-mount PIN diodes, is shown in Figure 6.

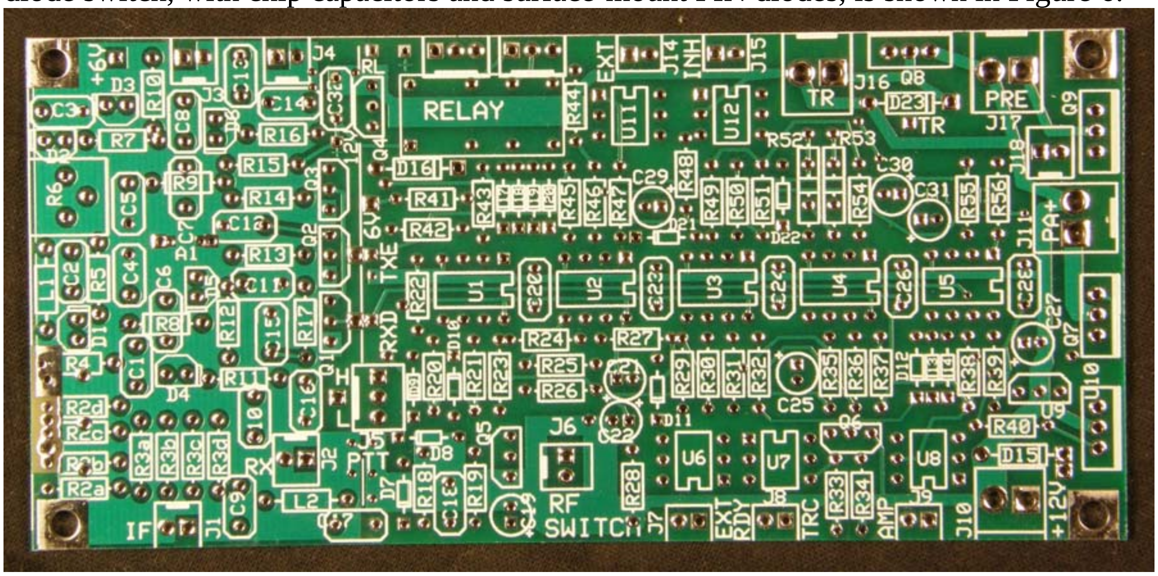

Figure 3 - PC board

All component locations are identified with silkscreen, and most of the components have leads which are soldered into plated-thru holes in the board. The IF interface may be built with leaded components except for A1, the MMIC amplifier, which is on the bottom of the board. Optionally, there are also surface-mount pads on the bottom of the board for chip capacitors and PIN diodes in the IF section; chip capacitors have better RF properties, and PIN diodes with leads are becoming obsolete. You might notice that R8 crosses C6 and R9 crosses C7 – this is easier if the capacitors are on the bottom.

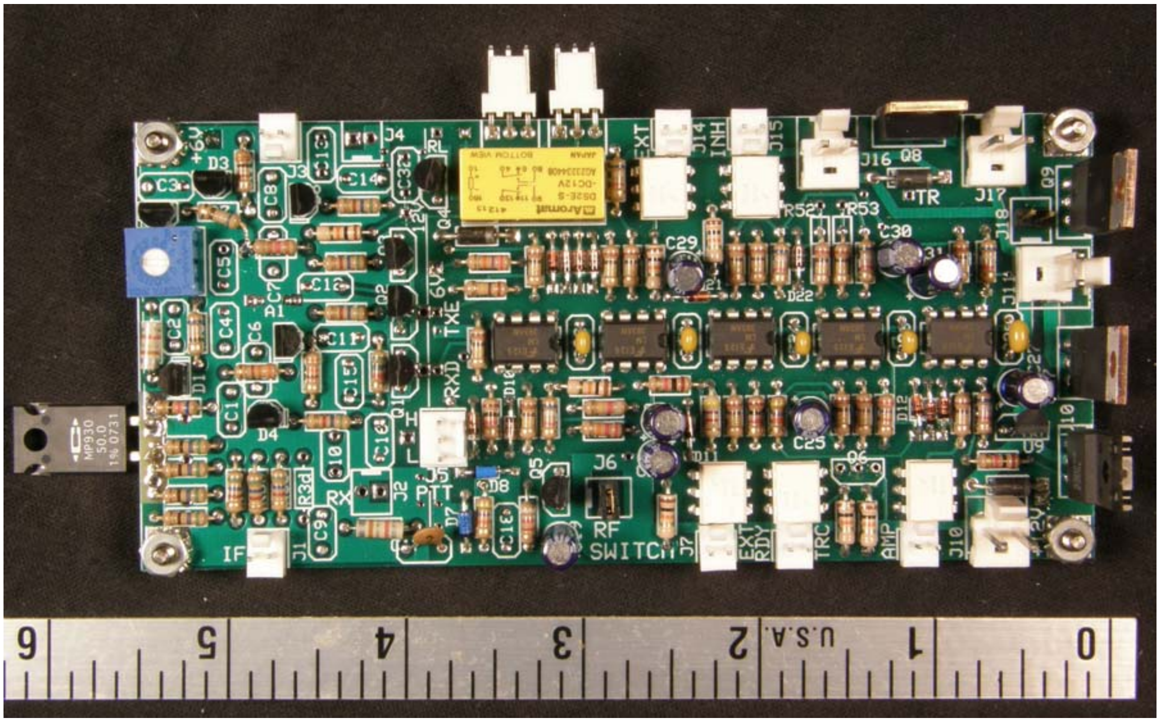

Figure 4 - Assembled Sequencer

Parts layout is a regular pattern, and locations are numbered sequentially, so assembly is straightforward – find the next part in the parts list, insert in the next location, and solder. My preference is to first solder the chip capacitors on the bottom, then resistors, diodes, ICs, and capacitors, in that order. Finally come the large components and connectors around the edge.

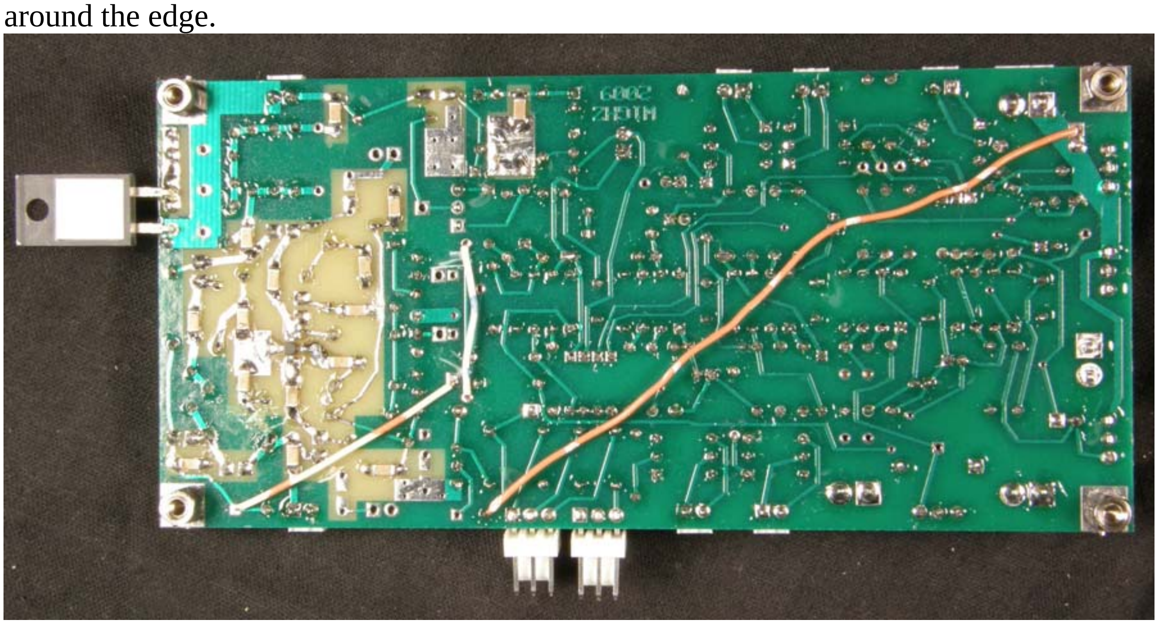

Figure 5 – Bottom of board showing additional wiring

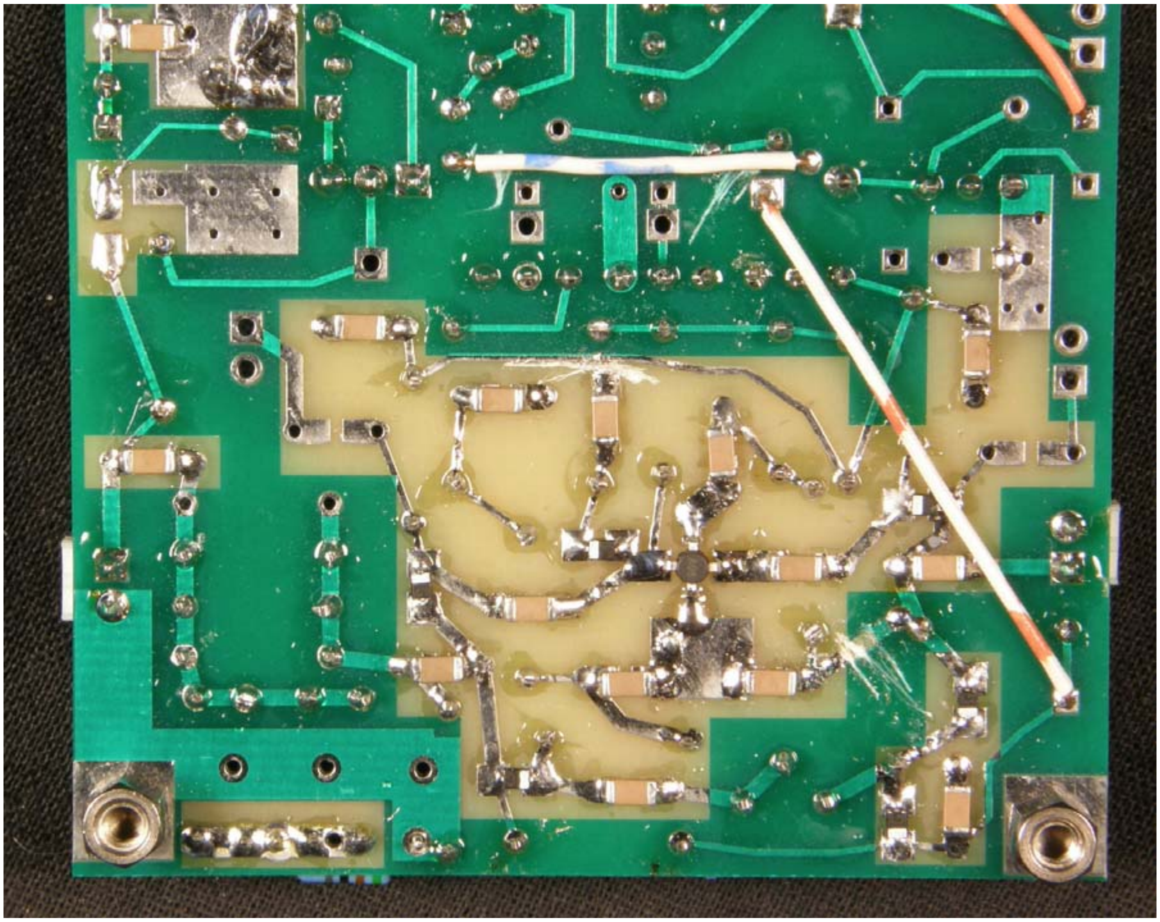

Figure 6 - Bottom of PIN switch area, showing caps and PIN diodes, and cut traces for errata

Printed circuit boards are available.

Connections

Most of the connections allow for the use of inexpensive Molex connectors, as shown, or just wires soldered into the holes to minimize expense. Unless otherwise indicated, the square pad is the hot or more positive connection.

J1, marked “**IF**”, is the connection to the IF transceiver, or to the IF transmit port if separate connections are used.

J2, marked “**RX**”, is the optional connection (option 5) for the IF receive port if separate connections are used.

J3 is the connection to the transverter mixer, or to the transmit mixer if separate mixers are used.

J4 is the optional connection (option 4) to the receive mixer if separate mixers are used.

J5, marked “**PTT**”, is a three-pin header to allow jumper selection of the PTT polarity , **H** or **L**, (option 1) delivered through the IF cable to J1. For hardwired PTT, simply wire or jumper the PTT to the appropriate pin of J5.

J6, marked “**RF SWITCH**”, is a jumper that is closed to allow switching with RF sense (option 2).

J7, marked “**EXT RDY**”, is the input from an external sequencer to signal completion of the external sequence (option 11).

J8, marked “**TRC**”, detects closure of external contacts on a coax relay or waveguide switch (option 8).

J9, marked “**AMP**”, is an input to detect than an external amplifer is ready (option 9).

J10, marked “**+12V**”, is the +12 volt input to power the sequencer and transverter. If the power FET switch in the sequencer is used to control the PA directly, adequately sized wire should be used.

J11, marked “**PA+**”, is the switched +12 volt output to the PA. If this supplies the PA current directly, adequately sized wire should be used. Switching is done by a power FET, Q7, which should be capable of switching the current, and attached to an adequate heat sink.

J12 and **J13** are three pin headers wired to the optional RELAY (option 12) contacts. The square pin of each header is the wiper.

J14, marked “**EXT**”, is the output to start an external sequencer (option 11).

J15, marked “**INH**”, is intended to drive the inhibit pin on an FT-817, and probably some other rigs. The square pad goes to the FT-817 inhibit pin on the ACC connector and the round pad to FT-817 ground (option 10).

J16, marked “**TR**”, is output to the TR relay, pulling the bottom end of the relay to ground – the top end of the relay goes to whatever positive voltage the relay requires. The switching is done by a power FET, Q8, which must be capable of switching the required voltage plus some margin.

J17, marked “**PRE**”, is the switched +12 volt output to the preamp or other receive amplifiers.

J18, is an optional jumper to allow use of a bi-directional amplifier (option 13).

Also, two jumper wires are required to power the IF PIN diode switch: one from a square pad marked “**6V**” near R41 to another marked “+**6V**” near D3, and the other from a square pad between D13 and the “**+12V**” marking next to J10 to the square pad next to the RELAY near the pad marked “**RL**”.

Finally, if the optional relay is used (option 12), a jumper wire to switch it at the desired time is required. One end goes to the pad marked “**RL**” near Q4 and the other:

a. PA power – connect to **J11**
b. TR relay – connect to square pad marked “**TR**” near D23.
c. TX enable – connect to square pad marked “**TXE**” near Q2.
d. Preamp power – connect to **J17**

Summary

This sequencer should be quite fool-resistant, but fools can be very resourceful. I have tried to also make it flexible, so options can be included as needed. It ended up using a lot of parts, but they are really cheap parts, and soldering them all is not difficult. I hope that it prevents a few disasters and enables more contacts.

References

1. Paul Wade, N1BWT, “A 'Fool-Resistant" Sequenced Controller and IF Switch for Microwave Transverters,” ***QEX***, May 1996, pp. 14-22. www.w1ghz.org/QEX/A_Fool-Resistant_Sequencer.pdf

2. http://www.sm5bsz.com/dynrange/eme2004/ft817_1e270433_144cwk500mw.gif or http://www.sm5bsz.com/dynrange/dubus205/dubus205.htm

An Even More Fool-Resistant Conditional Sequencer

Errata October 2009

There were a few errors that crept into the first pass of boards, marked W1GHZ 2009 on the back as shown in the sketch below.

1. Some part values have been adjusted – make sure parts list is dated October 2009 or later.
2. Q6 silkscreen is backwards. Insert part opposite of direction shown if using option 8, external TR relay contacts.
3. Q6 needs a pullup resistor from drain to +6 volts if using option 8. Shown as R101, 27K, in latest schematic, but no board location. Probably tack on bottom of board.
4. The board has several errors in the copper traces on the bottom, which require cutting the trace with an X-Acto knife or Dremel tool, then adding wires to correct the wiring. In the sketch below, the copper traces on the bottom of the board are shown in blue. Red lines indicate where to cut the traces, and green lines are wires that must be added. The lead of R7 nearest to the cut is bent to a new location rather than adding an additional wire.