

Add Full Break-In QSK Keying to your Linear Amplifier

James C. Garland W8ZR

The famous “Q” codes, known to all amateur radio operators, date from the earliest days of wireless communication. “QSK,” meaning “Can you hear me between your signals?” dates from approximately 1909 and was formally assigned by the British government at the 3rd London International Radiotelegraph Conference of July 5, 1912.

Of course, in those days the notion of copying signals between transmitted Morse code characters (today called “full break-in” keying) was mostly wishful thinking, and it remained so for many decades. The stumbling block was the slow turnaround time between transmitting and receiving. In those early days, this task was accomplished manually by throwing one or more switches. By mid-century relays had partially simplified the job; old-timers and vintage radio collectors still revere the satisfying “ker-chunk” of the ubiquitous Dow Key relays that in the 1950s transferred a station antenna from receiver to transmitter, muted the receiver, and brought the transmitter on-line.

But as technology marched forward the proliferation of 100 Watt SSB transceivers in the 1960s and 70s spawned the development of compact high power linear amplifiers. For these, SSB was the dominant mode, and CW operation, while not exactly an afterthought, was mostly relegated to secondary status, with transmit-receive (T/R) amplifier switching handled by clunky open-frame relays. “Semi break-in” CW became widely used because a transceiver’s VOX circuitry could do double duty by also automating an amplifier’s CW T/R switching. This solution was acceptable for casual CW operators who were comfortable with a leisurely turnaround time for their transmissions.

However, modern transceivers, with their compact high-speed T/R relays or solid state keying circuits can now accommodate full break-in QSK keying, and CW operators increasingly want the same performance from their linear amplifiers. CW contesters and DX-chasers, especially, now recognize that full break-in keying is important for competitive operation. If you fall into that category, or just want to modernize a homebrew or older amplifier that uses slow, noisy relays, then this simple yet sophisticated high-speed QSK circuit will do the job for you. Even if you’re not a QSK devotee, the circuit will guarantee smooth T/R switching with properly sequenced relays. It is easy to build and can readily be retrofitted into most existing linear amplifiers. It also is just the ticket for incorporating QSK into that homebrew amplifier you’ve always wanted to build.

Why is QSK Switching Difficult?

There are two reasons – timing and sequencing. Consider first the timing requirements. A single “dot” sent at 30 wpm is approximately 40 mS duration. To amplify this dot without appreciable shortening or distortion, an amplifier has to switch from its bypass (receive) mode to its amplify (transmit) mode in approximately 1/10 this time, or 4 mS. Once the dot has been amplified and transmitted, the amplifier then has to drop back into its receive mode in a comparable time. These transfer or “turnaround” times are so short that they pretty much rule out the use of conventional open frame RF power relays, which typically have “make” and “break” contact closure times of 15 mS or longer.

Meeting QSK sequencing requirements is also challenging, since we want our transceiver always to be presented with a proper load and our amplifier never to be operated into a momentary open circuit. This is an essential requirement when operating QSK CW, since your amplifier will have to switch itself on- and off-line more than a hundred times a minute! What further complicates this requirement is that there is no standardization in the interface between transceivers and amplifiers, the details of which can vary widely among different transceiver brands and models.

Consider for example this common scenario. Suppose that at time $t=0$ an operator presses a CW key connected to a transceiver. After a few milliseconds delay, say at time t_1 , an “AMP RELAY” line on the transceiver’s rear panel closes, in effect notifying the amplifier to prepare to accept RF from the transceiver. After a further delay, occurring at time t_2 , RF from the transceiver actually appears at the amplifier’s input. Until time t_1 , the amplifier has no way of knowing that RF from the transceiver is imminent, and once it receives this information, it has a time $(t_2 - t_1)$ in which to go on-line and prepare to receive the RF. If $(t_2 - t_1)$ is shorter than the amplifier’s intrinsic turnaround time, then the RF will arrive before the amplifier switching is completed, causing the transceiver to see a potentially damaging SWR spike or, worse, causing the amplifier momentarily to face an open circuit that can damage costly tank circuit components.

There are typically two ways to prevent this situation. The first is to delay the arrival of RF at the amplifier’s input so that it is always later than the amplifier’s turnaround time. (Modern transceivers often have menu settings that allow this delay time to be adjusted) Although lengthening the delay time protects the operator’s equipment, it does so by slowing down the amplifier’s overall response to a key closure, which obviously is the reverse direction we want to go to facilitate QSK operation.

The other way to prevent switching damage is to route the CW key or keyer output through the amplifier before it ever connects to the transceiver. An interlock circuit in the amplifier then delays sending the key closure to the transceiver until after the amplifier is on-line and ready to receive RF. In this scenario, the transceiver’s “AMP RELAY” line is not used. Instead, the amplifier itself inserts enough delay between each dot and dash to allow amplifier switching to be completed. Like the first method, this approach prevents damage by stretching out the time delay between a key closure and the amplifier’s response. Although this approach is the safest, in that it does not depend on transceiver delay times (whether adjustable by menu settings or not) to prevent premature amplifier operation, it cannot be used with transceivers having a built-in electronic keyer, the reason being that the keyer output is not available for routing to the amplifier interlock circuitry.

The bottom line, therefore, is that either approach can prevent damage caused by an amplifier-transceiver switching mismatch, but neither approach, in and of itself, can allow QSK CW to be used with an amplifier that has intrinsically pokey switching. Implementing QSK switching is only possible if the amplifier’s turnaround switching time can be made sufficiently brief.

Vacuum Relays or PIN Diodes?

The gold standard for QSK circuits is high power PIN diodes. PIN diodes are silent and fast, both highly desirable traits in an amplifier intended for high speed CW operation, but unfortunately they are also costly and easily damaged. While PIN diodes

are quite reliable when the amplifier is operating into a matched 50 ohm load, they can be destroyed in an instant if the operator inadvertently selects the wrong antenna, resulting in a momentary high VSWR. As a result, many CW aficionados prefer to use high-speed vacuum relays to handle the T/R switching in their amplifiers. Nearly all vacuum relays are rated well above the U.S. legal power limit, and if carefully mounted are nearly inaudible. Despite being mechanical devices with movable contacts, they are also quite reliable if sequenced properly to avoid hot-switching. I have used vacuum relays in my homebrew linear amplifiers for several decades and have never experienced a failure.

QSK Design Objectives

In the QSK circuit described here, vacuum relays are used for T/R switching of both the amplifier's input and output, with a turnaround time of less than 5 mS. (A fast reed relay can substitute for the input relay.) Additionally, the circuitry has several safeguards that provide full protection against switching transients caused by transceiver-amplifier timing mismatches.

The two key goals of the design are first to ensure the linear amplifier is brought on-line in a logical manner, so that a live amplifier will never "look" into an open circuit while waiting for its output relay to close. To prevent this possibility, the QSK circuitry closes the output relay, bias switch, and input relay in that order, allowing for relay closing times and contact bounce.

The second design goal is to protect relays from hot switching, which can occur if RF is present at the amplifier input while the relays and bias switch are closing, or if the relays open while RF is already being amplified. This QSK design also provides protection against the slight possibility that RF could be applied in the brief interval after the relay sequencing has begun but before it is completed.

Selecting a Vacuum Relay

Some vacuum relays are nearly as fast as PIN diodes (two or three milliseconds), and are nearly inaudible. Furthermore, most types can easily handle kilowatts of power, and because of their high voltage ratings can also tolerate a wide VSWR mismatch. The important parameters, besides power and voltage ratings, are the switching speed and the absence or near-absence of contact bounce, the latter shortening the relay's life expectancy and making hot-switching more likely.

After performing timing tests on several popular vacuum relays (See Figure 1), I have found the most suitable type to be the compact Jennings RJ1a (or the Kilovac HC-1 or Gigavac GC-1a clones).

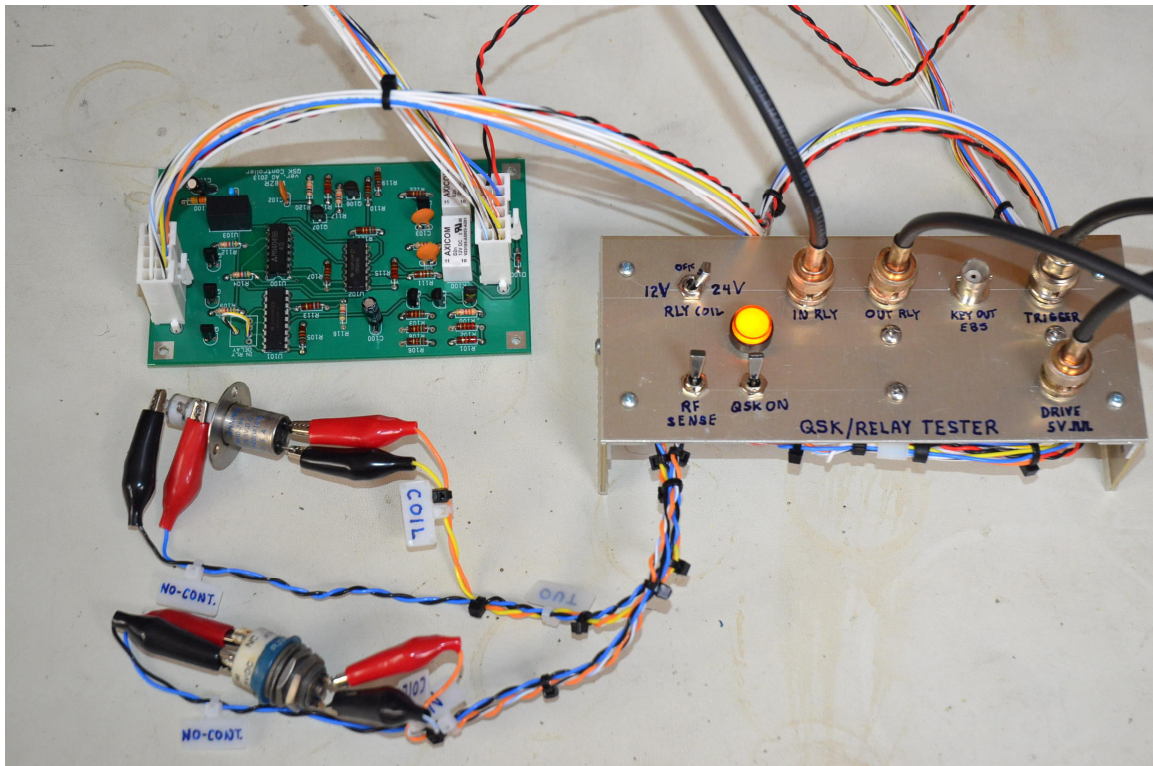


Figure 1: A homemade relay test fixture compares the timing characteristics of a Jennings RF1d and RJ1a vacuum relay. The printed circuit board is the QSK circuit discussed in this article.

As shown in Table I, the RJ1a is very fast, 2.1mS closing time typical, has no contact bounce, and has a comfortable power-handling safety margin. The RJ1a is also nearly inaudible, producing only a very faint click in operation. Figure 2 is a comparison of the switching characteristics of a particularly fast Jennings RJ1a (closing time 1.2 mS) and a Gigavac G41c vacuum relay. Notice the multiple contact bounces of the G41c, which extends its total “make” time by about 2 mS. The G41c was also the noisiest relay tested, making an audible “twang” when actuated.



Figure 2: Timing comparison of a Jennings RJ1a (bottom curve) and a Gigavac G41c (top curve) vacuum relay. The RJ1a contact closes in 1.2 mS and shows no contact bounce, making it well suited for QSK operation. By contrast, the G41c contact closes in about 5.9 mS and shows appreciable contact bounce.

Circuit Description

This QSK circuit is intended to be used with vacuum relays for both input and output switching. Any type of SPDT vacuum relay can be used so long as it is designed for switching RF. (Some vacuum relays are intended for switching DC voltages only.) With the recommended Jennings RJ1a (or equivalents from other manufacturers), the total amplifier switching time is about 4 mS, which is suitable for QSK operation at CW speeds at least as high as 30 wpm. Note that the circuit incorporates a small DC to DC converter (U103) to boost the +12V power supply voltage to +24V for powering the vacuum relays, thus obviating the need for a second power supply. (The majority of vacuum relays have a nominal coil rating of 26.5V).

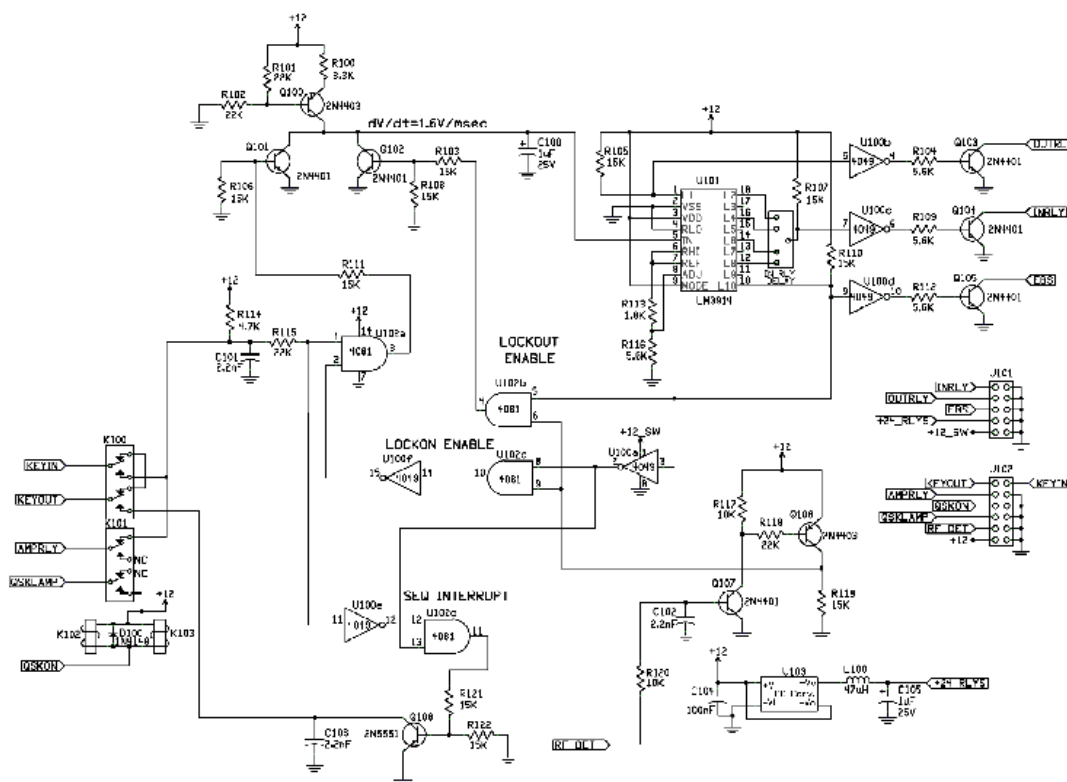


Figure 3: Schematic diagram of the QSK controller. The control circuitry is housed on a 3"x5" printed circuit board.

The circuit was designed for amplifiers using vacuum tubes, although there is no reason it could not be used also with solid state amplifiers. In either case, it is assumed the amplifier uses electronic bias switching (EBS) to provide cutoff and operating bias. EBS switching has been the norm in amplifier design for more than thirty years and is normally controlled by a transistor switch. In this circuit Q105 provides an open collector output for this purpose. In older vintage amplifiers, such as the Drake L4B or Heathkit SB220, bias switching is typically done by a set of relay contacts. In the event this circuit is retrofitted into one of these older amplifiers, Q105 can operate a small, fast, open frame relay with at least a 2A rating to control amplifier biasing. A suitable candidate is the Tyco/P&B V23105.

Once installed, the only control for the circuit is a "QSK On/Off" switch. When the QSK function is turned off, the amplifier is controlled by the normal AMP RELAY line from the transceiver. Even in this mode, the circuit continues to sequence the relays properly so that relays cannot be damaged by hot-switching.

Referring now to the circuit details, Q100 and bias resistors R100, R101, R102 comprise a constant current source of approximately 1.6 mA. Ignoring Q101 and Q102 for the moment, the main function of this current source is to charge capacitor C100 at a linear rate of 1.6V/mS until it reaches 5.7V. It takes 3.6 mS for the voltage across C100 to stabilize, at which point Q100 is driven into saturation.

The rising voltage across C100 is sensed by U101, an LED bargraph generator, which sequentially grounds outputs L1-L10 as the ramp voltage rises. Three of these outputs, L1, one of L2-L9 (selectable with a jumper), and L10, sequentially turn on, via inverters U100b, U100c and U100d, the switching transistors Q103, Q104, and Q105, which control the output relay, the input relay, and the amplifier bias respectively. By increasing R100 (which sets the ramp time constant) and choosing a different jumper setting L2-L9, the sequencing circuit can be changed to compensate for the settling time of slower relays. If using the recommended Jennings RJ1A, the "IN RLY DELAY" jumper should be set to L6 for proper timing.

U102a and Q101 are used to turn on the ramp circuit when the key is depressed or, alternately, when the PTT/AMP RELAY line is closed. When the key line is open, R106 and R111 force Q101 into saturation (provided the control input of U102a is high), diverting the current sourced by Q100 away from C100 and clamping the voltage across C100 to near zero. When the key line is closed, Q101 is switched off, allowing the ramp to begin charging C100 and thereby to sequence the relays.

The L10 output of U101 has two purposes. One is to bias the amplifier into its operating mode, via U100d and Q105, while the other is to indicate whether the amplifier is in its ON state (T/R relay sequencing completed) or OFF state (T/R relays open or sequencing not yet completed), the latter condition indicated by a High on L10. The amplifier status indicated by the L10 output serves three functions: (1) it controls the lockout circuit, which keeps the amplifier off-line if input RF is sensed before the relay sequencing has been completed. (2) it controls the lock-on circuit, which prevents the amplifier from dropping off-line so long as input RF is still present; and (3) it controls the KEY OUT line, ensuring that the keyed output to the transceiver cannot be closed until the amplifier is ready to receive RF. This last function prevents a race between the amplifier relay contacts and the keying circuits of the transceiver. The RF detector consists of a capacitive voltage divider and voltage doubler, whose components are mounted on a terminal strip at the amplifier's RF input jack.

The lockout circuit consists of U102b and Q102. If the amplifier closing sequence is not yet completed while RF is present on the RF sense line, then U102b receives a High at both inputs. The resulting High output of U102b turns on Q102, which discharges C100 and clamps the voltage at the signal input of U101 to zero, thus locking the amplifier off-line (bypass).

The lockon circuit consists of U102a, U102c, U100a and U100f. If the amplifier is biased online while RF is present at its input, then U102c receives a High at both inputs, which results in switching Q101 off, thus keeping C100 charged and locking the amplifier on-line irrespective of whether the key is open or closed. This situation, although unusual, can occur if the amplifier becomes "unkeyed" while transmitting RF, as might happen if a relay control cable accidentally becomes unplugged.

The KEY OUT circuit consists of U100e, U102d, and Q108. When the key is closed, the input to inverter U100a is Low, resulting in a High at the input of U102d. If the amplifier is on-line when the key closure occurs, then the control input of U102d is High and the output keying transistor Q108 is switched on. If the amplifier is off-line when the key is closed, then U102d delays the switching of Q108 until the amplifier comes on-line. Mode select relays K100 and K101 toggle the circuit between full QSK operation and PTT/AMP RELAY operation.

This circuit only provides total “bullet proof” protection for the amplifier circuitry and the input/output relays when operating in full QSK mode. However, it provides almost total protection if QSK is not used, for example when the amplifier is operated on SSB or AM, or on CW with speeds up to about 35 wpm. In this case, the lockon, lockout, and relay sequencing provisions are still fully implemented. The only feature that is not implemented (in non-QSK mode) is the Sequence Interrupt circuitry, which prevents the transceiver from outputting RF while the amplifier is midway through a switching transition. As a workaround to this unlikely situation, operators can use the menu setting on their transceiver to delay the output of RF in order to give the amplifier transfer relays time to settle. This time delay should be set to as short a time as possible, consistent with good amplifier operation. If the delay time is inadvertently set too short, the circuit will automatically sense the presence of RF and not allow the amplifier to come on-line. Thus, in no case, can the amplifier or its transfer relays be damaged.

III. Construction and Operation

The QSK circuit operates on +12 VDC, and with the exception of a few external components is fabricated on a double-sided printed circuit board that measures 3 in x 5 in. Other than the cost of the printed circuit board and the vacuum relays, the parts cost of the unit is roughly \$30, except for the DC-DC converter U103, which adds another \$12 and is only necessary if 26.5V vacuum relays are used. If U203 is unneeded, the builder can simply jumper across its input and output pads on the PCB pattern.

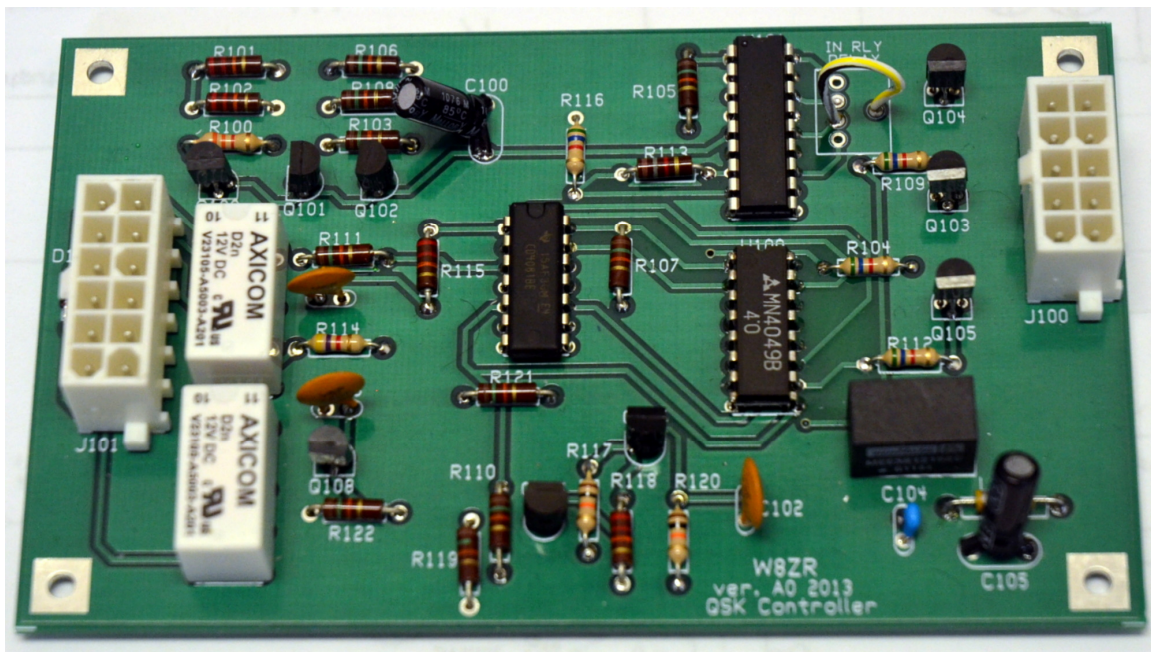


Figure 4: Printed circuit board pattern of the QSK controller, illustrating the double-sided construction. A ground plane minimizes the potential for unwanted RF pickup. Bare printed circuit boards are available from the author at www.w8zr.net/QSK, along with parts lists and other details.

Retrofitting the QSK circuit into an existing amplifier is straightforward. First, the owner should verify that +12 VDC is available somewhere in the amplifier to power the circuitry. If not available, then it is likely a filament voltage winding on a power transformer can be rectified and filtered to provide the necessary voltage. If only 5-6 VAC is available, a voltage doubler circuit can be used. In most cases, it will not be necessary to regulate the filtered DC voltage.

The second step is to find a place to mount the 3 in. x 5 in. (76 mm x 127 mm) printed circuit board. Ideally, it should be secured on small standoff posts, but if chassis space is at a premium it can be mounted almost anywhere, e.g., on the side of a filament transformer, using Velcro or double-sided tape. Try to mount the circuit board on the underside of the amplifier and out of the way of strong RF fields.

Next, the builder should remove the existing antenna transfer relay(s) and, if used, any existing bias switching relay. The two vacuum relays (and a substitute bias relay) can then be located in the vacated space. To dampen the sound each relay can be secured with a large rubber grommet (for the RJ1a, a 3/4 diameter inch grommet is a perfect fit). Then, a “QSK ON” switch and an optional +12 VDC indicator lamp or LED should be installed on the amplifier’s front panel (often an existing hole can be used for the switch, such as from an unneeded ALC switch), and two RCA phono jacks installed on the amplifier’s rear panel (labeled KEY IN and KEY OUT). If desired, a third RCA jack labeled PTT/AMP RELAY can be installed on the rear panel if the owner prefers not to use the amplifier’s existing relay control jack.

Wiring up the circuitry is straightforward and is summarized by the interconnection diagram in Figure 5. The RF detector components can be mounted on a terminal strip adjacent to the RF input coax jack or, as shown in Figure 6, on a small printed circuit board attached to the RF input connector. Next, the builder should connect the EBS output of the printed circuit board to the amplifier’s EBS circuit or to the amplifier bias relay. EBS circuits are usually quite simple, but vary somewhat among amplifier brands; the builder will therefore have to study the circuit diagram of the particular amplifier in order to decide the best way to connect Q105. As a guide, two common bias circuits are shown in Figure 5, one for an electronic bias design and one for an older relay bias design.

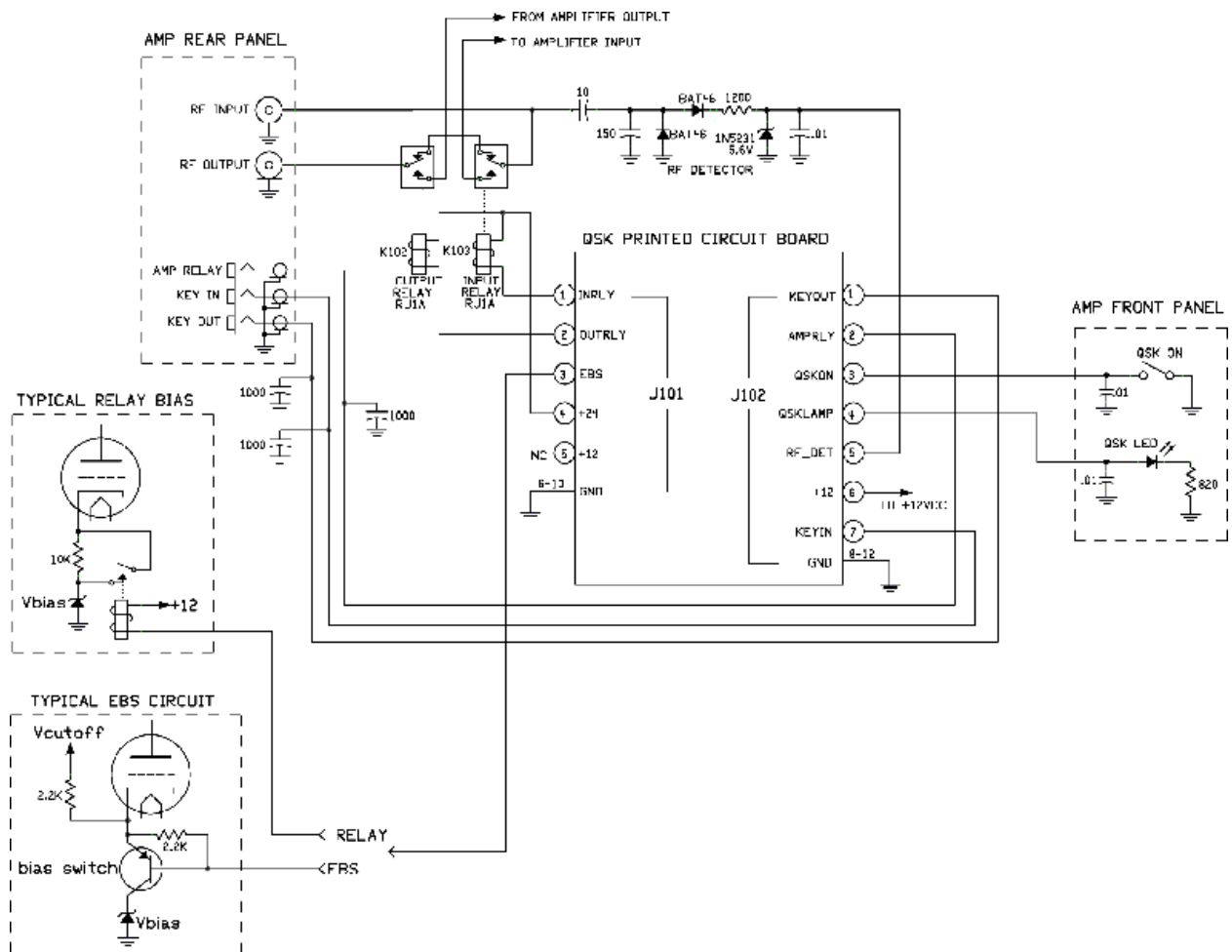


Figure 5: Interconnection diagram for the QSK controller showing the typical connections to amplifiers using both relay switching and electronic bias switching.

No special precautions are required to wire the relays, although coax cable should be used between the relays and the rear panel RF connectors if the distances are more than a few inches. Since the required lengths are short, you can use flexible RG-58 or RG-8X cable, rather than hard-to-manage RG-8 or LMR-400 cable. If possible, keep the two vacuum relays close together with a short wire jumpering their normally closed contacts. The wire size should be large enough to accommodate several amperes of RF current, preferable 20 AWG wire or larger.

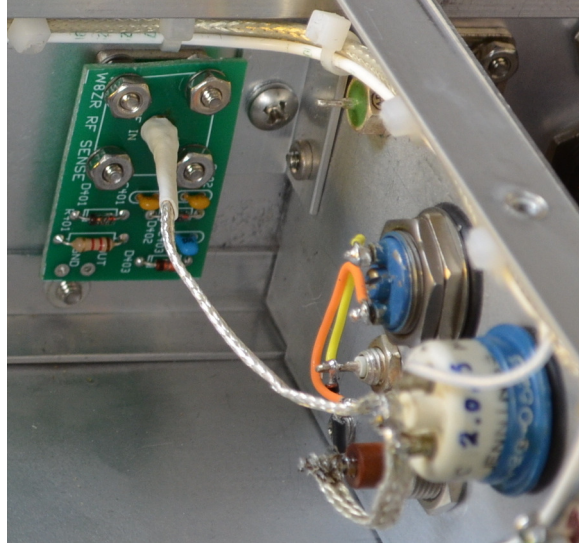


Figure 6: The Jennings RJ1a relays are mounted in grommets attached to an interior panel in the author's homebrew amplifier, with the RF detection components mounted on a small printed circuit board attached to the RF input BNC connector.

Operation of the QSK circuit could not be simpler. Hook up your keyer output to the “KEY IN” rear panel jack on your amplifier, and the “KEY OUT” jack to the key jack on your transceiver. (If you use your transceiver’s built-in keyer, then just skip this step.) Connect the AMP RELAY jack to your transceiver, and start operating. You’ll be amazed at how silent and convenient your new QSK circuit operates. In fact, once you’ve made a QSO or two, you’ll wonder how you ever got along without it!

Author Information: Jim Garland holds an Amateur Extra Class license and is a former Ohio State University physics professor and president of Miami University (Ohio). He is a life member of the ARRL, a member of the ARRL Diamond Club and Maxim Society, and currently lives in Santa Fe, NM. His amateur radio website is www.w8zr.net. He may be contacted at w8zr@arrl.net.

Table and Figure Captions:

Table I. Measured Open/Close Times in mS for Popular Vacuum Relays

| | close | bounce | | open | bounce |
|---------------|-------|--------|--|------|------------------------|
| Jennings RF3a | 3.5 | 1.0 | | 1 | 4 (w/ 75V zener clamp) |
| Jennings RF1d | 2.9 | 0.5 | | n/a | n/a |
| Jennings RJ1a | 2.1 | none | | 0.5 | (no diode clamp) |
| Gigavac G41c | 4.0 | 3.0 | | n/a | n/a |