Perfecting a QSK System

A reed relay and a sequence timing circuit allow the author to hear received audio between dots and dashes at 30 wpm.

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The first item listed under The Amateur's Code in *The ARRL Handbook* is "CONSIDERATE …never knowingly operates in such a way as to lessen the pleasure of others." When we are operating CW, trying to work a rare country and the DX station is listening, "up 2," we often hear stations continuing to call the DX station even though the DX station has already begun an exchange with another station. This is either the result of bad manners or the offending station is not equipped with a transceiver that is capable of QSK operation.

Full break-in operation, or QSK, has its roots in the early days of radio communication and CW traffic handling. When an operator sent QSK?, he was asking if the other operator had the ability to hear between CW characters when he was sending. If both operators had QSK capability, then they could easily interrupt each other if they missed a word while copying a message.

In the early 1960s I worked as a commercial radio operator in the high arctic. Our station employed separate receive and transmit antennas spaced a considerable distance apart. Our station was thus capable of QSK operation, and it was a feature that I really learned to appreciate.

When I built my own transceiver, which I named the HBR-2000, one of the features I decided to incorporate was full break-in keying. My design goal was to be able to hear other stations between CW elements at 30 words per minute. At 30 wpm the length of a space between character elements is 40 ms.[1] I decided to aim for a "transmit to full audio recovery time" of 10 ms or less. At 30 wpm that means the receiver is operating for 75% of the time between elements. As an example, when sending the letter "A," the receiver will be fully recovered from transmitting the dot for 30 ms or 75% of the length of the break time before beginning transmission of the dash.

To fulfill this requirement, a friend helped me design a TR switching circuit to do the following:

1. On key-down: activate audio and IF mute, CW sidetone and TR reed relays.

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[1]Notes appear on page ??.

2. 3 ms after key-down: turn on carrier oscillator.
3. On key-up: turn off carrier oscillator and sidetone oscillator.
4. 4 ms after key-up: TR relays switched to receive position.
5. 10 ms after key-up: audio and IF stages unmuted.

There is nothing unusual in this design approach. After building the circuit and implementing it in the transceiver, however, I was greeted with thumping/popping sounds in the audio output when keying the transmitter. It was very unpleasant to listen to. The thumping/popping sound became even more objectionable when I switched to my narrow 250 Hz IF filter. Connecting an oscilloscope to the audio output of my receiver, I was able to clearly see the distortion. See Figure 1.

I was able to reduce the annoying thumping by doing what commercial Amateur Radio manufacturers do: lengthening the time that the audio stage remains muted after key-up to about 27 to 30 ms rather than the 10 ms I desired. I tried this for a while but I was not happy, as I could not hear between dots when I was sending CW at 30 wpm. Actually, it was just about the same as using semi-break-in. Obviously, I had to do something if I wanted to meet my original design goal of a full-break-in TR system.

To understand what is happening you have to know a little about my HBR-2000 architecture. The receiver is a single-conversion receiver with no RF amplifier. The receiver mixer is a high-level +17 dBm double-balanced mixer followed by a single-stage classic W7ZOI-design 2N3688 post-mixer amplifier, then a 6 dB pad. Five selectable, relay-switched, crystal IF filters are located between the post-mixer amplifier and the input to the IF stage. I enclosed the different stages in boxes constructed of circuit-board material, and used BNC connectors for all RF runs and feedthrough insulators for all dc and control lines between the different boxes.

I use one reed relay for switching the antenna between transmit and receive (TR switching) and two more reed relays to switch band-pass filters (BPFs) between the receiver front end and the transmitter low level amplifier section. Since TR relays do not provide 100% isolation between contacts, there is some leakage of the transmit signal through to the receiver mixer and post mixer preamplifier when transmitting.

To get an idea of the level of signal at the receiver mixer port when in the transmit mode, I measured the RF level with a power meter when transmitting at 5 W. It was –59.6 dBm. I switched my 100 W amplifier in and out with separate input and output reed relays. Five watts is equivalent to +37 dBm; therefore there is about 77 dB of isolation between the transmitter output and receiver input when transmitting. This means that the receiver front end is being exposed to a very loud 10-dB-over-S9 signal when transmitting.

As mentioned above, after key-up, the TR relays do not switch from transmit to receive until 4 ms has passed. Relays do not switch instantaneously and though the relay speci-

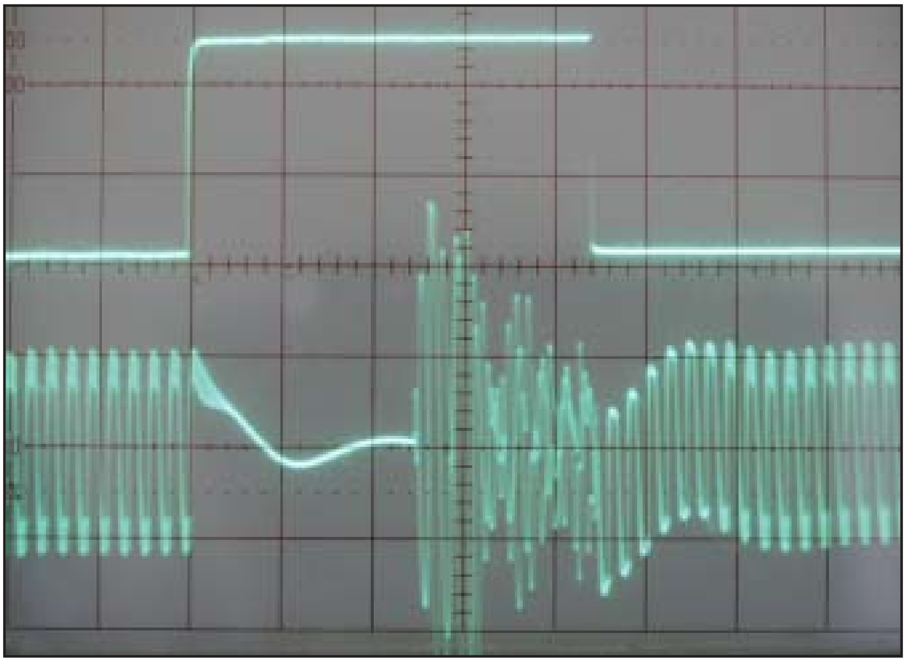

Figure 1 — This is the oscilloscope trace of keying line and audio output, showing the loud thumps when the receiver recovers. The oscilloscope time base was set to 5 ms per division.

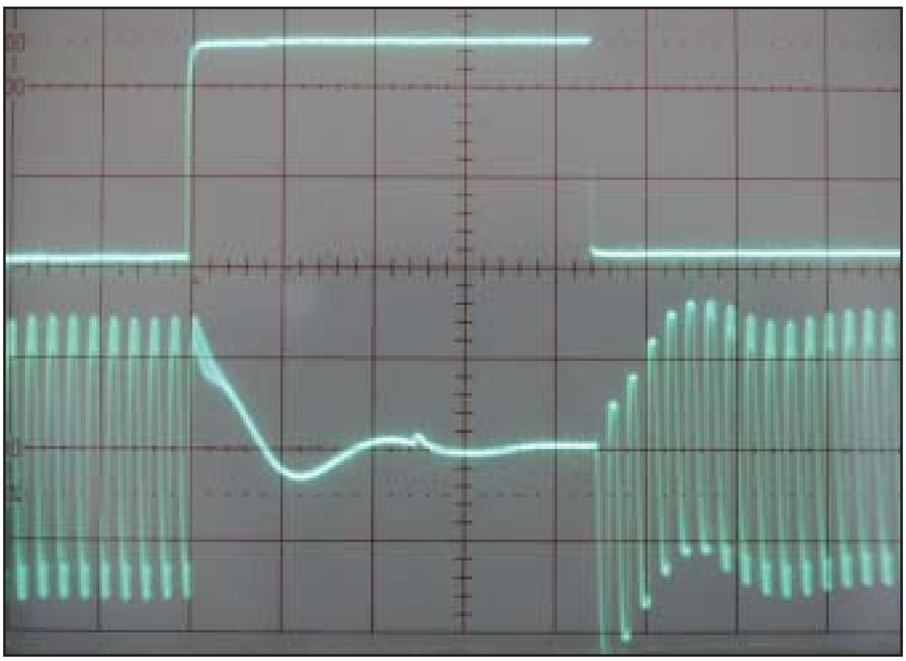

Figure 2 — Here you can see the sine wave on the break of the CW sidetone. That was the cause of the low sounding thump.

fications call for a switching time of less than 1 ms, the contacts bounce a little, producing a transient pulse. Since it takes about 3 ms for the CW carrier to diminish to zero, 4 ms is sufficient time to ensure that I am not hot switching the TR relay.

Transients produce the thumping/popping sound in the receiver audio output when switching between transmit and receive. The transients are produced by a combination of events all happening very quickly: the TR relay switching, the carrier oscillator turning on and off and so on. The transients flow between the TR relay contacts and on to the mixer, post-mixer amplifier and crystal filters before reaching the IF input.

Previously I mentioned that the thumping sound was particularly bad when choosing the narrow CW IF filters. What I discovered was that when a wide IF filter (2.5 kHz BW) was selected, I only needed an audio mute time of 10 ms after key-up to achieve no thumping sound in the audio output. When I selected my narrow 250 Hz IF filter, however, I had to increase the audio mute time to 27 ms to achieve the same clean sound.

The length of time that it takes RF transients to diminish to zero varies with the bandwidth of the stage through which they pass. Compared to a 2.5 kHz wide filter, a narrow filter such as my 250 Hz filter increases the time that it takes a transient to diminish to zero by a considerable amount. That is why there is still some RF energy at the IF input after the TR relay and carrier oscillator have switched to receive when listening with a narrow filter. In my particular case it takes about 17 ms longer for a transient to diminish to zero for the 250 Hz filter compared to the 2.5 kHz filter.

It became obvious after the initial investigation that if I wanted to achieve my original goal of being able to hear between CW dots, then another course of action had to be taken.

I reasoned that if I could come up with another method of providing further isolation between the TR switch and the mixer input, I could achieve my goal. One thought was to incorporate a diode attenuator in conjunction with the TR reed relays to obtain additional isolation. This in turn would reduce the level of the transients before they reached the IF filters. I was not keen on this idea, because I had purposely avoided using diodes in the receiver signal path. I wanted to avoid the possibility of introducing diode-associated IMD problems.

After explaining my problem to my friend, who has helped me a lot when I ran into problems while building the HBR-2000, he suggested I should switch off the LO power to the receiver mixer while transmitting. Our first thought was to use electronic switching but since I had an extra reed relay on hand we decided to use the relay instead, as it was easier and quicker to incorporate than a diode switch. When there is no LO power applied to a double diode balanced mixer, it is actually an electronic attenuator. The LO power forward biases the mixer diodes and causes the diodes to conduct.

Upon adding a reed relay in series with the LO to the first mixer, I was able to reset the audio mute time after key-up to 12 ms when listening with the 250 Hz filter. The sound of the audio output was considerably improved. The relay contacts switch between the LO and a 50 Ω resistor so that the mixer LO port is looking at a 50 Ω impedance on transmit. However, there is still a little low frequency thump when the CW sidetone breaks, as Figure 2 shows.

The problem is that the sidetone oscillator (a switching astable oscillator) produces a supply-to-ground square wave having a half-supply bias that produces a transient. This is the low-frequency thump heard in the audio output, upon key up. The combination of the LP and HP filters be-

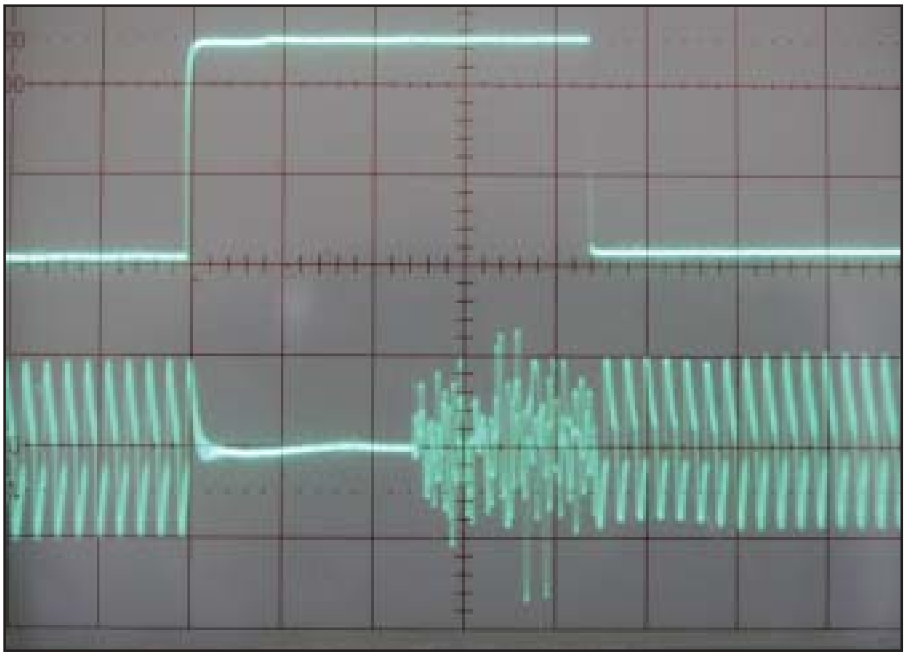

Figure 3 — Here the low frequency sine wave has been eliminated. No transient in the audio output, just receiver noise.

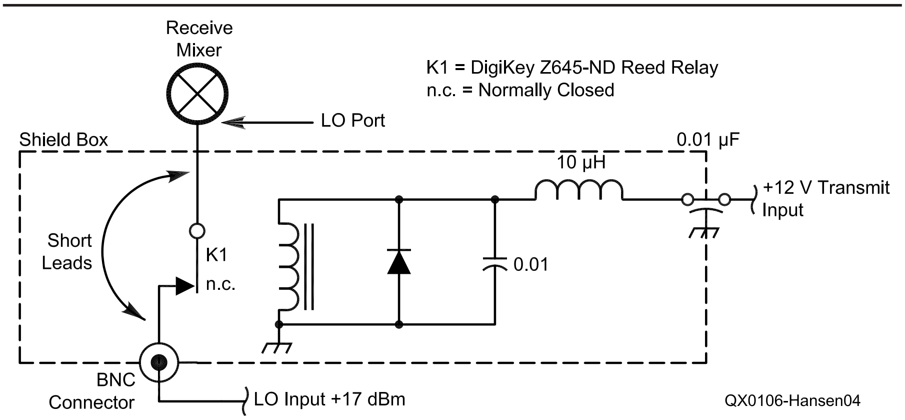

Figure 4 — This is the wiring diagram of the LO relay.

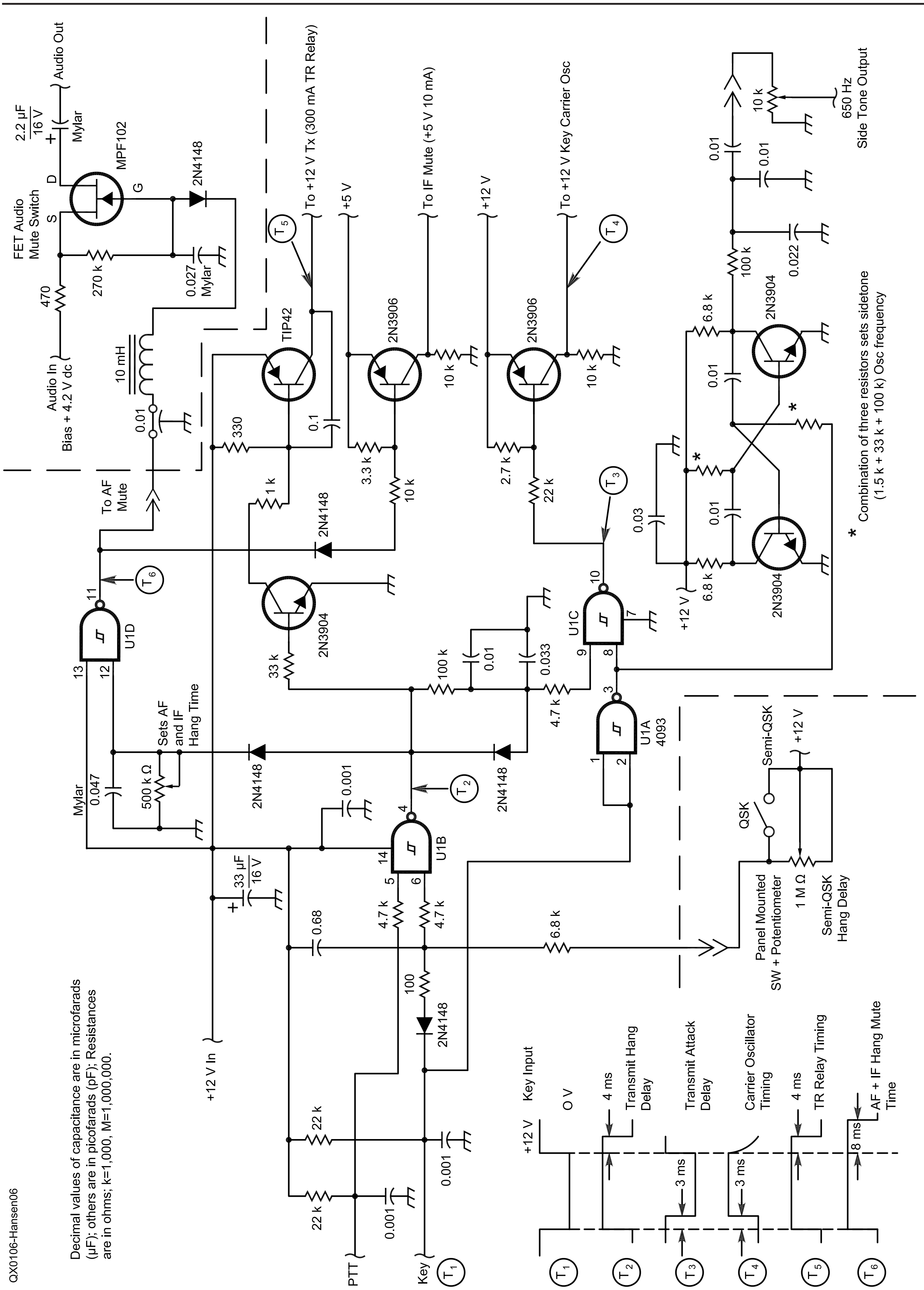

Figure 6 — TR System Diagram.

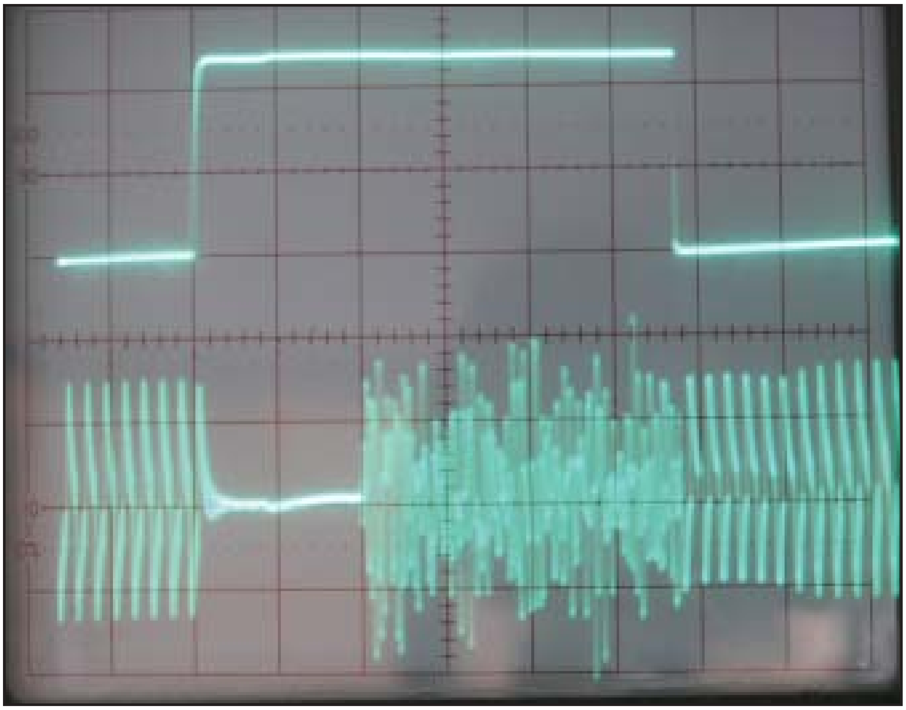

Figure 5 — The final result.

tween the oscillator output and 10 kΩ level control will cause thumping if their time constants aren't matched. By installing a coupling (0.01 µF) capacitor with a value matched for the time constant of the LPF, the low frequency thump was eliminated. Figure 3 shows the result of our efforts.

I still had not reached my goal of a 10 ms receive recovery time, though. As mentioned previously, I had wired the LO reed relay so that when transmitting, the receiver mixer LO port was connected to a 50 Ω resistor. I decided to change the wiring of the relay so that when transmitting, the LO port was grounded instead of being connected to a 50 Ω resistor, hoping to achieve further isolation in the mixer stage. See Figure 4 for the revised wiring. Very short leads from the BNC LO input connector to the reed relay and a shield between the relay and the mixer all play a roll in improving the isolation when the mixer port is grounded by the relay.

This wiring change improved the LO-to-mixer port isolation, and I was able to reduce the receive recovery time to 10 ms. By adding 0.01 µF capacitors across the coil contacts of all the reed relays as well as a 10 mH choke in series with the +12 V dc supply line on the inside of the box to the post mixer amplifier, I was able to further reduce the receive recovery time to 8 ms. Could it be improved further? If I had used better quality RF reed relays I may have been able to achieve an even shorter receive recovery time. I believe that there comes a point of diminishing returns, however. Remember that we are dealing with a transmitter and a very sensitive receiver in the same box. Figure 5 shows the receive audio waveform for the final circuit.

How does the QSK system sound after making the above-mentioned changes? Wonderful! In fact, when I am listening to a CW pileup, if I set the CW sidetone oscillator level so that it is at the same level as the incoming signals, I am not even aware that I am transmitting (because I still hear the other signals). The CW sidetone oscillator blends in with the incoming signals.

Figure 6 is a diagram of the final version of the TR switching system and sidetone oscillator. The sidetone oscillator frequency is 650 Hz, which corresponds to my transmit frequency offset. Also shown is the audio FET mute switch that is located in the audio module box, which is in a separate enclosure from the TR circuit board.

Recently I had the opportunity to make side-by-side comparisons of my HBR-2000 with three different commercial Amateur Radio transceivers. Not one of the commercial transceivers was capable of hearing signals between CW dots when operating at 30 wpm, using narrow CW IF filters. Two transceivers in particular produced objectionable thumping sounds that would be very difficult to bear for any length of time. I suppose that explains why many operators still use semi break-in when operating CW.

When you build your own equipment, you have the option of optimizing it for your own use. With careful measurements and some help from my friend, I was able to achieve my goal for a smooth and pleasant sounding full break-in QSK system.

Notes

[1]ARRL Technical Information Service, Morse Transmission Timing Standard, **www.arrl.org/files/infoserv/tech/code-std.txt**. For purposes of specifying code speed, the "PARIS" 50-unit standard is used. From that standard, the following relationship is derived:

u = (1.2)/c

where:

u = period of one unit, in seconds
c = speed of transmission, in words per minute (wpm)

The length of a DOT and the space between elements of a character is one unit. The length of a dash is 3 units and the space between words is 7 units.

Markus Hansen has been an Amateur Radio operator since 1959. He has no formal electronics training but likes experimenting and writing articles about his experiences. He has had articles published by ARRL in QST, QEX *and the* Antenna Compendium *series. You will find Markus in many of the HF CW contests as well as on 6 meters. He is always on the lookout for the last few countries that he needs for DXCC honor roll. His Web site describes more technical details of the HBR-2000 plus other homebrew projects and antennas that he has built.* □□