A Pocket Sized 20M QRP SSB Transceiver

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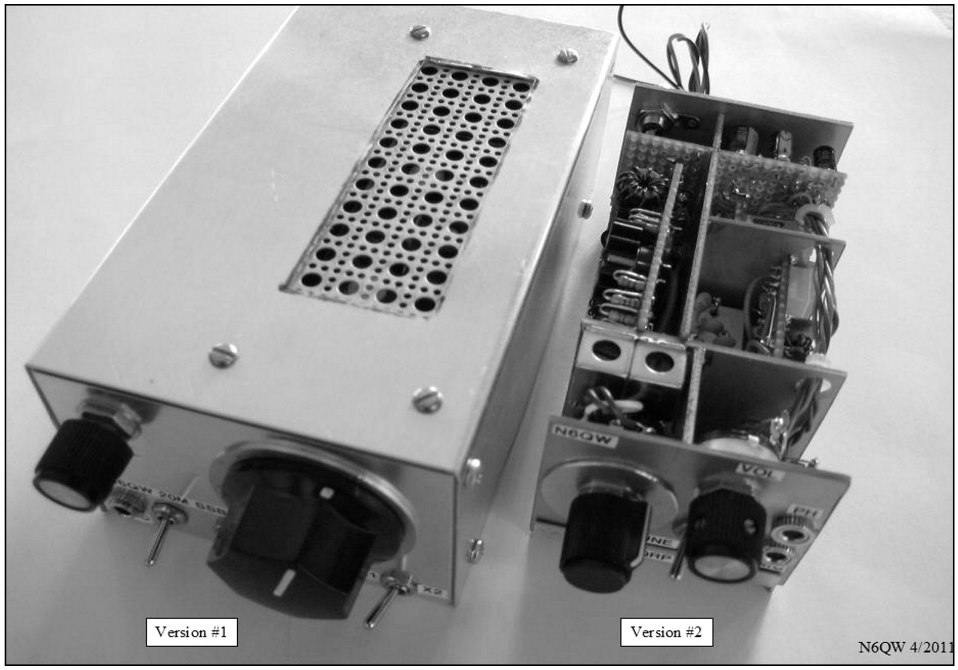

Figure 1—Size comparison of the two transceiver versions.

In a June 1963 *QST* article, Ben Vester, W3TLN described a homebrew 20M SSB transceiver which measured 5 x 7 x 2 inches and had a power output of 250 mW. It was virtually dwarfed by the famous D-104 lollipop microphone sitting nearby. At that time, his radio was leading edge technology and true QRPp! Operating at 6 VDC, it was to be used mobile in his Volkswagen Beetle. [Pre-1966, all Beetles were 6 volt.] Some of you may remember that the Beetles were pretty small cars, especially for their day, so space was probably at a premium which caused Vester's quest for a small mobile rig. The architecture of Vester's radio had a four-pole homebrew filter crystal filter at 8.55 MHz and a VXO operating at 22.9 MHz, which results in a signal at the high end of 20 Meters! Portions of the circuit were bilateral, used both for transmitting and receiving, and the switchover to transmit was done with mechanical switches.

Following that lead of some 48 years ago, this article describes the construction of a shirt pocket sized 20M QRP SSB Transceiver. The radio described in this article is the second generation of a radio built earlier in 2011. The first version was 2 x 3 x 5 inches, so you would need a large shirt pocket. The second version weighs in at 2 x 4 x 2 inches and is the result of seeing a project by Allison Parent, KB1GMX, who built a really small SSB transceiver for use on six meters. I simply followed how she physically constructed her radio and made a remarkable volume reduction of nearly 50% compared to the first version of my transceiver. The key to her design was the use of double-sided copper PC board that was arranged in small compartments to create a skeletal framework. Her approach adds greatly to circuit isolation and stability. Figure 1 is a photo of the completed radio sitting beside the original version (V1). If you search You Tube for N6QW, there are several videos which show the various stages of construction for both versions.

In shrinking down the size of the radio, I already knew it was a proven design and had the first version as a benchmark. With Version 2, the challenge was to shrink down the size and not necessarily prove that the design worked. That said, let me not mislead you. Making the physical construction much smaller, in itself created problems with interconnectivity, control wiring routing and heat transfer. One cannot approach Version 2 in a casual manner and expect everything to work from the get go. KB1GMX provided much insight into considering all of these factors and was most helpful with technical information. Thank you, Allison!

Sufficient information is provided here to replicate this project. Schematics are provided in this article as well as available for download from my website, www.jessystems.com. However, I primarily want to focus here on some of the design decisions that were made to shrink the radio down to its current size. In general, I was able to preserve almost all the features in Version 2 that were in Version 1. However given that Version 2 is a good bit

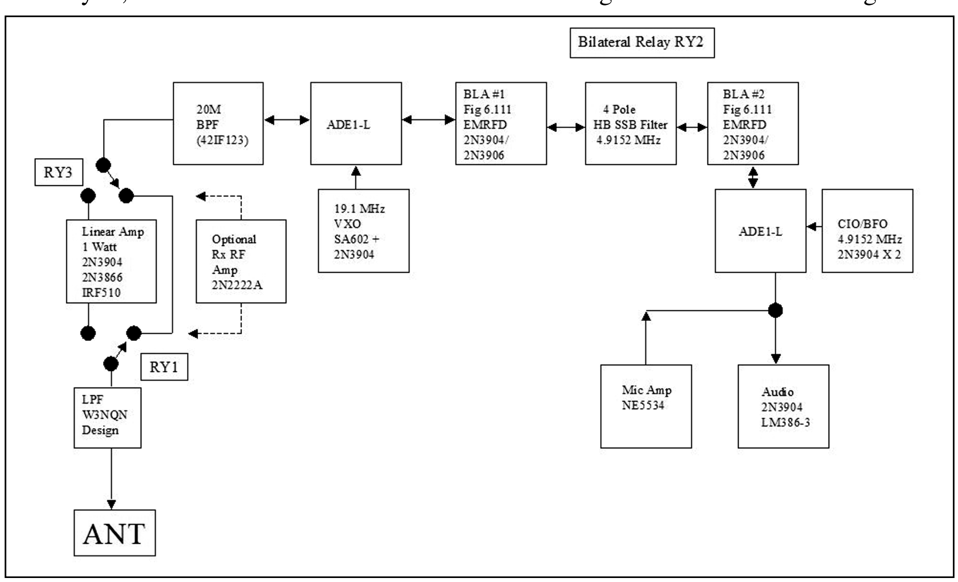

Figure 2—Transceiver block diagram.

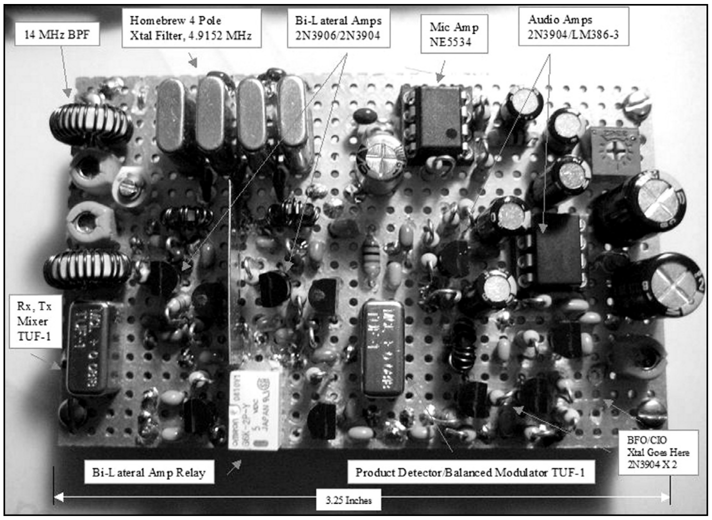

Figure 3—Main board photo of Version #1.

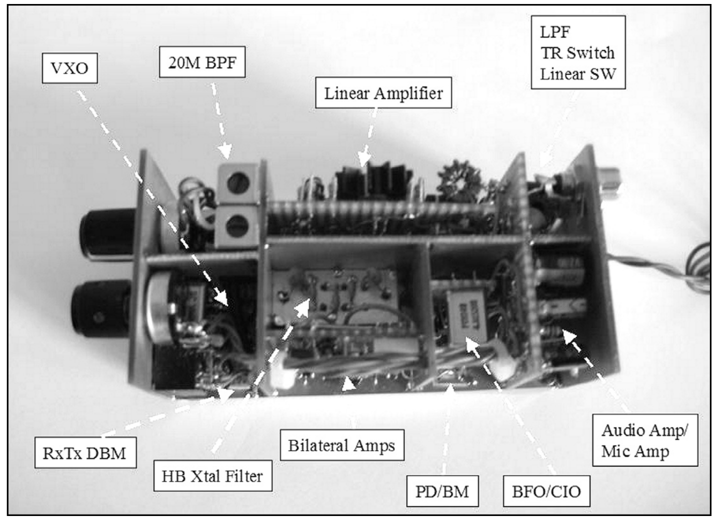

Figure 4—Plan view photo of Version #2.

smaller, I had to make some concessions on power output. Version 2 is limited to one watt while Version 1 can do over 2 watts. Fortunately, both have the capability to switch on a ten watt external "after burner" which I will also discuss here. Running V2 with the external amplifier at 10 watts PEP, I have had about 6 DX contacts in the first few days of operation. I have also had two 1 watt QSOs. Not bad for something that fits in the palm of your hand. Signal reports have all been excellent and frequency stability is superb owing to the VXO. Version 1 also had a receiver RF amplifier that is absent in the second version and not missed.

This radio evolved from some design specifications of my own. The radio had to be small, ideally something that would fit in a shirt pocket but more realistically something that could fit in the palm of your hand. The output power needed to be at least one watt in order to drive an external amplifier and the tuning had to cover more than just a few kilohertz. The audio stage should have enough "umpf" to drive an external loud speaker. It had to have a stable output with enough sensitivity to actually hear DX stations on 20M. It would not involve a PC Board. Bilateral circuits would be employed so that the part count would be reduced and there would be no AGC circuit in order to save space. It would be a SSB only radio. The IF frequency would be 4.9152 MHz. (Later you will see why this was a really good choice.) Standard transistors and IC's would be employed so that parts procurement would not be a problem. As it turns out, all required parts can be purchased from Mouser or Digikey with three exceptions. The ADE-1L double balanced mixers can be obtained from Mini-Circuits Labs, ferrite and iron powder cores came from Amidon and some inexpensive (about $1 a piece) ultra-miniature 5 VDC DPDT relays came from All Electronics to make it all possible.

Let us start with Figure 2, which is the block diagram. There is not too much unusual about my approach nor are there any exotic parts. Several SMD parts were used to take advantage of their smaller foot print and these include the double balanced mixers (ADE-1L), the VXO that uses the venerable SA602 in an SOIC8 version and finally a couple of size 1206 10 nF bypass caps. Basically it is a bilateral transceiver where many circuits are being used for both transmit and receive and this same approach has been successfully employed in many of the transceivers I have built. To transition from receive to transmit merely involves changing the signal direction.

My main challenge in transitioning to Version 2 was to find out what made the most sense in arranging the circuit blocks. In Version 1, there were essentially four boards that make up the transceiver. The first was the main board that contained all of the blocks from the band pass filter to the audio amplifier and microphone amplifier. Figure 3 shows the main board as it was built for Version 1. The second board was the switched crystal heterodyne VXO. The third board was the Tx and Rx RF amplifier board and finally the fourth board contained the TR switch and LPF. These circuits had to be made into smaller chunks so they could fit into the various nooks and crannies in Version 2. Much thought was given to space allocation, mounting options and board sizes. I soon realized in both versions that the final size was largely driven by the input and output devices and the real estate required for these parts. Even 3.5 mm stereo audio connectors do take up a finite amount of panel space. Even if the radio were to be converted to all surface mount parts, the I/O would still be problematic. Also, I have not found a really good source for ultra-small pots such as are used for the varactor tuning in the VXO and volume level in the audio amplifier. In Version 1, I was able to use a coaxial type connector for power to the radio. In Version 2, there was no room for such a connector so there is a short "pigtail" for power wiring coming out of the back of the radio.

For Version 2, there are seven separate sub-assemblies consisting of: 1) the audio and microphone circuits, 2) the BFO/CIO board and double balanced mixer (DBM), 3) a bilateral amplifier board, 4) a crystal filter board, 5) a switched crystal VXO, the band pass filter and DBM, 6) the transmitter RF amplifier board and 7) the last board containing a control relay and the low pass filter stage and external linear switch. All of the boards with the exception of those housing the VXO and two DBM's use single-sided copper Vector board. The use of the Vector type board provides a built in ground plane and all point to point wiring is done on the underside of the board. Connections going to ground are soldered

Figure 5—Bilateral amplifier and BFO photo.

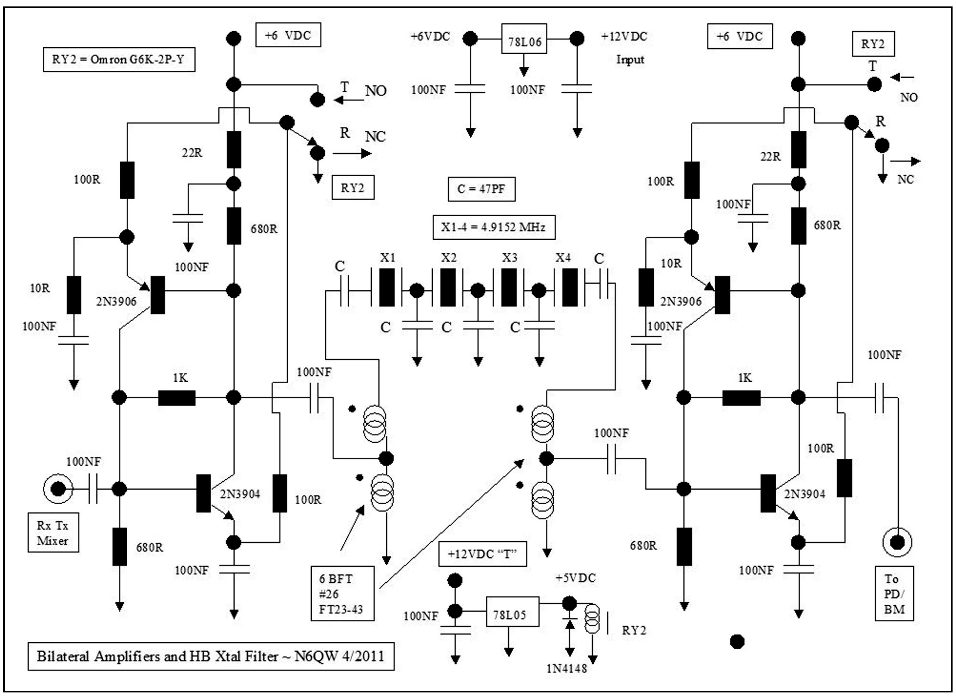

Figure 6—Schematic of bilateral amplifiers and crystal filter.

directly to the top of the board. Components that are connected to other components are passed through the board and connected to each other on the insulated side of the board. For components not connected to ground, I enlarge the top of each pass through hole with a couple of twists of a drill bit. This prevents shorts to ground. These individual assemblies are then soldered to a skeletal frame that is made entirely of double-sided PC Board. This affords a convenient total ground plane while providing isolated shielded compartments to discourage unwanted circuit interactions. Holes at convenient locations are used for passing control cables and power wiring. Figure 4 is a photo of the completed transceiver, which shows a plan view of how the circuit blocks were integrated into the final assembly. I should mention that it was actually possible to test most of the sub-assemblies before they were installed in the skeletal frame. This is absolutely mandatory, as once they are installed it is difficult to troubleshoot where there might be a bad component or shorted part. One of the crystal filter-matching transformers had a nicked wire and I found that it was shorting to ground. It would have been very difficult to find once it was installed. The base underneath the PC board that supports the PCB skeletal frame is a small piece of aluminum stock that will enable placing a "U" shaped cover over the entire assembly to form a box enclosure.

The final configuration has the switched crystal heterodyne VXO, the band pass filters (BPF) and the Rx-Tx DBM sitting directly behind the front panel. This facilitates short leads to the tuning potentiometer and allows the heterodyne crystals to be directly soldered to the panel mounted SPDT switch. This also enabled having the BPF a short distance from the Rx-Tx DBM and the shortest distance from the output of the VXO to the input of the DBM. In looking at the transceiver straight on, the bilateral amps, crystal filter, BFO/CIO and the audio and microphone amplifiers are installed along the right hand side of the assembly with appropriate shielding of the bilateral amplifiers and crystal filters from the BFO/CIO. Wiring for the audio and microphone circuits are in a twisted pair cable bundle, which runs along the top side of the right hand assemblies through a series of holes in the shielded assemblies. These terminate in the panel-mounted jacks and the volume control on the front panel. Along the left side, is the transmitter linear amplifier stage. The location of the band pass filter enables a short connection to this board and the ultra-miniature DPDT relay located on the transmit board. In the NC (normally closed) state, the Transmit stages are bypassed and a short length of ultra-miniature coaxial cable connects the low pass filter (LPF) to the band pass filter. On transmit, the linear amplifier stage is connected between the LPF and BPF. The final board mounted near the real panel houses the TR relay, LPF and the transistor switch used for keying an external linear amplifier. The antenna and linear amp switching connectors are the standard RCA type connectors. Much thought went into this configuration, much of it driven by what Allison, KB1GMX shared with me.

The bilateral amplifiers are a straight

lift from Figure 6.111 in *EMRFD* and a small ultra-miniature board mounted relay controls the signal direction. A modification suggested by KB1GMX was incorporated in the V2 build. She suggested adding two 10-ohm resistors to reduce the gain on transmit, as the level going into the Rx-Tx DBM would be quite high. Undoubtedly there will be the purists who will opine that the more elaborate form of the bilateral amplifiers should have been used, citing the need for constant impedance characteristics over a wide range of frequencies. Get a grip, as this is not intended to be a laboratory grade transceiver. The simple bilateral form works quite well and does a good job! Just watch the You Tube videos and you too will be amazed at how the venerable 2N3904/2N3906 combination works so well. That said, attention was paid to holding 50 ohm interfaces and two small matching transformers were constructed using FT-23-43 cores to match the 50 ohm in/out of the bilateral amplifiers to the approximately 200 ohm impedance of the crystal filter. On the other ends, the bilateral amplifiers interface with the ADE-1Ls which of course are 50-ohm.

Before I actually built the bilateral amps, I took a 4 x 6 inch piece of plain vector board stock and using a fixture I have, elevated the board so I could pass components through the holes. I initially masked off an area approximating the bilateral circuit board where I could place parts on the board to follow the circuit with an eye toward eliminating any crossovers and minimizing real estate usage. This worked very well. Figure 5 is a photo of the bilateral amplifiers and the BFO/CIO as the boards were being installed.

Figure 6, is the schematic for the bilateral amplifiers and the homebrew crystal filter. Crystals for the filter were selected from a larger stock of 4.9152 MHz crystals. Specifically, the crystals selected should be the four crystals whose resonant frequency is in closest proximity to each other. In no event should the crystals have more than a 50 to 100 Hz frequency spread. Typically a batch of ten to twelve crystals will be sufficient to find four crystals meeting the frequency spread requirement. Note also that the BFO/CIO crystal, also at 4.159 MHz, may require replacement in order to match the filter slope point. You will find out if your choice was correct when you do the final tuning procedures. For this reason, the BFO/CIO crystal was placed at the top of the board so that it could be easily replaced.

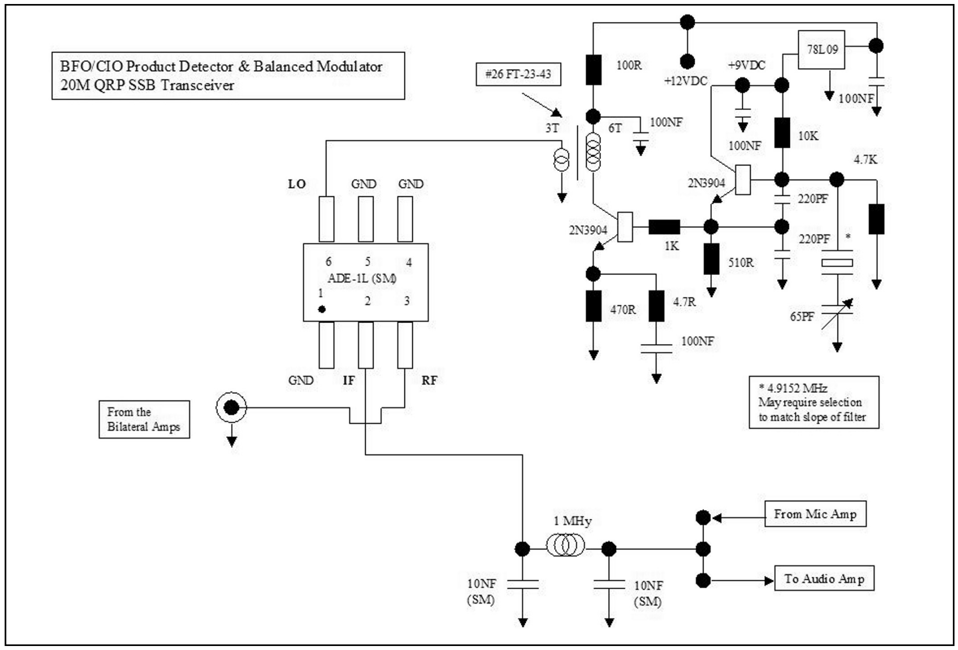

Figure 7—BFO/CIO product detector and balanced modulator schematic.

Figure 7 is the schematic for the BFO/CIO, the product detector and balanced modulator. The product detector/balanced modulator is an ADE-1L. Note that this is a +3 dBm device, which means it needs less than 1 volt peak-to-peak of LO for optimum operation. The actual value needs to be 0.9 volts p-p. If you were to use another DBM such as the TUF-1 or SBL-1 then you would need about 1.414 volts p-p. In another N6QW transceiver featured in the Spring 2011 Edition of *QQ*, I included a small variable gain amplifier to assure +7 dBM is fed to an SBL-1. ADE-1Ls can be purchased directly from Mini-Circuits. A quantity buy dramatically drops the individual price of these units.

The choice of LO frequency was governed by the use of a Cohn crystal filter in the transceiver and by the availability of stock computer crystals used in the VXO. The asymmetric shape of the Cohn filter favors the generation of LSB and of course USB is the convention for 20M. The way to achieve USB with an LSB filter is to place the LO above the IF which in this case is 4.9152 MHz, e.g., 19.1 MHz - 4.9152 LSB = 14.184 MHz USB. This IF was chosen, by the way, because I have had excellent luck in the past with finding stock computer crystals that could heterodyne this frequency into suitable portions of the amateur bands. For example, you might want to look at the 17M QRP SSB transceiver on my website which uses 11.52 MHz computer crystals in a doubled super VXO configuration. In the present case, we need to generate an LO frequency in the range of 19.2652 MHz to 19.0652 in order to cover the SSB portion of the 20M band. Of course, covering the above entire range would be a tall order for a VXO. But, now I knew which crystals to look for in order to cover a usable fraction of the 20M band.

So, I spent some "quality time" with the online catalogs looking at the standard frequency computer crystals available. I found some 12.96 MHz crystals and some crystals in the low 6 MHz range which would heterodyne into the desired LO range. Based on my experience with the 17M transceiver mentioned above, I expected to achieve a usable frequency range using the 12.96 MHz crystals in a super VXO configuration. Some experimentation showed that three such crystals provided a 30+ kHz shift in frequency. Of course, the shift was to lower frequencies as is the usual case for a super VXO. By switching 6 MHz crystals, similar to the scheme I used in the 17M transceiver, I could achieve even more range. In the end, I found crystals at 6.144 MHz and 6.176 MHz. There was a third usable crystal at 6.25 MHz but it proved not to be available in small quantities at a reasonable cost. So my two 6 MHz crystals translated to a fre-

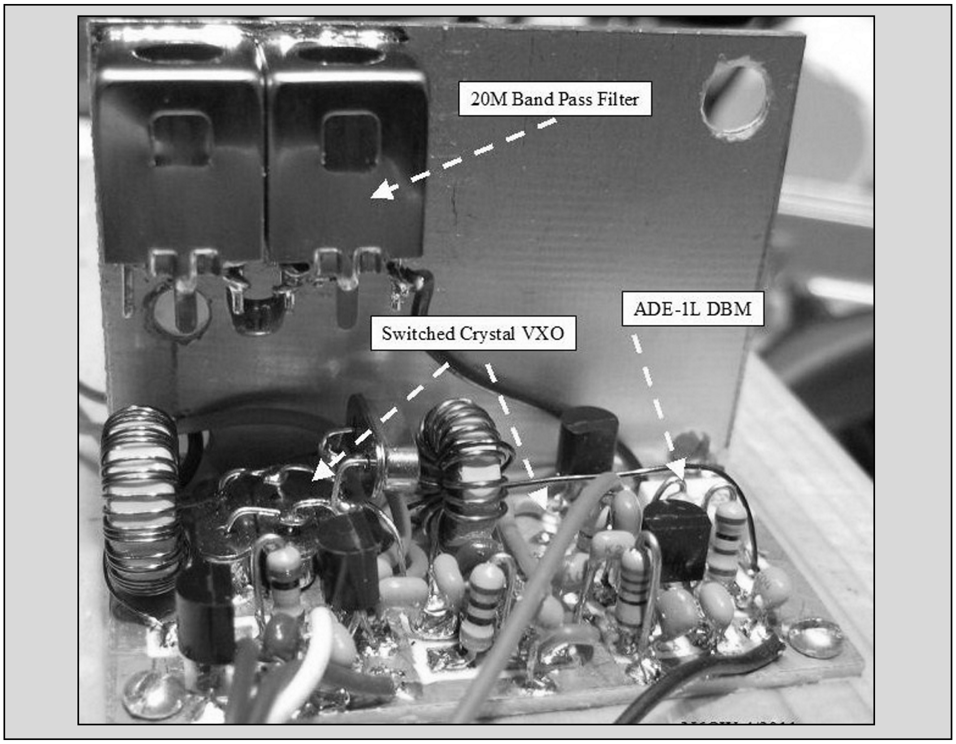

Figure 8—VXO photo.

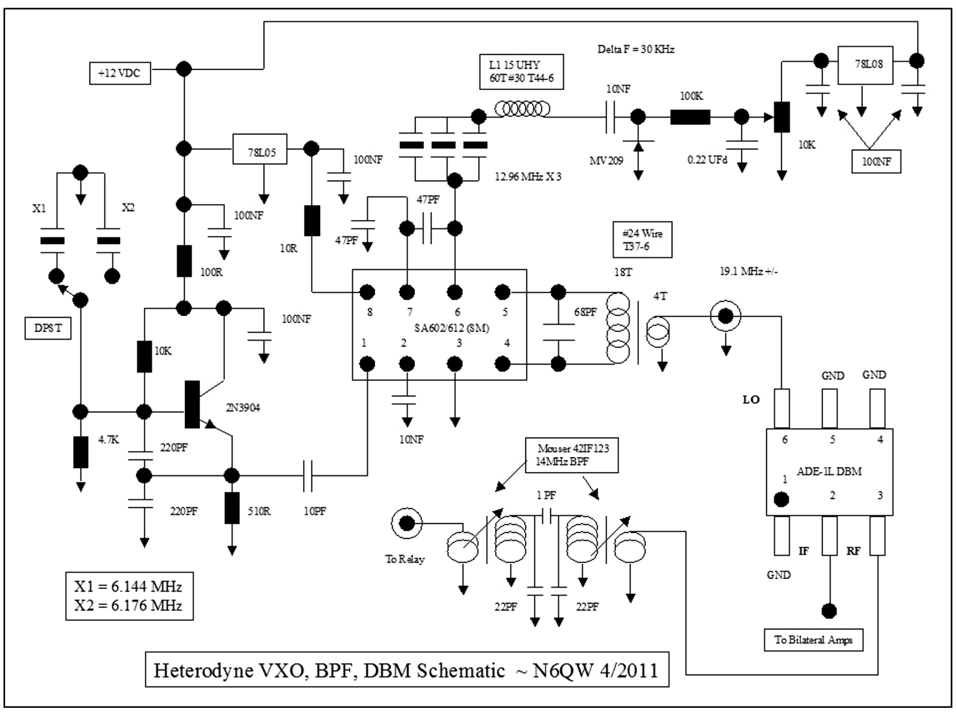

Figure 9—Schematic of VXO, band pass filter and RxTx mixer.

quency range of 14.160 MHz to 14.220 MHz, a very useful portion of the 20M band.

The implementation of my VXO is shown in Figure 8 and the schematic is in Figure 9. The horizontal board is about 2 inches by 1 inch and the vertical board containing the band pass filter is 1.75 inches high. The 6 MHz crystals (not shown) are attached directly to a front panel-mounted DPST switch. Some space was saved by using an SA602/612 as both the 12.96 MHz oscillator and mixer. VXO tuning is achieved using an MV209 varactor biased with a regulated 8.0 VDC supply. The change in capacitance is about 30 pF, which is a good tuning rate for a single-turn, panel-mounted potentiometer. The switched 6 MHz input is provided by a simple 2N3904 oscillator fed into pin 1 of the IC. A balanced output is taken across pins 4 and 5 which has a tuned network centered on 19.1 MHz.

The only remaining portion of the receiver is the audio amplifier, the schematic for which is shown in Figure 10. The microphone amplifier is shown in the same schematic, as the two stages are physically near each other. Figure 11 shows the parts placement for these two stages.

It is strongly recommended that the receiver be made operational at this point before proceeding on to the transmitter board. If the radio works flawlessly on receive then the transmitting function will work as designed. The VXO range should be calibrated and performance peaked. Proper operation of the VXO is by observation on an oscilloscope and measurement with a frequency counter. Alternatively, alignment and calibration can be done by tuning a general coverage receiver to 19.1 MHz and listening for the VXO signal.

Now we will shift to the transmitter RF amplifier board. Shown in Figure 12 is my second attempt at this board, which is about 1.75 inches high by 2 inches long. Figure 13 is the schematic for the Transmit Amplifier stage, which is straight out of EMRFD figures 2.93 and 2.98. It is run at one-watt output. On this board is another ultra-miniature relay which on receive connects to the receive side on the TR relay. Should a receiver RF amplifier (Figure 17) be added, it is a simple insert between the two relays.

A special note and caution about the IRF510. This device can be biased for more output but, given the small heatsink, STOP at 1 watt! The TO-220 heat sink is not enough and on the backside of the vector board is a slab of copper that is 1/8 inch thick and the same size as a TO-220 finned heatsink. This slab is in thermal contact with the IRF510 through a 6-32 by 1/2 inch long bolt which is attached to the IRF510 drain tab and passes through the regular heatsink, through the vector board and finally to the copper slab. I smoked the first IRF510 after a lengthy QSO as I exceeded the thermal ratings. I have often wondered why I have seen such very large

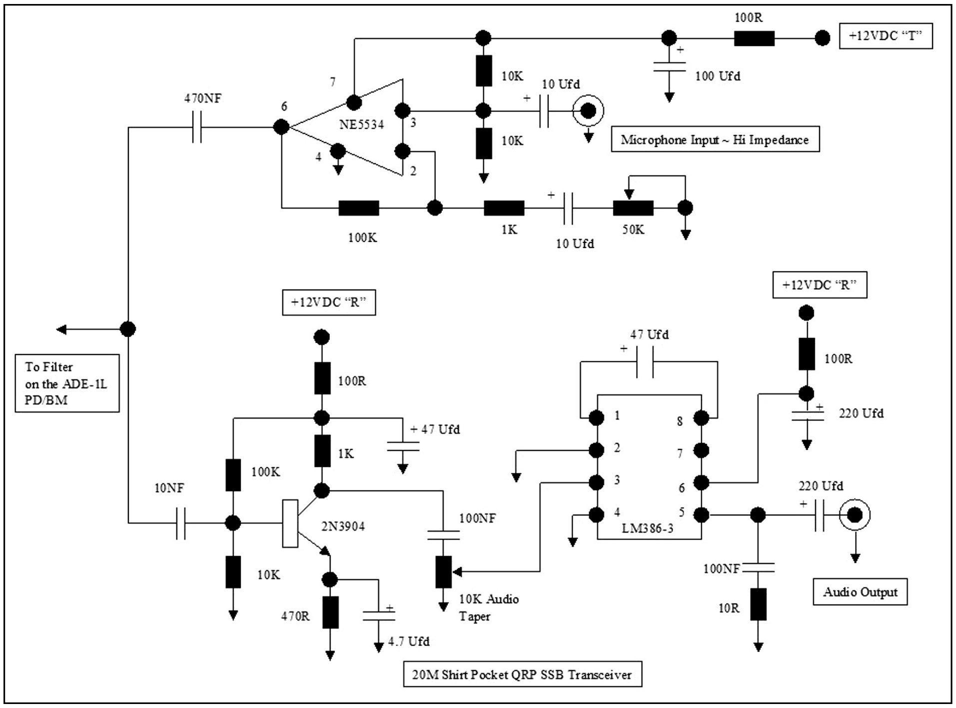

Figure 10—Audio and microphone amplifier schematics.

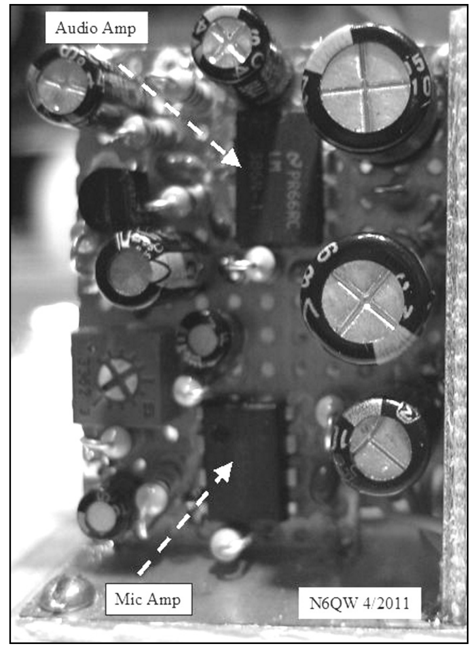

Figure 11—Audio and microphone amplifier photo.

heatsinks on MOSFET RF amps—now I know why! The IRF510 can safely pass 5.6 amps and a small clip-on TO-220 heat sink by itself is not enough. The final stage will do one watt safely but any more bias will cause the IRF510 to get so hot that it will finally fail! KB1GMX has used the entire skeletal frame as the heat sink for her project and this is where I should have taken advantage of her suggestion. She is using an entirely different RF amplifier chain but has purposefully held the output to 1 watt for the same thermal reasons.

Before installing the final amplifier board in its permanent position, it would be a wise idea to test the transmitter board and peak the circuits as necessary. Alignment of the transmitter board entails looking at the signals coming out of the various stages. I indicated earlier that it is wise to test the boards prior to final installation. I knew the microphone amplifier was working properly and simply probed the signal as it progressed through the transmitter stages looking at the output of

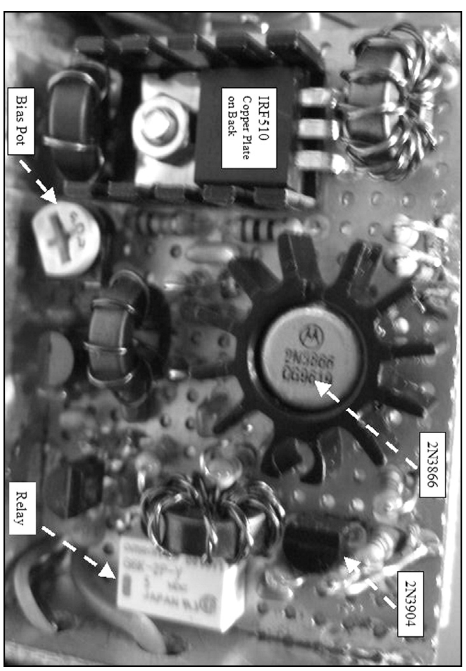

Figure 12—Photo of RF linear amplifier board.

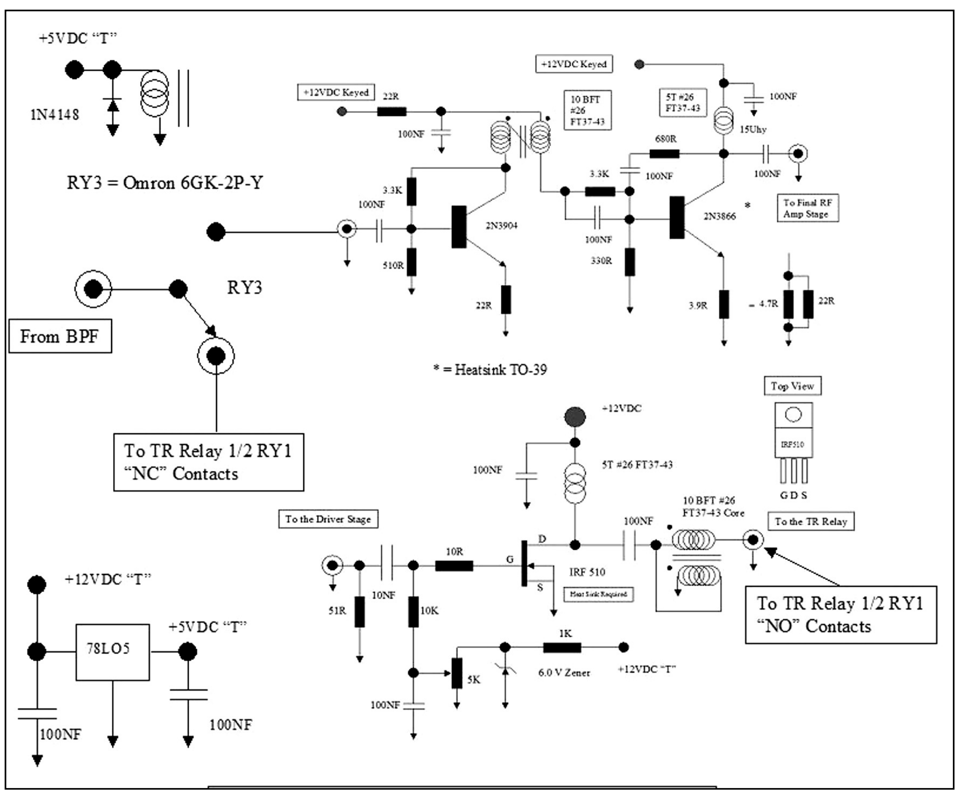

Figure 13—Schematic of the RF linear amplifier.

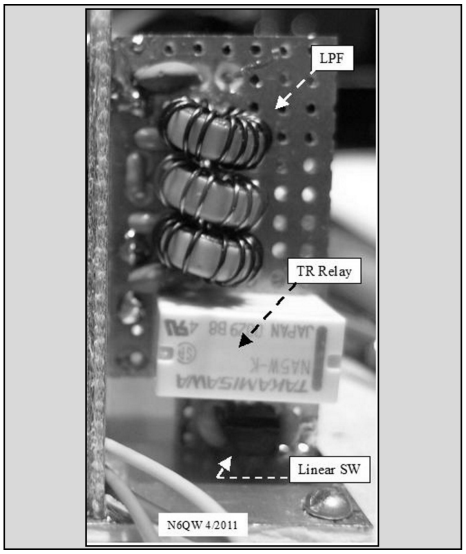

Figure 14—Photo of the TR switch, low pass filter and linear amplifier switch

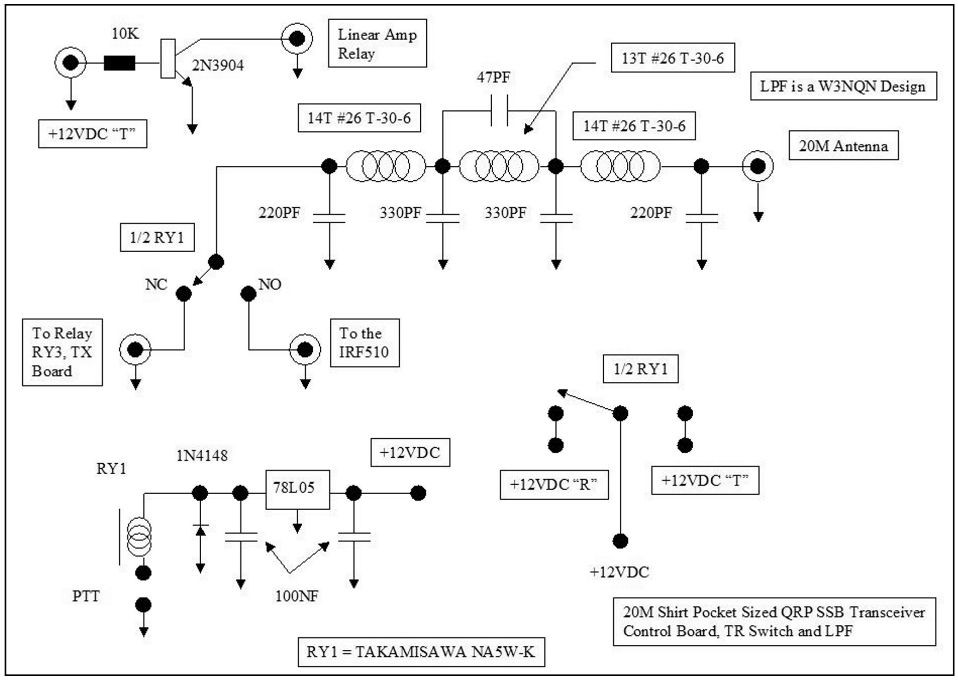

Figure 15—schematic of TR switch, low pass filter and linear amplifier control.

the balanced modulator, the bilateral amps and at the output of the band pass filter. I had the standard Christmas tree Pattern of about 50 mV p-p out of the BPF so I knew I was on track.

The last board is the TR relay and low pass filter (W3NQN design). The TR is a DPDT relay and one set of contacts provides DC voltage routing to bias on the various circuits in the receiver and transmitter. The PTT on the microphone jack controls this relay. The other half of the relay routes the antenna to either the transmit board or to the receiver input. The TR relay is permanently connected to the low pass filter. Figure 14 is a photo of this board and Figure 15 is the schematic. A simple 2N3904 is used as the DC switch for an external linear amplifier.

The band pass filter construction was greatly simplified by using an idea from Paul Daulton's article on the SESE 80 Meter receiver in the Winter 2011 issue of *QRP Quarterly*. In that article, Paul demonstrated how commercial 10.7 MHz IF transformers available from Mouser (P/N 42IF123) can be modified and used as a band pass filter on 20M. The modification entails removing the built in ceramic capacitor and replacing it with a 22 pF C0G capacitor. Pretty simple! These transformers are less than $1 and take up about the same amount of real estate as iron powder cores and trimmers. Being able to solder the IF cans to any copper surface is a real plus and gives much flexibility for mounting options. A big Thank You to Paul Daulton, K5WMS.

Tune-up entails the usual checks such as insuring the CIO/BFO is functioning. The final selection of the actual CIO/BFO crystal may take some cut-and-try to insure proper placement on the filter slope. A trimmer is provided for this purpose but it may take trying several crystals. The crystal was purposefully mounted at the top of this board to enable removal which I actually had to do.

Connecting an antenna directly to the band pass filter should net some on air signals. Here is where we apply TMS (Tune for Max Signal). 20M signals can be peaked by adjusting the cores on the band pass filters.

The one critical item in the tune-up is the setting of the bias potentiometer of the linear amplifier. Setting this potentiometer correctly insures that the output is linear and that the current drawn does not exceed

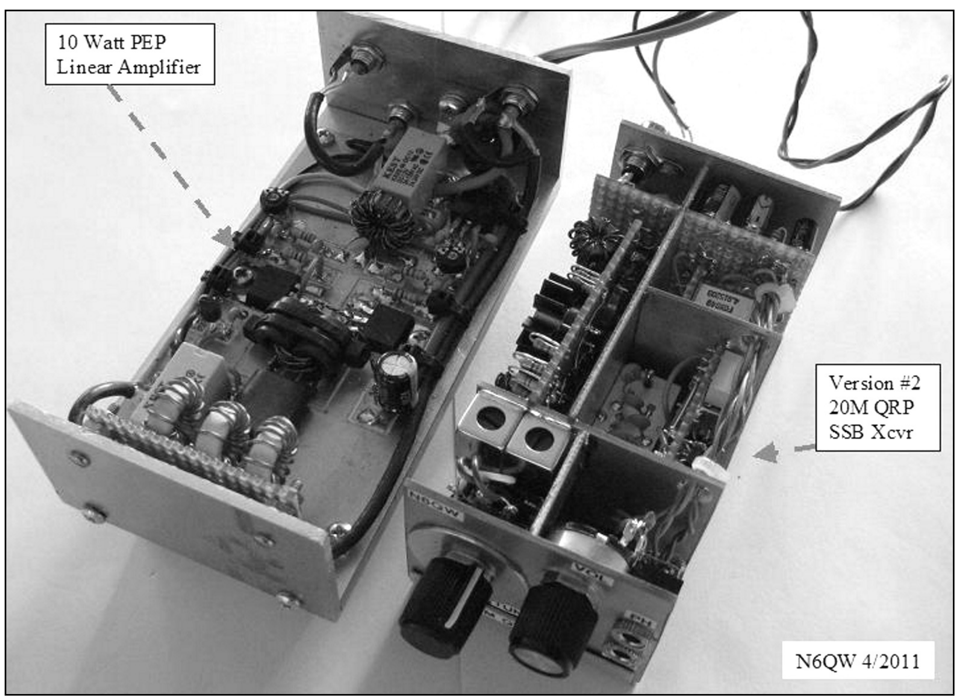

Figure 16—Photo of the 10 watt linear amplifier next to the radio.

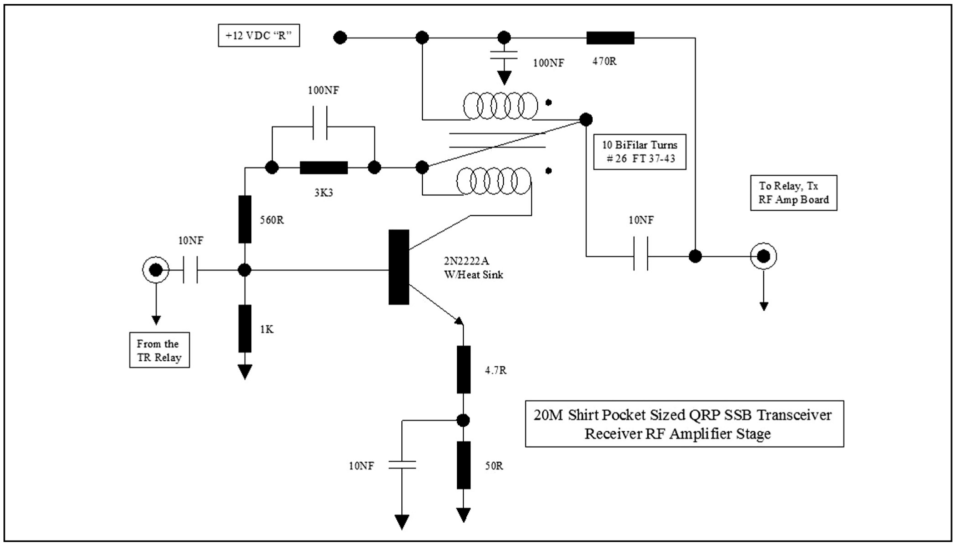

Figure 17—Schematic of the optional receiver RF amplifier.

the IRF510 rating. I started with the small bias pot about mid-scale and using an oscilloscope observed the output connected to a 50-ohm dummy load. Speaking into the microphone I noted when the peaks hit 20 volts p-p. That, my friend, is 1 watt rms.

At this point, you might want to try a few on-the-air QSO's and make sure everything is working. Once you are convinced of proper operation, you can do the final packaging at your leisure and consider building the separately packaged ten watt afterburner described here.

Following the V1 version, I completed a companion 10-watt MOSFET linear amplifier, very similar to the one found in *EMRFD*, Figure 2.101. Figure 18 shows the modified circuit as it appears in my unit. Circuit modifications include a relay bypass on receive, adding a low pass filter with circuit constants, and a slightly different bias network. The amplifier is operated on 12 volts DC. It is about the same size as the transceiver and I hope to actually test this in a mobile installation. I am almost ashamed to say that, especially when pioneers like Vester were doing 20M mobile with several hundred milliwatts. Operating with the 20M XCVR and this new amp from the home station, I have consistently worked across the US and even managed to snag a half dozen DX stations. Figure 16 is a photo of the 20M Shirt Pocket Size QRP SSB Transceiver and the companion 10-watt Linear Amplifier.

Hypothetically, you have now spent around $100 to build this radio and now you ask was the expenditure worth it? Well, I will give you my biased opinion: There is no greater joy than telling the station at the other end that you are running a homebrew pocket sized QRP SSB transceiver. The objectives stated early on have been met! QSO's have been made and the signal reports attest to the viability of the design and signal quality. However, you should realize that this is not a $700 radio—it does not have AGC and it only puts out one watt. It will not do CW, has a limited frequency range of roughly 60 kHz and will not mow the lawn nor take out the trash! But it is shirt pocket size and will give a good account of itself by providing many hours of fun and enjoyment.

AGC could be added if another form of bilateral amplifier was used like the one designed by Ron Taylor G4GXO and published in the GQRP *SPRAT #128*. A small board mounted relay could be used on receive to provide AGC control to the first bilateral amp using his design. In transmit, a fixed voltage is applied to this stage to set the gain. I built a dual conversion tri-band QRP SSB transceiver using this technique, which can be seen on my website www.jessystems.com.

Could this radio be made smaller? I would have to give a qualified "Yes," but that would now move the project to a circuit board. I have determined that the bilateral amps, the BFO/CIO, the audio amp stages and the VXO could be shifted to virtually all SMD parts. A different SMD op amp would need to be selected for the microphone amp but that does not seem like an obstacle. There are SMD parts that could be employed for the linear amp stage but that would require significant development work and be way beyond my skills. Could this radio be reduced by another 50%? Someone out there is already probably working on it! But the I/O and the available panel space still drive the final size!

—73/72, Pete, N6QW

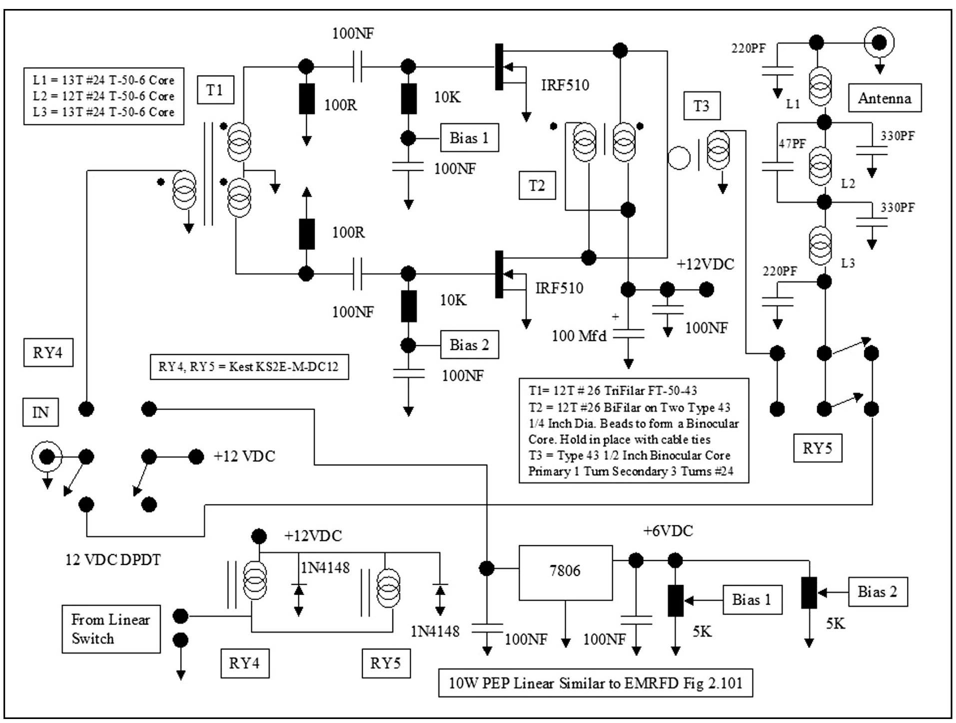

Figure 18—Schematic of the 10 watt PEP linear amplifier.