20 Meter MMIC-Based QRP SSB Transceiver

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Anyone who has seen my website knows that I am an inveterate builder with a motto of "Build it, don't buy it." Much of the fun of amateur radio, at least for me, is trying new ideas and making them come to life. Of course like many other hams, I have two boxes of radio projects. The smaller box has the ones that work; the much larger box has the ones that didn't. But, I sure learned a lot from the projects in the larger box.

In 2007, I started on a project to build a pocket sized QRP SSB transceiver. While the effort was successful, meaning it worked, it definitely was not pocket sized. But, the effort did show me that shrinking down a transceiver would involve something other than through-hole components and conventional circuits. My latest version of this project is a 20M sideband transceiver with some surface mount components and several bilateral circuits, meaning that the same circuits are used for both transmitting and receiving. This allows a reduction of some components, such as transformers and filters, with a consequent reduction in size. Some purists would argue that the circuits are not bilateral but bi-directional as two separate devices are required per circuit stage to achieve the forward and reverse directions. Some more recent bilateral circuits use a singular device with diode steering to route the signals forward and backward through the same device. A good example of this type of circuit can be seen in the GQRP *SPRAT* magazine, nr. 128. Ron Taylor, G4GXO was the circuit designer.

A goal of this project was to investigate the use of monolithic microwave integrated circuits (MMICs) as gain blocks in the previously mentioned bilateral circuits, with a view toward further reducing the transceiver's size. A second goal was to gain knowledge as a building block to the next generation transceiver, which will be an all band, dual conversion MMIC based QRP SSB transceiver. That transceiver probably won't be pocket sized, but it will be useful to me for other purposes and further my goal of learning more about electronics.

At present, the current transceiver is a "work in progress," but it is functional and quite a few QSOs have occurred with it. While there is sufficient information given in this article and on my website, http://www.jessystems.com/20M_MMIC_XCVR.html, to replicate the transceiver, my objectives were experimental. My focus was really on determining how the MMIC devices could be successfully employed in a modern homebrew transceiver. The transceiver uses the experience I gained on a 40M QRP CW transceiver built in 2009 using four MMIC devices. With that experience, I decided to try for a pocket sized QRP SSB transceiver using eight surface mount MMIC devices from TriQuint. These MMICs, Model #AG303-86G, are good from 0 to 6 GHz with 20.5 dB of gain. The real purpose of this article is to share with the readers how I went about building this transceiver, focusing on the decision processes, parts selection, the design criteria and construction techniques.

As an up front disclaimer, I have not made any MDS measurements, IP3 calculations nor subjected the radio to spectrum analysis. Listening tests on my Ten Tec Omni VI + and on the air reports have confirmed that indeed it is a viable transceiver and puts out a respectable signal. I do hear weak signal stations and

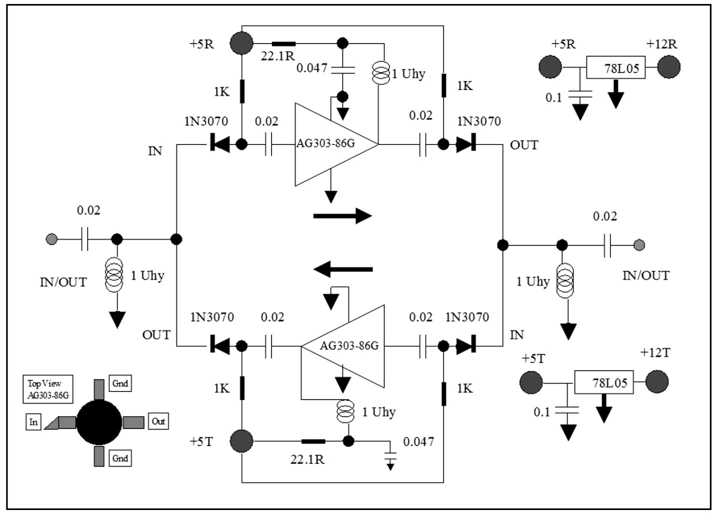


Figure 1—Bi-directional amplifier schematic.

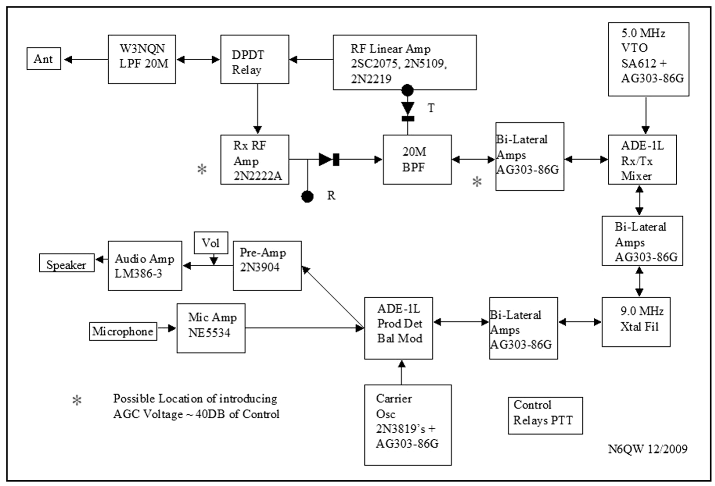


Figure 2—Bi-lateral transceiver block diagram.

have made many contacts with the transceiver operating at one watt output power. However, I must confess I have occasionally driven my homebrew 3CPX1500A7, RF amplifier to 1 kW using this tiny transceiver with a small intermediary amplifier at 40 watts.

The Design Process

My first thoughts on the design were about how to use the MMICs in bi-directional circuits. I had already bought the MMICs, (TriQuint P/N AG303-86G) in 2008 with the idea of testing them out in one of my projects. That particular MMIC was chosen as it had great specs and it was of a physical size that I could see and actually solder to a board.

Typically, the bi-directional (or bilateral) approach involves biasing certain circuit elements to the "on" state, such as those involved in the receive mode, while others are biased to the "off" state. To go to transmit, receive circuits are biased "off" and transmit circuits are biased "on." Think of the bi-directional

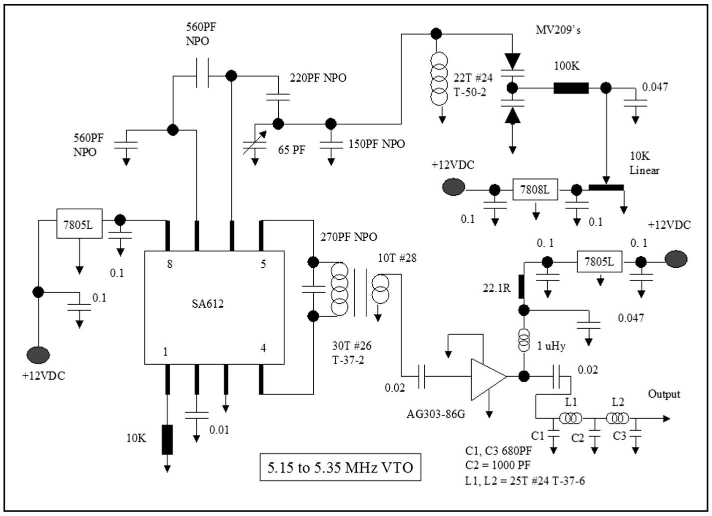


Figure 3—Varactor tuned oscillator schematic.

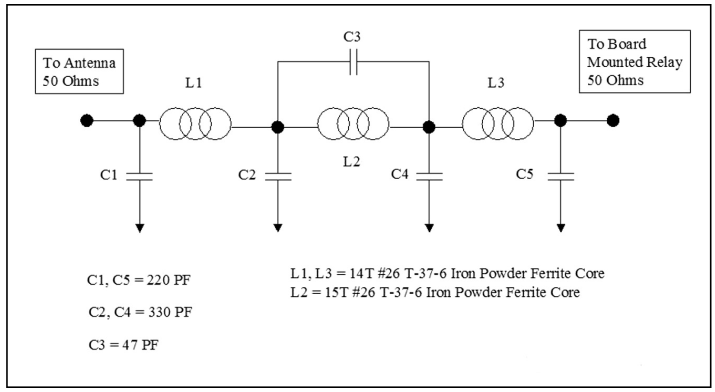


Figure 4—W3NQN low pass filter.

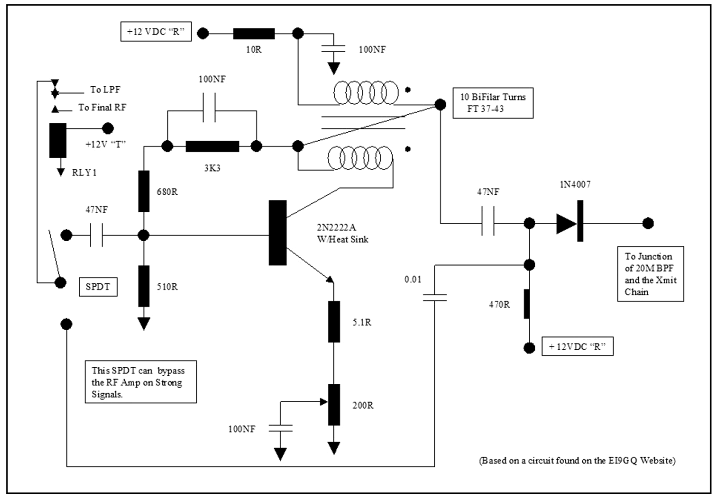


Figure 5—Receiving RF amplifier schematic.

amplifiers as two amplifiers in parallel but feeding the signal in opposite directions based upon which of the two amplifiers is turned "on." In this case, bi-directionality could be easily achieved by simply turning on the supply voltage to a particular MMIC. Finally, John Bellantoni, WB1LAZ, from TriQuint (www.TriQuint.com) assisted me with the selection of circuit components so that the design gain (20.5 dB) and an input/output impedance of 50 ohms would be preserved in either direction. A constant 50 ohm input/output impedance requirement would be critical for those instances where the amplifiers would be at the input or output of mixers and filters. Otherwise, the filters or mixers would likely not operate as expected.

Figure 1 depicts the resulting MMIC bi-directional amplifier schematic and this is the basic building block for the entire transceiver. TR switching (discussed later) consists of providing 13 VDC to one of the two on-board 5 VDC regulators so that the appropriate circuits are powered "on" depending whether the radio is receiving or transmitting. Separate on-board 5 VDC regulators, each connected to one of the MMIC devices, were used to further de-couple the MMIC source voltages.

After convincing myself that the bidirectional amplifiers were achievable, my thoughts then turned to gain distribution throughout the transceiver.

Two critical components were the combination transmit/receive mixer and the product detector/ transmit up-conversion mixer. Strong signal performance and the local oscillator (LO) power required were important considerations in the design. Choices included the TUF-1 and/or SBL-1, which are frequently seen in amateur designs. These are +7 dBm devices and have a conversion loss of around 8 dB. Another product made by Mini Circuits Labs is the ADE-1L, which is a +3 dBm device (0.9 V PTP) and has only a 5.8 DB conversion loss. The TUF series or SBL series mixers are generally larger devices than the ADE-1L but do exhibit better dynamic range characteristics. In the end, I chose the ADE-1L because of the smaller size and lower LO power requirements, and because this was an experiment into a shirt pocket radio where size and power minimization were important issues. If performance were paramount, I would probably have chosen a TUF series mixer

Typically, the output of a mixer requires an amplifier at the output in order to isolate the mixer from any follow-on filtering. Otherwise, the mixer output is presented with a frequency-dependent load impedance and neither the filter nor the mixer are likely to operate properly. This meant I would need amplifiers at two of the transmit/receive mixer ports since different ports are used for output on transmit and receive. However, too much gain at the front end before filtering and you end up amplifying the signal and the noise. I used a bi-directional MMIC amplifier on the transmit output port since (a) the small transmit signal out of the mixer would need considerable amplification before achieving output power levels and (b) with transmit/receive switching in the proper places, the bi-directional amplifier used on transmit could also be placed in the receive chain, thus lowering parts count in the transceiver. Each bi-directional gain block stage is good for about 20.5 DB. So ahead of the crystal filter on the receive side, we have 41 DB, not including the Receiver RF amplifier which adds in another 10 to 15 DB. The ADE-1L takes up 5.8 DB and a bi-directional gain block amplifier following the crystal filter gives another 20.5 DB. Assuming another 5.8 DB loss in the Product Detector the overall gain to this point in the receive chain is about 60 DB not including the audio stages. That seemed like a good starting place. Any further gain needed in the transceiver could easily be provided in the audio stages.

With the gain plan in hand, I was ready to sketch out the

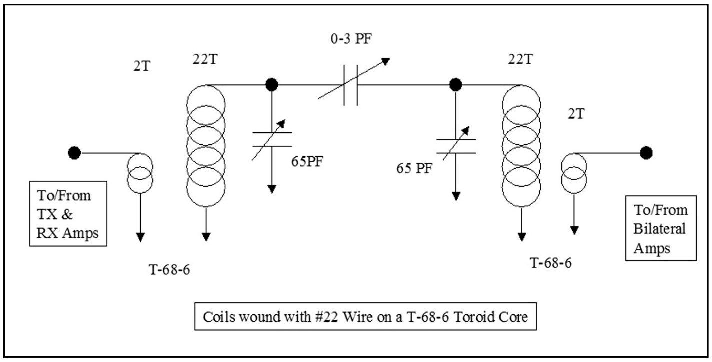


Figure 6—20 M band pass filter.

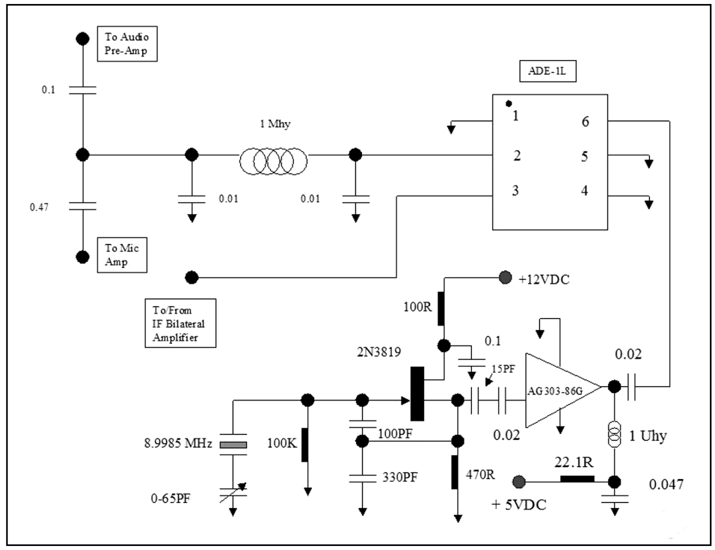


Figure 7—Carrier oscillator schematic.

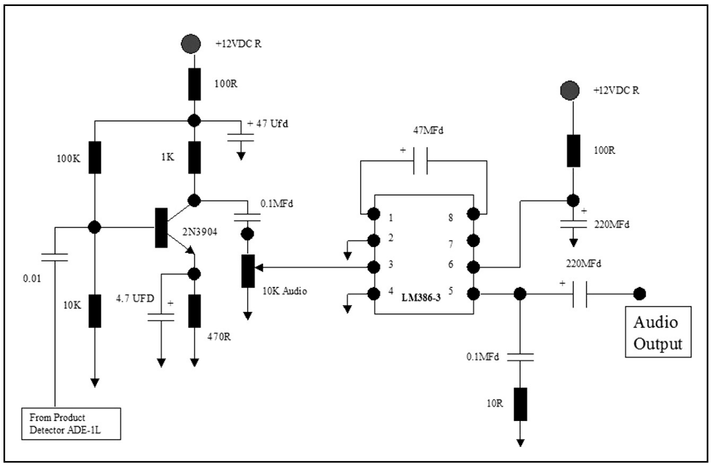


Figure 8—Audio stages schematic.

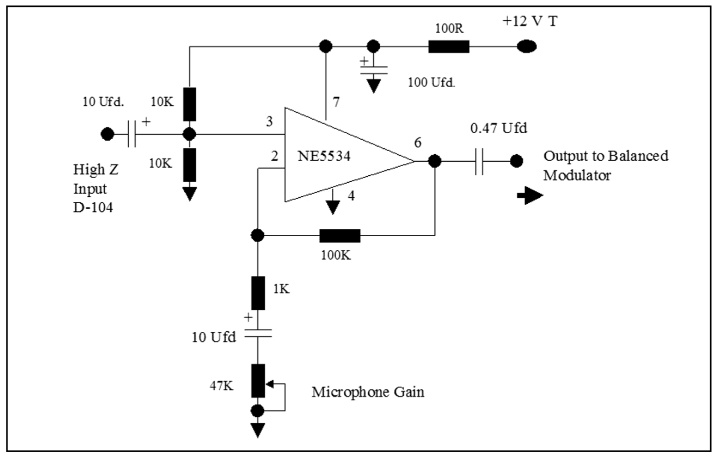


Figure 9—Microphone amplifier schematic.

transceiver block diagram of Figure 2. Eight MMICs appear in the diagram. Three pairs of MMIC devices are used as bi-directional amplifiers on receive and transmit. One pair follows a 20 Meter Band Pass Filter ahead of a Mini Circuits Lab ADE-1L Double Balanced Mixer used for both transmit and receive. A second set of MMICs follows the ADE-IL ahead of the Crystal Filter and a third set follows the Crystal Filter ahead of a second ADE-1L that is used both as a Balanced Modulator and Product Detector. One additional AG303-86G follows the carrier oscillator and another follows the variable frequency oscillator (VFO) used for tuning (labeled VTO in the diagram). These latter two devices are intended to boost the signal level to the 3 dBm that is necessary for the LO level on the ADE-1L's.

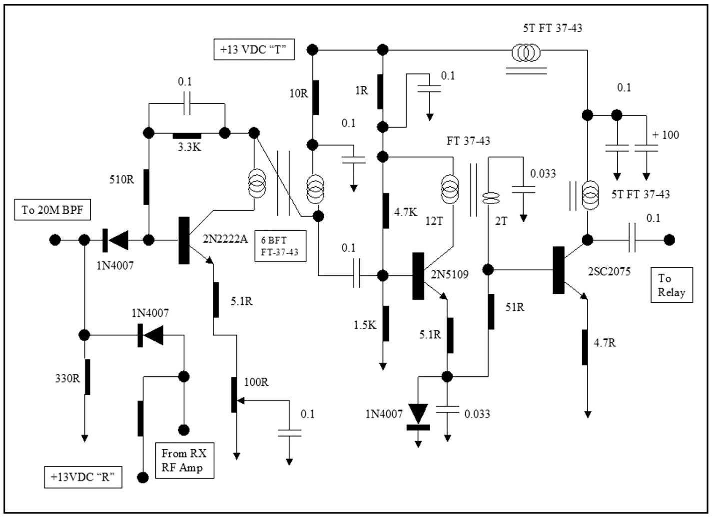
Now that I had an overall design, I began to design the various blocks in the diagram. Selection of the other meat-and-potatoes circuits was based purely on past successful implementations and the use of commercial components. Using familiar designs from past projects meant I didn't have to invent new circuits and could rely on their ability to perform in this radio After all, this was an investigation into bi-directional MMIC amplifiers, and it made sense to minimize the efforts associated with other parts of the transceiver.

For the above reason, I chose to use a commercial 9.0 MHz Crystal Filter, an eight-pole unit that came from a Yaesu transceiver. I could also have used the less expensive crystal filter sold by the GQRP Club, which is also 9.0 MHz but a six-pole unit. Or, there is no reason why a homebrew filter could not also be used with this radio! I have built several 4 pole and 6 pole filters using frequencies from 4.9152 MHz, to 10 MHz, with stops at 8.0, 9.0 and 9.8304 MHz. However, I opted for the Yaesu filter because of the steeper skirts and to avoid the effort of a homebrew filter which would have required effort not immediately associated with the bilateral MMIC amplifiers.

The choice of a 9 MHz center frequency for the filter meant that I could use a 5 MHz variable frequency oscillator for tuning, and that gave me the option of a two-band radio. By selection of an appropriate bandpass filter and lowpass filter, 20 and 75 Meters could be covered with the IF and VFO combination. Such a transceiver could use a plug in filter approach for band changing.

As is the case with many homebrew transceivers, most of the interfaces are at 50 ohms. This is a convenient choice because many components expect a 50 ohm interface and keeping all interfaces at this value where possible makes it very convenient for simply tying various circuit blocks together. One exception is the commercial Crystal Filter impedance which is 500 ohms (in and out). That exception is easily taken care of with a 4T to 13T transformer wound on a FT-37-43 core. I used #26 wire for the transformer.

My original choice for the VFO was the Varactor Tuned



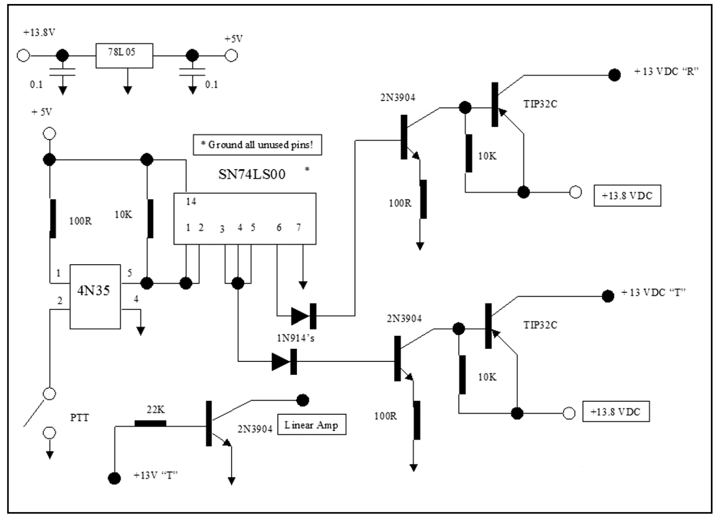


Figure 10—Transmitting linear amplifier chain schematic.

Figure 11—Solid state T/R switch schematic.

Oscillator (VTO), shown in Figure 3, which is built around a Phillips SA612SM. [The NXP (Phillips) website has good info on using the SA602 and SA612 as Oscillators.] Following the SA612 is another one of the ubiquitous AG303-86G MMICs. Earlier in 2009 I had built a similar unit for a 40M MMIC XCVR and was amazed at its stability and performance.

While the VTO was a reasonable choice and could have remained as the transceiver frequency control, I have made a change in implementation since getting the transceiver operational. The means of frequency control has been under constant evaluation and shortly after entering the operational period I shifted from the VTO to a Drake TR-7 PTO coupled with a LCD frequency display that has been offset with the IF frequency. This has been in use for almost a month and has proven itself both in frequency stability and the ability to know where you are in the band. The Drake PTO of course tunes the whole band whereas the VTO only tuned 200 kHz. Plus, the VTO even with a 10-turn pot had to be "eased" onto the appropriate frequency. However, the Drake PTO and the LCD Display are literally larger than the whole transceiver and that prompted the purchase of a Si570 Frequency Generator kit and LCD Display kit available from K5BCQ. Not only is the K5BCQ kit physically smaller, but it is also more accurate in holding the frequency than the Drake TR-7 PTO. The Si570 Frequency Generator now installed in the radio is superb and just about the size of the VTO board. The added bonus is the display. See the sidebar to this article if you are interested in this option.

Other circuits used on the receive side or for common components include the following. The lowpass filters (Figure 4) are a direct lift from a paper published by W3NQN. For the receiver RF amplifier, I used what I call a 2N2222A utility gain amplifier (Figure 5). The bandpass filter (Figure 6) was designed using the design equations in the W7ZOI *Solid State Design* manual. A 2N3819 circuit was used for the Carrier Oscillator (Figure 7). The audio stages (Figure 8) consist of a 2N3904 with an LM-386-3 for the audio output amplifier. Both the Carrier Oscillator and audio stages are from previous projects.

For the transmitting RF chain, I used a design that was an amalgam of many circuits I have seen on the Internet. For the Microphone Amplifier (Figure 9), a NE5534 does the duty here. The only other transmit component not common to the receiving chain is the transmitting RF Linear Amplifier chain shown in Figure 10. The RF Linear Amplifier is a design that I have used about 5 or 6 times, always with good success—except for this time when I encountered oscillation problems in the transmit chain. The radio would work fine into a dummy load but connect it to an antenna and the oscillations were evident. I addressed that problem by placing a gain pot in the emitter on the first transistor RF stage and then added swamping resistors across the broad band transformers. That has solved the problem; but the gain now is only one watt. Usually this amplifier chain can do 4 to 5 watts. Some shielding and a more linear layout of the circuit very likely would prevent the unwanted coupling and solve this problem.

There were two exceptions requiring new design—a T/R switch and a tone amplifier for tune-up.

In my design, the appropriate set of bi-directional, gain block amplifiers are biased "on" based on whether the radio is in a receive or transmit mode. In the receive mode, in addition to those MMICs that are "on," the receiver RF amplifier and the audio stages are "on." The microphone amplifier is "off," as is the transmit RF chain. In transmit, the process is reversed as well as the signal path through the balanced modulator/product detector, crystal filter and receive transmit mixer and so on. In transmit the receiver audio stages and receiver RF amplifier are in the "off" state. A solid state, switching scheme provides T and R voltages to turn on the various amplifiers and stages depending upon whether the circuits are being used for transmitting or receiving. See Figure 11. In addition, I have one board-mounted DIP DPDT relay wired as a DPST. It is used to switch the Low Pass Filter from the receiver RF amplifier input during receiving to the output of the RF Linear Amplifier chain when transmitting.

In designs where I have used an SBL-1 or a Balanced Modulator and Product Detector made from discrete components, I have a method of unbalancing the circuit so that a carrier is provided for tune up. The ADE-1L as well as the TUF-1 double balanced mixers are essentially 4 pin devices and the circuit unbalancing is not possible. So to have something a little more elegant than whistling into the microphone or shouting "Hola" several

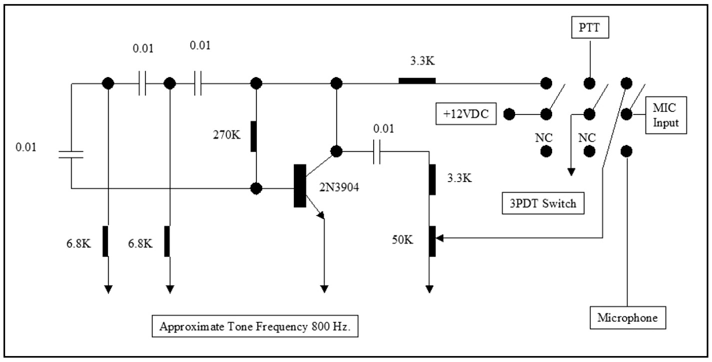


Figure 12—Tone oscillator schematic.

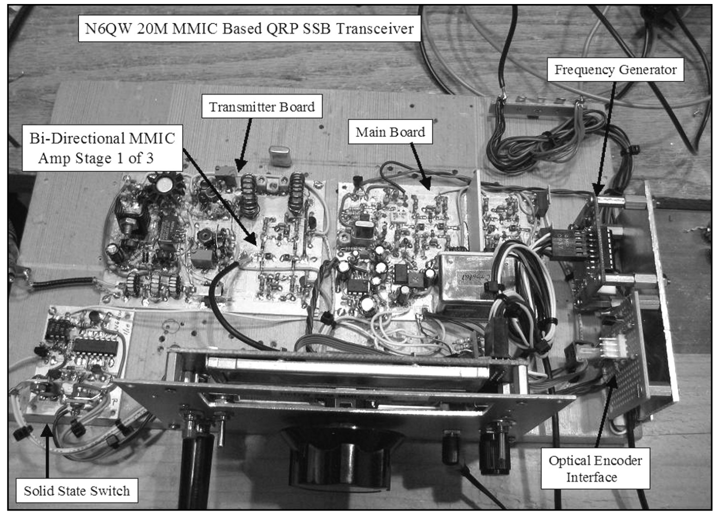


Figure 13—To 20M MMIC-based transceiver.

hundred times, I designed a Tone Oscillator that is controlled by a 3PDT switch. One set of poles switches the main board transceiver microphone input from the microphone to the tone oscillator. A second set applies 12 VDC to the tone oscillator and the third set of contacts engages the PTT switch. The whole circuit is built on a small "perforated" board, which is in turn soldered to the switch. In my case I used a 4DPT switch as it was in the junk box and the 4th set of terminals provides solder anchor points for the perforated board. The Tone Oscillator schematic is shown in Figure 12.

Construction Information

Figure 13 shows a top view of the transceiver in its current state, with the optional Si570 frequency generator. Figure 14 is a front view of the transceiver. As you can see from Figure 13, the transceiver boards are currently mounted on a wooden board that is a part of the PC board construction process. Leaving the copper board attached provides an elevated work platform so that it makes the soldering process ten times easier than trying to chase a board around the workbench. It also is a handy platform for the transceiver during the experimentation phase.

For reference purposes, the two larger boards are 2.75" × 4". The larger board on the left side has one bilateral amplifier stage (following the ADE-1L mixer stage), the 20 Meter bandpass filter, the Receiver RF Amplifier (can be switched in or out of the circuit), the transmitting RF chain and the 20 Meter lowpass filter. The larger board on the right side contains everything from the first ADE-1L transmit and receive mixer through the audio amplifier and microphone amplifier. Extra care was taken on the larger board to the right as it houses the crystal filter and the input and output of the filter need to be isolated. The filter case plus a "T" section shaped copper board soldered to the main board provides a modicum of isolation and reduces the possibility of signal leakage around the filter. That has worked nicely. The boards by design are also a common ground plane, so that helps too! The vertical boards on the right side contain the Si570 frequency generator and optical interface. These two boards together are approximately 2" × 2", which is about the same size as the original VTO. The T/R switching board on the left was constructed on a 1" × 2 1/2" scrap PC board. My plan was to stack the two larger boards and thus shrink the size. I envisioned that the two stacked boards plus the VFO and solid state switch could fit in a metal box 3" × 4" × "5—small, but not quite shirt pocket size! But I am getting closer to my goal.

My PC board construction process derives from a Mini-Milling Machine I purchased several years ago to try my hand at making circuit boards. I use a 1/32-inch end mill and that seems to be about the right size for electronics work. The Mini-Milling Machine costs about $500 so it is hard to justify the purchase price, but it is a big factor in being able to shrink the size of the boards.

My process for making a board takes about two hours from board grid lining to the final board. The advantage of the milling process is that you only remove a minimal amount of copper and the remainder provides an excellent ground plane. I start by laying out 5 mm grid lines using a mechanical pencil and a good square on copper side of the single sided copper board. After the board is laid out I identify the squares that will become islands for connection points.

After that step is done, I drill 1/8 Inch holes in each corner. These holes are on the grid and must be done with care. Once that is complete, I simply screw the copper board into a wooden base that fits into a machining vise on the mill. See Figure 15. A critical step before attaching the board to the wooden board is to align the copper board to the wooden board using the square. The wooden board when it was made was aligned to the bed of the mill. So by using this process, all cuts will align with the grid lines on the copper board. As noted earlier, leaving the PC board attached to the wood also aids construction and experimentation.

How well does it work?

The radio has been in constant daily use for the past month and I can truly say I am amazed at how well it works as I have worked over 100 stations. At the one-watt level, I have contacted stations from Coast to Coast and Alaska from my QTH near Seattle, WA. With the small outboard amplifier running at 35 to 40 watts, DX has been worked in Australia, Spain, Japan, France, Wales and England. I find that at the 30 to 40 watt power levels many US stations think I am running far more power. I have also used the radio on 75M by swapping out the 20 Meter transmitter board for a 75M transmit board that was installed in another radio and that has worked as expected.

I should mention that my antenna is an extended Lazy H up in the pine trees. The top dipole is at 50 feet and the overall length is

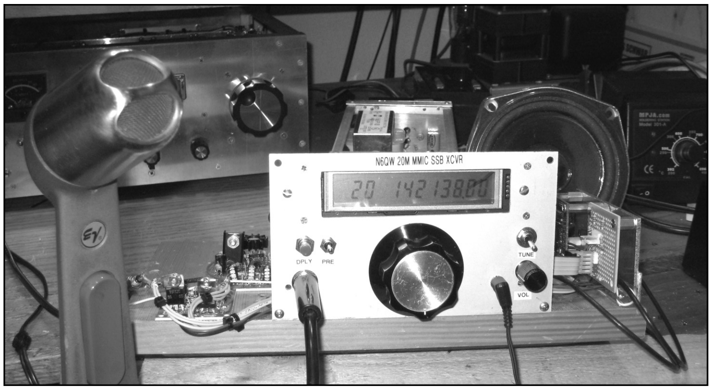


Figure 14—Front view of the transceiver.

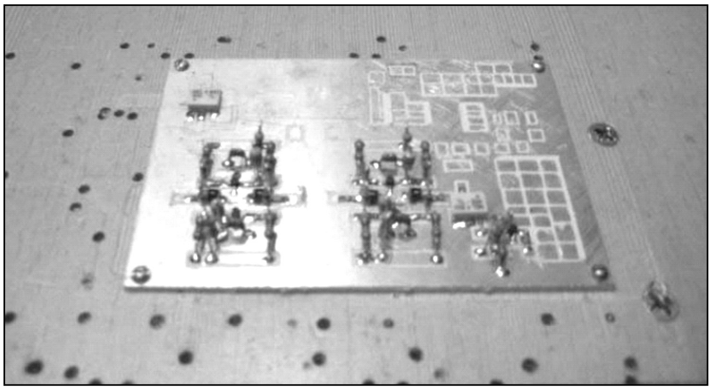


Figure 15—A machined PC board during construction.

110 feet. The lower dipole is 25 feet off the ground and the two dipoles are connected with 25 feet of 450-ohm open wire line fed in phase at the center of the connecting line. Paul Carr, N4PC is the antenna designer.

This radio has proven itself at the one-watt level and with more effort could be made even smaller which would make it an ideal radio for QRP portable operations. It does not have CW capability and that is a limitation for some whom would want both modes of operation. A CW-only MMIC based radio would be easier to construct and has been done by me for 40 Meters. That project can be seen at http://www.jessystems.com/40M_MMIC.html.

Early in the operational phase, audio signal reports consistently stated that it has very clear audio, but possibly lacked some lows. That I attributed to the Heil DX microphone cartridge and possibly some of the circuit components in the microphone stage. I also thought that it might be where I placed the carrier oscillator frequency on the filter slope. Initially I was concerned about carrier leak-through, and so the lack of the lows might be also caused by the carrier placement. Switching to a high impedance Turner hand-held dynamic microphone has resolved the lack of lows and resetting the carrier oscillator using a different crystal has resolved any carrier leak-through problems.

Possible Improvements

The receiver hears the weak stations; but let us be realistic - this is a single conversion, no frills radio. It does not have roofing filters, audio tailoring, a dual noise blanker and AGC. And, until recently there was no DDS synthesizer.

Moreover, the radio is currently sitting on the wooden board

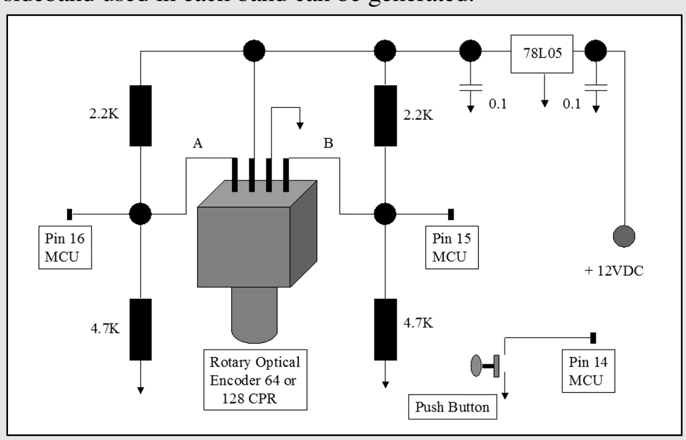
Option—Using the Si570 Frequency Generator as a VFO

The Si570 kit offered by K5BCQ is an excellent means of upgrading the bilateral transceiver, especially if you are considering operating on more than one band. However, the kit does require a small modification and additional circuitry to optimize its use.

The main modification comes about because the kit contains a mechanical encoder for changing frequency. While the encoder is adequate for use with the Soft Rock-type transceivers for which it was designed, use in a hardware-oriented transceiver demands a more durable optical encoder. Optical encoders are easily available, but do add a small cost to the overall transceiver. In the original kit, the mechanical encoder presents a ground to one of two Micro-Controller Unit (MCU) input pins. The other pin is kept at a higher voltage. As the encoder control knob rotates, the 0 V condition alternates between pins indicating that the frequency is being changed. The direction of rotation is transmitted to the MCU by noting which input pin went to ground first. The Si570 can be adapted to an optical encoder by using the simple circuit shown in this sidebar, with the outputs going to the input pin connections originally used by the mechanical encoder.

In addition, the output from the Si570 generator must also be modified in order to properly drive the ADE-1L mixer. The generator is intended to drive an analog switch, and so produces a square wave at a voltage that is too high for the 20m bilateral transceiver. This condition is easily alleviated by a 10 dB pad and a low pass filter which removes the higher harmonics of the square wave. The resulting output should be a sine wave at about 1.4 V peak-to-peak.

By making the low pass filter such that harmonics of the output frequency are significantly attenuated above 32 MHz, additional amateur bands can easily be added to the transceiver by operating the generator above the IF frequency on each band. With this arrangement, I have operated the receiver on 160M (LO= 11 MHz), 75M (LO = 12.5 MHz), 40M (LO = 16 MHz), 30M (LO = 19 MHz), 20M (LO = 23 MHz), 17M (LO = 27 MHz) and 15M (LO = 30 MHz). The only downside is that the sideband generated prior to mixing with the VFO is reversed. Thus, two crystals must be available to the carrier oscillator so that the conventional sideband used in each band can be generated.



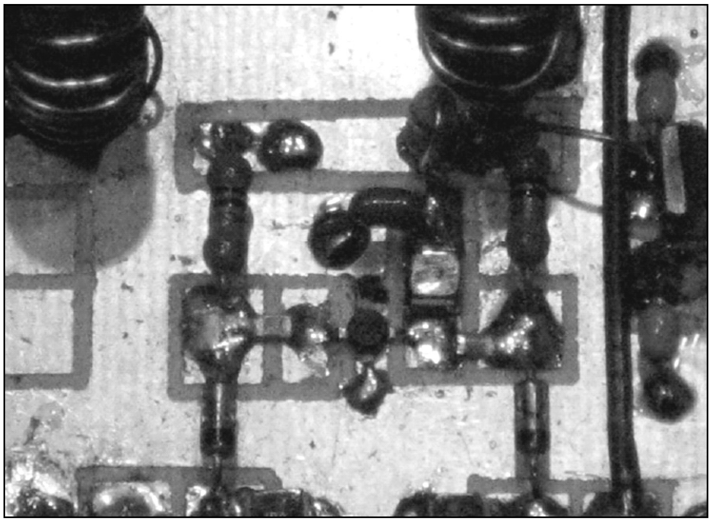


Figure 16—Close-up of a bilateral MMIC amplifier.

and perhaps may never be put in a case. The two major boards are interconnected by a piece of RG-174/U coax. Thus lots of possibilities for further experimentation—not easily done when buried in a case.

On the subject of the AGC, two additions have been incorporated into the "as built" radio. The first addition is the installation of a 10-turn gain pot trimmer in the emitter lead of the receiver RF amplifier. This pot could have been replaced with a single turn pot on the front panel to provide a RF gain control. This is not a desirable approach as it is not a true RF gain control and with strong stations this could make the problem worse. It also would involve routing signal leads to/from the front panel. The pot should remain board-mounted pot and an optimum gain level set to provide a 10-15 dB gain boost then left alone. One fault of adding too much front end gain is that the noise as well as the signal gets boosted. Too much gain also results in overload. 10 dB of gain appears just about right!

The second addition is a miniature bypass switch soldered to the receiver RF amplifier circuit board. This switch could also be implemented using a small board mounted relay controlled by a SPST switch on the front panel. With the gain pot set for full gain and the RF amp "on," a strong station can overwhelm the receiver. Bypassing the RF Stage as well as cranking back on the audio gain clears things up nicely. That is why setting the RF stage gain for around 10 dB and using the switch in/out is a better approach.

A third approach, not in the current radio, would be to replace one of the receive gain block amplifiers with a dual gate MOSFET or a pair of J310's in cascode and this would provide a port for the introduction of AGC voltage. I have done this on other transceivers I have built using these two devices. Reference 1 has several detailed circuits for such a stage employing either approach.

A fourth approach would be to construct an audio-derived AGC. There are well-known circuits for accomplishing this purpose. However, I am not aware of many users of audio-derived AGC for SSB transceivers. Ah well, so many opportunities to learn.

Summary

As stated earlier my real goal was to test the concept of using bi-directional MMIC Gain Block Amplifiers in a QRP SSB Transceiver. To that end I would say it was extremely successful. The TriQuint MMICs as used in this project are just under $2 in single lot quantities and so are somewhat expensive.

When compared to recent work by W7ZOI and K3NHI who have constructed superb bilateral amplifiers using relatively inexpensive common components, the only advantage may be less board space. Shown in Figure 16 is a close-up of one of the amplifiers that was used after the 20M bandpass filter. This circuit has a mix of SMD and through-hole components. For reference, the copper area that has been removed is 1/32 inch wide. Clearly, it would be hard to produce an amplifier of this size with discrete components. However, the lower cost common components do have a cost advantage. I have not done a cost trade study on the two methods but certainly 2N3904 and 2N3906 transistors can be bought for pennies. The real measure is performance and I believe both approaches will do the job.

I would guess the real measure of any completed project is an answer to the question: What did you learn from this project? For me it was many new lessons such as working with surface mount components, the use of MMIC devices and a challenge to use minimum board space. I have as a future project, an all band, dual conversion, QRP SSB transceiver that will employ the same bi-directional amplifiers as used in this project.

References

1. Hayward, W., Campbell, R., and Larkin, B. *Experimental Methods in RF Design,* ARRL Press.

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