

# Let's Build Something: Part II (final)

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In the last issue of *QRP Quarterly*, we described a simple, direct conversion receiver built from an Arduino microprocessor, direct digital synthesizer (DDS) module and a simple, homebrew double balanced mixer (DBM), along with assorted bandpass filters and amplification stages. The authors have learned through e-mails that quite a few of our readers have already successfully completed the Part I receiver and we are gratified to learn of your success. Several have said that the project was exactly what they were looking for as a means to get started with homebrewing.

Part II of this project takes that receiver and turns it into a simple SSB transceiver. Figure 1 is the revised block diagram, which accounts for a design change resulting from some new technology that is now available. We have also added an optional additional receiver preamplifier stage. Later in the article, we will give you some ideas for adding circuitry that could result in a much more sophisticated device. But for now, let's see about finishing the project we started.

As before, we hope to provide all the information needed for a newcomer to successfully complete the project and overcome the intimidation faced by new builders. To that end, the authors have also generated a builder internet reference page, which is available at [http://www.jessystems.com/LBS\\_Detail.html](http://www.jessystems.com/LBS_Detail.html). There you can find photographs, a complete set of schematics and any of the sketches you will need for controlling the Arduino. As additional help, the web page also references several YouTube video presentations concerning building various components and testing the transceiver.

In a few cases, we have heard from builders who have run into problems building the Part I receiver. Virtually all of those problems had a common thread. The builder was in a hurry, didn't take the time to test each module individually, and didn't use the resources on the reference web page and the video presentations. Please make sure you have used those resources and save yourself some trouble. Take your time and make sure you have each module

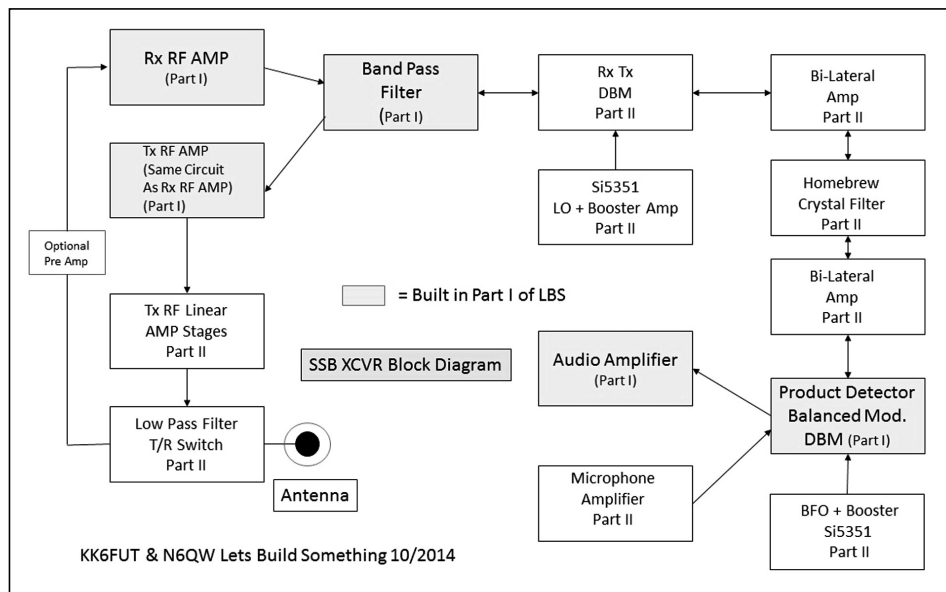


Figure 1—Revised SSB Transceiver block diagram.

working as it should. Remember, this is a learning experience and the resources are there to help you.

Key features of this transceiver are:

- Uses existing 16x2 display used in Part I
- Simple, single band software code (LSB), using a polling approach
- Preserves most of the blocks in Part I
- Fully functional, LSB transceiver (USB support for PSK requires a minor modification to the basic code beyond this Part II project. One additional part is also needed.)

We will also discuss a change to one portion of Part I, namely the Arduino controlled VFO. This change was not made lightly. But, technology has simply progressed faster than we have been able to get the design into print. The change also simplifies the building of the transceiver, which is a plus.

If you have not yet built Part I, go back to that article and begin building the direct conversion receiver part of this project! Building this project in stages is a key part of the learning process, and if you skip over Part I, it's highly likely that there will be issues which are a fair bit more complex to debug in transceiver form than in LBS

Part I. The whole intent of this article series is to learn, teach and build, with Part I being the basic foundation for Part II. For Part II to work properly, Part I MUST be operational. You cannot skip that step! However, before building Part I, you will want to read further here and see how the VFO has changed.

Once you have finished the receiver, adding the additional modules will get you a fully functional, sideband transceiver for 40 meters. You can proudly put it on the air as your first homebrew rig. *Note:* This project is not supposed to be the ultimate in transceivers. This is—as we continue to stress—a simple rig designed to get the new builder into homebrewing. However, as we hinted, this is not far off from a far more sophisticated radio which you can customize to your heart's content.

As a final note before we begin, we would like to say how happy we have been to receive e-mails from quite a few of our readers who have already successfully completed Part I of the project and are looking forward to Part II. Several have said that the project was exactly what they were looking for as a means to get started with homebrewing. A few have had some difficulty, which has always been traceable to an attempt to build the entire receiver

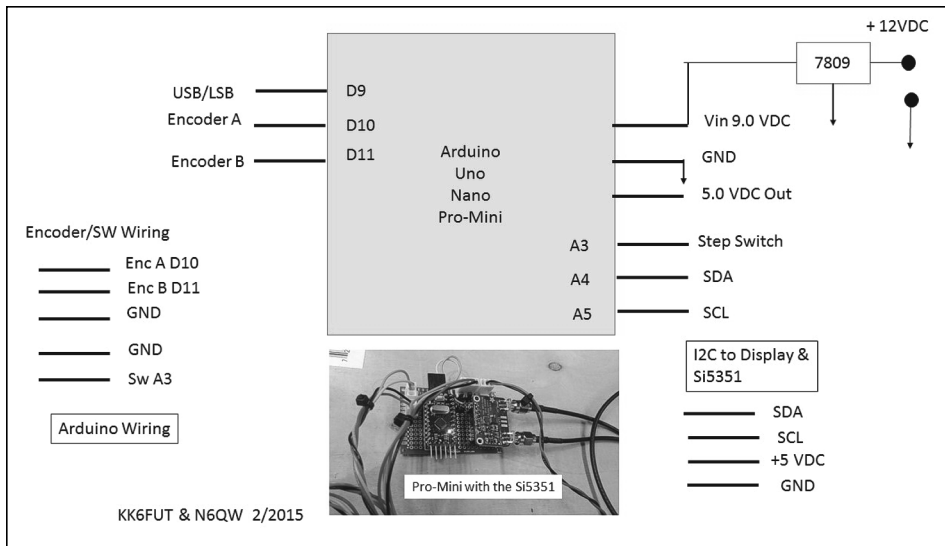


Figure 2—Si5351 + Arduino schematic.

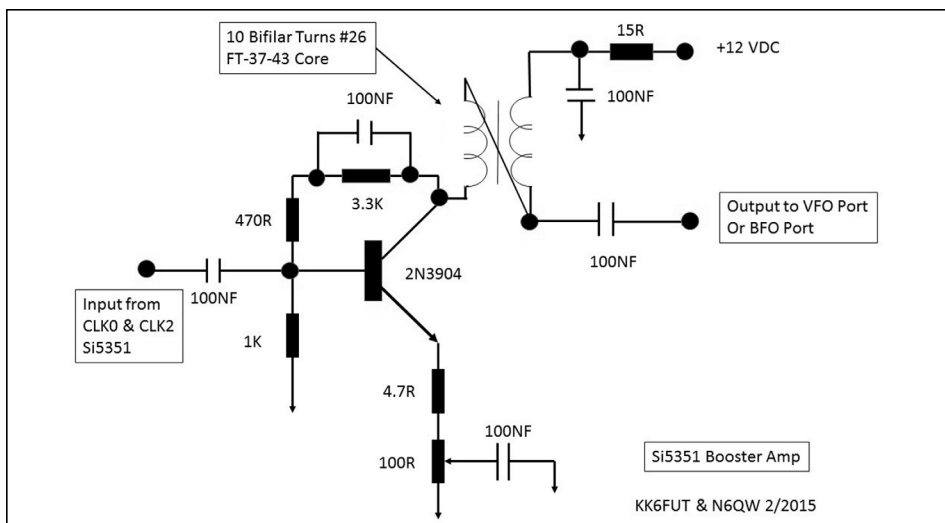


Figure 3—Si5351 Booster Amplifier stage.

without testing each stage as it is built. It is very, very important to build each stage in the order we have suggested and then test that stage to make sure it works properly before proceeding. Only then should you hook the stages together and test the receiver as a whole.

Now, let's get to building!

### Switching Horses Midstream: Enter the Si5351

Before we get into the project, we have to make a quick, mid-project switch. In between the time when we published Let's Build Something: Part I, and this article, a new hardware component—the Si5351 PLL Clock Generator—has come onto the scene. This PLL is available on a breakout board for a mere \$7.95 from Adafruit and only recently became available. It allows

for three (3) separate, independent RF outputs between 8 kHz and 160 MHz. Two of the outputs can be used for the VFO and BFO, eliminating the need for building a separate BFO module. The third output can be used for a future expansion. A software-driven BFO also allows us more flexibility in placing the BFO signal with respect to the crystal filter and allows us to easily add an upper sideband mode needed for PSK-31 transmissions.

The reader may be aware that there has been some online chatter about the degree of phase noise in the output of the Si5351 compared to the AD9850. It is true that the Si5351 phase noise is somewhat higher. Nevertheless, we have found the Si5351 to be adequate for this project, and the advantage of multiple output frequencies simplifies the project. The Si5351 phase noise

could be reduced to make it comparable to the AD9850 by simply programming the Si5351 to operate at four times the needed output frequency and then adding divide-by-four circuitry to generate the needed frequency. This action lowers the phase noise by as much as 6 dB. We have chosen to make this project simple and avoid requiring the new builder to generate circuitry that would have to operate at much higher frequencies, which could cause additional problems for the new builder. For the more sophisticated builder, we will describe this additional circuitry on the web resource page. However, we reiterate that the circuitry described here is adequate to the purpose.

If you have already built the AD9850 DDS described in Part I, all is definitely not lost! In fact, the availability of that DDS is key to testing our next steps. We recommend you leave the DDS, its display and the Arduino intact and turn it into a piece of test equipment that every homebrewer needs—a wide range signal generator! You will find the necessary software changes on our web resource page. Your new signal generator allows you to test LBS part II in several ways, including: (1) Testing your crystal filter, (2) Injecting an RF signal for testing your amplification stages and (3) Testing your BFO and audio. If you already have a signal generator and are looking for another use for this piece, the authors also presented a design in the Spring 2014 issue of *QRP Quarterly*, which uses this same exact stage—coupled with a few resistors and diodes—to build an antenna analyzer. Alternatively, this same Arduino/DDS combination has been used as the basis for the Poor Ham's Scalar Network Analyzer [1]. The AD9850 DDS with the 16x2 display is a very versatile tool in any homebrewing project. (If you do keep the DDS and its display intact, you will need a new display and I<sup>2</sup>C backpack for the Si5351.)

Figure 2 is a photo of the Si5351 and a schematic of the Arduino/Si5351 interconnections. The beauty of the Si5351 is that it simply connects to the I<sup>2</sup>C bus. Very few connections are actually made to the Arduino. For the Arduino connections in Figure 2, note that the pins called out in the schematic are the functional Digital and Analog Pins for the several processors that can be used. These are NOT the physical pins 1, 2, 3 etc. You will see that Digital

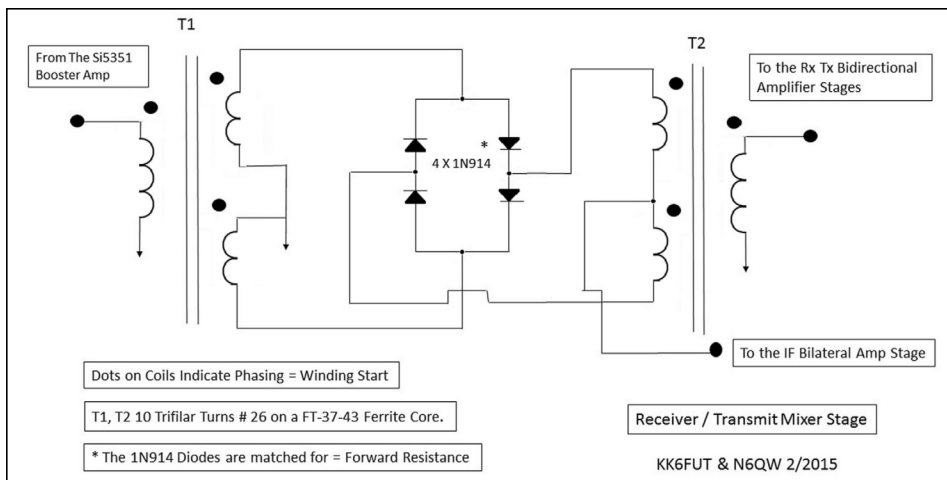


Figure 4—RxTx Mixer stage.

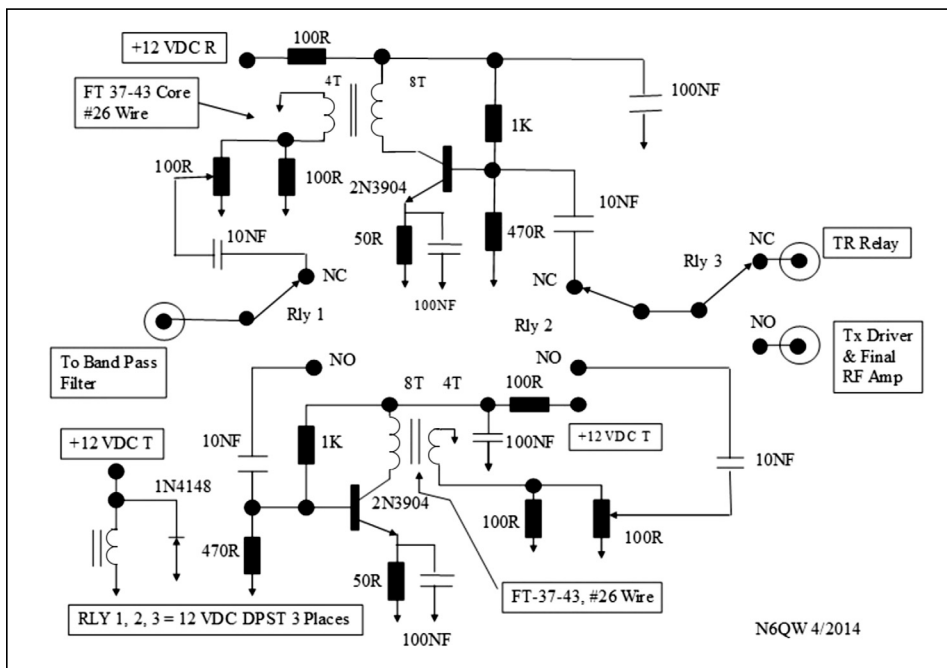


Figure 5—RxTx Bidirectional Amplifier stage.

Pin 9 is marked as USB/LSB. That pin connects to a SPST toggle switch on one end with the other end to ground. The default “open switch” is LSB. The USB “closed switch” is for those who choose to use the LBS for the digital modes. IF you implement the USB functionality, the software sketch recognizes the switch position and shifts the BFO frequency accordingly. Now that is amazing! [Note: The webpage has the sketch for USB/LSB operation.]

Following the Si5351 is a booster amplifier needed to bring up the level of the VFO clock generator CLK0 to a level sufficient to drive the homebrew double balanced mixer (DBM). The DBM requires something near 7 dBm, or about

1.414 volts peak-to-peak for the VFO. There is insufficient voltage coming directly from CLK2 (lower frequency) to drive the product detector and DBM directly, especially for the unbalancing of the DBM during tune up. So, we have added another identical booster amplifier following the Si5351. This feeds into the Product Detector/Balanced Modulator to bring that level to 7 dBm. Figure 3 is the Si5351 Booster amplifier. Just to keep score, the same amplifier is used in three places. Two amplifiers are used for the Si5351 outputs and the third amplifier is the optional receiver pre-amplifier stage. So once you’ve figured out how to build one, you just need to build two others.

## Minor Modifications and Copies of Part I Modules

As you’ll recall from our prior article, we’ve already built a big chunk of the circuits needed for our SSB transceiver. In order to complete our build and turn our direct conversion receiver into a transceiver, we need to build the circuits listed below. You’ll note that several of these stages are exactly same circuit as in our DC receiver build in Part I, although there is a worthwhile improvement in one of them.

**Audio Amplifier Improvement**—a simple change of two devices provides a significant improvement. After adding the optional receiver pre-amplifier stage it was found that there was some audio distortion on strong signals. This is easily cured with two parts swaps. In place of the 2N3904 substitute a TIP31 (NPN 20W dissipation) and for the 2N3906 substitute a TIP32 (PNP 20 W dissipation). Both of these devices cost less than \$1. This adds immeasurably to the improvement in the received audio and increased volume level.

The blocks which are almost a duplicate of what we built in Part I are:

**RxTx DBM**—another nearly identical mixer, this time used to mix the output of the VFO with the incoming signal on receive to produce the signal for the IF stage, or on transmit to take the low level SSB signal at the IF frequency and mix that to produce the transmitted signal. The small differences are that this DBM does not have the balance potentiometer. Instead, the connections originally going to the balance potentiometer go directly to ground. Also, the Audio Low Pass Filter is also not present in this mixer. Figure 4 is the Schematic of the RxTx Mixer stage.

**Tx Amplifier**—Another identical 2N3904 amplification stage to increase our signal strength on transmit, built identically to the Rx Amplifier in LBS Part I. Note that the actual physical construction should follow the photographs on the website. This arrangement avoids any unwanted coupling from the toroids. Electrically, the schematic and the physical build are the same. The schematic for this amplifier was shown in Part I as the bi-directional amplifier stage. The only difference is the addition of a third relay. This is Figure 5.

## Unique Part II Modules

These new circuits are:

**Microphone Amplifier**—for amplifying

audio from a microphone. Figure 6 is the schematic for this stage. We originally had a microphone amp with two transistors, but found in final integration testing that only one was required—less is better!

*Crystal Filter*—used for extracting sideband information from our RF signal. Following the initial testing of the whole transceiver, modifications were made to the Good Enough crystal filter and those are outlined later in the text.

*Bilateral Amplifier Stages*—amplification for both RX and TX before and after the crystal filter. Figure 7 details the Crystal Filter build as well as the two bilateral amplifiers. For those so inclined, the bilateral stage, with the exception of the matching toroids, can be built entirely from SMD parts.

*Tx Driver and Final Amplifier*—final amplification to take us to nearly 5 watts. Figure 8 contains the information to build these stages.

*Low Pass Filter & Control Circuits*—needed for cleaning up the transmitter output and to control the Receive to Transmit switching. Figure 9 presents the Control Circuits and Figure 10 is the schematic of the Low Pass Filter based on the W3NQN design.

*Optional Receiver Pre-Amp Stage*—the LBS design purposefully attempted to keep the hardware to a minimum and to use all discrete components. That comes with a price as the overall receiver systems gain, while adequate, is more suited for earphone operation. A pre-amp stage using the common booster amplifier can drive a loud speaker to room filling volume. But that comes with a price on very strong signals as that will really drive the audio amp to distortion. So we have added a bypass switch that enables adding/removing the preamp. That circuit is shown in Figure 11. This is the third of the three identical amplifiers mentioned earlier.

### Microphone Amplifier: Can You Hear Me Now?

The microphone amplifier is used to amplify audio from a high impedance microphone, connected into our DBM

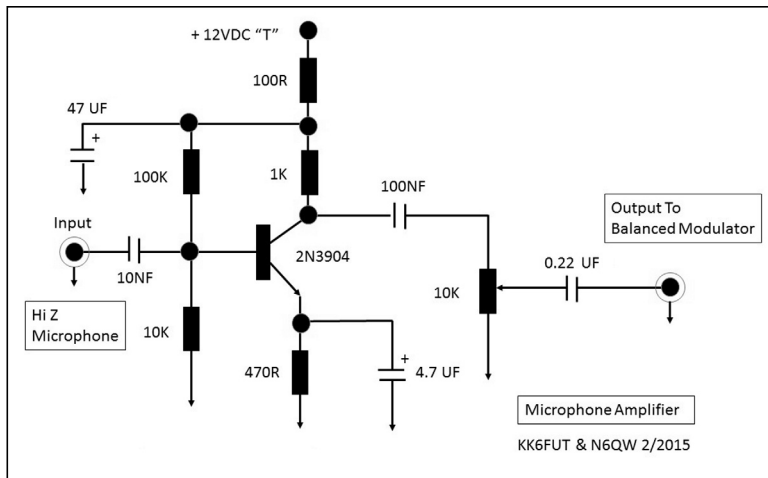


Figure 6—Microphone Amplifier stage.

built in Part I. That DBM is acting as a balanced modulator, which mixes microphone audio with the BFO, goes through the crystal filter, then is mixed with the LO, and eventually is amplified into an SSB signal at the correct transmitted frequency.

The microphone amplifier stage uses a single 2N3904 transistor as a simple audio amplifier, with output going to the balanced modulator. A small, audio taper trim potentiometer at the output provides the gain adjustment. Once gain is set, there is no need for any further adjustment. A word here about microphones—We would like to emphasize that the microphone amplifier is intended for high impedance microphones. Many microphones sold today are of the low impedance variety and will not work well directly with the amplifier described here. There are several popular high impedance microphones on the market, so it should be fairly easy to obtain one if you don't already have one in stock. Examples are the Shure 440 and EV (Electrovoice) 619. A third, very popular microphone is the Astatic Corporation D-104. The D-104 is no longer in production. But since the microphone was made from the 1930's until 2001 and was very popular during that period, there are still thousands of them on the used market. Besides, a D-104 will look really "cool" next to your homebrew transceiver.

There was also no attempt made to provide the bias voltage used by electret microphones. However, that DC bias voltage is very easily supplied. Current requirements are very low, so the bias voltage could be supplied from the transceiver power supply through a dropping resistor

or regulator. Or, it could even be supplied by a 9 V battery. Since the current requirements are so low, the battery should easily last for months.

### Crystal Filter: Thank You PC Designers

The next component you need is a crystal filter, which is used to extract only the sideband information we need from our RF signal. In our case, we are using some commonly available, 4.9152 MHz crystals from the personal computer industry.

Fortunately for us, these crystals are used so heavily that they are available for pennies apiece and can make a great filter. Note: Use standard, high profile, HC49 crystals—DO NOT use the low profile ones! We have found the low profile crystals do not work well in this application.

A crystal filter is generally constructed using a number of crystals in series, connected and shunted by capacitors of the proper value. Figure 7 includes the crystal filter we used. The construction is relatively straightforward, as you can see. However, you cannot just buy any four crystals of the same nominal frequency, plug them into the circuit and expect it to work! If they do happen to work together, consider yourself very lucky and immediately go buy a lot of lottery tickets! In the normal case, the crystals must first be tested for closeness in frequency to each other. Other tests are often done to completely characterize the crystals, and these tests can be very involved. However, we will offer a simple test which has shown to work for simple filters of the type used here. It will be worthwhile to do these tests as the filter is really the heart of this (or any) radio.

For the newbie, utilizing one of the published crystal filter building processes and software programs may seem overwhelming. However, we will describe a method that will produce a filter that is "Good Enough" to get the radio working (first step). N6QW has built many filters using this approach and they are good enough—but, they are not precise!

Start by purchasing twenty 4.9152 MHz crystals of the H/C 49U variety with

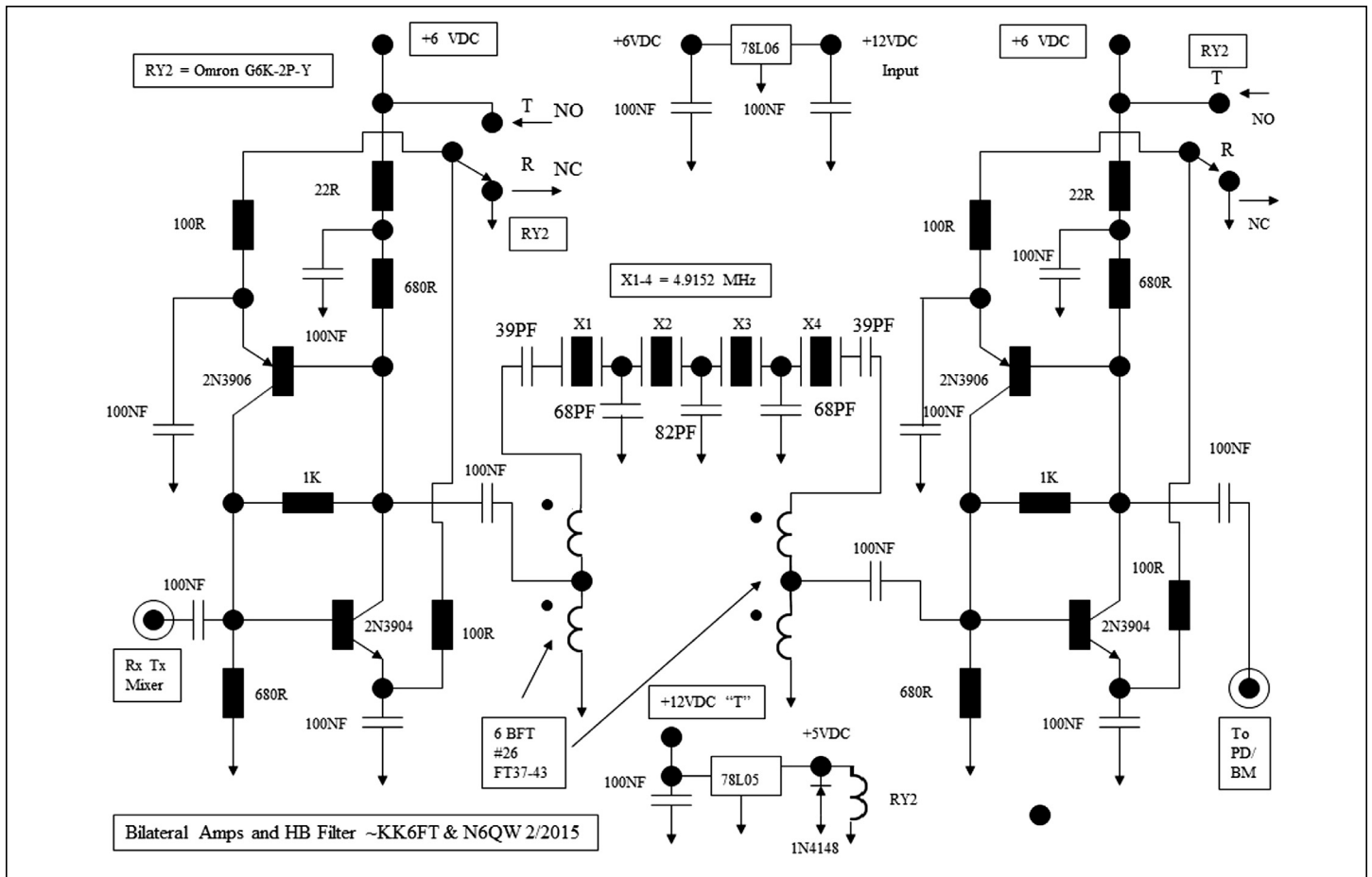


Figure 7—Crystal Filter and Bilateral Amplifier circuits.

a 20 pF load capacitance. All crystals should be bought at the same time and have the same part number. Typically, twenty crystals will only cost about \$0.40 USD each so it should not be a financial hardship. The reason for purchasing so many crystals is that statistically, this number will likely produce four crystals that will have very closely matched parameters of interest to us. In fact, you will most likely find that out of a group of twenty crystals as many as four filters can be built with the caveat that the center frequencies of each group will all be slightly different. Once you have the 20 crystals identified, mark each crystal with a number or letter (doesn't matter) so that you can identify each crystal later. N6QW happens to have a small tape label maker (Brother) where he can make adhesive backed numbers/letters that can be affixed to each crystal, but several other methods will work. Later, we will build a spread sheet using that identifier to characterize each crystal. This is a key point in that the final software for the Si5351 will need to be "fine-tuned" so that

the LSB and USB frequencies fall on the proper part of the filter slope. A couple of runs may be necessary to get these frequencies correct.

Next, take a test oscillator (one is shown on the N6QW website under Konstruktion Korner) connected to a 50 ohm load and cycle each of the twenty crystals through the test oscillator, noting the frequency of oscillation utilizing any of the following: frequency counter, oscilloscope with a counter built in, or (most likely with a new homebrewer) a general coverage receiver tuned to the oscillator frequency. If you are using a general coverage receiver, your ear will probably be good enough to provide a crude method that will get you closer than just plugging in any four crystals. Just set the nominal frequency of the radio to 4.9152 MHz. Most modern radios have digital displays and therefore the frequency can be read directly from the radio dial. Place the radio in CW or SSB mode. Then without moving the dial, cycle each of the crystals through the test oscillator and listen to the audio fre-

quencies produced by each crystal.

Just carefully listen to the radio and, without moving the dial, "listen" to each crystal and grade them by creating several piles. Listen for the ones that seem higher in frequency and put them in one pile. Next sort the ones that seem lower in frequency and a third pile that seem to be close in frequency to the tuned radio frequency. On the spread sheet mark the ones that are High and the ones that are Low. Now take each group of crystals and repeat the above process separately for each group. Repeat this process several times until you have four crystals that are really close in frequency and mark those on the spread sheet. These four crystals are now our group of filter candidates. (By using precise measuring equipment, finding four crystals with no more than a 50 hertz spread across the four crystals is fairly typical. Measurement by ear may give a bit wider spread. But with a bit of practice, our ears and internal computer (brain) can do a pretty decent job.)

Now to design the filter [2]. Most of

these homebrew “Ladder” type filters are low impedance devices which typically means their input/output impedance is in the 200-400 ohms range. We will assume a value in that range and design coupling transformers with a 4:1 impedance matching ratio so that the filter appears as a 50 ohm circuit at the input and output. The five coupling capacitors work in a sort of inverse fashion. Higher capacitance values result in a narrow filter, whereas lower values result in a wider filter. After final testing, we settled on the outer two coupling capacitors two being 39 pF, the next inner two being the 68 pF and the center capacitor being 82 pF. These values improved the received and transmitted articulation and are reflected in Fig 7.

### Characterizing the Filter

If you have an oscilloscope or can use the oscilloscope of a friend, then you can easily determine the shape and frequency limits of your filter passband. If this isn't possible, then you can likely tune the Si5351 BFO frequency by ear once the receiver is complete. Assuming the oscilloscope is available, connect one side of the filter to a 220 ohm resistor and place the oscilloscope across that resistor. Now connect the Part I AD9850 synthesizer (or another DDS signal generator) to the other end of the filter and set the Arduino software so the tuning range is 4 to 5 MHz (see our website to learn how). Use the 100 Hz step range to sweep the filter in 100 Hz increments and record the oscilloscope readings in an Excel spreadsheet. From there, a plot of the filter response can be made. From this data, tweaks to the filter can be made if necessary to improve the shape of its response. You should see that the filter allows signals through near the center frequency (4.9152 MHz) with a drop off on either side of the center frequency. If your selection of crystals worked out, you should see an approximate bandwidth of about 2.2 kHz, nicely allowing through your chosen sideband signal. In our project, the LO is placed above the incoming received signal, which implies that the signal sideband is inverted during the conversion to the intermediate frequency where the filter is located. This results in a transmitted LSB signal becoming a USB signal as a result of the conversion. So to receive and transmit on 40M Lower Sideband, the BFO has to be below

the filter center frequency by about 1.5 kHz. Thus nominally, the BFO Si5351 starting plug-in frequency should be 4913700 Hz.) Were there not a sideband inversion, the BFO frequency for LSB would be 4916700 Hz and that value would be used in the code to set the PLL clock generator. Given the current frequency conversion scheme, 4916700 Hz is correct if the user decides to transmit USB for the purpose of generating data signals. Using the N6QW “good enough” method and applying an external BFO signal to check the needed BFO frequency—it was indeed found that on N6QW's build that 4913700 was the correct frequency. A YouTube video link at the end of the article demonstrates the filter and the BFO frequency selection. Good Enough!

A note here about test equipment—Characterization of the filter and other tests need something more than a flashlight and a rusty screwdriver in your tool box. An oscilloscope provides a very visual method of seeing and measuring the filter response. Builders should either have a scope or locate one with a local ham friend. Even a 10 MHz scope would work fine for many tests, including the characterization test since the filter is centered at less than 5 MHz. A high frequency AC VTVM would also provide measurement capability for this test, if you happen to have one of those antiques. Some of the DVM's have capabilities to measure RF signals. The last option would be the RF probe described on our web page connected to a DVM. Bottom line, the actual signal magnitude passing through the filter is not as important as the relative signal magnitude which would yield the shape factor. If you truly want to be successful in building homebrew radios, especially projects like an SSB transceiver, you are going to eventually want to invest in an oscilloscope or locate one you can use. Without one, homebrewing is workable but much more tedious.

### Bilateral Amplifier Stages: The amazing 2N3904/2N3906 amp circuit.

The bilateral amplifier stages are ahead of, and following, the crystal filter. The reason for the bilateral amplifier is that putting an RF signal through a crystal filter results in a significant loss in signal strength. In order to handle that loss, you need to amplify the signal going into the

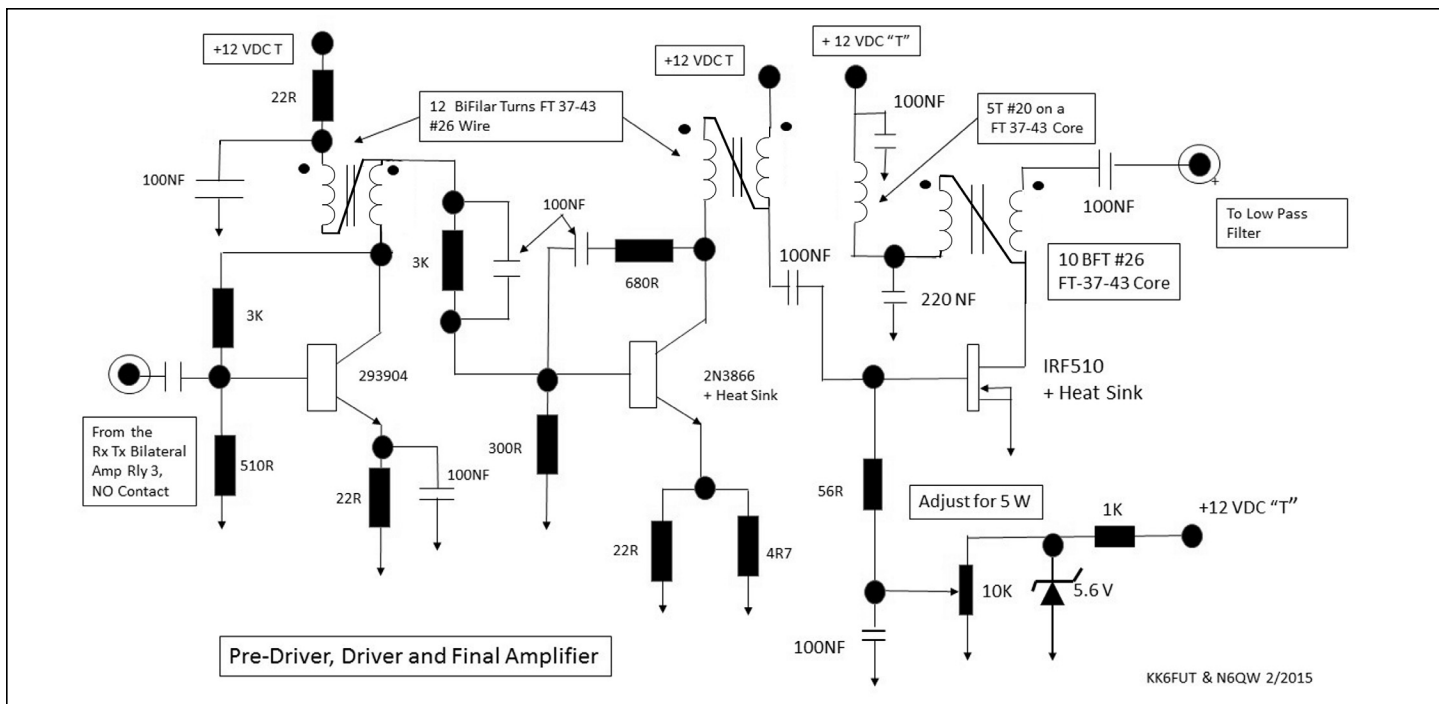
crystal filter as well as the signal coming out of the crystal filter.

The bilateral amplifier circuit is nothing more than two transistors that can be had for about four cents each and a few passive components. These circuits, also shown in Figure 7, function in a manner such that when appropriate voltage is applied the circuit will pass signal from left to right. When voltage is applied in another manner the signal passes from right to left. This circuit was developed by Plessey for use in military radios and is a direct lift from Reference 2, Figure 6.110. There is no tuning required, as these circuits are broadband in their operation. The heart of the N6QW shirt pocket SSB transceiver is this very same circuit and same crystal filter frequency. The gain of each stage is about 15-17 dB and so, across this circuit module, there is more than adequate gain for such a simple radio. Switching from Receive to Transmit involves powering “on” a small relay which changes the application of ground to 6 VDC and thereby turns one pair of transistors from on to off and another from off to on. The signal is not being switched but simply re-routed.

### Driver Stage: Almost There

Following the bilateral stage is the driver stage, where we take the low signal levels in the previous modules discussed and start amplifying the signals to get them to the antenna. The first part of this amplification chain is the driver stage, which combines another 2N3904 (pre-driver) and a 2N3866 (driver) and takes us to 400 mW. Both amplifiers come directly from Reference 2 and have been successfully used many times. It's best to build this one portion at a time (like our entire project). First, construct the 2N3904 pre-driver amplifier and see that it is properly amplifying signals. You will need a clip-on heat sink to efficiently remove heat generated by its operation. Then, tackle the 2N3866 amplifier with its larger heat sink.

The heat sink is important, as we are now approaching power levels that can quickly destroy a transistor if the heat generated by operation is not efficiently removed. The 2N3904 is a TO-92 device and heat sinks made for the TO-18 metal transistors can be fit over the 2N3904. The 2N3866 is a TO-39 device and the “hat type” TO-5 style heat sinks are appropri-



**Figure 8—Transmitter Pre-Driver, Driver and Final Amplifier stages.**

ate. Typically, these heat sinks will be a pressure fit. So, install the heatsinks on the MePads. Because of the pressure fit, a heat sink “goop type” compound is not required.

Once you have constructed both amplifiers in this stage, you should see amplification between the input and output of this driver when DC power and input signal are applied.

Note to newbie homebrewers: You can pause here, and have a fully functioning, contact-capable radio! N6QW has made a dozen contacts in three states running just this driver stage into the low pass filter. If you do not have tools like an oscilloscope, we recommend that you pause here, perform the applicable tests in the section on testing, and start using your new transceiver on the air to make some real contacts! We estimate that, given band conditions during testing, you have a range of around 250 miles on 40M using just the driver stage—more than enough for QRP contacts! By pausing here, you’ll be able to confirm that the rest of the transceiver is working, before you tackle what can be a very challenging piece of the puzzle: the final amplifier. It will be very nice for you to know that the all the rest of your transceiver is not a part of any problems you may encounter once you start on the

final amplifier.

**Tx Final Amplifier: The IRF510**

Last, we need a “Final RF Amp” stage to take us from the low RF levels we have been working with to the antenna. In order to boost our power to just around 5 watts of output, we’ve selected an IRF510 MOSFET device. This useful device is readily available and very inexpensive (typically less than \$2.50). We are again borrowing this final amplifier chain from Reference 2 and from the BITX project. The amplifier employing the IRF510 is a slight modification from that which is used in the BITX from Ashlan Farhan, VU2ESE. These are proven circuits and easy to replicate, which is why we chose these circuits.

As with the driver, it is even more important that you properly heat sink the IRF510 because of the significant amount of heat it generates in operation. Five watts is easily attainable BUT there are some cautions regarding circuit layout, proper grounding and not pushing the circuit for max smoke! Follow the layout shown in the photos. This part of the transceiver cannot be built in a haphazard manner. Short, direct leads are mandatory. The best heat sink for an IRF510 is the square extruded metal type, about 2 inches square and often called CPU heatsinks. You must also use a TO-220 mica insulating kit when installing

the IRF510 on this type of heat sink. A trick used by N6QW is to find several sizes of TO-220 heatsinks that have a common mounting hole. Then taking the several sizes, he nests the heatsinks so there are multiple sets of fins. The key is a good deal of surface area to dissipate the heat.

You should also be aware that constructing the final amplifier requires careful attention to the physical layout and proximity to other circuits in the transceiver. The problem is that, as power levels increase, it becomes much easier for stray RF energy to re-enter a previous stage and cause unwanted oscillation. This can cause distortion in the output waveform and unwanted spectral components. (The FCC generally frowns on such goings on if the spectral components are of any appreciable magnitude.) In severe cases, the oscillation takes over the amplifier and causes the amplifier to generate so much power it overheats and ultimately destroys amplifier components.

Fortunately, there are some things you can do to mitigate problems before they appear. First, keep your connections as short as possible. Connecting wires of any appreciable length should be made with small diameter coaxial cable, such as RG 174/U, with the shield soldered to ground at both ends. Second, coils and transformers should be physically oriented such that

a transfer of RF energy to adjacent coils and transformers is less likely. This typically means they should be placed at right angles to each other and with as much separation as possible consistent with keeping connections short. In some cases, you may need to shield these components from each other using small pieces of blank PC board or other conductive material soldered to the main board (ground plane). If your experience with these amplifiers is limited, it is best to carefully study the photos of this stage on our website. Look closely at the placement of all components, especially wiring and coils. Do some thinking about why components are placed the way they are in the photos. Copy the circuit layouts in the photos as closely as possible. You will save yourself many hours of debugging and frustration.

Finally, it is possible to push this amp to what appears to be 10 watts output—DON'T. Your signal will sound awful and you will be violating FCC regulations regarding spectral purity. Five watts is plenty. As mentioned earlier, N6QW made a dozen contacts in three states running just the driver stage into the low pass filter for a whopping 400 milliWatts to the antenna.

### TR Switching, Low Pass Filters and Final Integration

The architecture for our transceiver appeared in Figure 9 of the LBS Part I, repeated here and somewhat modified in Figure 1. In Part II, we need to account for the interconnections, relay switching and voltage switching from Receive to Transmit. See Figure 9 of this Part II article, which shows the switching and interconnections.

- The Low Pass Filter needed for the Transmitter is permanently wired to the transmitter and connected to the NO side of the TR relay. The NC side of the TR Relay is connected to the NC side of a third relay on the TxRx bidirectional amp board. The Transmit only circuits include: the relay on the IF amp board to switch signal paths, the Tx portion of the bidirectional amp, and the TX RF amplifier pre-driver all the way to the IRF510. The VFO/BFO plus booster amplifiers, the RxTx Mixer, IF board, and the PD/BM are always powered on.

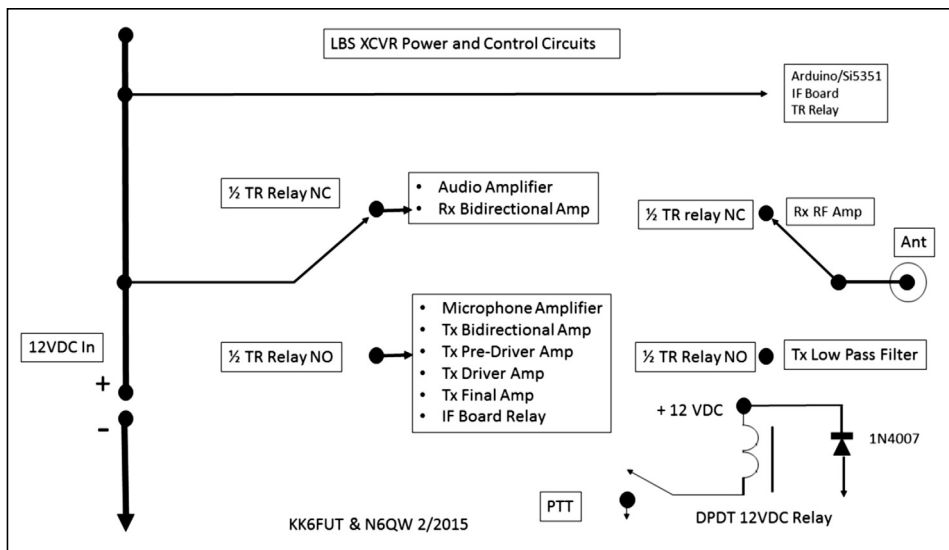


Figure 9—Transceiver control circuits.

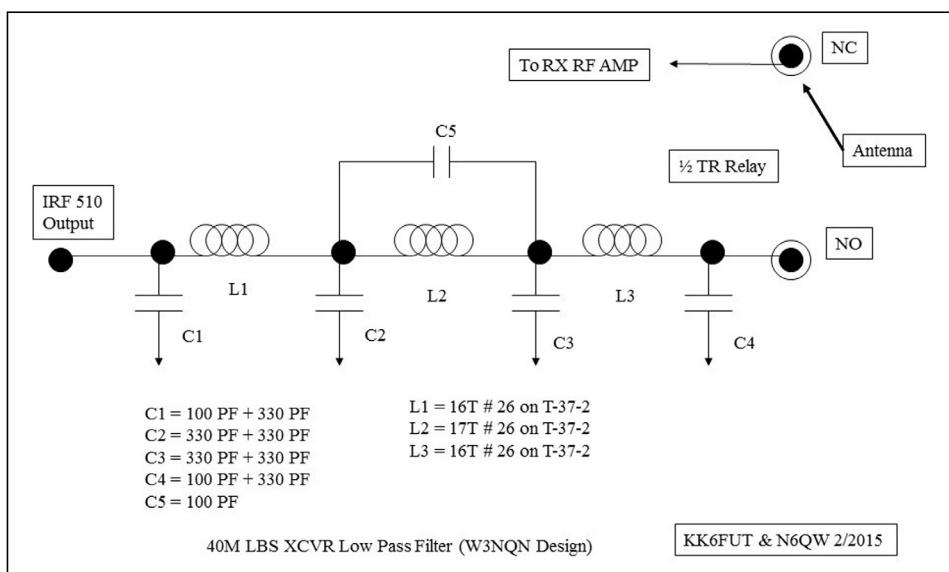


Figure 10—40M Low Pass Filter (W3NQN design).

- The T/R relay is a DPDT type and the second set of contacts is for switching voltages from circuits that are used for receive only to circuits that are used for transmit only. The Receive only circuits include the audio amplifier and the Rx portion of the RxTx bidirectional amp board. The Transmit only circuits include: the relay on the IF amp board to switch signal paths, the Tx portion of the bidirectional amp, and the TX RF amplifier pre-driver all the way to the IRF510. The VFO/BFO plus booster amplifiers, the RxTx Mixer, IF board, and the PD/BM are always powered on.
- The PTT switch simply engages the TR relay and everything is done with that relay closure.

### Putting It All Together: Testing the LBS Transceiver

The basic premise of our integration testing is that, before starting Part II, you have completed the Part I direct conversion receiver have it operating satisfactorily. As we have said before, building Part II without having Part I working is only asking for trouble. We cannot emphasize this enough.

Assuming Part I was built and operating, follow the process below for testing Part II in Receive mode. The first task is to make sure individual modules are working. We highly recommend checking each module before connecting things together. It makes life easier.

1) We'll start by adding the micro-



### Power Source for the LBS SSB Transceiver

If you don't already have one, you are going to need a small power source for your workbench. Depending upon how your station is set up, it may be inconvenient to use your station power supply.

One simple rule—stay away from Wall Warts. These cheap supplies vary all over the place in terms of noise, susceptibility to feedback, poor regulation and on and on. There are several recommendations which include the following:

- A 13.8 VDC linear regulated 2 amp DC supply. These can be found on various websites and from commercial manufacturers
- A 12 VDC Gel Cell rated at a couple of amps, with a constant float charge. The battery acts as a huge sink for the float charge and will have no noise. Great also if you want to make the LBS portable.
- The only power requirement to worry about is for the Arduino, which should not be over 12 VDC. Save your Arduino and install a 9.0 VDC 7809 1 amp regulator and feed the Arduino with that source.
- Keep in mind a 1 volt drop from a nominal 13.8 volts WILL significantly reduce the output power.

phone amplifier in its intended position to your working receiver. Recall that this amplifier is intended to be connected to the Product Detector/Balanced Modulator (PD/BM) at the same point as the audio amplifier input. Coupling capacitors are used for isolation of the outputs of the two units. In normal operation, these two stages have no interaction with each other because one is only powered in the receive mode and the other is only powered when transmitting. However for this test, turn the volume down (but not completely off) on both units and power both units at once. When you plug in the microphone, you will hear your voice coming out of the loudspeaker. This indicates the microphone amplifier is working.

2) The parts which can be tested individually in this stage are the bandpass filter (BPF) and the crystal filter. Each filter will be tested using the AD9850 DDS or other signal source as input to each filter. The other end of the filter should be connected to a 50 ohm dummy load and either an oscilloscope or general coverage receiver used as a detector. If using a receiver, you will need a wire a few feet long to act as an antenna which will be placed near the transceiver circuitry to detect signals. Tune the signal source across the 40M band and observe that the bandpass filter passes the signal and rejects signals outside the 40M band. You may have to carefully adjust the windings on the coils used in the filter to achieve better performance. Then, hook up the crystal filter in place of the bandpass filter and tune the signal

source across the frequencies that are a few kHz on each side of 4915.2 kHz. Again, observe the frequencies that are passed and rejected.

3) Now that you've tested the modules that can be tested independently, connect all of the modules insuring that there are no shorts, opens, solder splashes. Common grounding of all of the boards is really critical, especially if the modules are mounted on wood that is an insulator. Connect the antenna and before throwing the power switch make sure the Plus lead is connected to the plus side of the power supply and to the plus lead of the radio. For the initial testing it is a good idea to put a diode in series with the power supply and then connecting it to the radio. The anode end connect to the supply and the cathode to the radio (The arrow symbol of the diode points the way.)

4) Now everything should be in place and you can test the receive path of the transceiver. As soon as the transceiver is energized, make sure there is no power applied to the transmitter circuits. If there is, shut things down and start looking for connections that should not be there. With the circuits connected as above, signals should be heard on the 40M ham band. If not start the N6QW troubleshooting process looking for shorts, opens, solder bridges and bad components. Since the assumption is made that the Part I receiver was operational, those circuit blocks can initially be ruled out as the problem source. The first step is to determine if your crystal filter and the amplifier stages are work-

ing. You can use the AD9850 DDS, or another test oscillator as shown on the N6QW website under Konstruktion Korner. If using the test oscillator, plug in one of the extra 4.9152 MHz crystals that were originally acquired for the crystal filter. Place a 50 ohm load across the output of the signal source, connect a 10 nF cap to the output lead of the source and solder a 12 inch piece of wire to the other end of the capacitor. Power on the signal source and bring the free end of the wire near the PD/BM. A tone should be heard in the speaker. If not, check the audio amplifier and the DBM.

If a tone is heard, bring the lead near the base of the 2N3904 of the bilateral amplifier following the crystal filter and listen for the tone. No tone indicates a possible problem with that circuit. If a tone is heard, move to lead to the input side of the crystal filter and repeat. This methodology will work all the way up to the front end of the first bilateral amp.

5) Next, you can also use your ADS9850 DDS and tune the DDS to 7.040 or 7.030. Or if a 7.040 or 7.030 crystal is available, replace the 4.9152 MHz crystal in your test oscillator with either one of these crystals and bring the test wire to the input side of the RxTX DBM mixer and listen for the tone. The Si53515 must be likewise tuned to the same frequency as the crystal. The test oscillator can then be moved to the input side of the Band Pass Filter and the cores adjusted for maximum signal. Again, if there is a tone move the test lead to the input side of the 2N3904 Rx RF amp and listen for the tone. If there is no tone and your DBM was successfully tested earlier, you either have a connection issue or a problem with either the bilateral amplifier or the Rx RF amp.

6) As a final check on the receiver, note that when a 40M signal is being injected at the receiver input there should be an increase in signal level each time the signal passes through a stage using an active device. Either an oscilloscope (preferred) or an RF probe (OK, but not perfect) should be able to detect the signal. You may need to turn the signal on and off to detect the change, particularly if you are using the probe. Passing through the crystal filter or other passive stage, you will probably notice a decrease in signal level. This is quite normal, providing it is not too severe.

Here are the steps for transmit testing. It is important that the low level stages be properly operating before hooking up the final amplifier and connecting to an antenna. The use of an outboard receiver, while helpful, is not a perfect substitute for an oscilloscope to visually see the effect of the various adjustments on the transmitted signal. Tuning for maximum signal may not always yield the best signal quality. At this point, finding someone with an oscilloscope is a worthwhile investment of time. The time spent finding the oscilloscope will probably be less than the time required to get the transceiver working properly without the scope!

*Note:* For steps 1-6 of transmit testing, do not connect power to the final amplifier board! Connect power to the remaining units in the transceiver. Connect the output of the driver stage (which is a 100 nF capacitor) to a 50 ohm resistor to provide a load for the transmitter.

1) DBM/Microphone. As you probably recall, we have already tested the microphone amplifier and PD/DBM. So, it should work unless there is a bad connection to the input or output of that stage. If an oscilloscope is not available, then set up a general coverage receiver in SSB mode at the BFO frequency. You will need a few feet of wire to act as an antenna for the receiver. Place the wire near the circuit you are testing. Speaking into the microphone should produce a hearable signal in the general coverage receiver.

In Part I, it was strongly suggested that the 100 ohm trim potentiometer and 39 ohm resistor be installed on the DBM. For the receive part that is optional, but quite necessary for the transceiver testing. So if you have not done so previously, please attach these parts now. The 39 ohm resistor will be used in tuning the transceiver. Its free end will be connected to a switch, which will ground that end, thus unbalancing the DBM when the transceiver is being tuned. At other times, the free end will not be connected to anything. At N6QW, a two pin header was installed with one end soldered to the MePad where the free end of the 39 ohm resistor was soldered and the other side of the header directly to the circuit board. The builder has the option of using a shorting header for tune up or can simply wire a front panel toggle switch to the two pin header. If a DPDT toggle switch is used, it is possible to have the

other half of the switch be paralleled with the PTT and the transmitter is automatically placed in TUNE and a signal sent out over the air.

Next, we will be making a preliminary carrier balance adjustment in the DBM. Making this adjustment minimizes the carrier strength at the DBM output, thus producing a double sideband suppressed carrier signal. With the oscilloscope connected to the DBM output, or the receiver antenna nearby, adjust the trim potentiometer for the minimum signal. We will be returning to this test after going through other stages of the transmit chain.

2) Bilateral amplifiers and Crystal Filter. Place the transceiver in TUNE mode to unbalance the DBM. Using the oscilloscope or general coverage receiver as before, determine that the signal level increases going through the bilateral amplifier attached to the DBM. Next, look at the output of the crystal filter. The signal level should be somewhat reduced because of the filter but still detectable. Finally, look at the output of the second bilateral amplifier connected to the Rx/Tx DBM. The signal level should increase compared to the level at the input of this amplifier.

3) Rx/Tx DBM and Tx RF Amplifier. If you are using a general coverage receiver, tune the receiver to the output frequency of the transceiver. For an oscilloscope, no adjustments are necessary. Place the transceiver in TUNE mode, thus jumpering the 39 ohm resistor to ground, and observe the level of the output signal from the Rx/Tx DBM. It should be somewhat diminished in level from the signal observed at the output of the second bilateral amplifier, and changed in frequency from BFO frequency to the transceiver output frequency. Next observe the output of the Tx RF Amplifier. You should see a definite increase over the signal level observed at the amplifier input. Turn off the TUNE switch.

4) Pre-Driver Amplifier. Next, we will be testing amplifiers on the Final Amplifier board. Because of the increased RF output involved, it is suggested that the transceiver be switched to TUNE mode only long enough to observe the signal level. This will cut down heating in the transistors being tested. Similarly, each stage will be connected to DC power only after the previous stage is tested.

Start by connecting power only to the

pre-driver amplifier, using the 12 VDC connection furthest to the left on the schematic of Figure 8. Briefly switch to TUNE mode and observe the signal level at the 300 ohm resistor attached to the base of the 2N3866. There should be an increase in signal level compared to the level observed at the output of the Tx RF amplifier. If you are using an oscilloscope, determine if the output waveform appears to be sinusoidal. If not, you may have a parasitic oscillation.

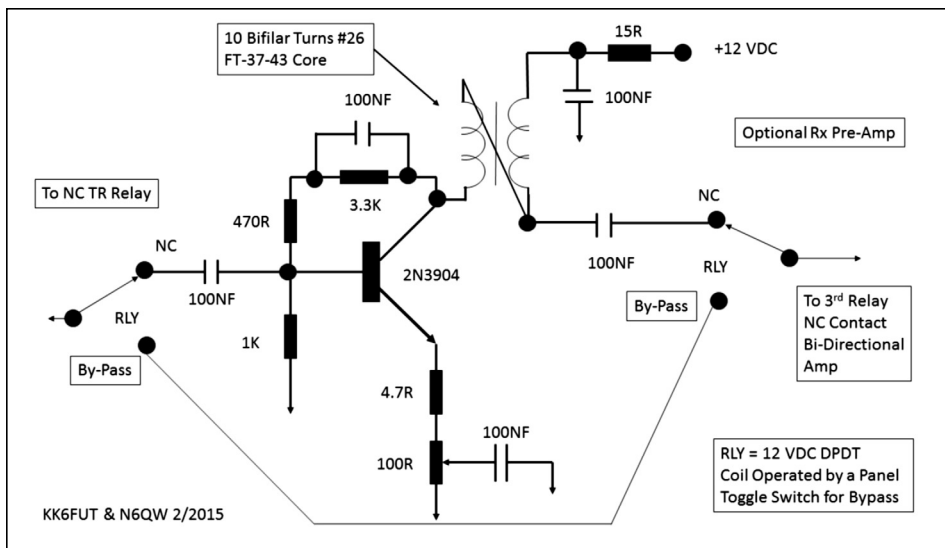
5) Driver Amplifier. Make a second 12 VDC connection using the middle connection at the top of Figure 8. Briefly switch to TUNE mode and observe the signal level at the 56 ohm resistor attached to the base of the IRF510. You should see the usual increase in power compared to the output of the previous stage. The output should again appear to be sinusoidal if there are no parasitic oscillations. If you have an oscilloscope, you should see between 10 and 13 volts peak-to-peak at the 56 ohm resistor attached to the base of the IRF510. This voltage level corresponds to 225 to 400 mW.

6) Final Carrier Balance Test. Disconnect the microphone and use the PTT switch to put the transceiver in transmit mode. Observe the signal from the output of the Driver Amplifier. Whatever signal appears should be the result of carrier imbalance. Use the trim potentiometer in the Product Detector DBM to minimize the output signal. The final adjustment is probably best observed by the general coverage receiver because of the receiver sensitivity. You should show a minimum reduction of about 30 dB (equivalent to about 5 S-units if the S-meter is accurate) from the levels observed in the TUNE mode.

At this point, you have made enough tests to use the transceiver as a very low power transceiver.

If you intend to do so, connect the low pass filter and make any necessary connections to control circuitry.

When you are ready to attach the final amplifier to your project, make all 12 VDC connections shown in Figure 8. Remove the 50 ohm resistor at the driver output that you used for previous testing. The 12 VDC connection going to the final amplifier (far right connection at the top of Figure 8) should include a milliamp meter capable of reading 200 mA or so. Make sure that the carrier balance is still adjusted for mini-



**Figure 11—Optional receiver pre-amp stage with bypass.**

mum carrier. Adjust the bias potentiometer attached to the 5.6 V Zener diode in Figure 8 so that it exhibits its lowest value of resistance. Connect a sensitive power meter capable of reading QRP power levels to the amplifier output.

At this point, you are ready to begin testing. Again, a note of caution—things can get fairly difficult at this point, especially when you are putting out five watts. Keep one hand near the power switch in case something begins to go awry. Tests should be done in the shortest reasonable time to avoid overheating the driver and final amplifier. You may have to interrupt a test to allow cooling, then continue testing.

Ground the PTT switch to shift to TRANSMIT mode and adjust the bias potentiometer so that the milliamp meter reads about 100 mA of quiescent current. Release the PTT switch and shift the transceiver mode to TUNE. The power meter should read a value close to five watts. If you have an oscilloscope on the final amplifier output, you should see about 45 V peak-to-peak. Observe the output waveform. You should see something very close to a sinusoidal waveform. Deviations from a sinusoid may indicate unwanted oscillations.

If you do see a distorted waveform, try shielding one of the toroids from its neighboring toroid. Observe whether the shield changes the distortion. You can do this with a small piece of copper sheet. Make sure the copper sheet has a good connection to the PC board used to construct the amplifier. With a little care, you can prob-

ably cure the distortion and stop the unwanted oscillations.

Now, you should pat yourself on the back. Your first homebrew project is done!

### Future Enhancements

The authors' purpose was to present a project that would step the builder through a process where a simple Direct Conversion receiver is transformed into a working SSB transceiver that can be literally hand built using standard, available, low cost parts. Hopefully, we've achieved that goal and provided a path to getting more people to homebrewing their own transceivers.

Could we have designed in more fancy bells and whistles? Obviously, but that was not the point. However, now that you have a successful first project there is no reason why you can't add extra features that interest you. We will suggest a few such features here. However, our purpose has been achieved. We don't plan to publish a Part III upgrade article adding those features. If you do plan to tinker with any of our suggestions, you probably should consider leaving the transceiver in its breadboard state rather than enclosing it in a cabinet.

One of the easiest changes is to move the transceiver to another ham band you might like better. A good choice would be 17 M, where with 5 watts you have a DX Machine. The code change for this involves changing three numbers in the Arduino sketch, and only a change of your band pass filter and low pass filter in the hardware. You will also need to change from LSB to

USB if your frequency conversion scheme inverts the sideband of the received signal as the original conversion scheme does. This is a simple matter of changing the BFO frequency as discussed earlier. You could make the choice of sideband an option by installing a switch which grounds one of the Arduino digital pins. The state of that pin could then be used to specify the choice of sidebands. With just a little more code and a few relays, you could even have a two band radio.

Want an improved crystal filter? Just plug it in and make appropriate changes to the VFO and BFO frequencies in the Arduino sketch. N6QW made such a change in just fifteen minutes, using a Yaesu commercial filter. Or, you could make your own filter using G3URR's method for crystal characterization available on the Internet. Almost All Digital Electronics (AADE) has a free software program for designing homebrew filters. If you have Reference 2, the enclosed software CD has a crystal filter design program. There are others as well.

Need AGC or ALC? A different bilateral stage employing JFET's can readily be adapted for AGC and ALC control. [3]

Want a really unique display? N6QW has a version of this radio using a TFT color display, which rivals the flashy displays of a commercial rig. The addition of a TFT color display really jazzes up the front panel. There are only a few code changes required for the color display and to change the radix tuning step rate to add 50 Hz steps—all doable.

Feel like you really need more power on occasion? The 5 watt output will easily drive a solid state linear amp to over 100 watts. There are several kits on the market, or you can roll your own.

### Summary

Figure 12 shows the transceiver builds from N6QW and KK6FUT depicting the difference in the open build to one in a case—builder's choice here. In this article, we have described how to go from building a very simple, direct conversion receiver using the Arduino and a DDS to a full SSB transceiver which runs on 40 meters (but could easily be adapted to nearly any other band). We've also covered a lot of the debugging and learning process required to get your first transceiver to work. If we haven't emphasized it enough, it's very

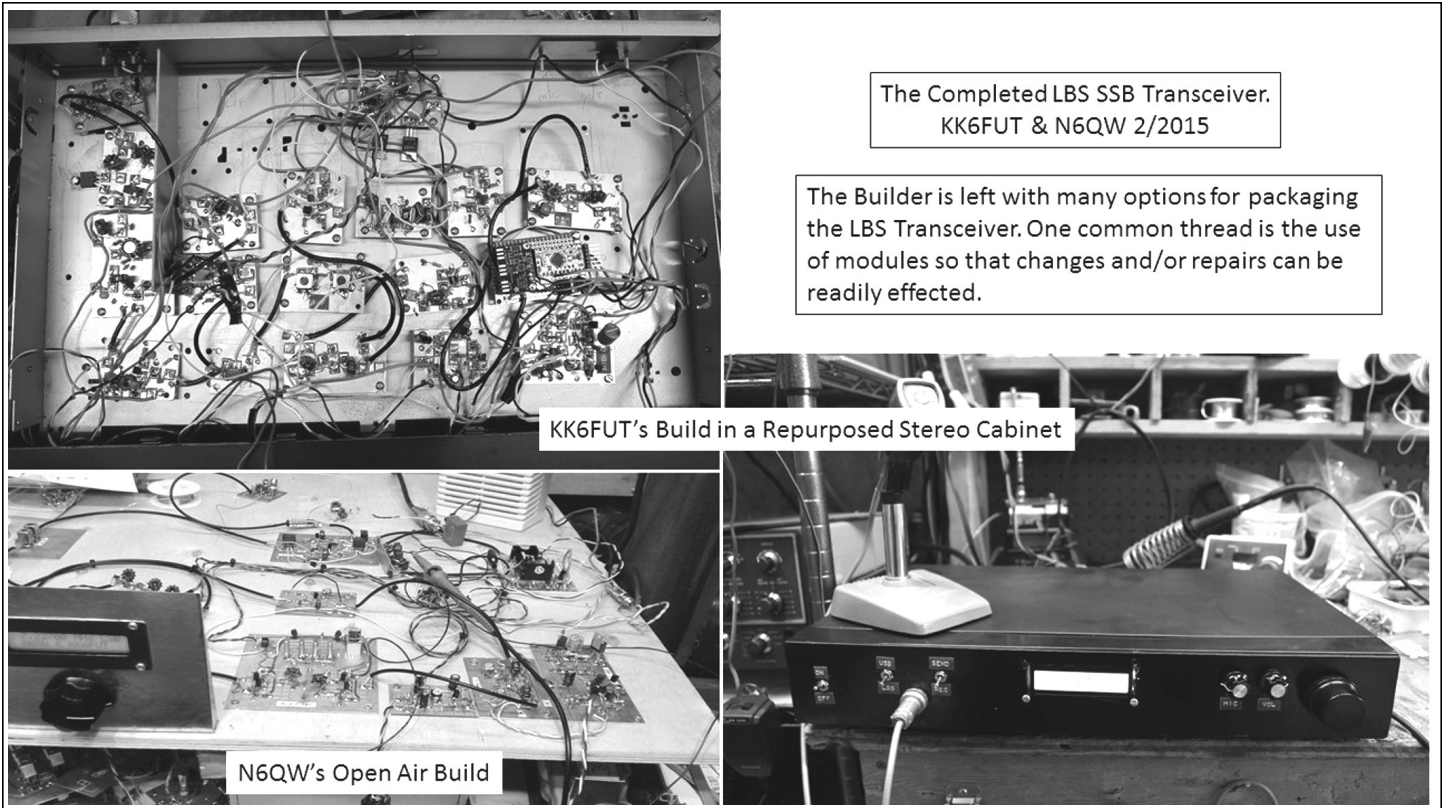


Figure 12—N6QW's open build and KK6FUT's transceiver in an enclosure.

important to build this project in stages, first as the receiver, testing each of the modules, and then putting together the whole as a system, in order to have a working SSB transceiver. Hopefully, we've helped new and old homebrewers both in

building a working radio, and learning a lot along the way.

#### References

1. Nick Kennedy, "The Poor Ham's Scalar Network Analyzer," *QRP*

*Quarterly*, Spring 2014.

2. W. Hayward, et al, *Experimental Methods in RF Design*, ARRL, 2003.

3. W. Hayward, and J. Damm, "The Hybrid Cascode—A General Purpose AGC IF Amplifier," *QST*, Dec. 2007.

(The following material should have accompanied the article, "Let's Build Something: Part I" in the January 2015 issue of *QRP Quarterly*. Its purpose was to show an efficient means of providing the PC boards for the project. —Ed.)

#### Let's Build Something Circuit Board Matrix

Start with two pieces of 4" x 6" single sided copper board, using the 0.069 thick board material. Use a miter box for cutting the PC board and cut with 32 tooth Hacksaw blade. Wear a mask

while cutting the board—the residual dust is a health hazard! Three saw cuts are all that is required.

Board	Size
Audio Amplifier Board	2" X 4" Cut from the 2 <sup>nd</sup> PC Board
Double Balanced Mixer	2" X 3" Cut from the 1 <sup>st</sup> PC Board
Band Pass Filter	2" X 3" Cut From the 1 <sup>st</sup> PC Board
Rx & Tx RF Amplifier Board	2" X 4" Cut From the 1 <sup>st</sup> PC Board
DDS/Arduino Base Board	4" X 4" Cut from the 2 <sup>nd</sup> PC Board

