Let’s Build Something: Part 1

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This article is the first of a series designed to introduce newcomers to the wonderful world of home brewing your own equipment. Absolutely no experience is required beyond an ability to read simple schematics and do some basic soldering. If these two skills are new to you, there are many excellent resources on YouTube and similar sites, or in the *ARRL Handbook*.

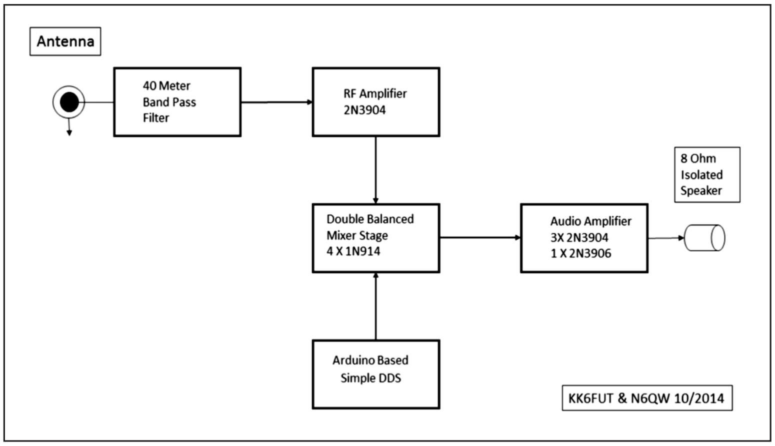

Figure 1—Direct conversion receiver block diagram.

The authors realize that building your first, home-brewed radio project can be very intimidating, especially if you don't have an Elmer in your neighborhood for ongoing guidance. We hope to provide the next best thing in the form of a series of supplemental YouTube videos which show the details of building many of the circuit blocks for this project. A listing of the URL's for the portion of these videos that relate to the first part of this project appears at the end of this article.

We have further simplified the overall project by using a very simple building technique that is as old as ham radio itself—breadboarding. Early radios were often constructed by fastening parts to a board meant for cutting bread. We will do something very similar. In our case, we will be constructing each stage on a small piece of PC board stock obtainable on the popular web auction sites and then mounting each stage on a board for interconnection. We will worry about packaging the total project later. “Al Fresco” construction greatly aids in understanding the circuit elements and most importantly for making changes or repairing modules. Later once everything is perking along you can think about optimized packaging and shrinking down the size. There is nothing wrong with a bread board radio—our ham forefathers operated exactly that way!

The stages will be built using an easy method of Manhattan construction. This involves gluing small pads of PC board stock to a larger blank board for use as junction points. For ease of construction, we will be using MePads and MeSquares available from W1REX at www.QRPme.com. These boards take Manhattan construction way beyond super gluing copper squares to a PCB and enable the homebrewer to focus on building hardware and not removing super glue from their hands! Our goal: make this a fun experience without having to have years of tribal knowledge before soldering the first connection.

Where is this project ultimately going? We will tell you if you promise not to panic. When you finish this deliberately simple set of projects, you will end up with a fully functional QRP SSB transceiver. But don’t worry as we promise to take it slow and easy. In the meantime, you will be building all of the modules that will eventually comprise the transceiver. You will find that, as the project progresses, you will finish intermediate, useful pieces of equipment at the end of each article in the series. The various modules will be reused at each stage, so nothing (or at least not very much) becomes a dead end.

For this Part I article, we describe a very, very simple receiver project, which takes advantage of the wide availability of the Arduino microprocessor and direct digital synthesizer (DDS) modules and couples that with a simple, homebrew double balanced mixer (DBM), a one transistor RF amplifier, a band pass filter made from commercial IF transformers and a few simple transistors as an audio amplifier, which gives you the ability to listen to sideband (voice) [and CW] ham radio transmissions. It goes without saying that both of us were amazed at how good the receiver sounds and we you think you will be too!

Why Sideband?

Traditionally, the first ham radio homebrewing projects have been CW transmitters and receivers. However, with the removal of the code requirement to becoming a ham radio operator in recent years, there has been a dramatic falloff in the use and proficiency in code. That lack of code ability means that there is an entire generation (or two) of ham radio operators for whom code is non relevant. Putting aside the politics and arguments over the loss of code in the ham radio community, this poses a huge problem for attracting prospective homebrewers to the hobby. Many new hams simply want to talk, using radios they built and not resort to pounding brass. This project sidesteps the CW code issue by going directly to SSB.

Unfortunately, coupled with the lack of CW proficiency, there has been a big loss of available kits for new homebuilders—the traditional entree into homebrewing for radio. Kits like the single band SSB White Mountain—a traditional entree into building your own SSB transceiver—are now discontinued, and projects like the BITX and Minima—although excellent designs—are a huge jump for the new builder. This project attempts to help the new builder along the path to building more complex projects or, hopefully, tackling their own radio designs from scratch!

How Direct Conversion Receivers Work

The first part of our project will be a direct conversion receiver. You’ll see later how the parts to this receiver will be used in the final project. In a receiver of this type, an oscillator (in our case, a DDS) operating at the exact frequency of the sideband signal is used as one input to a double balanced mixer. The desired sideband signal is the second input to the mixer and the difference frequency is the desired audio output. In this case, there is no intermediate frequency (IF) and the result is sometimes referred to as a zero IF receiver. Direct conversion involves, as its name implies, a direct conversion of off the air signals to an audio base band. A typical example would be a 40 Meter (7 MHz) SSB signal that is converted to audio directly via a mixing process. For this to happen, we need but a few circuit blocks, shown in Figure 1.

A double balanced mixer produces sum and difference frequencies of the signal coming from the antenna, and the local oscillator. For example, an incoming signal at 7.2 MHz would be mixed with either a 7.199 MHz local oscillator or a 7.201 MHz local oscillator—depending on what sideband (upper or lower) we want. In the first case, two frequencies would be produced: the sum which is 14.339 MHz and the difference is 1 kHz, which is the one we want. In the second case the sum is 14.401 MHz and the difference is 1 kHz, again this is the one. All mixers are capable of producing these sum and difference products. The term "double balanced" implies that the original signal and local oscillator frequencies are deliberately nulled out as part of the mixing process and do not appear at the output.

To clean things up a bit we do a bit of audio filtering following the DBM and top that off with an audio amplifier block.

As shown in Figure 1, there are five major blocks to this project: the local oscillator (Arduino with DDS); our homebrew double band mixer (DBM); the audio amplifier circuit, the input band pass filter and finally an RF amplifier block. All of these blocks will be used in the final SSB transceiver circuit.

We have found that building "backwards," that is building projects from the output to the input, is a key to success in these projects. We will use that method here. This allows you to carefully debug the circuits, ensuring each block or stage is fully working before moving on to the next part. Most kits and construction instructions today tend to emphasize a "stuff and smoke" approach—stuff all the components, plug it in, and see if it smokes.

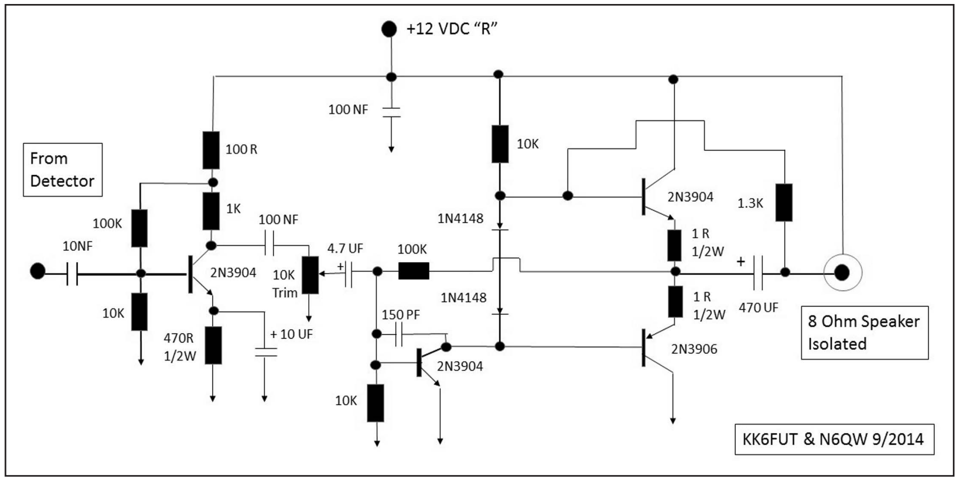

Figure 2—Audio amplifier schematic.

However, that approach means lots of smoked parts, and no understanding on what does or does not work in your circuit! We will start with the audio amplifier and work our way forward.

Before we begin, let's talk a bit about construction. After you have built each stage, you will be attaching the stage to a large board (2 ft. × 2 ft.) using a few wood screws. Then, you will need to supply power for operation. A suggestion is to bring the power into terminal strips (available at Radio Shack) and then power can be distributed to the various modules where power is required. You might also want to cut all of the blank PC boards used for the various stages at once. The sidebar to this article shows a plan for efficiently cutting these boards. If you are not familiar with how to cut the boards, there are quite a few methods exhibited on YouTube videos. However, most of these methods release fiberglass dust into the air. For this reason, you should always wear a mask and safety glasses during this activity.

First Major Piece: The Audio Amplifier

It would have been a simple matter to pop in a packaged amplifier such as an LM-386 or TDA7052 for this project. But, we think you will learn more by working with discrete components. Figure 2 is the schematic. The audio amplifier consists of a 2N3904 pre-amplifier, a second 2N3904 as a pre-driver and a complementary pair 2N3906/2N3904 for the output. Word of warning here—The audio output jack is "hot," so if you later install the amplifier in a metal box you will need to insulate any output connections from that box as you cannot directly ground the output connector to the chassis.

YouTube Hint: If you want to see how the amplifier is laid out, just watch the corresponding YouTube video. You will be able to see how the pads are placed on the blank PC board and how the various components connect.

Testing of the amplifier once completed follows the rigorous N6QW amplifier testing process. Step 1: After checking for shorts, solder bridges, wrong connections, wrong part values or the wrong polarity of the power being supplied AND finally using an isolated phone jack with 8 ohm speaker attached, apply power. If it doesn't smoke or your power supply trips proceed to Step #2 where you take a metal objects such as a tip of a screw driver and touch the input—if you hear a large hum in the speaker—the test is complete. If no hum, go back through step 1. How much more rigorous can you get?

Tribal Knowledge tip! A simple way to avoid hooking the wrong polarity to the circuit is to place a diode in series with the + lead to the board under test. The cathode connects to the circuit and the anode to the source supply. If you get the source leads reversed current will not flow. The arrow part (banded end) of the diode points the way!

Mixing It Up: The DBM

The Double Balanced Mixer (DBM) can be thought of simply as a frequency converter. In Part I we are converting signals in the 40 Meter ham band to an audio output. In applications such as a mixer stage which we will do in the final SSB

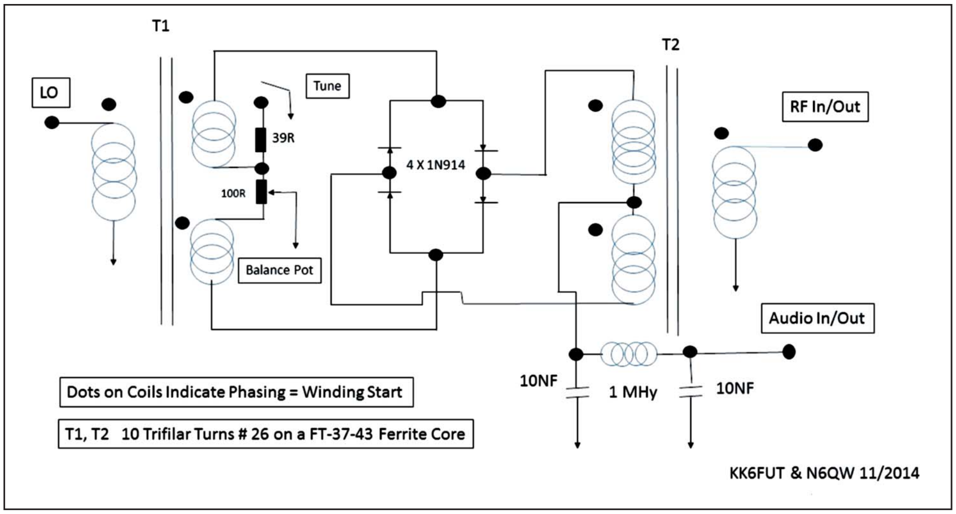

Figure 3—Double balanced mixer schematic.

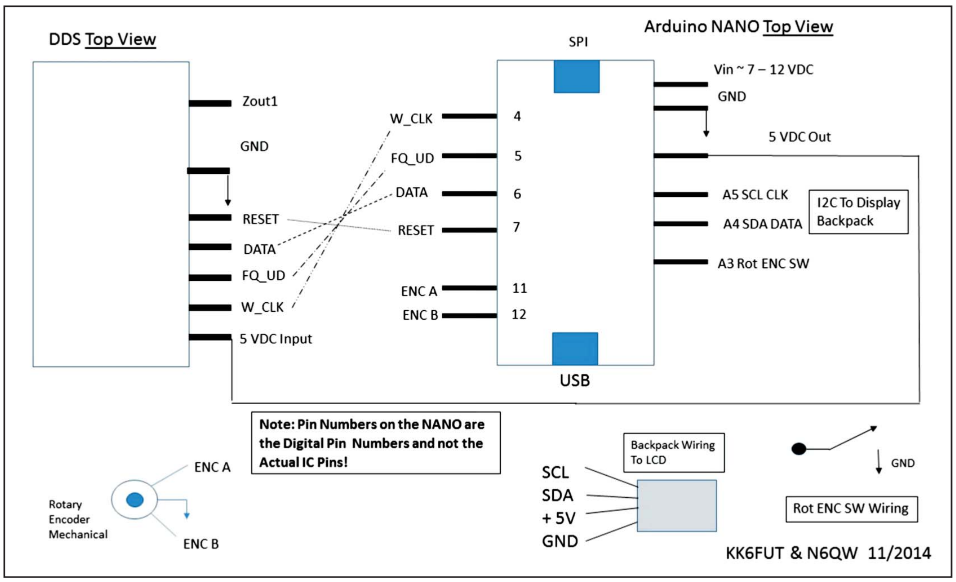

Figure 4—Arduino DDS schematic.

transceiver build, the DBM is employed as both a receiver and transmit mixer stage so that on the air signals are converted not to an audio based band but to an intermediate frequency (IF). Example: 40 Meter signals at 7.2 MHz are mixed in the DBM with an LO (VFO supplied by the DDS) of 12.1152 MHz and the difference frequency (which is what we want) is 4.9152 MHz. Our homebrew crystal filter will operate at this frequency where the signal will pass on to a second Double Balanced Mixer stage. Here, this DBM becomes a Product Detector on Receive and a Balanced Modulator on Transmit. The signal coming in at 4.9152 MHz is mixed with a BFO signal slightly above (or below depending on the sideband in use) 4.9152 MHz and the difference is audio. In the transmit mode, the first mixer stage now outputs the signals back to the 40 Meter band. We'll describe this more in the rest of the series.

This is where the mental light bulbs should light brightly. Our Part I direct conversion receiver is nothing more than a product detector connected to an antenna and in lieu of a fixed BFO frequency we are making it tunable. So what is being built in Part I is the back end of the SSB transceiver. Notice we said light bulbs as the second bulb is that the DBMs are bidirectional! If we hook up a microphone amplifier instead of the audio amplifier, that same product detector circuit becomes a balanced modulator. So what was the input to the product detector is now the output of the balanced modulator. This means that Part I will give us much of the circuitry needed for the low level transmit part of the SSB transceiver. The Double Balanced Mixer Schematic is shown in Figure 3.

YouTube Note: There are a series of three YouTube videos on the DBM that take you from the basics of the DBM through the final construction and these appear on the N6QW YouTube channel.

Tribal Knowledge Tip: The Importance of Heat Sinking any Diodes before soldering!

One of the keys to constructing a double balanced mixer (DBM) is proper construction technique. One of those techniques is making sure that sensitive components—in this case, your diodes—are properly heat sunk during the soldering process. The authors are a fan of using a hemostat, affixed between the point of soldering and the device itself, to make sure you do not overheat the diode. Soldering tips can reach an excess of 800 degrees, enough to render a diode (and other components) useless. Those hemostats are removed after the solder has cooled. We are now careful to mention this removal process for in an earlier article we failed to mention the removal of the hemostats. An email from a builder inquired how to fit that project into an enclosure with the hemostats dangling all over the circuit.

Modern Oscillator: The DDS

When we first started working on this project, we looked at a number of different options for an oscillator, including a VFO, varactor tuned oscillator, and a DDS. After building several versions of this oscillator, we decided that the easiest option—surprisingly—was to go directly to a DDS, due to the ease of soldering modules together, and the ability to directly use this DDS for our full fledged transceiver in the future.

There are three major parts to the DDS: the Arduino microprocessor to control the DDS, the DDS itself, and an LCD display and rotary encoder to allow us to change the frequency. Fortunately for us, there are only four lines we need to connect between the Arduino and the DDS, and only four lines between the Arduino and our LCD display. This actually makes using a DDS one of the simplest parts of this project.

The schematic for this oscillator is shown in Figure 4, which includes the hookup for the Arduino Nano and the AD9850 DDS Board. The Nano and the

AD9850 can be found on the major auction sites for very little cost. The Nano was chosen because of its small size. That said, the Uno R3 or even the Pro-mini can be used. The Uno is much larger physically and the Pro-Mini lacks the serial interface hardware. Moreover, no matter which Arduino device is used, just wire to the Digital and Analog pins for those respective boards. The other observance is that when loading the sketch you must select the device you are using and the appropriate COM Port. Most of the Arduinos like to see an input power to the Board in the range of 7 to 12 VDC. The easiest answer is a 9 VDC 1 amp regulator that is hung off of the main power supply rail (12 - 13.8 VDC).

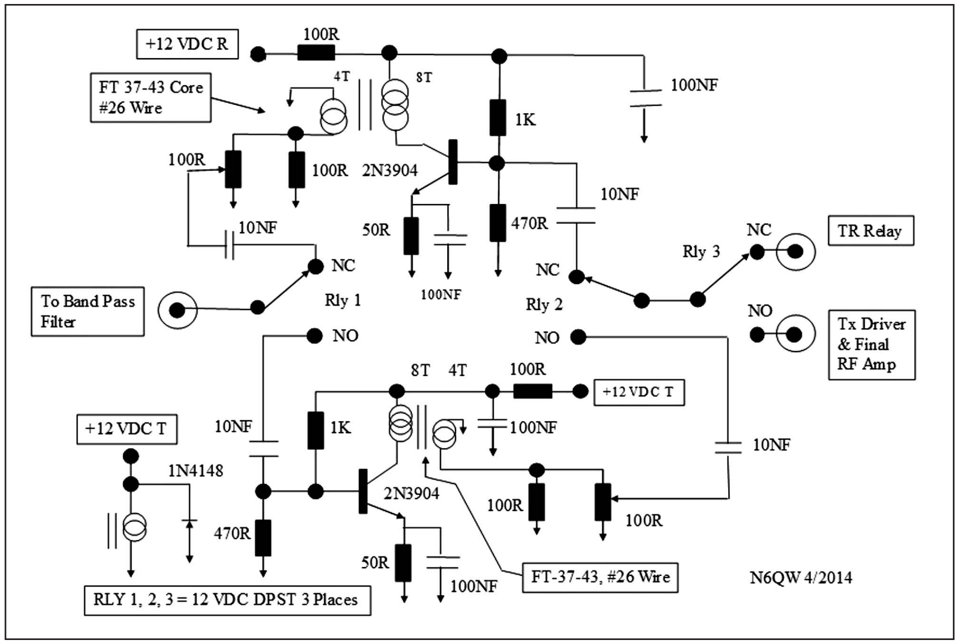

Figure 5—Bilateral Rx/Tx RF amplifier schematic.

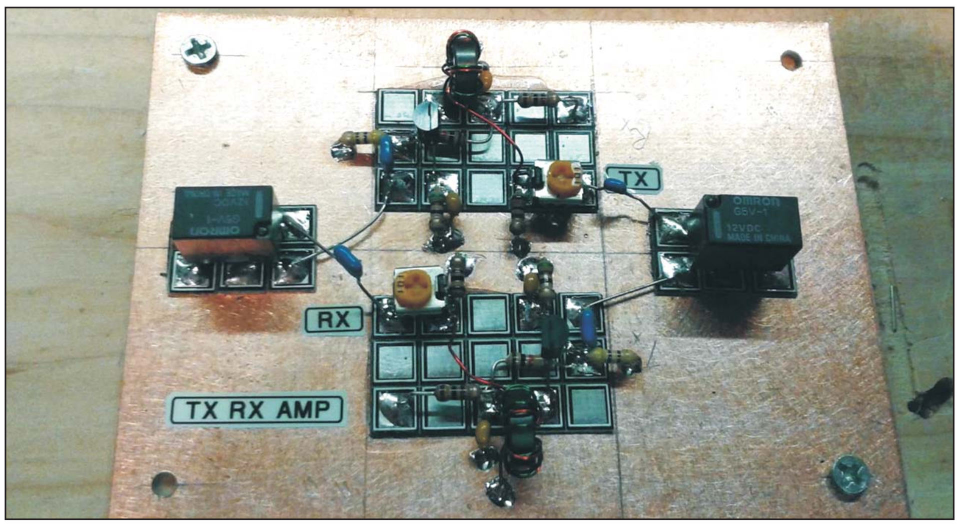

Figure 6—The completed Rx/Tx RF amplifier.

We have NOT shown a booster amplifier on that schematic, which is optional for the receiver project, but may be required for full driving of the mixer stage when the transmit functions are added. The booster is a utility type amplifier stage employing a 2N3904 that is used in other parts of the radio—remember reusable blocks? Just build another RF amp as described later and insert it between the DDS and the mixer stage.

We've also included pre-built software (Simple DDS), which allows the use of the DDS on a single band, and handles input from the rotary encoder to change the frequency. You do not need to know how to write software on the Arduino to use this—we've already included everything you need, and all you need to do is load the software onto your Arduino using the Arduino IDE.

The software needed is on the N6QW Website under the Arduino Link. Use this link to find the software, http://www.jessystems.com/arduino_build.html. This link has the software in the section marked Sketches.

The RF Amplifier: So Much from a 2N3904

The signal levels coming from your antenna are pretty small, and running those through a DBM is not all without some penalties. For all of the good stuff about a DBM, such as rejection of the incoming and LO signal at the output and lower noise than active mixers, the offsetting penalty is that they are a gain loss device suffering up to 5 or 6 dB loss. (DBMs are what is known as passive mixers meaning they do not provide any gain.) That means that off-the-air signal levels are further reduced in the mixing process. There are many ways to handle this, including tacking on a post mixer amplifier, using a high gain audio stage and adding an RF preamplifier to boost the signals ahead of the DBM. We did two of the three by adding an RF pre-amplifier stage and a high gain audio stage.

This pre-amp is un-tuned and thus broad banded, so everything coming into the antenna is amplified. Because of that, we need to include a band pass filter, which limits those signals to only the ones within our desired, 40m ham band. The Rx pre-amp stage provides better than 10 dB of gain which helps make up for the gain loss in the DBM. The parts cost is low in comparison to the gain available. (Certain circuit configurations of a 2N3904 can result in 15 dB of gain—so quite a lot of uumphf for a transistor that when bought in bulk can be had for 3 or 4 cents.)

This circuit block will be used in the final SSB transceiver serving the same purpose. In addition, the very same circuit will be duplicated and will serve as the Tx pre-driver circuit in the SSB radio. So, building two at the same time is probably a good idea, even though only one amplifier is used in the direct conversion receiver. Figure 5 shows the schematic for a two amplifier configuration with relay switching. The completed amplifier is shown in

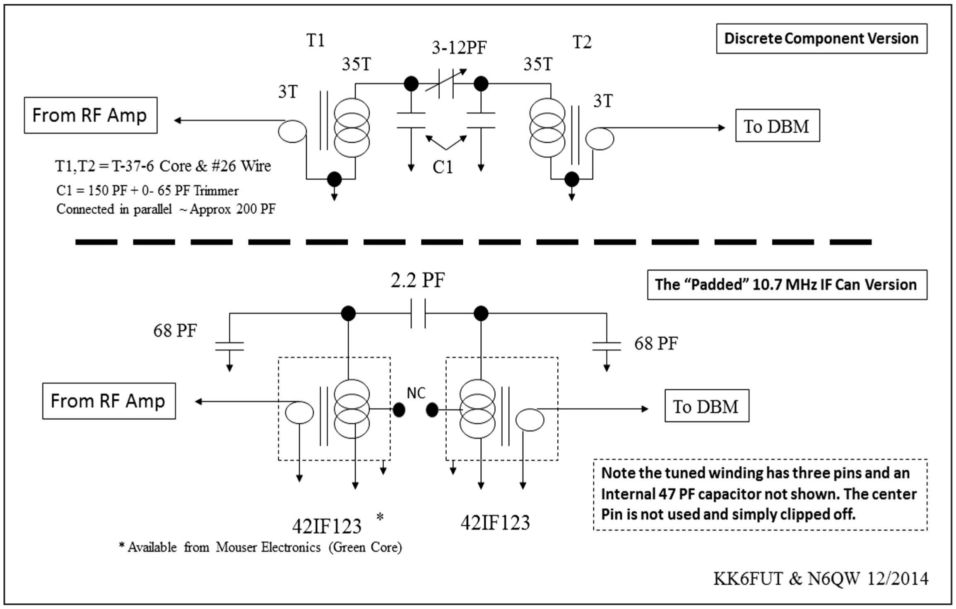

Figure 7—Bandpass filter schematic, with two options for building.

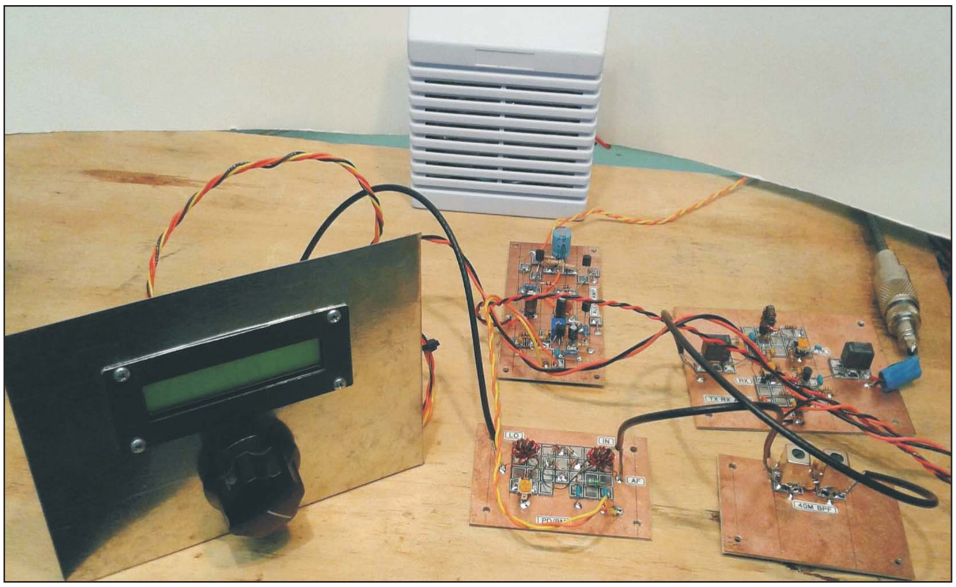

Figure 8—The finished direct conversion receiver.

Figure 6. Once again, when the circuit is completed follow Step 1 in N6QW's rigorous test process before applying any power!

The Band Pass Filter: Nothing to do with Rock Music

As mentioned earlier, the RF pre-amplifier being broad band will amplify anything coming through the antenna. As we tested this, we found you can faintly hear WWV and nearby shortwave stations coming through the speaker, which is a testimony to as "broad as a barn". The addition of a band pass filter helps keep most of the crud from being heard. The filter is a critical part that will be used in the SSB transceiver so that is another block that will be re-used.

There are two ways to build the band pass filter, both of which are shown in Figure 7: one involves a hand calculation using discrete components (harder but worth learning about) and the other uses packaged IF transformers (Mouser P/N 42IF123) along with three fixed capacitors. Since our goal in this article is to get you up and running, we suggest you build the IF transformer version as we will describe here. In a later part of this series of articles, we will suggest and describe a hand calculated band pass filter.

Building the filters requires adding some capacitance to the packaged IF transformers to lower the tuning range from 10.7 MHz to the 40M band. The 68 pF capacitors in parallel with the transformers accomplish this function. The external 68 pF adds directly to the 47 pF capacitor inside the transformer and resonates with the 4.7 µH coil at approximately 7 MHz. The tunability of the inductance accomplishes a resonance inside the 40M band. The third capacitor (2.2 pF) establishes the degree of coupling between the two transformers. Simply connect the parts as shown in Figure 7 and proceed to the tuning process described below.

Alignment of the homebrew filter following the Step #1 process involves N6QW's "Tune For Maximum Smoke" (TFMS) procedure. The circuit can be peaked for the loudest signal once installed in the radio. Or if a scope is available, feed the DDS signal operating at 7.2 MHz into the filter input and terminate the filter output with a 50 ohm non-inductive resistor. Next place the scope probes across the 50 Ohm resistor and observe the scope pattern. Adjust the pattern for a peak and note the value. Then tune at 7.1 MHz, and at every 25 kHz points, up to 7.3 MHz take similar readings. One can then plot a curve of the voltage reading versus frequency and thus characterize the filter. A flat response is what is desired and a bit of tweaking of the transformer tuning slugs will help improve that response. You will learn a lot about band pass filters using this method.

YouTube Hint: One of the "YouTube videos" that is referenced at the end of the article gives painful detail on how to do this.

Incidentally, these transformers can also be used as filters on other bands. For instance, N6QW has used these modified IF transformers in his multiband KWM-4 transceiver project. However, the transformers are not suitable for coverage across the entire 75M/80M band. In that instance, a filter using the hand calculation method is more suitable. For 30M and below, the procedure is very similar to what is described above. Just add a different capacitor to resonate with each transformer coil. Once you go past 30M up in frequency, one must "carefully" remove the 47 pF cap on the bottom side and use smaller values of capacitors across the tuned winding

Conclusion and Next Steps

Figure 8 shows what your receiver should look like at this point. It should be working successfully and you should be hearing signals.

We'll continue this series with our next article, which will allow you to proceed with the transformation of this simple direct conversion receiver into a SSB transceiver. Figure 9 shows how the modules built in Part I will be used in the SSB transceiver.

See the table below for YouTube video URLs and content descriptions. Hopefully, they will help you build this project successfully!

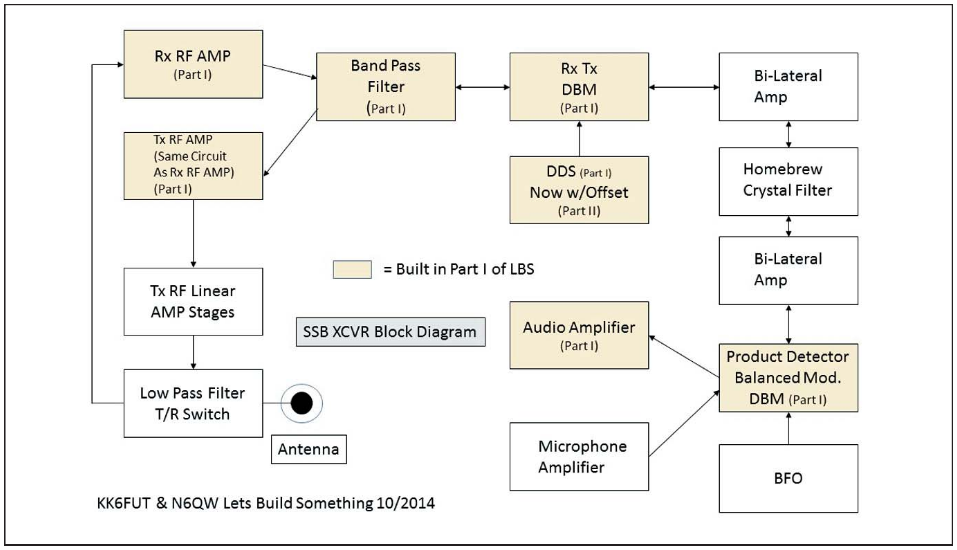

Figure 9—SSB transceiver block diagram.

YouTube URLs & Description

https://www.youtube.com/watch?v=GFZL8avwD3Y&list=UU4_ft4-oTdCMlWlL4XXHScg — Let's Build Something Demo of the Prototype

https://www.youtube.com/watch?v=kzcvNzpMv3U&list=UU4_ft4-oTdCMlWlL4XXHScg — Homebrew Double Balanced Mixer Part I of 3

https://www.youtube.com/watch?v=86n5gjlgmmI&list=UU4_ft4-oTdCMlWlL4XXHScg — Homebrew Double Balanced Mixer Part II of 3

https://www.youtube.com/watch?v=lShnfyXzCcs&list=UU4_ft4-oTdCMlWlL4XXHScg — Homebrew Double Balanced Mixer Part III of 3

https://www.youtube.com/watch?v=BjqvvzI1YLg&list=UU4_ft4-oTdCMlWlL4XXHScg — Building the 40M Band Pass Filter

https://www.youtube.com/watch?v=8p39-5Qcf3U&list=UU4_ft4-oTdCMlWlL4XXHScg — LBS Audio Amplifier Stage

https://www.youtube.com/watch?v=woFpYpSqzKA&list=UU4_ft4-oTdCMlWlL4XXHScg — Final Configuration

https://www.youtube.com/watch?v=b7BGB2oZNEo&list=UU4_ft4-oTdCMlWlL4XXHScg — Installing the Arduino/DDS in the Let's Build Something Direct Conversion Receiver