Part 1 - Heterodyne VFO

Build Sequence 1

Ceramic Resonator Oscillator

- ❑ **Step 1 – Install VR1**

  Be sure to observe the correct orientation of VR1 to ensure that the input and output terminals are placed correctly.

- ❑ **Step 2 – Install C33, C34**

  C33 is a polarized electrolytic cap, make sure that it is installed with the correct orientation.

- ❑ **Step 3 – Sanity Check**

  The +8 VDC voltage regulator is now complete. Connect a +12 VDC power supply to the VR1 input terminal (pin 3). Apply power and make sure that the voltage regulator is providing +8 VDC output at pin 1.

- ❑ **Step 4 – Install Q1**
- ❑ **Step 5 – Install R4, R5, R6, R7**
- ❑ **Step 6 – Install C3, C4, C5**
- ❑ **Step 7 – Install Q2**
- ❑ **Step 8 – Jumper Q2 collector to Q1 collector**
- ❑ **Step 9 – Install R8, R9**
- ❑ **Step 10 – Install C6**
- ❑ **Step 11 – Wind and install L1**

  L1 is a 43 uH inductor wound on a FT37-43 ferrite core. Wind 12 turns on the core and prepare the leads as specified in the Construction Methods.

- ❑ **Step 12 – Install X1**
- ❑ **Step 13 – Install D1**

  Varactor diode D1 is polarized and will not work correctly if it is installed the wrong way, so please be sure to wire it correctly.

- ❑ **Step 14 – Temporarily wire +8v Reg to R6**
- ❑ **Step 15 – Sanity Check**

  At this point, the ceramic resonator oscillator is complete, minus the tuning circuitry. Terminate the oscillator output (C6) in 50 Ω by connecting it to your dummy load or by tacking a 51 Ω resistor from the output to ground. Apply power to the circuit to confirm that it is oscillating correctly. On your general coverage receiver, you should be able to hear a clean and stable CW note somewhere very near 4.000 MHz (you may need to tack a small piece of wire or clip a test lead to the output as an antenna).

  If you have an oscilloscope, connect a probe to the oscillator output and be sure that you have a stable 4 MHz waveform. The signal level should be about 750 mVpp. Note that the waveform is not a perfect sine wave.

  If using a RF probe, you should measure approximately 120 mV at the oscillator output.

- ❑ **Step 16 – Install R3**
- ❑ **Step 17 – Install C2**
- ❑ **Step 18 – Install R1**
- ❑ **Step 19 – Install C1**
- ❑ **Step 20 – Install R2**

  R2 is the main tuning control for the transceiver. It operates (in conjunction with R1) as a variable voltage divider to provide bias to tuning diode D1. Prepare leads for the potentiometer as described in the Construction Methods above. In order to have this control tune upwards in frequency as the knob is rotated clockwise, the terminals must be wired in the correct way. As the bias voltage on D1 is increased, its capacitance is decreased. Therefore, the maximum tuning voltage will correspond to the minimum end of the tuning range. This means that we want to connect the terminal on the clockwise side of the pot to R1, and the other side to ground. The wiper terminal connects to R3.

- ❑ **Step 21– Temporarily wire +8v Reg to R1**
- ❑ **Step 22 – Sanity Check**

  Now that the tuning circuitry is complete, we need to verify that it operates correctly and that the tuning range is acceptable. If you have a frequency counter, connect it to output of the ceramic resonator oscillator and apply power. If you don't have access to a counter, then apply power and tune your general coverage receiver to zero-beat the oscillator note near 4 MHz. As you re-tune the oscillator, you will have to find zero beat on your receiver.

  Set the Tune control (R2) to fully counterclockwise and note the frequency. It should be somewhere around 4.000 MHz. Turn R2 clockwise and verify that the frequency is *decreasing* as you tune (due to the mixing scheme in the VFO, this is the behavior we are looking for). If it increases, you probably have the terminals of R2 reversed. At the full clockwise tuning position, again take note of the frequency. You should be measuring something near 3.910 MHz.

Crystal Oscillator

- ❑ **Step 23 – Install Q4**
- ❑ **Step 24 – Install R14, R15, R16, R17**
- ❑ **Step 25 – Install C17, C19**
- ❑ **Step 26 – Install Q5**
- ❑ **Step 27 – Install R18, R19**
- ❑ **Step 28 – Jumper Q4 collector to Q5 collector**
- ❑ **Step 28 – Install C20**
- ❑ **Step 29 – Install L4**

In the kit, L4 is a molded inductor, although a toroidal inductor may be substituted for those who do not have this particular component.

- ❑ **Step 30 – Install X2**
- ❑ **Step 31 – Install C18**
- ❑ **Step 33 – Sanity Check**

The main portion of the crystal oscillator has now been completed and is ready to be checked out. Temporarily terminate the oscillator output (C20) in 50 Ω and apply power to the circuit. As you did with the ceramic resonator oscillator, verify that the circuit is oscillating near 18.000 MHz.

If you have an oscilloscope, verify that the output of the oscillator is clean and stable, with an amplitude of approximately 1.5 Vpp. Using a RF probe, you should measure approximately 680 mV at the output.

Check that C18 provides a small amount of tuning so that the VFO can be trimmed to the desired lower frequency range later on. You should see about 10 kHz of frequency variation when tuning C18.

- ❑ **Step 34 – Install C16**
- ❑ **Step 35 – Install Q3**
- ❑ **Step 36 – Install R13**
- ❑ **Step 37 – Sanity Check**

The components installed in the previous three steps allows the VFO to be shifted in frequency during transmit. This is necessary in a transceiver in order to transmit an audio frequency to the other operator during a QSO. For example, let's say that we hear an operator calling CQ and want to answer him. When we tuned into this signal, we tuned the VFO to a frequency that is 600 Hz (or so) offset from the CW carrier. This is done so that when the incoming CW is mixed with the VFO, the result is 600 Hz audio. The other operator is expecting a return transmission on the CW carrier frequency. If no frequency offset were used on our end, then we would end up transmitting a signal 600 Hz off of this carrier frequency, which may end up out of the other operator's receiver passband.

Connect an alligator clip or wire to the +12V rail for temporary use in switching the offset. If you have a frequency counter, connect it to the output of the oscillator. If using an oscilloscope or RF probme, make sure that the crystal oscillator is terminated in 50 Ω. Apply power to the oscillator and take note of the frequency. Use the test lead that you attached to temporarily apply +12V to the +12V T terminal of R13(be careful not to short this lead to ground). Again, take note of the frequency of the oscillator. The oscillator should shift downwards by approximately 600 Hz. This circuit controls the frequency of CW note that you will want to tune into, so if you prefer to listen to a note other than 600 Hz, you can substitute a different value into C16. Either experiment with the value, or perhaps install a trimmer capacitor.

If you do not have a frequency counter, you will have to use your general coverage receiver for this check. Apply power to the oscillator and tune the signal for zero beat on the receiver. Apply +12V to the +12V T terminal of R13, and listen to the CW note produced on the receiver. You should hear a note that sounds to be about the same frequency as a CW signal that you would listen to on the band.

RIT

- ❑ **Step 38 – Install C32**
- ❑ **Step 39 – Install D6**

Varactor diode D6 is polarized and will not work correctly if it is installed the wrong way, so please be sure to wire it correctly.

- ❑ **Step 40– Install R40**
- ❑ **Step 41 – Install C31**
- ❑ **Step 42 – Install R37, R39**
- ❑ **Step 43 – Install Q8**

Be careful when handing Q8, it is ESD sensitive.

- ❑ **Step 44 – Install R36**
- ❑ **Step 45 – Install R38**

Center-detent potentiometer R38 controls the amount of voltage applied to tuning diode D6, which sets the RIT offset applied to the VFO.

Prepare the leads for R38 as specified in the Construction Methods. The potentiometer needs to be wired as a voltage divider, so that when it is turned counterclockwise the frequency decreases, and vice versa. This means that the pot terminal on the counterclockwise end needs to be wired to R37, while the other end needs to be connected to R39. Of course ,this leaves the wiper to connect to R40.

- [ ] **Step 46 – Wire +8v Reg to R37**

Connect a short piece of wire from the output terminal of VR1 to the appropriate R37 pad.

- [ ] **Step 47 – Wire +8v Reg to R6**

Connect a short piece of wire from the output terminal of VR1 to the appropriate R6 pad.

- [ ] **Step 48 – Wire +8v Reg to R1**

Connect a short piece of wire from the R6 pad just wired to the appropriate R1 pad.

- [ ] **Step 49 – Sanity Check**

Now that the RIT circuitry is complete we need to verify that it works correctly. Connect a test lead to +12V to use in testing the RIT disable. If you have a frequency counter, connect it to the crystal oscillator output (C20), other wise use a general coverage receiver to zero beat the signal as described earlier. Apply power to the oscillator and set the RIT control to the center-detent position and note the output frequency. Rotate the control to the fully counterclockwise position and note the output frequency again. Finally, rotate the control to the fully clockwise position and note the output frequency. You should see a tuning range of approximately 1 kHz for each direction turned from the center-detent position.

Build Sequence 2

Crystal Oscillator Pi-Attenuator

- ❑ **Step 1 – Install R20, R21, R22**

Single-Balanced Diode Mixer

- ❑ **Step 2 – Wind and install T1**

  Refer to the Construction Methods to wind T1, a trifilar broadband transformer.

- ❑ **Step 3 – Install D2, D3, D4, D5**
- ❑ **Step 4 – Install R10, R11, R12**

Double-Tuned Circuit (Bandpass Filter)

- ❑ **Step 5 – Install C7, C8, C9, C10**
- ❑ **Step 6 – Wind and install L2**

  L2 is a 700 nH inductor wound on a T37-6 iron core. Wind 16 turns on the core and prepare the leads as specified in the Construction Methods.

- ❑ **Step 7 – Install C11**
- ❑ **Step 8 – Wind and install L3**

  L3 is a 700 nH inductor wound on a T37-6 iron core. Wind 16 turns on the core and prepare the leads as specified in the Construction Methods.

- ❑ **Step 9 – Install C12, C13, C14, C15**

Broadband RF Amplifiers

- ❑ **Step 10 – Install C21**
- ❑ **Step 11 – Install Q6**
- ❑ **Step 12 – Install R23, R24, R25, R26**
- ❑ **Step 13 – Install C22, C23**
- ❑ **Step 14 – Install R28**
- ❑ **Step 15 – Wind and install T2**

  Refer to the Construction Methods to wind T2, a bifilar broadband transformer.

- ❑ **Step 16 – Install C24, C25**
- ❑ **Step 17 – Install R27**
- ❑ **Step 18 – Temporarily wire +12v to R27**
- ❑ **Step 19 – Sanity Check**

  By this point in the build, there should be enough signal present at the output of the first broadband amplifier to measure with an oscilloscope. Terminate C25 in 50 Ω and connect an oscilloscope to the output of the amplifier. Make sure that tuning control R2 is set for the center of its frequency range (approximately 14.040 MHz). Apply power to the circuit and observe the amplitude and quality of the waveform as you adjust C9 and C13 for a peak. Once adjusted correctly, you should see a waveform near 14 MHz which measures approximately 250 mVpp.

  If you do not have an oscilloscope, then you can still verify that a signal on the 20 meter band is being generated by the VFO. Attach a clip lead to C25 to act as a short antenna. Apply power to the circuit and use your general coverage receiver to tune around the lower end of the 20 meter band until you hear a strong carrier. As you adjust tune control R2, you should hear the carrier move off-frequency.

- ❑ **Step 20 – Install Q7**
- ❑ **Step 21 – Install R29, R30, R31, R32**
- ❑ **Step 22 – Install C26, C27**
- ❑ **Step 23 – Install R34**
- ❑ **Step 24 – Wind and install T3**

  Refer to the Construction Methods to wind T3, a bifilar broadband transformer.

- ❑ **Step 25 – Install C28, C29**
- ❑ **Step 26 – Install R33**
- ❑ **Step 27 – Wire +12V to R33**

  Connect a short piece of wire from the input terminal of VR1 to the appropriate R33 pad.

- ❑ **Step 28 – Wire +12V to R27**

  Connect a short piece of wire from the R33 pad just wired to the appropriate R27 pad.

- ❑ **Step 29 – Sanity Check**

  The final VFO broadband amplifier is now complete, which should bring the output signal level to somewhere near +13 dBm (before the hybrid power splitter). Terminate C29 in 50 Ω and connect an oscilloscope to the output of the amplifier. Make sure that tuning control R2 is set for the center of its frequency range (approximately 14.040 MHz). Apply power and readjust trim caps C9 and C13 for maximum output from C29. After the double-tuned circuit is adjusted, you should measure approximately 3.4 Vpp output (make sure it is no less than 2 Vpp) . The output should also be a very clean sine wave at this point. If you aren't getting the required power out, try readjusting the trim caps in the double-tuned circuit again(C9 and C13).

If you do not have an oscilloscope, use a RF probe to measure the voltage on the output of C29. You should measure at least 1.4 V at this point. If you are not seeing this minimum signal level, readjust the double-tuned circuit trim caps (C9 and C13).

Alignment and Performance Verification

❑ **Step 30 – Set VFO Lower Limit**

We need to ensure that the VFO tunes the desired range of frequencies and does not allow us to tune outside of the amateur band. Set tuning control R2 to the fully counterclockwise position (minimum frequency). Measure the VFO frequency using a frequency counter, or by tuning in the carrier on a general coverage receiver with a digital readout. Most likely, you will need to adjust this lower limit to suit your personal preferences or to comply with telecommunication laws. Adjust trim cap C18 for the desired lower frequency limit. If you find that you still cannot get the lower limit into the amateur band, R1 can also be changed to a higher value (try experimenting with this).

❑ **Step 31 – Verify Tuning Range**

Measure the final adjusted lower frequency limit and take note of it. Tune R2 to the upper frequency limit (fully clockwise) and note the output frequency. You should have a difference of approximately 80 kHz, depending on parts variations and how you constructed your VFO.

❑ **Step 32 – Verify RIT Operation**

Set RIT control R38 at the center position. Measure and note the frequency of the VFO output. Tune R38 fully clockwise and again note the VFO output frequency. Finally, tune R38 fully counterclockwise and note the VFO frequency. There should be an offset of approximately 1 kHz in each direction. The offset is a bit uneven on each side due to the simple nature of the circuit, but it works well in practice.

While the RIT control is set at fully clockwise, monitor the VFO frequency. Temporarily apply +12v to R36 to disable the RIT offset. While RIT is disabled, the output frequency should be about 600 Hz lower than the value you measured at the beginning of this step (due to the transmit offset).

If you do not have a frequency counter, reset the RIT control to the center-detent position. Zero beat the VFO signal on your general coverage receiver. Now tune the RIT control up or down and note that the received carrier sound frequency increases from 0 Hz upwards. Leave the RIT control set so that there is an audible tone in the receiver, then temporarily apply +12v to R36. If the RIT is functioning correctly, you will hear a 600 Hz tone regardless of where the RIT control is set.

❑ **Step 33 – Verify Output Level**

The output level of the VFO has to meet a minimum across the entire tuning range in order to drive the diode mixer in the receiver correctly. Due to the characteristics of the ceramic resonator oscillator, the output signal level is lowest at the top end of the tuning range.

Set tuning control R2 to fully clockwise to tune the VFO to its upper frequency limit. Make sure that the signal level is no less than +10 dBm (2 Vpp on the oscilloscope or 750 mV on the RF probe). Keep your measurement device on the VFO output and tune the VFO to the lower frequency limit. Check that the signal level does not drop below the +10 dBm limit at any point in the tuning range (the signal level will change a bit as the VFO is tuned downward).

❑ **Step 34 – Verify Signal Quality (*Optional*)**

If you have an oscilloscope with a bandwidth of 60 MHz or greater, then you can use it to verify that the output of the VFO is relatively clean and stable. When monitoring the VFO output across a 50 Ω dummy load, you should observe a near-perfect sine wave, with no fluctuation in the amplitude artifacts on the sine wave. Any deviation from a pure sine wave indicates large harmonic content in the signal.

If you a very fortunate and have access to a spectrum analyzer or an oscilloscope which has an FFT function, check the spurious response from the VFO. The 2^{nd} harmonic of the carrier should be no greater than -32 dBc. No other spurious products should be greater than this as well.

❑ **Step 35 – Verify Frequency Stability (*Optional*)**

If you want to verify the frequency stability of the VFO, you will need a frequency counter (resolution of at least 10 Hz), a location that is temperature stable, a clock or timer, and a method of capturing data (Microsoft Excel or OpenOffice.org Calc works great).

Setup your spreadsheet program with two column headings: Elapsed Time and Frequency. The time intervals that you enter into the Elapsed Time column are your choice, although I recommend that you measure in one minute increments for at least the first 10 minutes or so. After that, five minute increments seems to work just fine.

Connect your frequency counter to the VFO output, then apply power the circuit when you are ready. Immediately record the measured frequency in the first row (it should be “0” minutes elapsed). Start your timer or note the time that your testing started. After every interval marked on your spreadsheet, note the VFO frequency in the corresponding cell. An hour of measurement is probably enough to get a good picture of what's going on, unless there is an extreme amount of drift.

Once your data is collected, you can plot it into a nice chart to graphically visualize the behavior of your VFO. Highlight all of the data you collected, including the column headers. Start the Chart Wizard and select a XY (Scatter) chart, with lines connecting the data points.

Enclosure Construction

Due to LO leakage and other issues (consult chapter 8 of *Experimental Methods in RF Design* for the exact reasons), it is very important to operate the local oscillator of a direct conversion receiver in a RF-tight enclosure. You can find some DC designs out there where the LO is unshielded, but it's likely that the performance of the receiver will fall into the novelty category.

You have a few different options for enclosing the VFO. Perhaps the easiest, but most expensive, is to use a manufactured metal enclosure, such as one from Hammond. You could also be a bit more frugal, and creatively reuse an old enclosure that was destined for the scrap heap. A third option is to build an enclosure from scratch using raw materials. The easiest way to do this (if you don't have a metal shop) is to fabricate your enclosure from plain double-sided copper clad. All that takes is a combination square, a pair of tin snips, and a good, hot soldering gun (100 W or so).

The instructions that follow should be generic enough that they will be useful to you regardless of which method that you use.

- ❑ **Step 36 – Procure Enclosure**
- ❑ **Step 37 – Layout and Drill Holes for Circuit Board, Potentiometers, BNC Jack, and Feedthrough Capacitors**
- ❑ **Step 38 – Prepare Leads for Feedthrough Capacitors**
- ❑ **Step 39 – Prepare Cable for BNC Jack**
- ❑ **Step 40 – Install Circuit Board**
- ❑ **Step 41 – Install Potentiometers, BNC Jack, and Feedthrough Capacitors**