Willamette DC Transceiver

Winter 2008 qrp-l.org Group Project

Design by Jason Milldrum, NT7S

Overview

A Quick Geography Lesson

Recently, I've acquired the habit of naming my transceiver projects after the waterways in my native northwest Oregon. I've christened this project after the Willamette River, the waterway which runs through the most populous portion of the state. The name is pronounced *wil-LA-met*, with the stress on the middle syllable, which isn't usually obvious to non-natives. An Oregonian can tell that someone isn't from around here when they pronounce the name *willa-met*.

The Willamette River is a large tributary of the mighty Columbia River, but is navigable only a small portion of the way from its confluence with the Columbia. The head of navigation is at Willamette Falls in Oregon City, which is only 26 miles upstream from the confluence. However, the river spans a total length of 187 miles. The name seemed fitting since the Willamette River is the waterway which binds together a large portion of the people in our state. In the same way, I hope that this project can help to bring together a portion of the QRP community in the spirit of experimentation, learning, and fellowship.

Theory of Operation

The Willamette Transceiver features a heterodyne VFO, which provides a local oscillator signal for a direct conversion receiver and a QRP transmitter. Refer to Illustration 1 for a complete block diagram of the radio.

On the receiver side, incoming RF is first fed into a preselector, which is a simple tuned circuit designed to prevent strong out-of-band signals from overloading the receiver front end. This helps to preserve the dynamic range of the receiver. Following the preselector is a RF preamplifier of modest gain. The preamp helps to overcome the noise present on the higher HF bands, but serves a more important purpose in this receiver. The grounded-gate amplifier configuration has very good reverse signal isolation. This protects the front end from the LO leaking out of the product detector and being reflected back into it from a poor antenna match. Next, the incoming RF is more aggressively filtered by a double-tuned circuit before being applied to the RF port of a standard double-balance diode ring mixer. The incoming signals are mixed with the heterodyne VFO signal to convert them down to audio frequencies. A diplexer is placed on the output port of the mixer to terminate unwanted mixing products in 50 Ω. The very weak audio frequencies are next filtered through a few active low-pass stages and then preamplified, before heading into the volume and mute circuitry. Finally, the desired AF signal is amplified to headphone volume with a class-A audio amplifier, followed by a class-AB audio power amplifier which can drive a low impedance load.

The transmitter chain of the transceiver is very simple. A CW signal is generated directly on the desired transmit frequency by the heterodyne VFO. Since it is already on frequency, the only thing that we need to do to it is to amplify it to the desired output power and provided keying circuity. The VFO output of approximately +9 dBm is fed into a class-A broadband driver amplifier which boosts the signal approximately +25 dBm (330 mW). A potentiometer on the input of the driver amplifier allows the transmitter drive level to be adjusted all of the way to 0 watts. The output of the driver amplifier is fed to a simple class-C power amplifier, which brings the CW signal to a final output power of about +37 dBm (5 W). Since class-C amplifiers are non-linear, they produce an output rich in harmonics. In order to be courteous to fellow operators and meet FCC specifications, a low-pass filter is placed on the output of the power amplifier. A classic solid-state T/R circuit is connected to the low-pass filter to provide a signal path for the receiver.

Because we want to use a direct conversion receiver scheme on the upper HF bands, a simple VFO is not feasible due to stability problems. VXO control often leaves much to be desired due to the limited and non-linear tuning range. In order to overcome these obstacles, a heterodyne VFO design is used in this rig. Two different oscillators are used, a ceramic resonator oscillator and a crystal oscillator. The two signals are mixed to produce a LO signal on the desired amateur frequencies. The lower frequency ceramic resonator oscillator provides a fairly large tuning range, while having increased stability over a VFO. The higher frequency crystal oscillator provides a very stable CW

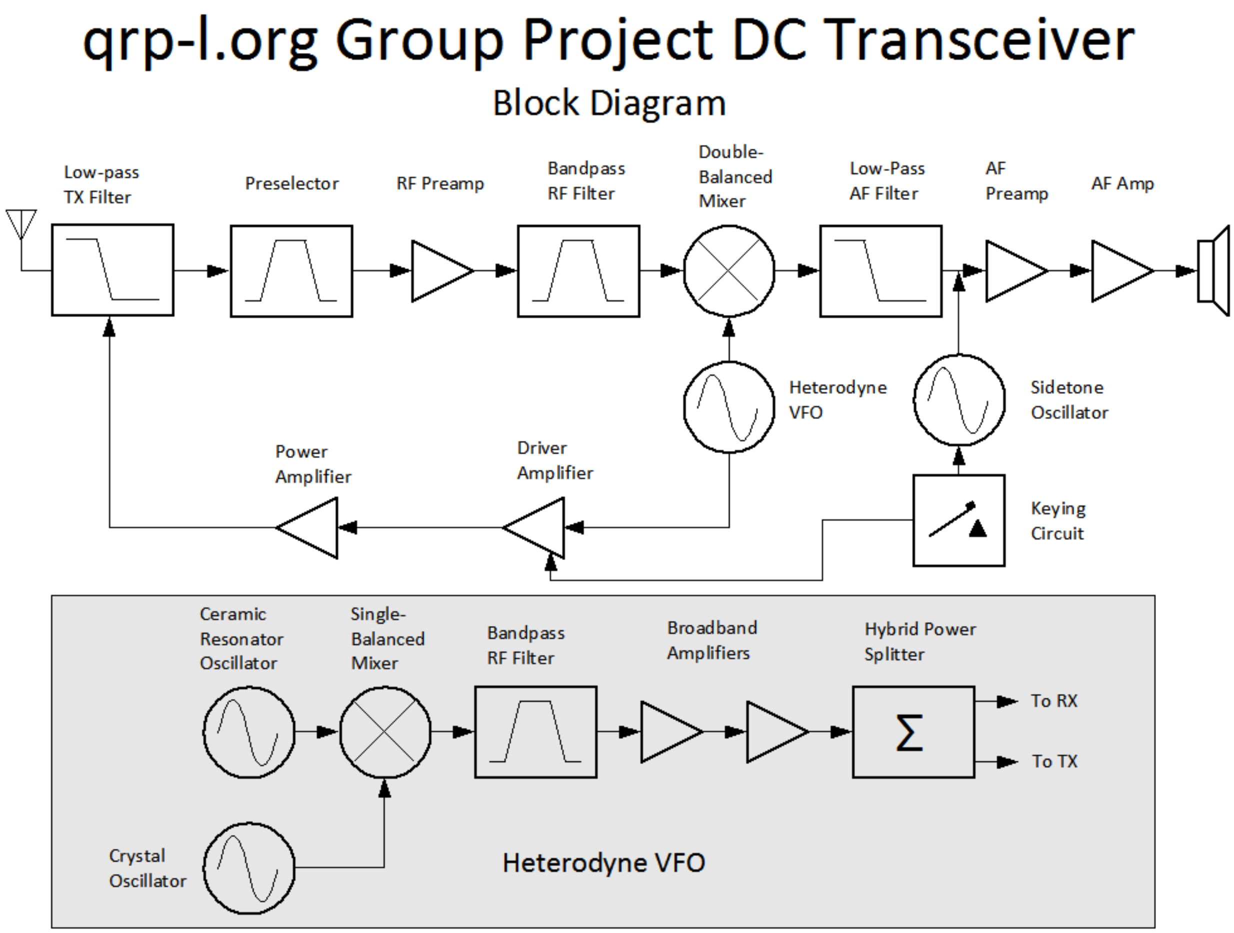


Illustration 1: Transceiver Block Diagram

note to mix to. It also allows a fixed amount of transmit and RIT offset regardless of where the VFO is tuned to, something that a single VXO or ceramic resonator oscillator does not allow. The two signals are mixed in a single-balanced diode mixer, then filtered through a double-tuned circuit. Because of losses in the mixer and filter, two broadband class-A amplifiers are used to bring the LO signal up to a usable level. Finally, a 3 dB hybrid splitter is used to provide two different outputs for receiver and transmitter use.

Sanity Checks

In order to maximize your success in building any radio of moderate or high complexity, it is best to test each stage of the radio as you build. These verification steps will be called sanity checks in this document. By performing these sanity checks after building each section, you can proceed with your build with the knowledge that all of your completed circuitry is working correctly. Not only does this build your confidence, but it makes it much easier to troubleshoot problems if they do crop up. A great example of this method is given in the article "Building Kits to Learn", found in the November 2007 issue of *QST*. A copy of this article (available to both members and non-members) can be found on the ARRL website (http://www.arrl.org/qst/2007/11/mitchell.pdf).

Caution: Be sure to remove power from any circuits under test when you are finished making measurements, before you start building again!

Margins

Many of the sanity checks will have specific measurements to check against. While it is nice to confirm a measurement that is the same as the build document, it's rare that you will actually see this. Due to variations in test equipment, power supplies, build methods, and components, your readings will be a bit different from the measurements noted here. Generally speaking, as long as your readings are within approximately 5% of the measurements listed here, your circuit is operating correctly. In some cases, you might be fine with variations of up to 10% (or more). If you are uncertain if your measurement indicates a correctly operating circuit, contact an Elmer for some advice. You are also welcome to contact me, see my website (www.nt7s.com) for details.

Preparation

Required Tools and Equipment

This list represents the bare minimum tools and equipment that you must have available in order to complete this project.

- ❑ **Digital Multimeter or VOM**

  Perhaps the single most important piece of test gear that a homebrewer can own. Even a cheap meter, such as those found on sale at Harbor Freight, will be good enough for our purposes.

- ❑ **RF Probe**

  This is not necessary if you have an oscilloscope, but it's still nice to have for quick measurements of RF power. If you don't currently have a RF probe, you can easily build one using instructions found at the end of the documentation.

- ❑ **General Coverage HF Receiver**

  A rig with digital frequency indication to 10 Hz resolution is highly recommended.

- ❑ **+12 VDC Power Supply, 1 A minimum**

  The completed transceiver draws about 850 mA on transmit, so a 1 A power supply would be the bare minimum. Current limiting is a definite bonus when homebrewing projects. An alternative would be a 12V battery (like a gel cell), although this is riskier since there is no overcurrent protection.

- ❑ **50 Ω Dummy Load (minimum 5 W capacity)**

  You can use anything from a commercial 1.5 kW dummy load to four 2 watt, 200 Ω resistors in parallel. Most of the circuit blocks in the transceiver are designed to be terminated in 50 Ω, so when testing virtually everything but the last two transmitter stages, you can just tack a 51 Ω resistor from the output of the circuit to ground to terminate it properly.

- ❑ **Soldering Iron**

  A good quality, temperature controlled iron is important for trouble-free construction of this project (or any other significant project).

- ❑ **Needle-nose Pliers**

  Just about any pair of small needle-nose pliers will do, although your life will be easier if you use a high-quality pair.

- ❑ **Diagonal or Flush Cutters**

  As with the pliers, almost any cutters will do for type of building, but you'll never regret owning a high-quality tool.

- ❑ **Hobby Knife**

  A good, sharp hobby knife (such as an X-acto) is necessary for scraping the enamel off of magnet wire, as well as for other cutting tasks.

Optional Tools and Equipment

Any tools or equipment listed below is optional for the construction of this project, although many will make your life much easier if you have to do any troubleshooting.

- ❑ **Frequency Counter**

  Very useful for verifying the proper operation of the heterodyne VFO.

- ❑ **Oscilloscope**

  Although this is listed as optional equipment, the usefulness of an oscilloscope cannot be overstated. A bandwidth of 60 MHz is probably the minimum for accurate voltage measurement, but even a 20 MHz scope will provide very useful qualitative information about the signals in your transceiver.

- ❑ **Signal Generator**

  A signal generator capable of providing a sine wave output in the HF spectrum is handy for injecting signals into the transceiver for tasks such as checking the receiver signal path and sweeping filters.

- ❑ **Power Meter**

  Insuring that the proper signal levels are present in the transceiver is very important. These can be measured using a oscilloscope and 50 Ω termination, but it is much easier and quicker to use a power meter with a scale calibrated in dBm. Good examples for the homebrewer are the W7ZOI meter or the M^3 Electronix FPM-1 kit.

- ❑ **Audio Oscillator**

  An audio oscillator of some kind is handy for checking the correct operation of audio amplifier and filter stages. Even if you don't have a commercial model, you can build the transceiver's Twin-T sidetone oscillator for use in verification and troubleshooting.

- ❑ **Noise Generator**

  A broadband noise generator can be useful for quickly checking that a receiver is operating correctly, as well as for measuring filter shapes if you have the correct test equipment.

Parts Inventory

Please do yourself a favor and take a few moments to inventory the parts in your kit before you get started. This will help you to organize the parts when it's time to build, as well as let you know if you are missing anything. If anything is missing or incorrect, please contact NT7S for an immediate replacement.

Manhattan Construction Methods

The Willamette Transceiver can be built using any method of RF construction that you prefer, however this tutorial will focus on the Manhattan method which is popular in the QRP homebrewing community. I won't go into great detail about Manhattan construction since there are many excellent tutorials already published on the Internet. If you are new to the method, I recommend that you study some of these detailed tutorials, then come back to this document for specific instructions for this project.

Pads

In Manhattan construction, pads of punched out copper clad material are used as circuit nodes and as mechanical anchors for the components. The pads are glued to the copper clad substrate with a cyanoacrylate glue (known as Superglue or Krazy Glue to most folks). I like to buy 3-packs of the gel-type Superglue from the local dollar store for my circuit construction.

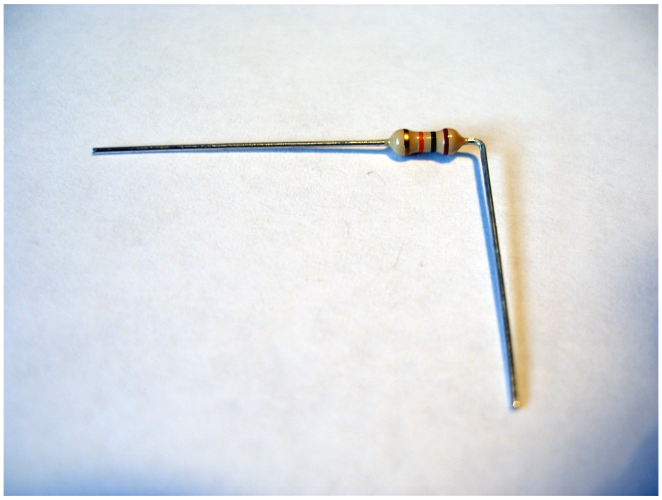
Builders use various shapes and sizes of pads based on their personal preferences and the needs of the circuit. In nearly all of my work, I have standardized on a 5 mm diameter circular pad. I've found that it is a very flexible size to use when working with through-hole components. The standard build instructions for the Willamette uses 5 mm pads throughout the entire rig. Usually, one pad will be sufficient for a circuit node, but there are times when too many connections need to be made to a single node to fit on one 5 mm pad. In these cases, you will find that another pad is glued nearby and is jumpered to the other pad with a small piece of excess component lead.

You can use various methods for locating and placing the pads based on your familiarity with Manhattan construction and your preferences. In working with a beta version of the rig, I found that it works well to print out a copy of circuit layout diagram for measurement purposes. When printed without any scaling, you should have a 1:1 scale diagram of the circuit. When you proceed to place the first component in a circuit section, measure the distance of one of the component pads from the nearest edges of the board on the layout diagram. If your copper clad is cut to the same dimensions as the board outline on the diagram, you can use this measurement to locate the actual pad placement. Use a marker (such as a fine-point Sharpie) to mark this location. Next, place a small bead of Superglue on this point and glue down the pad. When you place the subsequent pads, measure their locations relative to a pad that you previously placed in this circuit section. Keep proceeding in this fashion to complete the circuit section.

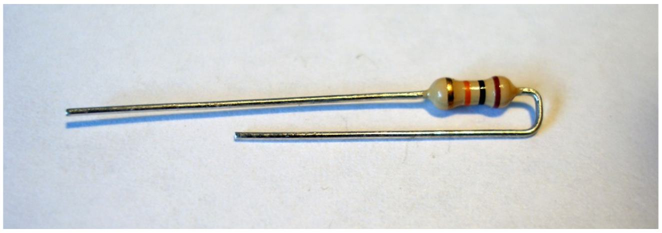
There is a bit of wiggle room when building a Manhattan circuit, so don't worry too much about getting the measurements exactly right. If you feel that you don't quite have the room that you need to locate a pad, you have a few different options. First of all, don't be afraid to locate a pad a little closer to others if necessary, as long as they aren't physically touching each other to create a short. You probably won't get a perfect match to the layout diagram, but you should be able to place things fairly close. Sometimes you can also leave extra lead length or shorten the lead length on components to get them to fit it tight spaces. The large 5 mm pads give you quite a bit of margin of error in placing the components. If it looks like you really can't fit a pad into the area it's supposed to go into, you can always use a smaller pad. It may be easiest to just cut the pad in half using some cutters. In most cases, you can still place components to a smaller pad just fine, unless you have a node with many connections. If all else fails, you can also unsolder some components and remove the pads you've placed in the circuit section. If you have to resort to this, I recommend that you grasp the pad with needle-nose pliers and twist the pad to break the bond with the copper clad. The truth is that there is no "correct" way to wire a Manhattan circuit, as long as it is electrically sound. Use your judgment and a little creativity, and all will be well.

Resistors and Molded Inductors

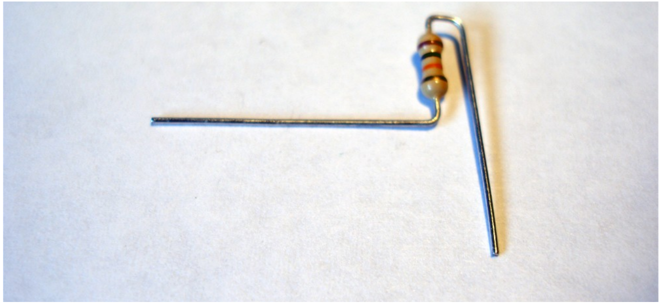
To begin forming resistors (and other similar components) for installation, first put a 90° bend in one of the leads.



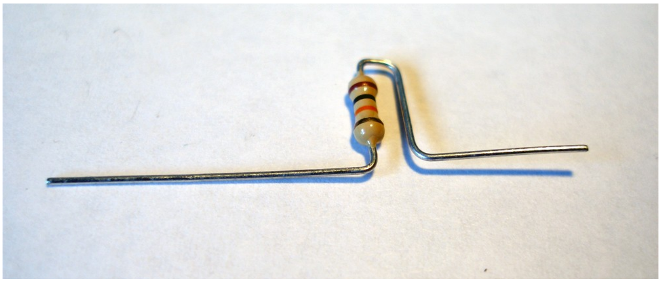
Next, place another 90° bend in the same lead just a little bit further away from the body, so that the lead bends back in the direction of the other lead.



Now bend the other lead 90° away from the first lead.



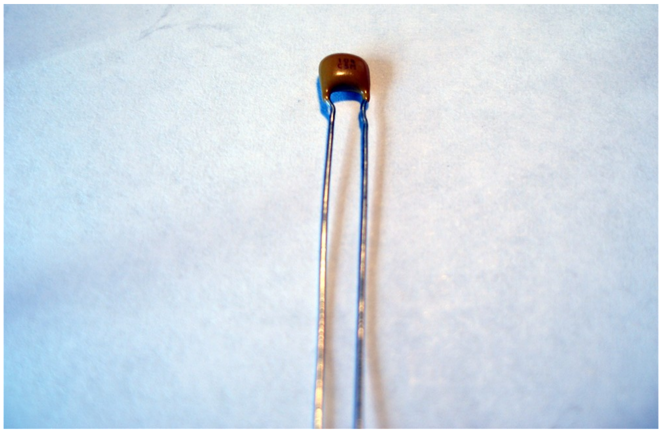
Put one more 90° bend in the first lead, so that the remaining length is aligned with the second lead, pointing 180° away. If this component has one terminal which connects to ground, then leave one lead slightly higher than the other to allow for the difference in height between the pad and the ground plane.



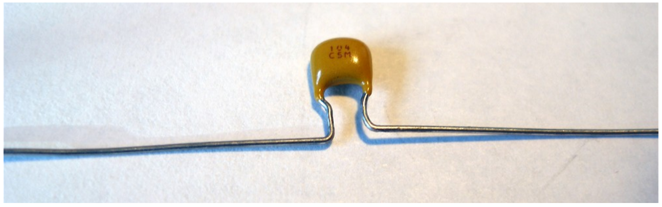
Trim the excess lead length from both leads.

Capacitors

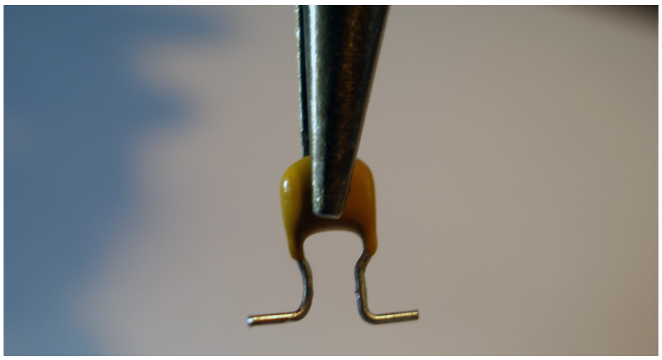
Capacitors are easy to prepare for installation. If you are installing monolithic 10 nF or 100 nF capacitors, you may have to straighten the leads before doing anything else. Many of the ceramic capacitors already have straight leads.



Place a 90° bend in each of the leads, pointing away from the body of the capacitor.



Clip the excess lead length to complete the preparation.

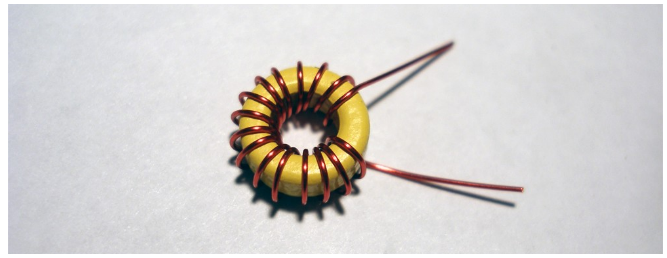


Toroidal Inductors

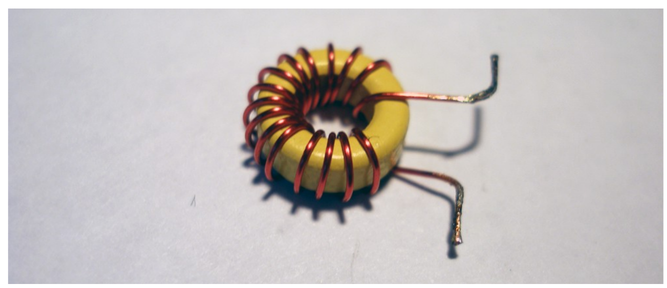
The first step in preparing a toroid for installation is to cut some magnet wire to the length specified in the build instructions. If you really want to play it safe (such as if you've never wound toroids before), you might want to cut off an extra inch or two to give yourself a safety margin. It's a bit more painful to unwind the toroid when you run out of wire than it is to clip off some excess.

Put the first turn on the toroid by inserting the wire through the center of the core. Leave about 1 inch of wire on one side of the core, then form the wire so that it wraps firmly around the outside of the core. Take the long end of the wire and place it again through the center of the core, in the same direction as the first turn. Pull the wire through the core and snug it up against the toroid body. Be careful when snugging the wire that you don't scrape off the wire enamel, which could give you an unexpected short.

Continue wrapping the wire in this way until you get the desired number of turns. Do not cross the wire over itself during the winding. Remember that each passing of the wire through the center of the core counts as one turn, so the initial placement of the wire is counted as your first turn. Trim off any excess wire length so that both leads are around an inch long. Ideally, there should be about 30° of the toroid not wrapped with wire, so you may need to expand or compress the turns to get the desired coverage of the core. The picture below shows the amount of wire coverage you want on a core.



Using your hobby knife, carefully scrape the enamel from the ends of the two toroid leads. Be very careful not to nick the magnet wire when doing this, as this will weaken the wire and could lead to a future wire break. Place a 90° bend in each of the two leads so that they point away from each other. Trim off the excess lead length so that only about 1/8” remains after the bend. Finally, tin the leads using a blob of solder on your soldering tip. You may need to hold the lead in the solder blob for a while to burn off any excess enamel which might remain on the wire.

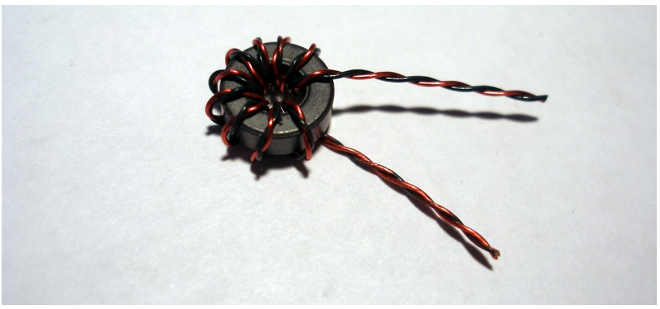


Toroidal Transformers (Bifilar and Trifilar)

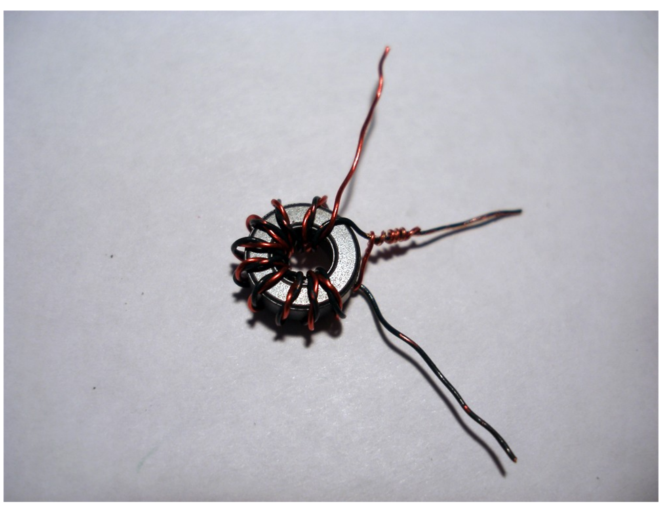
Preparing bifilar and trifilar transformers are a little more involved than simple toroid inductors, but they are nothing to be scared of. The first task when constructing one of these transformers is to prepare the wires. The wires need to be twisted together, then they can be wound around the toroid core as a single bundle. If you are making a bifilar transformer, you'll need two separate wires. A trifilar transformer needs three wires. Building the transformer is easier if you use separate colors for each of the wires, although it's not strictly necessary. You can also use your multimeter as a continuity checker to identify each individual wire.

Gather together a 12” length of each wire needed for the transformer. There's a few different ways you can go about twisting the wires. The easiest that I have found involves a vice and handheld drill. Place the wires parallel to each other, so that the ends are flush. Place one end of the bundle in the vice and secure it. Place the other end of the bundle in the chuck of your drill, then pull the drill away from the vice so that there is tension on the wire bundle. You can now use the drill to place a nice, uniform twist into the wire bundle. I like to shoot for about 6 turns per inch, but this is not very critical. You can also twisted together wire manually, but this is much harder and more time consuming.

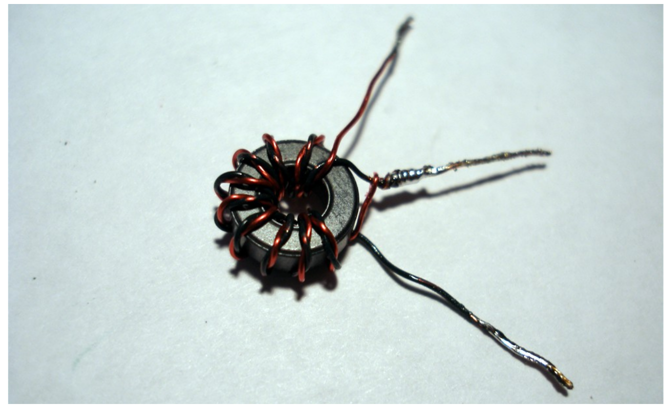
Now you can wind your wire bundle as you would a toroid inductor. Every bifilar transformer in this project (except for the one on the PA output) has 10 turns wrapped around a FT37-43 core.



Once the bundle is wrapped around the core, separate the individual wires from each end. If you used different colors (in this example, red and green), then you'll have two wire colors on each end. Now, the opposite wires from each end will need to be connected together to form the tap point. In this example, this means that the green wire from one pair of lead ends is connected to the red wire from the other pair of lead ends. Strip the enamel from each of these wires, then wrap one of the wires tightly around the other, as shown below.

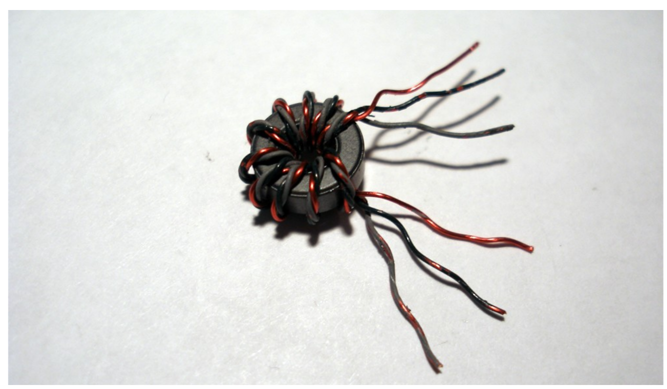


Solder together the wrapped wire to create the tap lead. Next, strip and tin the remaining leads to complete the bifilar transformer.

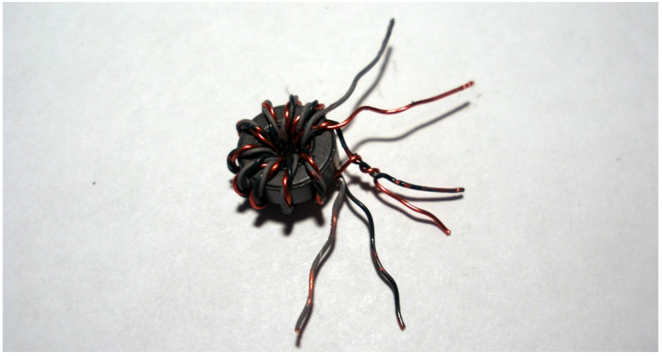


A trifilar transformer is constructed similarly. Wind the bundle of three wires around the core as specified.

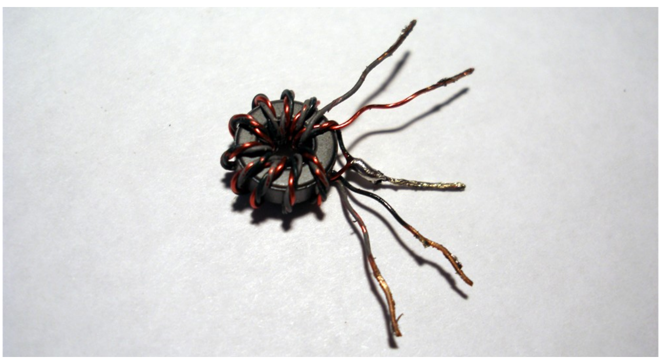
Separate the individual wires on each lead end.



Two of the different wires from each lead end are connected together to form a tap point (red and green in this example).

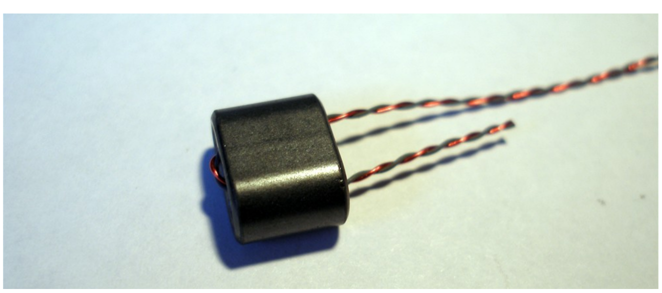


The remaining wire (grey in this example) is left alone. It is used as the input link when this transformer is used in a diode mixer.

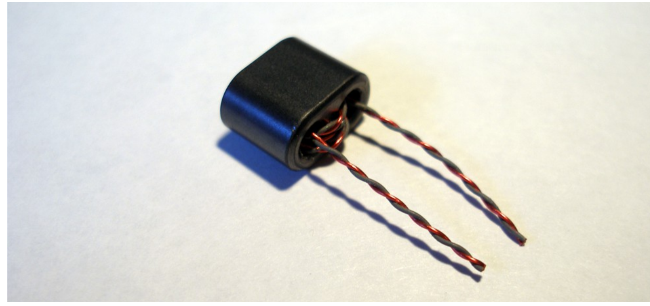


Binocular Core Transformer (Bifilar)

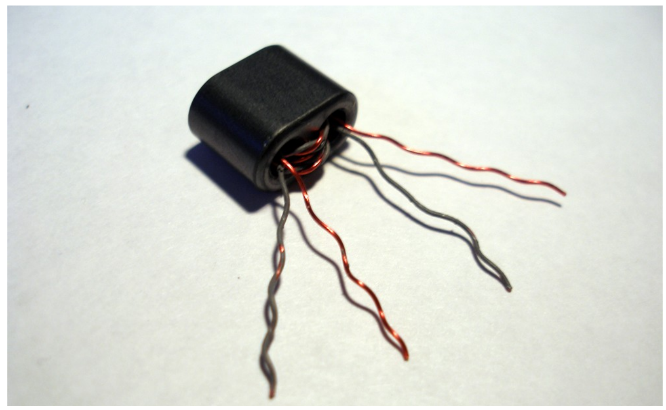
The bifilar binocular core transformer used in the transmitter power amplifier really just about the same as the bifilar toroidal transformers used in the rest of the rig. The only difference is how you wind the wire bundle around the core. Looping the bundle through one hole, then back down through the other counts as one turn. The picture below demonstrates the first turn of the binocular transformer.



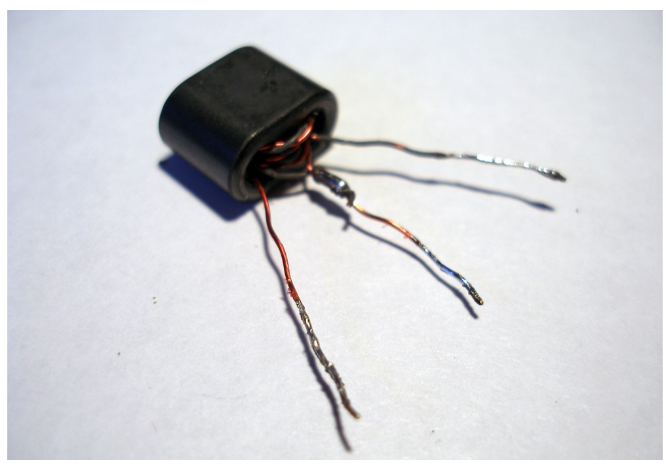
Wrap 5 turns around the core in total.



Separate the individual wires.

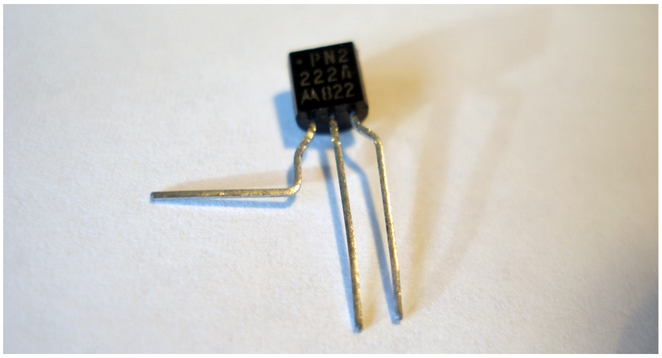


Solder together the two opposite wires to form the tap point.

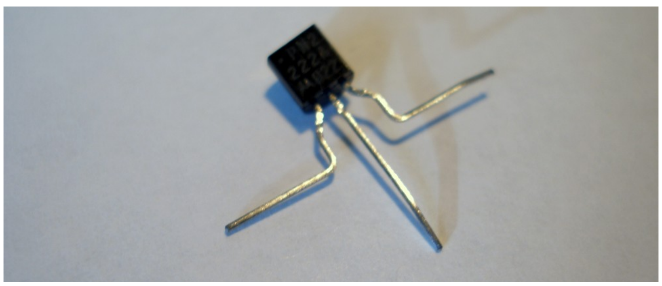


TO-92 Devices (Transistors and Voltage Regulator)

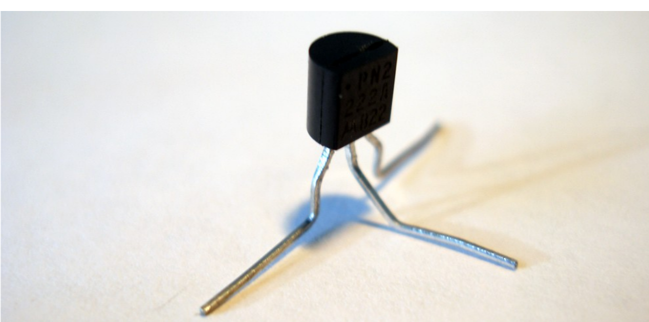
Begin by forming a 90° bend in one of the outside leads, so that it points away from the other leads.



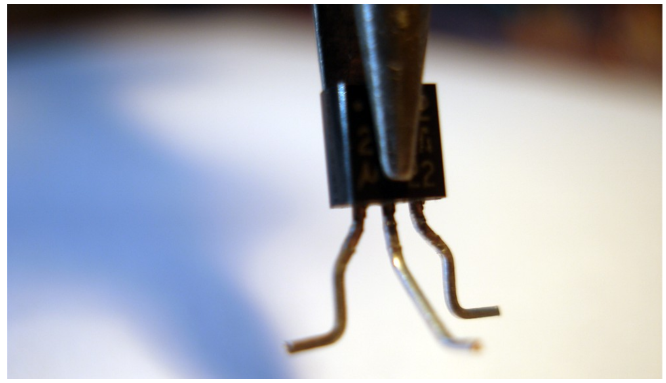
Form a 90° bend in the other outside lead, in the opposite direction from the first bend.



The middle lead will have to be bent near the package at a 45° angle, either towards or away from the flat side of the device. Check the layout diagram to see which way each particular device is configured. Place another 45° bend in the same lead at the same level as the other two bends so that it will sit flat as shown below.

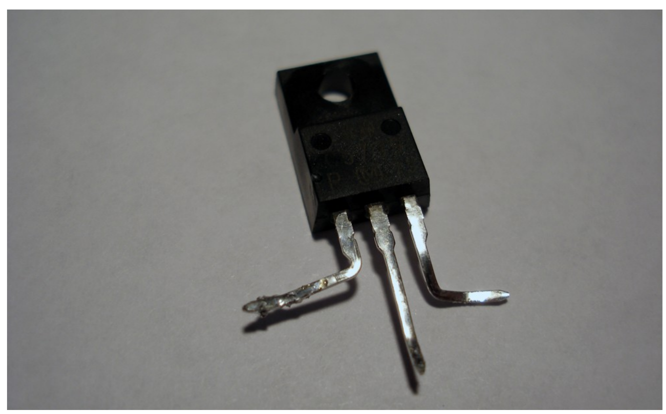


Finally, clip the excess lead length.



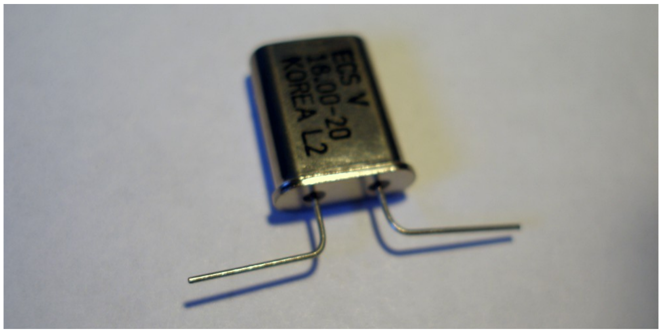
TO-220 Transistors

The PA transistor is in a plastic TO-220 case (it's actually called a TO-220D). When looking at the case in the orientation where you can read the markings, the leads from left to right are base, collector, and emitter. We need to form the base and collector leads to go to pads, while the emitter lead goes to ground. The case will lay flat on the copper clad in the way shown below. Place a 90° bend in the base lead and then bend the end of the lead down a bit to reach the level of the pad. The collector lead just needs to be bent down slightly to also reach the level of the pad. The emitter lead can be bent down to the level of the ground plane, then bent 90° to provide a convenient solder point.

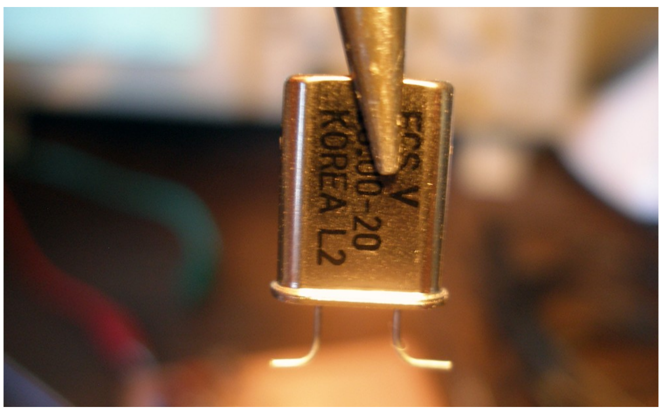


Crystals and Other Devices

You will have a few miscellaneous two-terminal devices to install, such as a crystal and ceramic resonator. These are very easy to prepare. Just bend the leads 90° away from the body in the way shown below. If you are unsure of the way the leads are formed, consult the layout diagram.



Trim off the excess lead length.



Pre-Build Procedures

Diode Matching

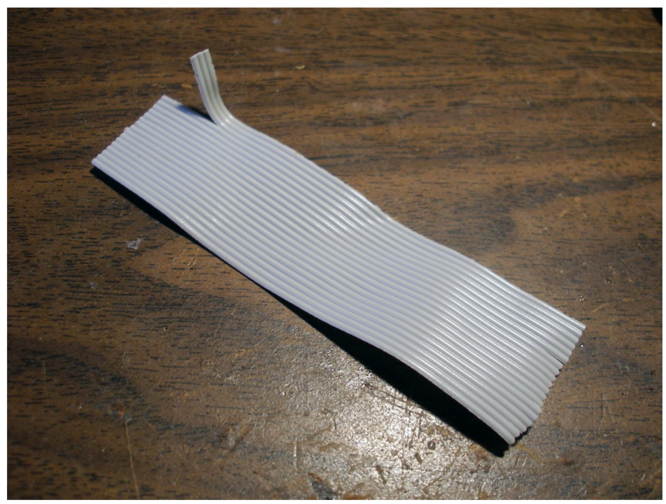
In order to get the best performance from our receiver mixer, we need to find a set of 1N4148 diodes with closest forward voltage characteristics. The easiest way to do this is to use the diode tester on your multimeter, if you have one. Gather together all of your 1N4148 diodes and measure forward voltage of each one with the diode tester setting. I've found an easy way to track each diode is to get a blank sheet of printer paper and poke one lead of the diode into the paper after it is tested. You can then write the forward voltage next to the diode.

If you don't have a diode tester function on your multimeter, you'll just have to improvise a little. Get a 10 kΩ resistor and a breadboard. Connect one terminal of the 10 kΩ resistor to +12 VDC. Connect the anode of the diode under test to the other terminal of the resistor. Finally connect the cathode of the diode to ground. Apply power to the circuit and measure the voltage drop across the resistor with your multimeter. Repeat the process for all of the 1N4148 diodes in the kit.

Once you have measured all of the diodes, set aside four of the diodes with the closest forward voltage measurements. These will be used in the receiver mixer as diodes D7-D10. Optionally, you can also pick out the next best four diodes for the mixer in the heterodyne VFO (D2-D5).

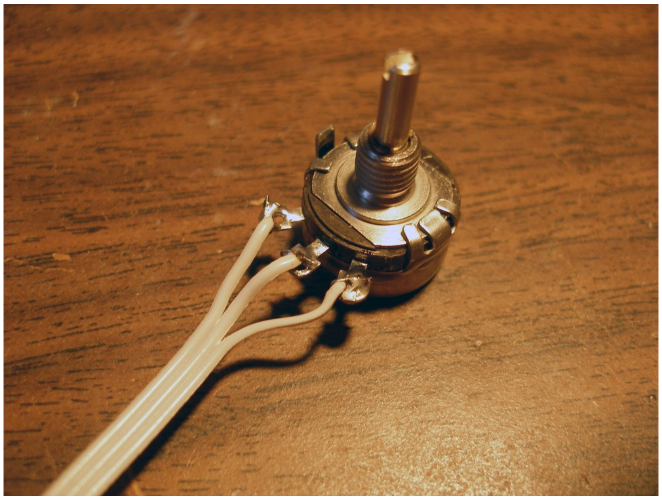
Preparing Potentiometers and Jacks

Included in the kit is a length of ribbon cable which will be used as leads for the potentiometers and jacks used in the kit. Take your hobby knife and trim the number of conductors needed from the ribbon cable (two for jacks and three for potentiometers).



Split off about 1” of the individual conductors on each end of the cable using the hobby knife.

Strip and tin the individual leads, then solder one end of your cable to the device.



Preparing Copper Clad

When building a Manhattan circuit, you'll want to trim the copper clad substrate to the correct size before you start building. The copper clad provided with the kit will already be cut to size, so you may not need to worry about this step. If you do need to cut your copper clad, there are many different options. The ultimate way is to use a shear, but many of us don't have access to a metal shop. I've found that a good substitute is to use a pair of aviation tin snips. Just use a combination square and Sharpie to mark your cuts, and the tin snips will cut the copper clad with no problems. They may warp the material a bit, but it is easily bent back into shape.

Next you will want to clean and prepare the surface. Use a Scotch Brite pad and water to scrub both sides of the copper clad so that it is clean and free of oxidation. Be sure to handle the board by the edges so that you don't get greasy fingerprints on the board while you are cleaning or when you are done. Dry off the board with some paper towels.

Finally, the board will need to be protected from further oxidation and contamination. I like to use acrylic lacquer in a spray can for this purpose. Apply a few coats of the lacquer to one side of the board in a well ventilated area and allow it to dry for about an hour. You can then spray the other side of the board as you did the first side. It's best to allow the lacquer a good 12 hours or so to dry before working on the board, but I have been known to get impatient and start working on the board after a few hours. Be aware that if you do this, you might have some melting lacquer on your hands and workbench after you start applying the soldering iron!