

## CRYSTAL SETS TO SIDEBAND

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## Chapter 15

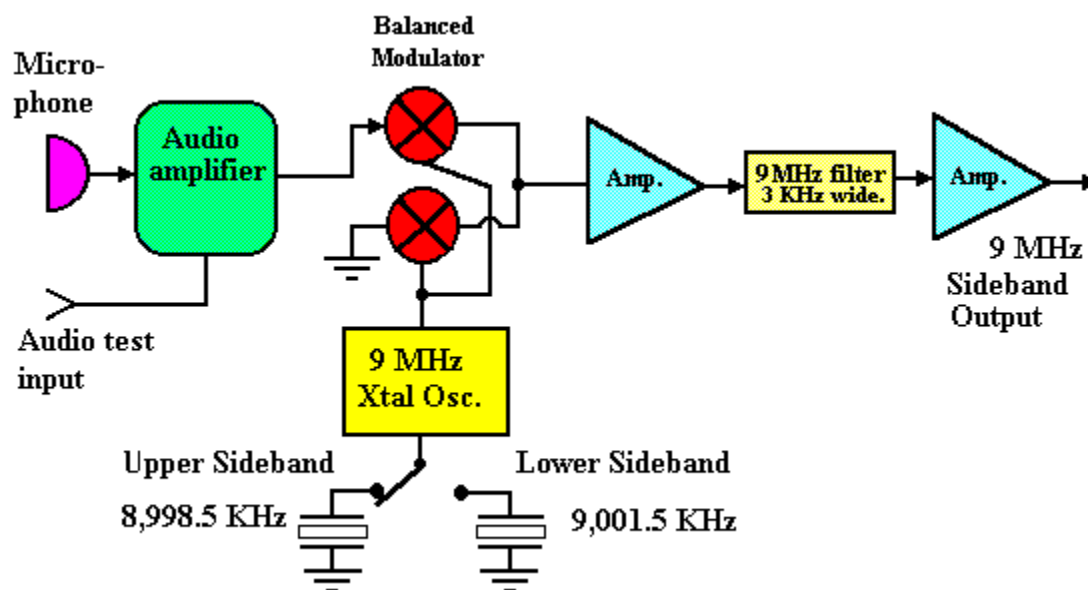
# THE NOBEL PRIZE FOR SIDEBAND

### How sideband works

In the beginning of the book I mentioned that Glenn Johnson, WØFQK, was a school principal who made a project out of recruiting kids into ham radio. We were in the 8<sup>th</sup> grade walking down the street minding our own business when Glenn ran out of his house and grabbed us. “Come on in boys and I’ll show you how sideband works!” Glenn’s wife served milk and cookies while Glenn worked bunches of guys on 20 meter sideband phone. I sat quietly and watched while Glenn effortlessly operated massive equipment that cost enough to buy a car. I was fascinated by ham radio, but I didn’t learn much about how sideband worked. I had the impression that sideband was *MODULATION FOR MILLIONAIRES* and too complicated to homebrew. The 1957 ARRL handbook’s opaque descriptions of “phase shifters” and “balanced modulators” only confirmed my opinion.

Today SSB is affordable, but the technology is still exotic to the average ham. I overheard a conversation at my local ham club meeting that went something like this: “I once knew a guy who built his own sideband rig.” “*REALLY!* That’s amazing. Are you sure it wasn’t a kit?” The implication was that homebrewing sideband was about the same level as a Nobel Prize in physics. So, is anyone interested in the Nobel Prize for Sideband? If you’ve already built homebrew QRP’s, VFO’s, and a receiver, then sideband is the next logical project. SSB uses all the same basic circuits. Besides, you won’t really understand sideband until you’ve built one.

### You begin with the sideband generator



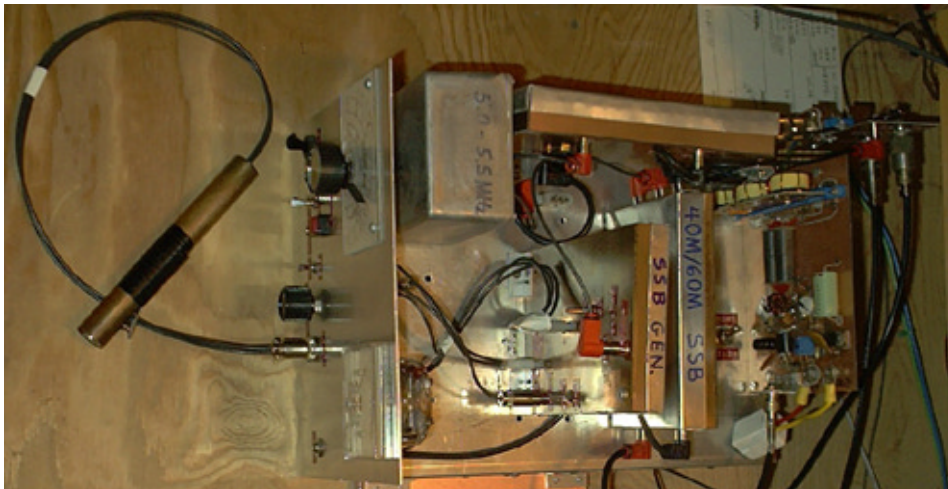
## 2. Chapter 15, Harris

There are different ways of generating an RF sideband phone signal, but the most straight-forward one I've seen is outlined above. The block diagram shows the five circuit blocks needed to generate a sideband signal on 9.000 MHz. This generator is similar to one found in the 1986 ARRL handbook. After the 9 MHz SSB signal has been generated, it must be moved to the desired ham band using a mixer and a high frequency VFO of the correct frequency range.

The circuits you've used in previous chapters are the audio amplifier, the crystal filter, the RF oscillator/ amplifier, and the conversion modules to move the VFO signal to ham bands. The audio amplifier design is similar to the one in the homebrew receiver in chapter 13. The 9 MHz RF oscillator/ amplifier uses the same technology used in the QRP described in chapter 6. In theory, the VFO could be the VFO signal from your receiver. When I started this project, I figured if the sideband generator didn't work, I would at least have a CW signal that was slaved to my receiver so that it would be easier to zero-beat my signal with the guy I was trying to talk to. Unfortunately, that goal turned out to be harder than it looked.

### **Don't burn your bridges**

If you're thinking about modifying a working CW transmitter to sideband, I don't recommend it. If you already have a working QRP driver based on chapters 6 or 11 from this book, those designs are full of tuned amplifiers and mixers. Tuned amplifiers tend to self-oscillate when used for sideband. To have a good chance of working, every gain stage should be converted to broadband. If you convert your old transmitter, you are likely to have months of struggle in which you aren't on the air at all. Start from scratch! Don't ruin a rig that works!

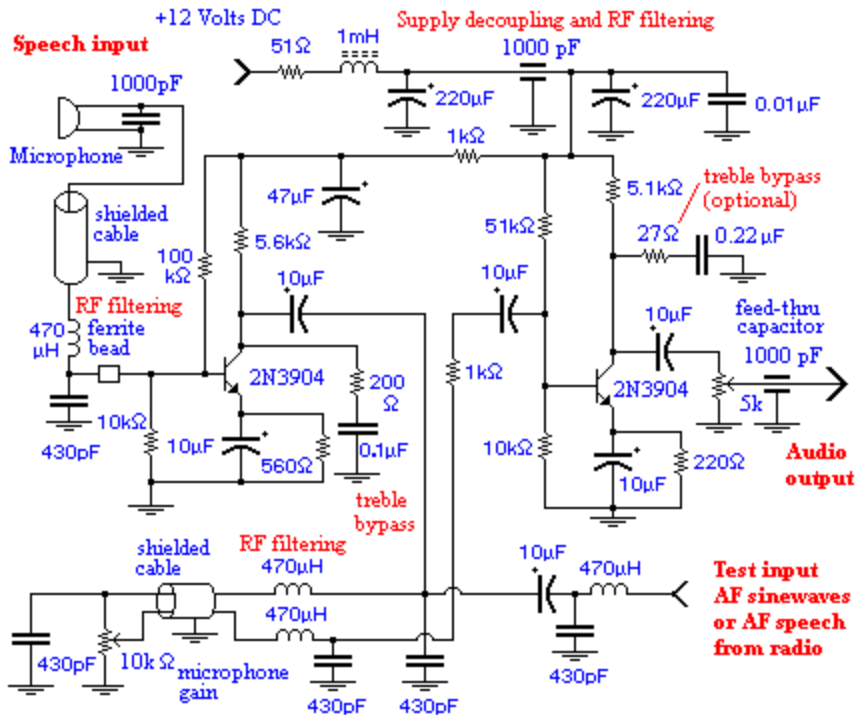


Homebuilt SSB transmitter

### **How sideband really works**

Ordinary broadcast band AM modulation transmits three separate signals. These are the carrier signal and two sidebands of speech modulation. Single sideband begins with AM, but a cancellation process removes the carrier leaving a double sideband signal (DSB). Next one of the two sidebands is filtered out with a crystal filter. Let's begin with the crystal oscillator:

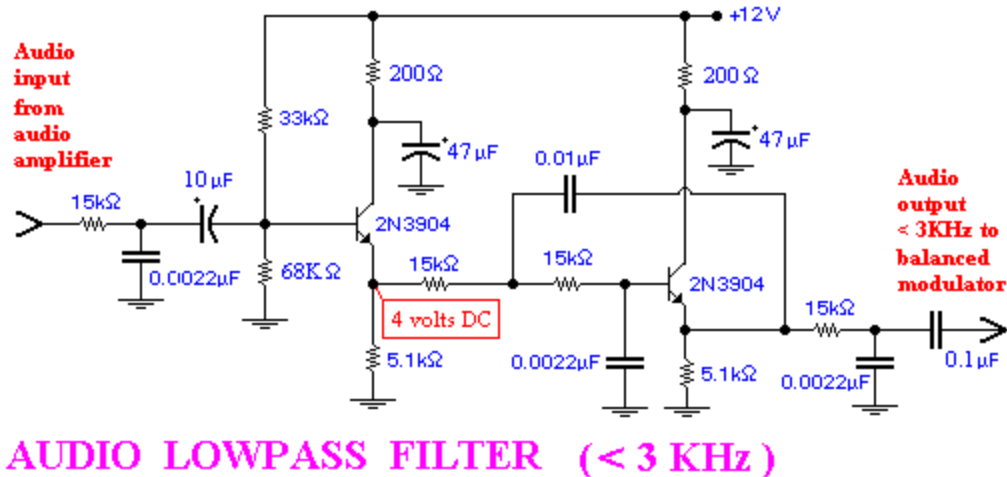




An audio amplifier with test input

The microphone needs a high gain audio frequency (AF) amplifier before it can drive the balanced modulator. The audio amplifier is pretty routine except that heroic effort is needed to shield it from RF. Notice the RF chokes and bypass capacitors on the two audio inputs, the audio gain pot and the 12 volt power input. Because crystal mikes have a puny output, it took me two stages to get the signal up to roughly 5 volts peak. My crystal microphone exaggerated the high frequencies, so I attenuated the high frequencies with series RC *treble filters* on the collectors of both amplifier stages. You may be tempted to add another stage of audio gain. Don't! It's much better to run the audio gain wide open than to have extra gain and keep the gain turned low. Surplus gain just invites noise and sensitivity to RF feedback. If you like, you can replace most of this circuit with an IC, but as always, building your own amplifier with discrete parts will be more educational.

After you get the amplifier working, look at the audio waveform critically. You may find that the negative and positive voice peaks are not symmetrical. If this is the case, you may have too much or too little forward bias on the second stage. That is, you may want to increase or decrease the resistance of the 51 K ohm resistor biasing the second 2N3904. Ideally, the amplifier should be able to deliver a 10 volt peak-to-peak symmetrical signal.



I added the *Butterworth* filter shown above to be sure the bandwidth of my final signal would be less than 3 KHz. Like the treble filters discussed earlier, your generator may not need this. The Butterworth sharply cuts off practically all audio signals higher than 3 KHz. In contrast, the treble filters will just emphasize the lower frequencies. The filter uses two transistor amplifiers wired in the *emitter follower* configuration. Notice that the load resistor (5.1K  $\Omega$ ) for each transistor is wired between the emitter and ground, rather than between the collector and the positive supply.

### The advantages of emitter followers

Emitter followers have the advantages that the input impedance is extremely high and the output impedance is very low. High input impedance means they will not load down or affect the input signal strength. Low output impedance means they deliver big currents into low resistance loads. Another feature of the emitter follower is that *the voltage gain is less than unity*. That is, they don't amplify voltage. This is an advantage here because it insures that the amplifier will not oscillate. Butterworth filters are usually implemented with operational amplifiers. Until this filter, I had never built a Butterworth with transistors. Yes, simple transistors work too.

No matter what audio amplifier circuit you use, it will be sensitive to RF interference from any strong RF signal in your radio shack. For example, if you are using a simple antenna coupler with no shielding like mine, those RF signals will tend to feedback into your microphone cable. To prevent this I added RF chokes, bypass capacitors, and a ferrite bead in series with the microphone input. Since my microphone gain pot is remote from the audio module, the shielded wires to the pot are also filtered with RF chokes and bypass capacitors. Even the output from the amplifier passes through a capacitive feed-through (bypass) capacitor on its way to the balanced modulator.

### The 0.1 $\mu$ F audio output capacitor

Notice that the output from the filter circuit is not the usual big 10  $\mu$ F capacitor but is only a 0.1  $\mu$ F cap. This cap goes to the audio input of the balanced modulator. If you use a larger capacitor here, the capacitor will take time to charge when the transmitter is first keyed and power is applied to the audio amplifier. A big cap would take two seconds or so to charge and

would cause the balanced modulator to turn on causing a brief, shrieking whistle to go out over the air. The input resistance to the balanced modulator is very high, about 100,000 ohms. Therefore, the time constant of 100K ohms times 0.1  $\mu$ F is about 0.01 second. This allows for 100 Hz audio and is plenty Hi-Fi for SSB ham work.

### **Decoupling for the power supply lead**

The 12 volt power supply lead for the audio amplifier also has a large RF choke (one millihenry) in series with the lead and passes through another feed-through capacitor bypass. In addition, the power supply lead is isolated or *decoupled* by means of the 51 ohm resistor and the large 220 microfarad bypass capacitors. The purpose of these capacitors is to insure that the voltage supplied to the amplifier cannot change as fast as the audio signals. All of the modules in an SSB transmitter, except the final amplifier, need to be decoupled from changes in the 12 volt supply level. Otherwise, as you talk into the microphone, the current drawn by the high power final varies rapidly and the voltage delivered to each module will rise and fall in time with the speech. Because the voltage is rising and falling, the RF output from each module will rise and fall too. This feedback produces surges in the radio signal that sound like noise superimposed on the speech. In fact, it makes nearly the same buzzing roar as RF interference.

The final amplifier draws too much current for it to be practical to decouple the 50 watt linear amplifier supply lead. In fact, it is the big 10-ampere surges of current drawn by the final that cause the noise in the rest of the transmitter. In general, the less current drawn by a circuit block, the more extreme the decoupling must be. For example, the audio amplifier has a series 51 ohm resistor and 440 microfarads bypass. In contrast the 5 watt RF driver stage has only a one ohm resistor and a 0.1 microfarad capacitor.

### **Microphones are important**

Not all microphones are equal. I tried three different crystal microphones. Two small Radio Shack microphone cartridges gave a “tinny” sound. I was able to compensate with RC bypass networks on the collectors of all three transistors to limit the high frequency components (treble) of the speech. For example, notice the 200 ohm resistor and 0.1  $\mu$ fd capacitor combinations going to ground from the first two transistor collectors. I also tried a 40 year old Hallicrafters crystal microphone designed for mobile radio. It worked fine without the RC bypasses. Next I tried two tiny condenser-type electret microphones. One was too “basey” and made a low frequency hum. The other, a Radio Shack PN # 270-092A, worked perfectly. To bias the electret with about 4 volts, I used a 3.9K resistor in series with a 7.5K resistor to step down the 12 volt supply.

When I finally had a working SSB generator, I was able to use either my ancient Hallicrafters mike or a homebrew mike built around the Radio Shack electret. To shield the electret I mounted it in a length of 3/4 inch copper pipe. I soldered copper disks (PC board) to the top and bottom of the pipe section so that the microphone would be well shielded. The electret is force-fit into a snug hole at the top of the pipe. I put a 1000 pF capacitor across the microphone to further reduce RF interference. The electret is connected to the transmitter by two short pieces of RG-174 coax: one for the audio signal and the other coax for the 4 volt DC supply line for the electret. Keep the microphone cord(s) as short as practical. A long cord invites RF interference.



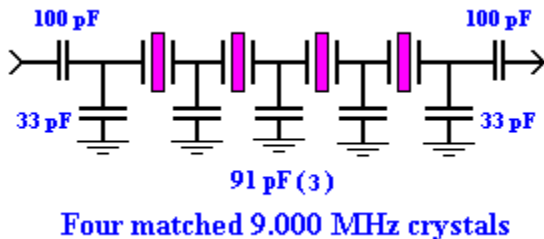


use transistors without any P-N diode junctions. According to the handbook, P-N junctions act like varactors and distort the speech slightly. I used dual gate MOSFETs simply because they were the only small RF MOSFET available. Single gate small RF MOSFETs are fine, but you may not be able to find any. I haven't tried JFETs, but they might work too. The above circuit was adapted from the 1986 Handbook.

To use this modulator for CW, there is a CW/SSB switch that unbalances the modulator and allows some carrier to pass through to the filter. Notice that when the switch is in the SSB position 12 volt power is fed to the microphone audio amplifier, thereby turning it on. When the switch is in the CW mode, pure CW carrier is sent to the filter. Unfortunately, this CW signal will be hard to use for actual CW contacts because the crystal filter will tend to remove most of the carrier again. However, this small 9 MHz sinewave is useful for tuning an antenna with a "test signal" or for "spotting" the VFO on top of the station you wish to call. For real CW operation, you could bypass the SSB filter with another switch or you could build a separate 9 MHz oscillator.

This sideband generator can also be modified to generate amplitude modulation. This is discussed in chapter 16. You can also go on the air with double sideband, DSB. Many homebrew sideband builders take this shortcut. It will sound like sideband, but the signal will be twice as wide as single sideband.

### The sideband filter



You can buy sideband filters that select a 3 KHz passband, typically 9,000 KHz to 9,003 KHz. Sometimes matched oscillator crystals are also available that will position the RF signal optimally to line up with a particular filter.

In chapter 13 we made a 4-crystal CW receiver crystal ladder filter that was quite similar. The difference is the sizes of the accompanying shunt capacitors. In the receiver the shunt capacitors were 220 pF. However, ***The smaller the shunt capacitors, the wider the pass band of the filter.*** The 91 pF capacitor value in the above filter was scaled from a sideband filter used in a sideband transmitter designed around an 8.000 MHz SSB generator that used 100 pF caps. This filter seems to work, so I haven't had to experiment.

The homebrew way to build the filter is to buy a bunch of 9.000 MHz microprocessor crystals from Mouser or Digi-Key for less than a dollar each. Using the RF oscillator shown earlier and a frequency counter, measure the frequencies of each of your crystals. When used as filters, their natural frequencies may not be the same as in your oscillator, but their *RELATIVE* frequencies will be comparable. Pick four crystals that are as closely matched as you can. Matching within 100 Hz should be adequate. I tried tuning each crystal to the same frequency using trimmer capacitors in parallel with the crystals. This proved to be unnecessary and I later



removed the trimmers. This application is not nearly as critical as crystal filters for receiving CW in a receiver.

Using a signal generator as a test signal, these filters seem to peak very close to their nominal frequencies. For example, a crystal might oscillate at 9.0015 MHz in your test oscillator, but the filter will peak quite close to 9.000 MHz. So far I have built three of these filters and each one worked well and was centered more or less on 9.000 MHz.

### **The crystal oscillators are misaligned for CW**

The crystal filter is set up to cut off either the upper or lower sideband. When you unbalance the balanced modulator to produce a CW signal, you will indeed get a small sinewave signal through the filter that may be strong enough to tune the antenna coupler or adjust the transmitter. However, because the center of the SSB crystal filter (9.0000 MHz) is lined up 1.5 KHz away from both crystal oscillators (8.9985 MHz and 9.0015 MHz), this CW signal will be far lower than the maximum power you would get on voice peaks in SSB.

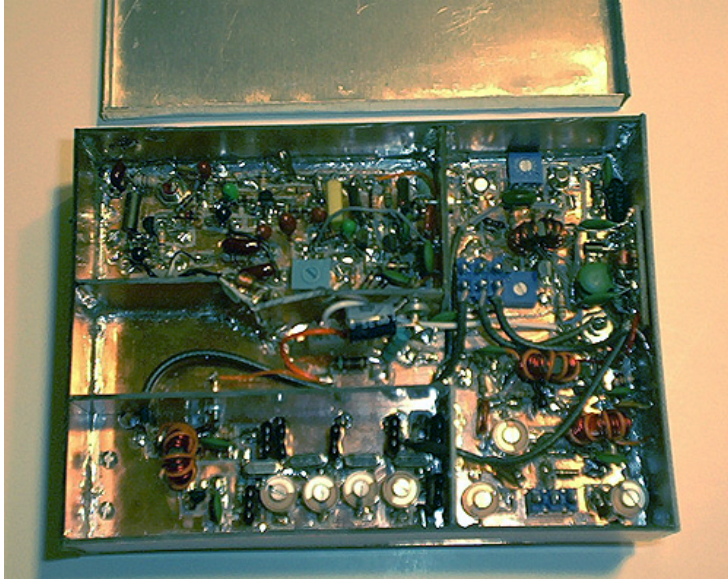
When I built a comparable filter for 8.000 MHz, the filter was centered on 7.995 MHz, 5 KHz low. I don't understand why this filter was different, because on an oscillator, the crystal frequencies were all well above 8.000 MHz. Because the filter frequency was so low, the upper sideband 8 MHz oscillator had to run on 7.9935 MHz. To drive the oscillator that low, I had to put a huge 150 pF cap across the 8.000 MHz crystal. I was amazed that the frequency locked in. Better engineering practice would dictate a custom crystal. A cheaper solution would be to start off with a different collection of cheap microprocessor crystals that center properly on 8.000 MHz.

## **MECHANICAL CONSTRUCTION**

### **Sorry! You must shield sideband.**

When building CW transmitters some of us think it's cool to have the parts out in the open where we can see them. Unfortunately a huge problem with SSB is RF feedback. To help prevent that, you must enclose all the modules of your SSB transmitter in metal. All the connections between modules should also be shielded cables. I started out using shielded power cables to my RF modules, but eventually I worked out a way to mount the Molex connectors directly to the shielded boxes. In this way I could plug the module onto the chassis with no long exposed wires.

Actually, I still leave the linear amplifier out in the breeze, but all the low power modules and the power supplies are well shielded. If I were building a new linear, I would design in a shield from the start. All my modules consist of a two-sided PC board with walls of PC board soldered onto the edges to make a box. Then I fold an aluminum cover over the top to provide the lid.



**The completed 9MHz SSB generator.** An aluminum lid fits over the top of the box.



**The 9 MHz SSB generator as seen from the control side**



**A dual frequency 9 MHz and 8 MHz SSB generator module is shown above**

After learning that 9 MHz was impractical on 17 meters, I built a new SSB dual frequency generator. The 8 MHz crystals are in a row at the top left. The 9 MHz crystals are in a row just beneath them. The two frequency oscillators are at the bottom left. The balanced modulator is at the lower right. Notice that many of the components are mounted on inch high PC board strips and soldered in vertically. This allowed me to cram in about 50 percent more components than would otherwise be possible.

A major advantage of this technique is that circuits that don't work well can easily be removed and replaced. The loose little board on the right is a low pass filter that I took out when it appeared to be unnecessary. I removed it with little or no damage to the module. As can you see, some components, especially those directly wired to controls and connectors, are mounted on the "floor" of the box. If you wish to replace the circuitry on the "floor," you can unsolder all the old components and start over with a new board that makes a "patch" over the old circuit board laying out all the circuitry on the floor of the module box in the usual way.

**Tuning and testing the sideband generator**

The essential tools for tuning up your generator are *a frequency counter, an oscilloscope, and a good ham receiver*. Ideally, you need one of those same modern receivers that will be listening to your signal. The SSB generator above can generate a sideband signal on 9 MHz. Keep in mind that when you listen to the 9 MHz signal on your ham receiver, unless your generator is well shielded, you'll still hear the carrier signal and the suppressed sideband leaking from your 9 MHz oscillator. That's because those signal components are present on your circuit board and your receiver will have little difficulty in hearing them.

To check out the generator introduce audio from a Walkman radio into the test input allowing you to align the generator. Tune the Walkman to a talk radio station and inject the audio into the test input. Speech should not only be understandable in your ham receiver, the fidelity should be good enough that you can easily recognize the person's voice. When you turn off the BFO and set up the receiver for AM modulation, speech should become unintelligible. Music should always sound awful. If music sounds pleasant, your bandwidth is too high.



The 9 MHz SSB voice signal seen on an oscilloscope.

An SSB voice signal should appear on your scope as shown above. The audio modulation is symmetrical about the zero axis. In between syllables or words, the signal strength drops to near zero. The edges of the sinewave bursts should be reasonably sharp, meaning that the frequency should remain pure with varying levels of speech. When there is no audio input, there should be essentially no RF output.

Checking out the microphone and microphone pre-amplifier can be complicated. It's hard to listen to your own voice critically. Also, the audio from the ham receiver loudspeaker will feedback into your microphone. My solution was to put the microphone up against a high fidelity Walkman headset. Then I wrapped the headset in cloth to muffle the sound. To hear how it sounded on the air, I listened to the sideband generator signal in the ham receiver using headphones. Unfortunately, when used with the 50 watt amplifier, the RF from the dummy load and transmatch interfered with the Walkman so this technique only worked well for 5 watts. I was able to partly test the 50 watt linear by listening to my own voice while wearing headphones with no receiver antenna plugged in. I could at least confirm that there was no RF feedback.

### **Audio signal generator testing**

It is instructive to feed an audio tone from an audio oscillator into audio input jack. As you sweep the audio spectrum from 20 Hz to 3 KHz, watch the sideband generator RF output on the oscilloscope. Unlike AM modulation, there should be no audio frequency modulation visible on the radio signal. That is, for each audio sinewave frequency you should see a pure, CW-like signal. Another way to think about single sideband is that it is a kind of extremely narrow-band frequency modulation. As the audio frequency changes, the signal frequency shifts up and down in direct proportion. Unlike AM modulation, the amplitude of the transmitted signal shouldn't change when you introduce a constant amplitude audio frequency. That is, with SSB, you shouldn't see ripples on the signal amplitude proportional to the frequency. The amplitude should only change with speech amplitude, not with speech frequency. In contrast, pure FM modulation does not change its amplitude with speech amplitude or with audio frequency.

### **Suppressing power supply RF feedback and low frequency coupling**

My first sideband contact said, “Sorry, old man! I hear some hissing noises, but I can’t understand a word you’re saying.” It turned out that the power supply leads in the generator and other modules in the transmitter needed low frequency decoupling. In the sideband generator this consisted of the 51 ohm resistor and the two 220 microfarad caps on the 12 volt line. Without decoupling, the audio turns into noise as the generator competes with the final amplifier(s) for operating voltage. That is, the 12 volt supply voltage surges up and down with the speech and the amplifiers exaggerate this.

After these improvements my next contact could understand me, but he said my voice was “raspy with popping sounds.” I didn’t have laryngitis, so I asked Jack Quinn, KØHEH, about the criticism. He instantly diagnosed the problem: “That’s RF feedback. Improve the shielding of your microphone and audio amplifier.” I placed the 1000 pF capacitor directly across the microphone, the 430 pF bypass capacitors and the 470 microhenry inductors in series with the inputs and power line. Also, the power and audio output pass through feedthrough capacitors to further attenuate the RF. When RF feedback is really bad, the signal turns into a roar of noise that can sound similar to low frequency power supply decoupling problems.

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## The Hard Part --- Moving the SSB signal to a hamband

### Is 9 MHz a hamband?

To get on the air you need to amplify the 9 MHz sideband signal up to 50 or more watts. Unfortunately, the last I heard, 9 MHz isn’t a hamband. The hardest part of this project turns out to be moving the 9 MHz signal to the band(s) of your choice. Alternatively, we could all write to the WARC to ask them to establish a little 3 KHz hamband centered on 9.000 MHz. Maybe not.

Although moving the SSB to a hamband is the most difficult part of sideband, maybe it won’t be so bad if you don’t make the mistakes I did. Six principles I learned the hard way were:

\* *Move your sideband signal only once.* Double conversion might appear convenient, but it’s extremely hard to do without distortion. In other words, don’t do the hardest task twice.

\* *In the conversion between 9 MHz and your HF band, make sure that the mixer input frequencies are far away from the final frequency.* For example, to get on 20 meters, it is practical to add a 5 MHz VFO to 9 MHz to get 14 MHz. On the other hand I found that it was impractical to move a 4 MHz sideband signal to 21 MHz using a 25 MHz crystal oscillator. Every time I stopped talking, a significant 25 MHz signal went right out through the transmitter output filters.

\* *Plan your VFO and sideband frequencies so they do not divide evenly into the desired ham band frequency evenly.* For example, 2 times 9 MHz is 18 MHz. This fact makes using a 9 MHz SSB generator and/or a 9 MHz VFO to generate 17 meters extremely difficult. Notice that 6 MHz is also difficult because 3 times 6 MHz = 18 MHz.

\* *Don’t use tuned amplifiers and mixers.* When you stop talking, tuned amplifiers tend to oscillate by themselves at the frequencies to which they were tuned. Actually, getting rid of the noise and oscillations when you’re *NOT* talking is harder than making the speech intelligible. Unlike CW, it is best to use broadband mixers and amplifiers and to put all your ham band filtering into two passive filter networks. Sideband is different from CW!

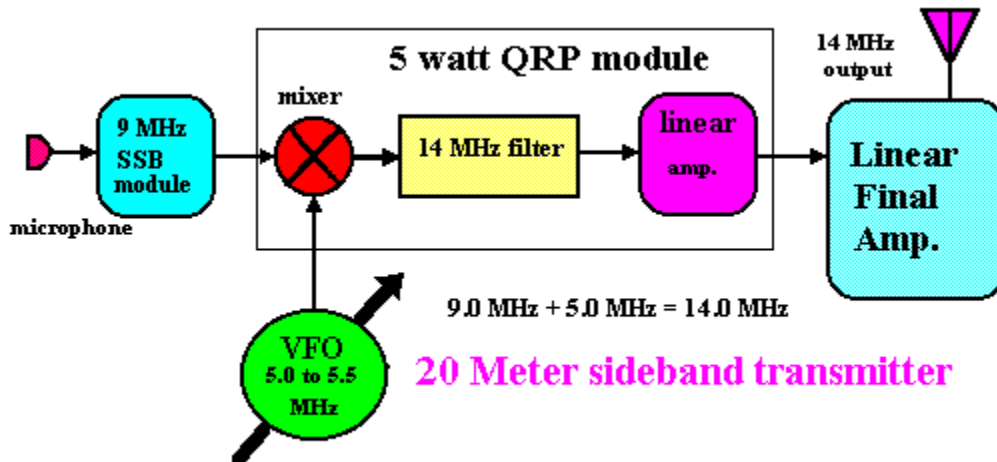


\* *Beware of having too much gain in your SSB generator and frequency converter.* I originally had extra broadband amplifiers in the generator output and also right after the converter mixer. These extra amplifiers amplified noise. Every time I wasn't talking, they often began to self-oscillate.

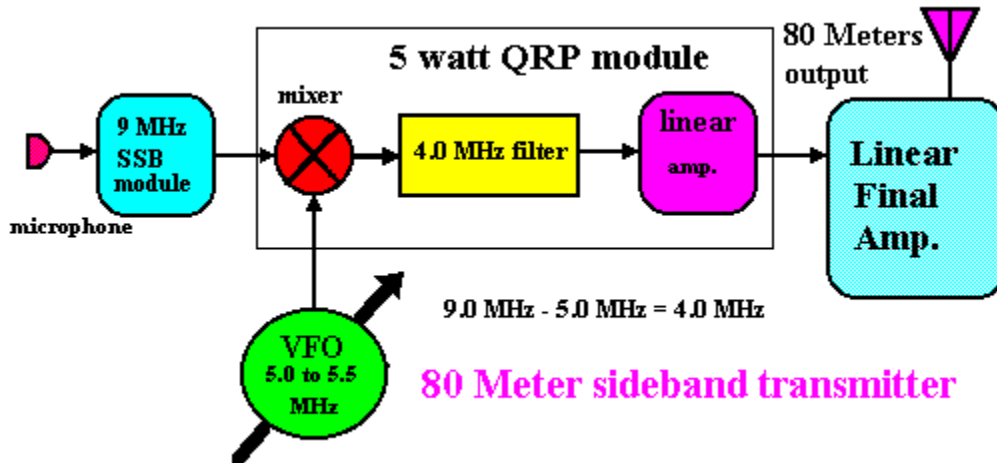
\* *It sometimes helps to connect all ground connections to the outside layer of your two-sided PC board.* The ground connections for all high current RF stages must be extremely low inductance. Otherwise, if your board layout isn't well designed, RF voltages on all the ground traces inside the PC board box will "bounce up and down" with the currents in the power amplifier stages. This feedback introduces noise into the mixer stage and makes the QRP module difficult or impossible to adjust. If you are using 2-sided PC boards, solid grounds can be added by drilling the PC board at each ground connection and soldering wire shunts through the board to the unbroken sheet of grounded copper outside the PC board.

## Getting on 20 and 80 meters

### Hetrodyne converter for the SSB generator



When starting with a 9 MHz sideband signal, 20 meters is the easiest hamband to reach. For 20 meters, a 5.00 to 5.35 MHz VFO signal is mixed with 9 MHz to give 14.0 to 14.35 MHz. 9 MHz is 36% different from 14 MHz. Consequently, building a filter to extract the 20 meter component and suppress the 9 MHz signal is relatively easy.



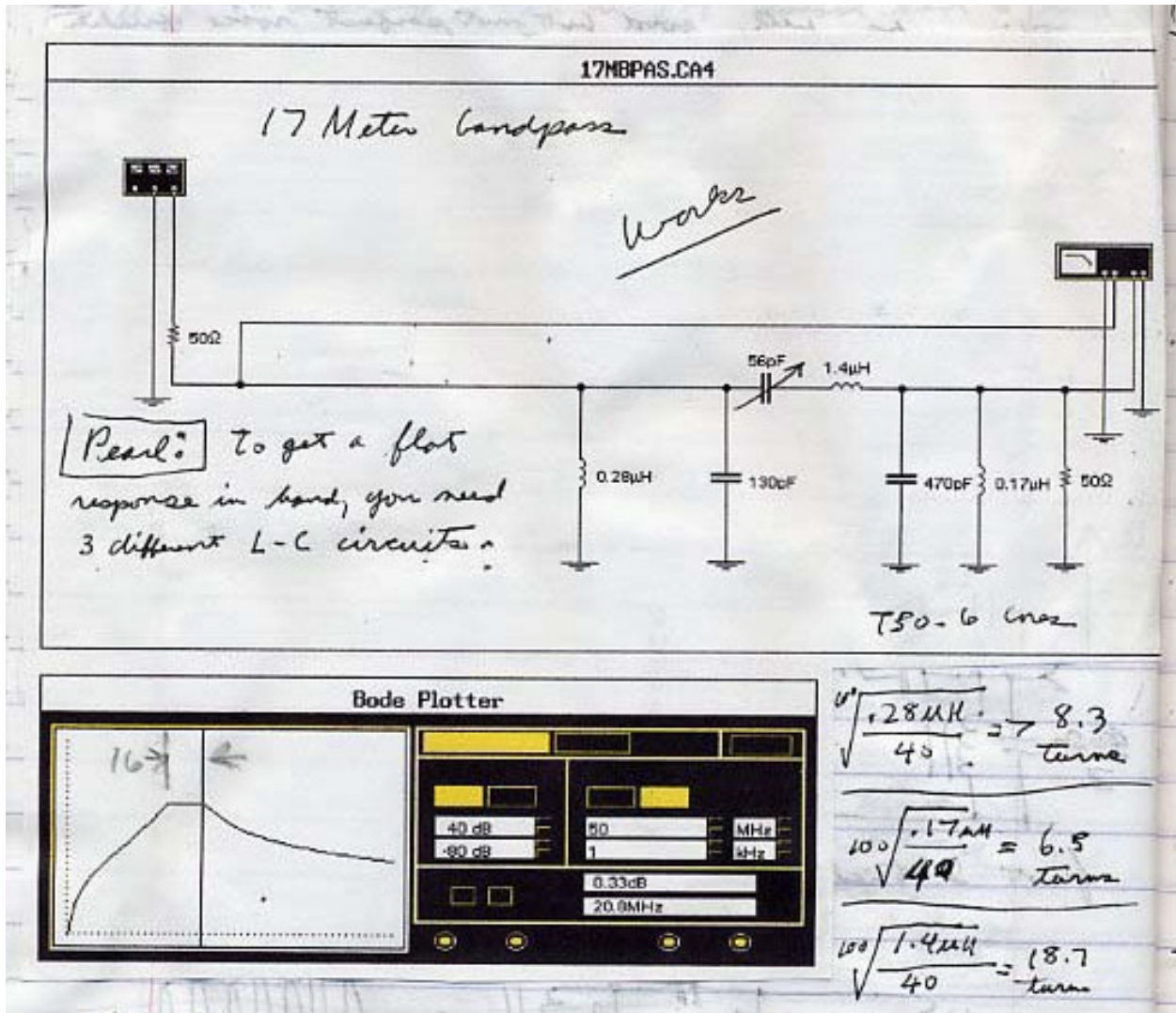
Now suppose that you wish to move the 9 MHz sideband signal down to 80 meters. 9 MHz minus 5 MHz is 4.0 MHz. The phone band extends right up to 4.0 MHz. So the 80 meter (75-meter) output signal can be as little as 20% different from the VFO signal. Filtering the 80-meter signal is almost twice as hard as 20 meters. What happens if your filtering is inadequate? Every time you stop talking, your linear final amplifier will be transmitting a sinewave carrier on your VFO frequency, 5 MHz. As we'll see, when you start with a 9 MHz sideband signal, all the other HF bands are harder than 20 meters.

### Spice will make filter design bearable

I found my Spice program essential for simulating filters before I built them. I use a rather elderly program called Electronics Workbench, version 4. If I had had to calculate the component values or build all the filters by trial and error using real components, this project would have completely stalled. Using the program I could enter a possible filter design with trial values. When I ran the simulation, it plotted the frequency response instantly. It would inevitably be way off from what I had intended. But I then I could quickly plug in dozens of values until I got the response I wanted. I get discouraged just thinking about building and testing those filters the old way and plotting the results at each frequency with real components.

Below is a copy of a page from my notebook showing one of the most difficult filters I built. It was a low impedance band pass for 17 meters. After it looked right on the computer, I built a real one and it tuned up immediately using the variable cap in the center. The simulations are amazingly trustworthy. I found that when the simulation predicted small capacitor values, it was wise to use a variable capacitor in that location. If the capacitance or inductance came out extremely small, for example, a few picofarads or hundredths of a microhenry, I changed the design until all the components had significant values. Once I had a design on paper, I built the real filter and tested it using a frequency generator and scope to confirm that it really behaved as simulated.





### Self-oscillation

When you build a high-Q amplifier-filter stage, it tends to oscillate on its own whenever there is no signal coming into the input. This means that, in between words, your QRP module may be oscillating on some random frequency on or near the ham band you are using. Sometimes this oscillation can be suppressed by placing a 50 or 100 ohm resistor across the input of the offending stage. Another method is to place a 1K to 2K resistor across the RF transformer primary on the collector or you may add a small resistance (such as 10 or 20 ohms) of un-bypassed resistor in series with the emitter of the transistor. Unfortunately, these tricks are usually not enough. **The best solution is to use untuned broadband amplifiers!** Even with broadband amplifiers, you will still have to use some or most of these tricks to keep them from oscillating.

### No wonder most rigs are transceivers

There is a great deal of similarity between a sideband receiver and a sideband transmitter. Once you've built a receiver, it dawns on you that the transmitter has most of the same modules and that you are building the same circuits twice. On the other hand, using the same circuit

modules for both tasks takes finesse. Unfortunately we homebrewers have enough problems without that extra complexity.

Ideally, it would be best to use the 5.0 MHz VFO from your receiver. That way the transmitter frequency and receiver frequency can zero beat exactly. When you answer a CQ, you don't want to take the time to tune the transmitter VFO. When I got on the air with my separate 5 MHz VFO, I found that, by the time I had it precisely zero beat with the guy calling CQ, he was often already talking to somebody else.

Unfortunately, using the receiver VFO isn't simple. If you simply connect it to the transmitter by a long cable, the receiver will suddenly acquire intermodulation, noise, and whistles. To get past this, the VFO signal must be isolated from the receiver by an isolation amplifier. Also, the 9.000 MHz BFO and the sideband generator oscillator must be on the exact same frequencies. Furthermore, the VFO band conversion oscillators in the receiver and transmitter must be aligned to within a Hz or two. Hmmm ... this isn't so easy after all. The transceivers solve the problem by using the same oscillators for all those tasks so alignment isn't a problem. I believe a homebrewer can enjoy all the convenience of a transceiver, but only if we design the transceiver from scratch. It seems to be impractical to merge your SSB transmitter with an existing receiver.

### **An 80 meter sideband QRP driver**

As explained above, an untuned mixer should be followed by a *totally passive filter*. That is, the filter should be just a network of LC circuits. It should have no transistors. Instead, the gain is provided by two or *three untuned stages in series*. Three high-gain broadband amplifiers in series can work without oscillating, provided that their input has very little noise. The basic design shown below has the advantage that, it can be used on any HF band. To change bands, you plug in different filter sections shown in the green boxes below.

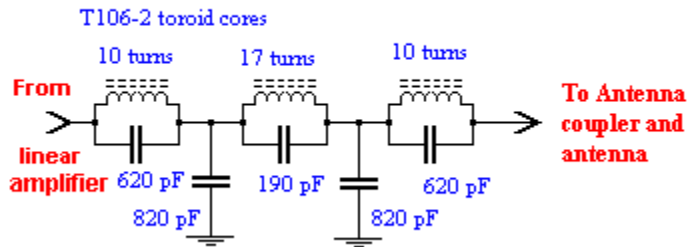


the equivalent of five parallel and series LC circuits were used to clean up the 80 meter signal. In contrast, as you'll see on the next page, a 20 meter QRP (5 MHz + 9 MHz) can be done with just two LC circuits and an output high pass filter.

### Beware of residual VFO signal

Once I had the 80 meter driver working well, I fed it into my linear amplifier described in Chapter 12. With the amplifier it produced 60 to 100 watts on voice peaks. However, whenever I stopped talking, the frequency counter probe on my antenna shifted to the 5 MHz VFO frequency, even though the amplitude of the signal on the scope screen looked negligible. When I turned up the scope amplitude, sure enough, there was a 5 volts peak sinewave on the output. That represented about 0.25 watts of 5 MHz sinewave. To get rid of it, I rebuilt the final amplifier 80 meter low pass output filter using another “elliptical” filter design. Notice that each inductor has a parallel capacitance that resonates at 5 MHz and keeps the 5 MHz out of the antenna. I used the values shown below. After that change the residual, no-speech signal was only 1 volt peak and the counter measured it as the correct output frequency, 3.9 MHz.

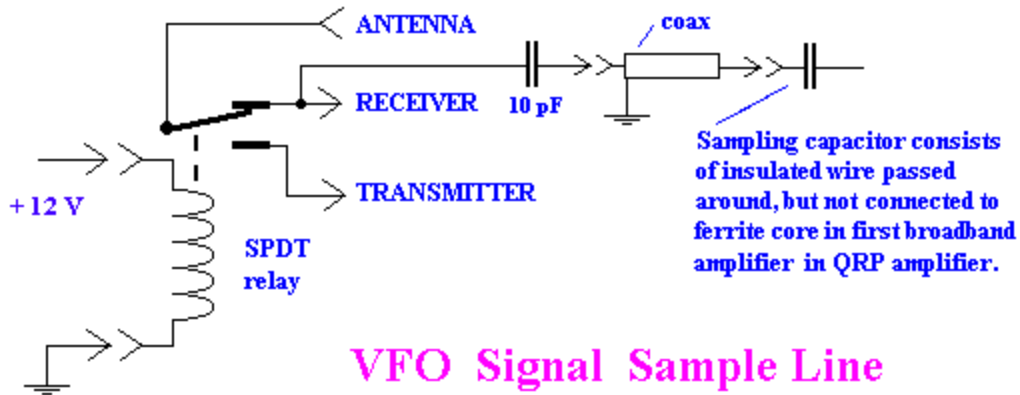
### 80 Meter lowpass Elliptical Filter for Linear



If you are like me, you will have a devil of a time getting your SSB drivers to produce intelligible speech without hissing and noise problems. All I can tell you is to keep your brain mulling over your difficulties. Shield and filter your prototype until the darn thing works. Keep careful notes so you don't make the same mistakes twice. Persistence will win in the end.

### Hearing the transmitter VFO in your receiver

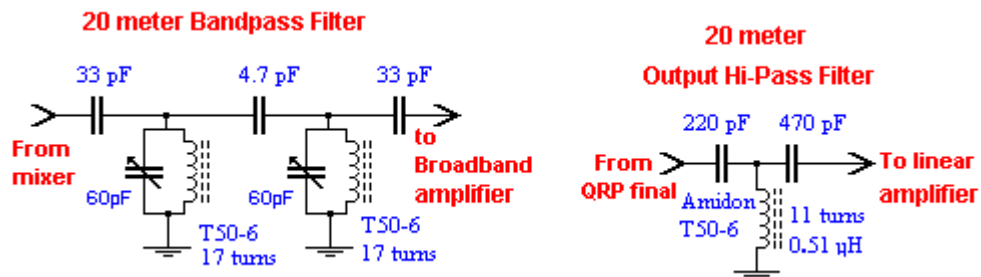
One consequence of shielding and filtering every low power module of my SSB transmitter was that I could not hear my own VFO signal. This made it impossible to tune the VFO to a station I might wish to talk to. Eventually I solved the problem by connecting a tiny capacitor, 10 pF, to the receiver antenna terminal on the antenna relay. This capacitor is connected to a shielded cable that runs over to my QRP module and plugs into a shielded phono connector on the side. Inside the QRP module an open-ended wire runs over to the first of the three broadband amplifiers (not the mixer) and passes one turn through the ferrite toroid core. This sampler wire is not a complete winding turn. It is *NOT* connected to ground or anywhere else. The wire just serves as a tiny capacitor or antenna to sample a bit of VFO signal for the receiver. During transmit the antenna relay disconnects the sampler wire from the transmitter to prevent it from causing feedback from the antenna into the transmitter.



When I push the "Spot" button on my transmitter, 12 volts power is connected to all the low power modules of the transmitter. During "Spot" mode, the 12 volt power is *NOT* connected to the last two power amplifier stages of the QRP. The 12 volts goes to the 5 MHz VFO, the SSB generator, the VFO frequency converter (if one is used on that particular band), the mixer, and first broadband amplifier of the SSB QRP module. The first amplifier is the first place in the transmitter where the actual broadcast frequency is present for sampling. Because the final frequency depends on the 9 MHz signal from the SSB generator, there will be no signal from the SSB generator unless you are actually talking or the generator is set to "CW." In summary, to hear the VFO without transmitting, the SSB generator must be set to "CW," the "Spot" button must be pushed, and the receiver antenna needs a tiny capacitive coupling to the first broadband amplifier. In SSB, even simple things are complicated.

### Adding 20 meter capability to the 80 meter QRP module

In the 80 meter module above there are two filter networks. You can put the QRP module on 20 meters by switching in a 14 MHz filter after the mixer and by replacing the low pass on the output with a high pass filter. On 80 meters the 9 MHz and 5 MHz problem signals are above 4 MHz. Therefore, the 80 meter QRP module has a low pass filter. In contrast, on 20 meters the unwanted frequency components are below 14 MHz. Therefore, a high pass is desirable for 14 MHz. The filters to put the module on 20 meters are shown below. My module uses two DPDT switches to switch back and forth between the 80- and 20 meter bands.



### Feedback and distortion – don't overdrive!

A frequent problem I ran into was using too much drive on a stage. For example, I built my prototype for 20 and 80 meters. And after many changes and fussing I got it to work. Then I

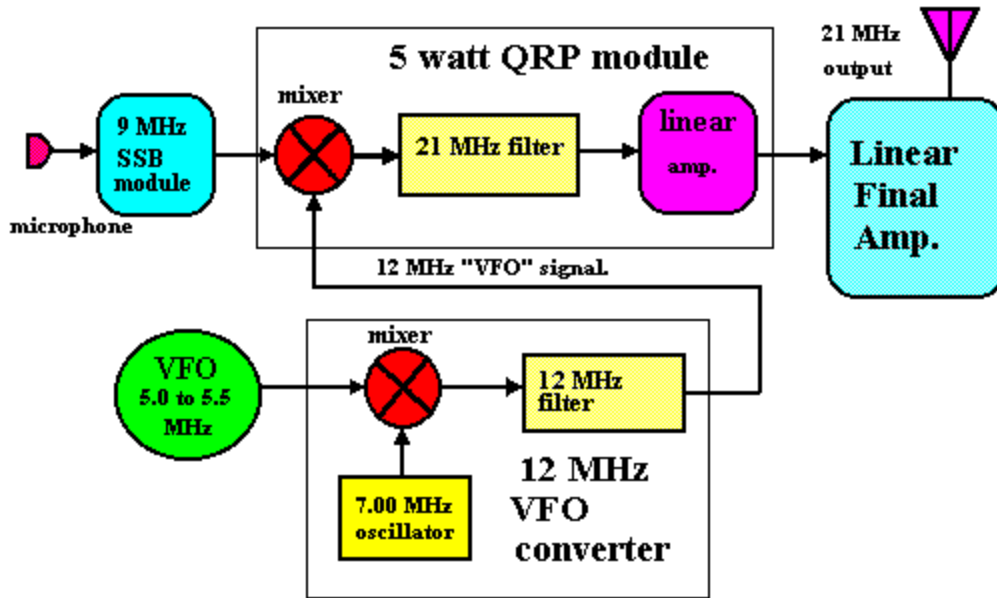
reproduced the circuit for use on 17 and 12 meters. However, the second time I knew what I was doing and the circuit was much “cleaner.” The result of my compact, pretty wiring was higher efficiency and more power out of each amplifier stage. Instead of 3 watts output, now I had 6 or 8 watts or more and I was overdriving the linear final. Excess drive gave my signal a rough, rasping sound and made the speech hard to understand. To fix this, I had to go back and decrease the output by various methods. I decreased transformer turns driving bases, used more negative feedback (emitter resistance), etc. Finally I put the 500 ohm pot in front of the 2<sup>nd</sup> broadband amplifier. This enabled me to deliver just what I needed and no more. Now the voice quality was acceptable. The pot worked so well, I went back and installed one in my 80/ 20 meter driver module.

### **Moving an SSB signal to the “difficult” hambands**

As explained above, the easiest hambands to reach with your SSB generator are 80 and 20 meters. Unfortunately, on weekends 20 meters is the most crowded ham band. It's full of guys running 2,000 watts peak into Yagi beam antennas 50+ feet in the air. If that weren't bad enough, their sideband transmitters are exquisitely designed to get the most modulation out of every watt. If you do get on 20 meters with your little homebuilt, it will probably average 20 to 40 watts on voice peaks. Combine that with your dipole antenna and it's going to be hard for those big guys to hear you. On the other hand, a band like 15 meters, or possibly 17 meters, is less crowded and you are more likely to make solid, enjoyable contacts there.

### **Getting on 15 meters**

How do we move the 9 MHz to 21 MHz with a 5 MHz VFO? My solution was to move the 5 MHz VFO to 12 MHz. Then I added my 12 MHz VFO to 9 MHz to get 21 MHz. ( $12 \text{ MHz} + 9 \text{ MHz} = 21 \text{ MHz}$ ) After mixing, the 21 MHz signal was 43% different from the nearest frequency component and filtering was relatively easy. Unfortunately, moving the VFO to 12 MHz is quite cumbersome. However, it uses technology you have already mastered. So, in the long run, I believe moving the VFO is the easiest way to go.



### Generating a 12 MHz VFO signal

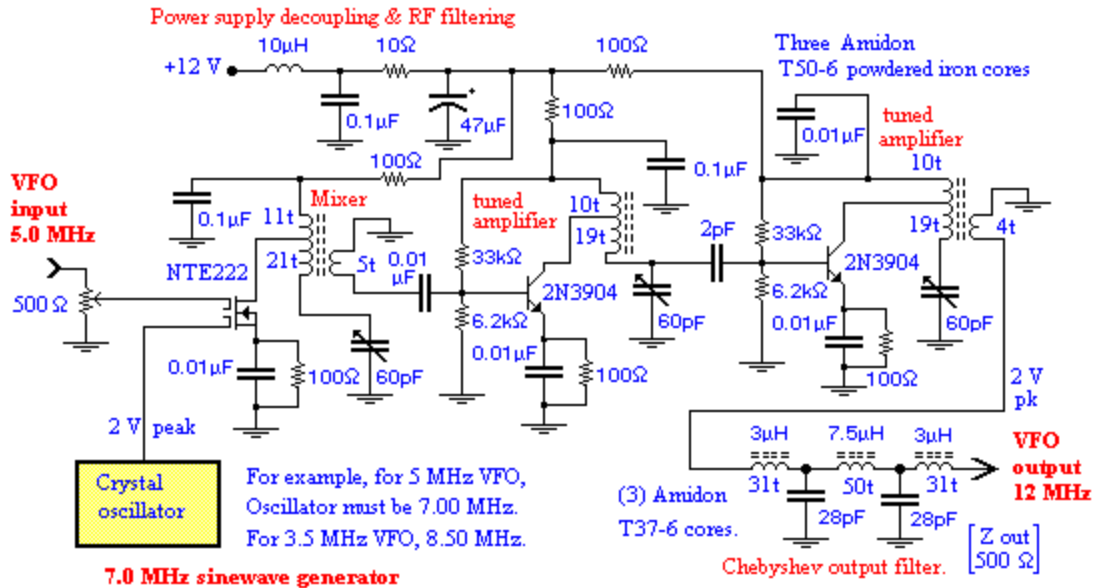
The VFO signal is just a sinewave. Therefore, compared to moving sideband, moving a sinewave to 12 MHz is relatively easy. There are no frequency or amplitude modulation components present, so the 12 MHz signal is easily filtered and purified. To move the 5 MHz VFO to 12 MHz, mix it with a 7.00 MHz signal from a crystal oscillator. Think of the VFO mover as a primitive frequency synthesizer.

### A 5 MHz to 12 MHz VFO converter

The frequency converter contains the same circuits I used in my CW QRP boards in which I used an 80 meter VFO to drive a CW signal on each HF band. I used the dual gate mixer because it was simpler than the bipolar transistor mixers I used in my first QRP boards. If you start with an 80 meter VFO, it can be combined with 8.5 MHz sinewave to give 12 MHz. You get the idea.

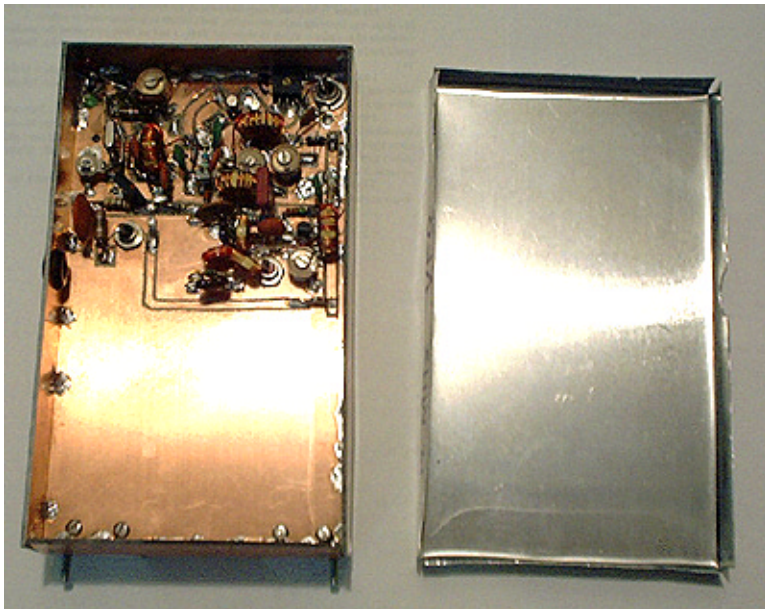


## 12 MHz VFO Converter for 15 Meters



The VFO converter moves the 5 MHz VFO up to 12 MHz

Before you build this, I suggest you look at the VFO movers for 17 meters and 10 meters shown later. I believe these newer VFO converter designs are more stable, more versatile, and easier to adjust.

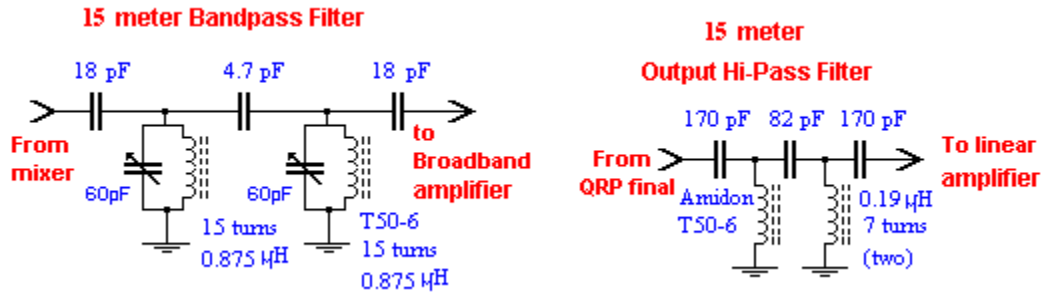


The 12 MHz VFO converter. I left room for a second VFO converter for some other band.

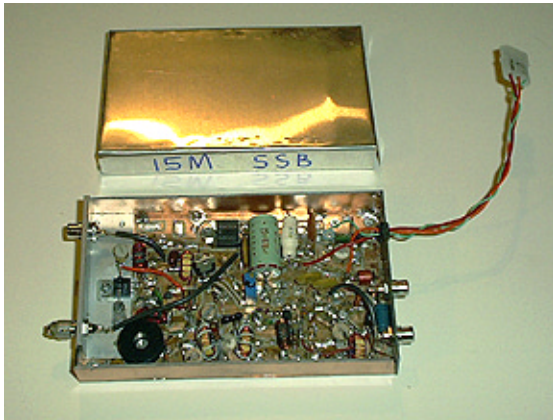
### A linear sideband QRP module for 15 meters

Once you have generated a stable 12 MHz VFO, it needs to be mixed with the 9 MHz

sideband signal to get on 21 MHz. Using the same design as the 80 meter QRP shown earlier, now all you need are the two passive filters to go into the QRP module. The bandpass filter is the same design as before, but I used a 5-element high pass filter on the output to get rid of the signals below 15 meters that tend to appear when I'm not talking. The two filters are shown below.



Notice that the output of the QRP driver described above has a *HIGH PASS* filter designed for 50 ohms that works best for driving a final amplifier. If you wish to run the driver “barefoot” and go on the air with just 5 watts peak, you’ll also need a low pass filter, just like the ones you built for the CW QRP drivers. The most troublesome unwanted frequencies are the second harmonic of the 12 MHz VFO (24 MHz) and the second harmonic of the SSB generator, 18 MHz.



A 21 MHz Driver module. The box lid is shown above the board.

Notice the “pigtail” power supply cable in the above driver. This was an invitation to RF interference. This cable acts like an antenna. I later modified the Molex connector so that it is imbedded in the bottom wall of the module. Now the module is plugged directly into the metal transmitter chassis with no exposed cable. RF feedback has not been a problem.

### 17 meters can be really tough

My first problem with 17 meters was that the sweep oscillator in my oscilloscope makes an 18 MHz signal that my receiver picks up right in the middle of the 17 meter band. Another odd problem with 17 meters was that it interferes with my cordless phone and my stereo. The other bands don't cause this interference so it's a mystery to me. More importantly, I'm nervous about what might be happening over at the neighbors.

Anyway, even without those troubles, 17 meters is particularly difficult when starting with a 9 MHz SSB generator. 18 MHz is the second harmonic of the 9 MHz SSB signal. Therefore the 17 meter frequency converter will also amplify the second harmonic of the sideband signal. This means that, although there may be a good signal on 17 meters where it is supposed to be, (for example, 18.130 MHz), there will also be a small sideband-like signal on 18.000 MHz. Of course the frequency deviation of the unwanted signal will have twice the audio frequency modulation. In the old days it was routine to move low frequency VFOs to high frequencies using frequency multiplier amplifiers. It is difficult to avoid building a multiplier/amplifier here and it will be hard to get rid of unwanted 18 MHz signals with simple filters.

In addition, if you generate a 9.130 MHz VFO signal to add to the 9.000 MHz SSB to get 18.130 MHz, you will also be transmitting the second harmonic of the 9 MHz VFO sinewave signal. That is, if the desired frequency is 18.130, there will also be another small sinewave transmitted on 18.260.

### **Practical approaches to getting on 17 meters**

In spite of these harmonic troubles I first pressed on with 9 MHz. To avoid the 2<sup>nd</sup> harmonic of a 9 MHz VFO, I added my 5 MHz VFO to a 22 MHz oscillator producing a 27 MHz VFO signal. Then I subtracted the 9 MHz from 27 MHz to get 18 MHz. ***Notice that when you subtract an SSB signal from a higher frequency, the upper sideband becomes the lower sideband and vice versa.*** The VFO worked fine, but occasionally I discovered that I was loading up on 18.000 MHz, the second harmonic of the SSB generator signal, not the correct frequency component. In short, the behavior with a 9 MHz SSB generator was too flaky to trust.

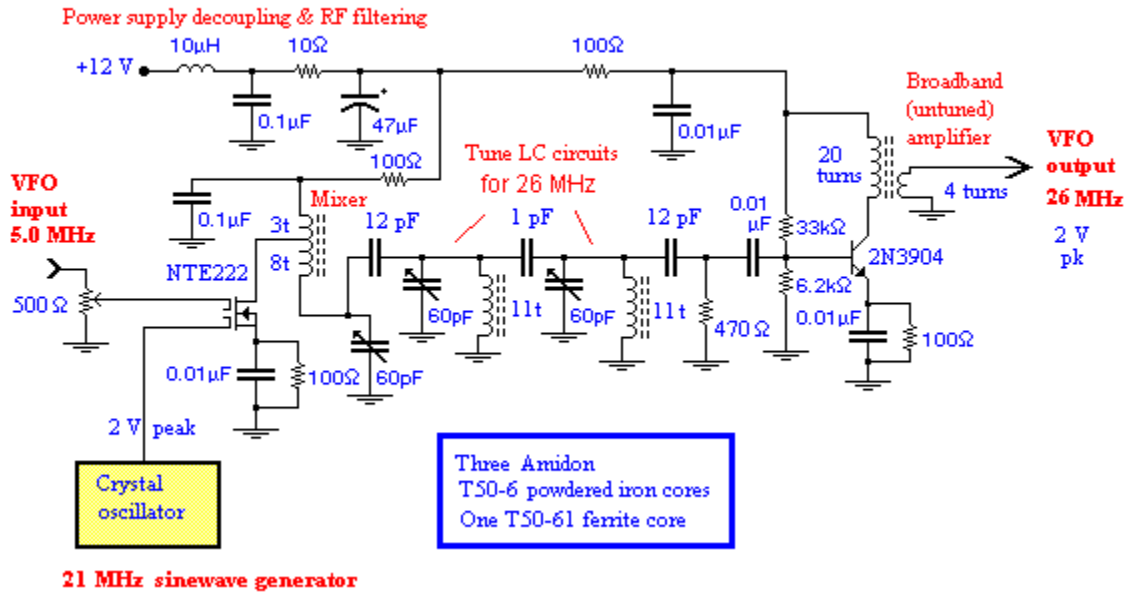
***The best way to get on 17 meters is to start over with a different SSB generator frequency, say 8.0 MHz.*** Then you can combine that with a 26 MHz VFO and it will work OK. In other words, 26.13 MHz - 8 MHz = 18.13 MHz. With this approach you aren't using any 9 MHz frequency components and second-harmonic, out-of-band emissions will be much less likely. I strongly recommend this approach. I really don't think a 9 MHz SSB generator can be reliable on 17 meters without first moving the 9 MHz SSB signal up above 18 MHz. That is, you would have to move the sideband signal twice. My solution was to start over and build a new SSB generator with two filters switch-able between 8 MHz and 9 MHz. My 8 MHz crystal filter was just like the 9 MHz filter, but the 91 pF capacitors were proportionately increased to 100 pF.

There are lots of ways to screw up on 17 meters. For example, ***start with a 6 MHz SSB signal and the 3<sup>rd</sup> harmonic of the signal will be on 18.000 MHz and will be just as bad as 9 MHz.*** You can also screw up with 8 MHz. For example, the 8 MHz SSB can be added to a 10.15 MHz VFO to get 18.15 MHz. Unfortunately, the 2<sup>nd</sup> harmonic of 10.15 MHz is 20.30 MHz. This continuous sinewave is close enough to 18 MHz to go right out over the air whenever you stop talking.

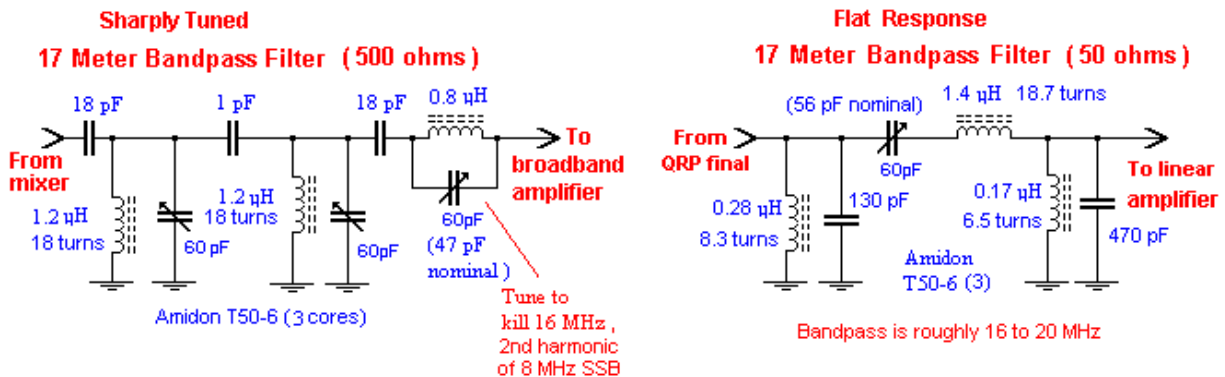
### **17 Meters with an 8 MHz SSB generator:**

As shown below, I eliminated the VFO harmonic problem by generating a 26 MHz VFO. The second harmonic of an 8 MHz SSB generator is 16 MHz. Fortunately it wasn't hard to avoid accidentally tuning it to 16 MHz. Notice again that the SSB is subtracted from a higher frequency so ***the SSB generator must be set to the lower sideband to get upper sideband on 17 meters.***

## 26 MHz VFO converter for 17 meters



The output of the 5 watt driver needs both a low-pass to get rid of the 26 MHz artifact and a high pass filter to avoid the low frequency “bursting” problem. Rather than choosing between high pass or low pass, I used a second 18 MHz bandpass filter that severely attenuates both 8 MHz and 26 MHz. This flat response bandpass filter is designed for 50 ohms. In contrast, the sharply tuned bandpass filter following the mixer is designed for high impedance, 500 ohms input and output. The 500 ohm bandpass filter is easier to design, but it can't handle any power and the impedance is incorrect for the QRP output.

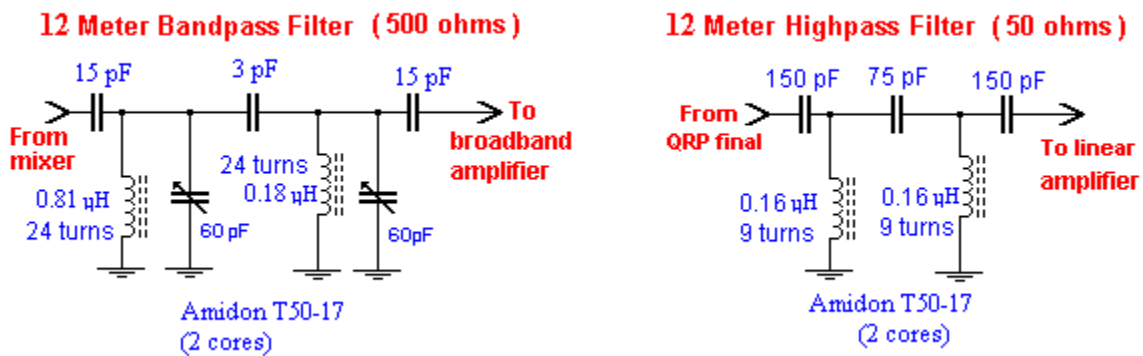


The filter on the right has a flat response from about 16 MHz to 20 MHz. In order to get the flat response, the three LC resonate circuits all have different values. And, of course, the three L-Cs interact, so a simple calculation wouldn't work anyway. I derived this circuit by trial and error using my Spice program. The component values must be rather precise otherwise the response has sharp peaks. Notice the fractional turns on the cores. These should help you be aware that wrapping the wire a tad more or less might make a difference. I found that making the

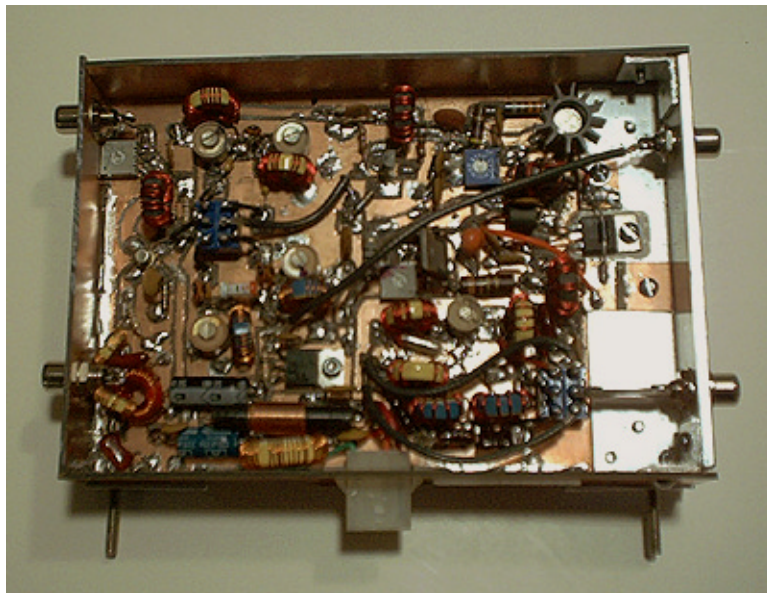
smallest capacitor(s) variable was useful for final tune up. A few picofarads can make a big difference. Anyway, it was a struggle but eventually it worked. Tuning the series variable cap peaks it up nicely on 18 MHz.

### Filters for 12 meters

In contrast to 17 meters, 12 meters was much easier. I generated a 15.9 MHz VFO signal by adding my 5 MHz VFO to a 10.700 MHz crystal oscillator. The QRP combines the 9 MHz SSB signal with the 15.9 MHz VFO to produce 24.9 MHz. The high impedance bandpass filter following the mixer is tuned for 24.9 MHz. At the output of the QRP module all the unwanted frequencies are well below 12 meters. Therefore the low impedance output filter is a simple high pass.



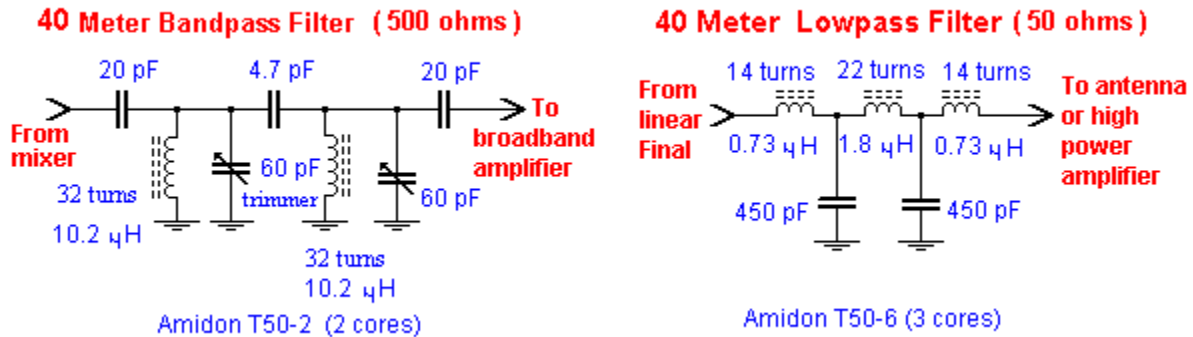
The driver for 12 and 17 meters is shown below. Notice how this module has its Molex power plug mounted on the bottom. It plugs directly into the transmitter chassis and avoids exposed wires. This QRP driver also has an aluminum cover to shield the circuitry from RF.



### Getting on 40 meters SSB

Forty meters was also straight-forward. I generated a 16 MHz to 16.5 MHz VFO signal by adding the 5 MHz VFO to an 11.000 MHz crystal oscillator. Then I subtracted the 9 MHz

SSB to get 7.00 to 7.50 MHz. Because of the subtraction, the upper sideband 9 MHz SSB signal generated the lower sideband signal on 40 meters. The 40 meter QRP mixer filter uses almost the same tunable bandpass filter used in the DC receiver in chapter 7. Since all the frequency components are well above 7 MHz, a low impedance lowpass filters the output. As usual, 40 meters was kind to me and it worked right away. I was immediately able to check into my local state-wide 40 meter noon net.

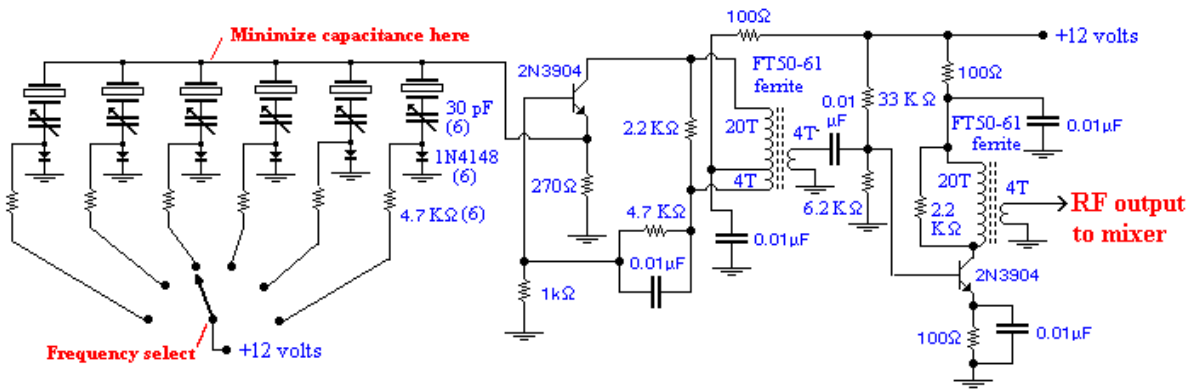


### SSB on 10 meters

The tricky part about 10 meters is that it's 1.7 MHz wide, 28.0 MHz to 29.7 MHz. My VFO only tunes a range of 0.5 MHz. Therefore it takes 4 crystal PMOs to cover the whole band. I solved the problem with a quadruple frequency crystal oscillator. A 6 position rotary switch switches in the appropriate crystals for 28, 28.5, 29.0, and 29.5 MHz. My oscillator uses the other two switch positions to cover 12 meters and 40 meters. The crystals aren't switched directly, but rather, they are grounded one at a time by means of diodes that are biased *ON* by means of a 12 volt DC signal passed through the 4.7 K resistors. The advantage of this DC switching method is that, if you like, the rotary switch can be far away from the oscillator up on the front panel.

Be sure to minimize the capacitances between the oscillator emitter and ground. All those crystals connected to the emitter will be affected by the extra capacitance. This will tend to pull each crystal frequency away from its nominal value. Too much capacitance and it may not oscillate at all.

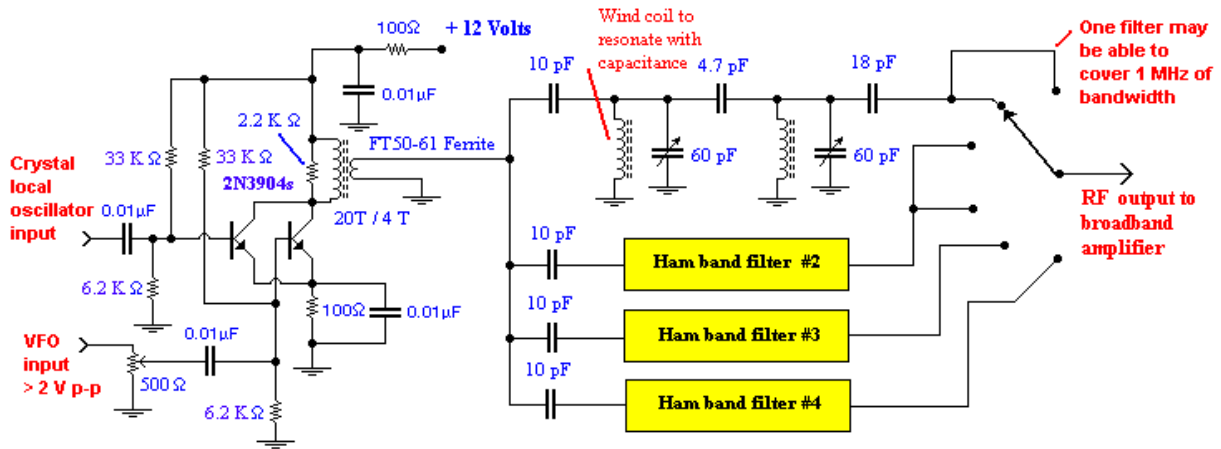




## MULTI - CRYSTAL OSCILLATOR

The multi-crystal oscillator covers a wide range so the oscillator could not be tuned and had to be broadband. Therefore the oscillator frequency is entirely controlled by the crystal frequency. Obviously the particular crystal must spontaneously oscillate on that overtone frequency and not a lower, primary frequency. And, because the oscillator stage isn't tuned, its signal output is tiny, tenths of a volt. Consequently, I had to pass the oscillator signal through a broadband amplifier to make it large enough, about 2 volts p-p, to be sent to the mixer to be mixed with the 5 MHz VFO.

After the mixer each VFO signal must be filtered to select the desired frequency component. My 6 position rotary switch has a second section that allowed me to switch in a filter for each frequency. I found that just two tuned filters could cover the whole 10 meter band. I didn't need 4 separate filters after all.



## MULTIPLE FREQUENCY MIXER

The tuned filters are high impedance and connected to the mixer with 10 pF capacitors. Because all the filters are connected to a low impedance transformer winding, the mixer can drive all of them at once. As shown the total load is only 40 pF. The rotary switch on the right then picks out the desired filter output. Another broadband amplifier amplifies the filter output before it goes to the SSB QRP driver where it is combined with the 9 MHz SSB signal. By the



way, I tried to use the switching-by-grounded-diode trick to switch filters but that idea worked poorly. For 10 meters this VFO converter generates VFO signals from 19 to 21 MHz.

Frankly, my 10 meter QRP only seems to work well up to 29 MHz. It doesn't work properly above that frequency because my QRP mixer filter isn't broadband enough. I guess I need two high impedance tuned filters. Also, since 10 meters has been dead for well over a year now, I have yet to make a 10 meter SSB contact. Needless to say, my 10 meter SSB is still a work in progress.

### **Getting on 60 meters SSB - don't bother!**

Before the 60 meter (5 MHz) SSB frequency became available to American hams on July 4<sup>th</sup> 2003, I thought it would be fun to get on the air before the commercial gear was on the market. I naively thought that homebrewers would own the band for at least a little while. What I didn't know was that some of the newest transceivers can be reprogrammed to operate on any HF frequency just by pushing some buttons. Anyway, the band was instantly clogged with commercial transceivers. Worse yet, 2 or 3 of the 5 frequencies were always busy with radio teletype. As a result there only 2 or 3 discrete channels available with everyone in the country trying to use them at once. 60 meters is another band on which I have never made a contact.

### **Checking out the QRP module**

You will have to experiment with how to listen to your sideband signal at a signal level that simulates what it would sound like if you were receiving it off the air. I run my QRP into a 50 ohm dummy load. Then I disconnect my receiver from the antenna and leave the antenna coax from the receiver lying on the bench a few feet from the sideband generator. If that's not strong enough, I clip a test lead to the transmitter ground, then clip the other end to the center conductor of the receiver antenna coax connector.

I start by feeding a 9 MHz sinewave (CW) signal into my QRP board and then tune the filters to produce the largest, stable sinewave output into the dummy load. I monitor the frequency with a counter to be sure the VFO is controlling the frequency properly over the entire ham band. I adjust the VFO input level to produce the maximum output signal. However I just use the minimum 5 MHz VFO level that achieves this. When you are *NOT* talking, excess VFO will tend to induce signals on unwanted frequencies. I increase the DC bias to the output transistor until that transistor draws about 20 milliamperes DC more than it does with the bias set to minimum.

After the CW mode is working properly, I switch to SSB and use an audio signal injected into the "test input" of the SSB generator. I use speech from a talk radio station as supplied by a little Walkman radio. If you're lucky, the speech should sound pretty good in your ham receiver. If it doesn't, decrease the drive to the last two stages of the QRP using the 500 ohm pot. You may also need to reduce the number of secondary turns on the transformer feeding the output transistor. For example, instead of 3 turns, 2 turns or even one turn may be optimum for your particular QRP board. I found that overdriving stages was a common cause of poor audio.

### **Driving a QRP linear amplifier**

A QRP sideband transmitter is just fine for communication around town. One or two watts are plenty for talking a few miles. But unless you have a great antenna and good

conditions, you won't talk to many stations with just a few watts. For distant stations a linear amplifier will be a big improvement. Building a 50 watt linear is explained in chapter 12. If you are going to have trouble with RF feedback and insufficient power supply decoupling, a big linear amplifier will bring out these troubles. RF from my antenna coupler feeds back to my Walkman radio and (usually) makes that speech source impractical for testing. I usually listen to the receiver with headphones with the receiver volume turned way, way down. Don't deafen yourself! When you speak into the microphone, your voice should sound clear, as though you were talking on a public address system. It should not sound rough and gravelly.

Watch the output waveform across the dummy load with your scope. The waveform should look just like it did coming out of the 9 MHz generator. You will probably find that speech sounds terrible before you have everything adjusted. It may just be bursting, sputtering sounds.

### **Adjusting DC bias to the final**

You'll have to adjust the DC bias to the final (50 watt) amplifier for optimum speech quality. As you increase the bias current, watch the DC current drawn by the entire transmitter. It should not be more than about 2 amperes when you are not talking. As you talk, the current should jump up to 6 to 12 amperes, depending on the drive levels, the band you're on, etc. As always, the higher the frequency, the more difficult it will be to obtain clear speech. ***DC bias for the high power amplifier that is adequate for one band, may not be enough for another.*** This little pearl of wisdom cost me days of frustration.

If the speech still sounds bad, RF chokes and RC decoupling filters for power leads to each module can help the problem. Also, filter the DC power line entering the transmitter chassis and the remote "mute" line going to the receiver. If troubles persist, filter all the wires entering your transmitter. Sometimes a clamp-on ferrite filter block around power leads or cables can be helpful.

### **Finally, SSB works best with a good antenna**

A high gain, beam antenna is highly desirable. As you listen to the other SSB stations, you'll find that most strong signals come from a beam antenna. Directional antennas improve the signal by focusing most of the RF energy toward the guy you are talking to. Think of beam antennas as being comparable to the mirror reflector in a flashlight. The mirror concentrates the energy in one direction only.

### **In conclusion**

My first real sideband contact was with W9WFE, a fellow about a thousand miles away. When I explained to him that my rig was homebrew, he said, "Well, it certainly sounds like sideband to me. It seems to work!" Sweet success.

My sideband transmitters are still in the experimental category. You will find that it takes a great deal of tweaking and fussing to get SSB tuned so it sounds good and doesn't radiate on unplanned frequencies. You won't believe how many diseases your SSB transmitter will create for you to conquer! Sideband is not a project for impatient people.

Shortly after I got my sideband working, I tried to arrange a schedule with Doug, KD6DCO, in California. We failed to make contact. In that weak moment I thought I should

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stop messing with homemade junk and buy a modern transmitter. No, wait. If I want to communicate with Doug, all I have to do is write him an e-mail or call him on the phone. I'm already on-line and long distance calls are cheap. If I wanted to use radio, I could even talk with him by cellphone. No, it was back to the drawing board for me.

And after some major redesign, my next schedule with Doug was successful, but my signal was pretty weak out in California. That's OK. I have to keep reminding myself that, so long as my station falls short of what is technically possible, my hobby continues. Woe to me if I ever finish. Long live homebrew!!

