

## CRYSTAL SETS TO SIDEBAND

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## Chapter 15

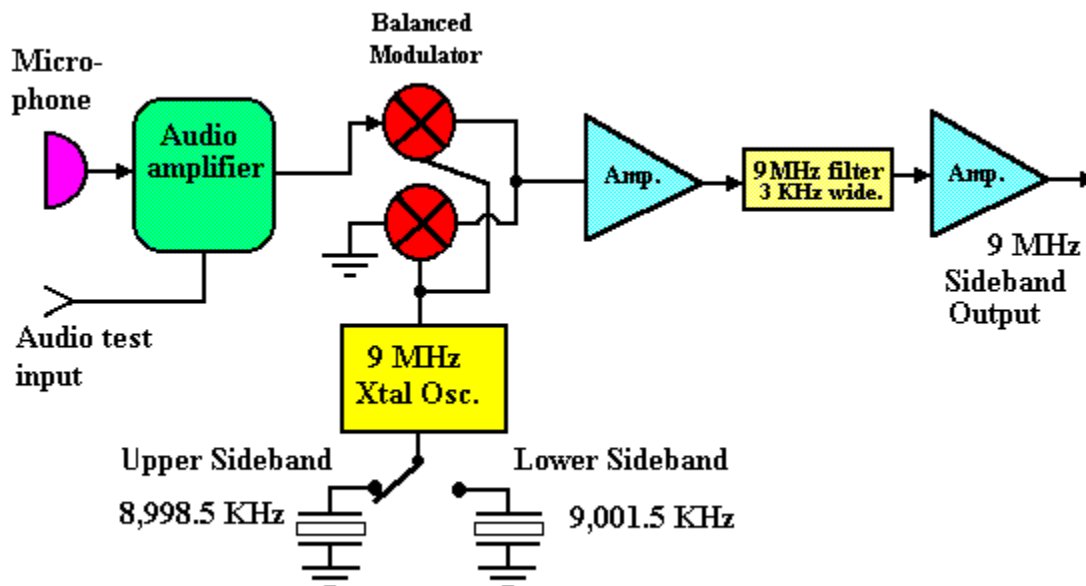
# THE NOBEL PRIZE FOR SIDEBAND

### How sideband works

In the beginning of the book I described how Glenn Johnson, WØFQK, recruited junior high school kids into ham radio. We were 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 Glenn effortlessly operate 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 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, anyone interested in a Nobel Prize for sideband? If you’ve already built homebrew QRPs, VFOs and a receiver, 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



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.

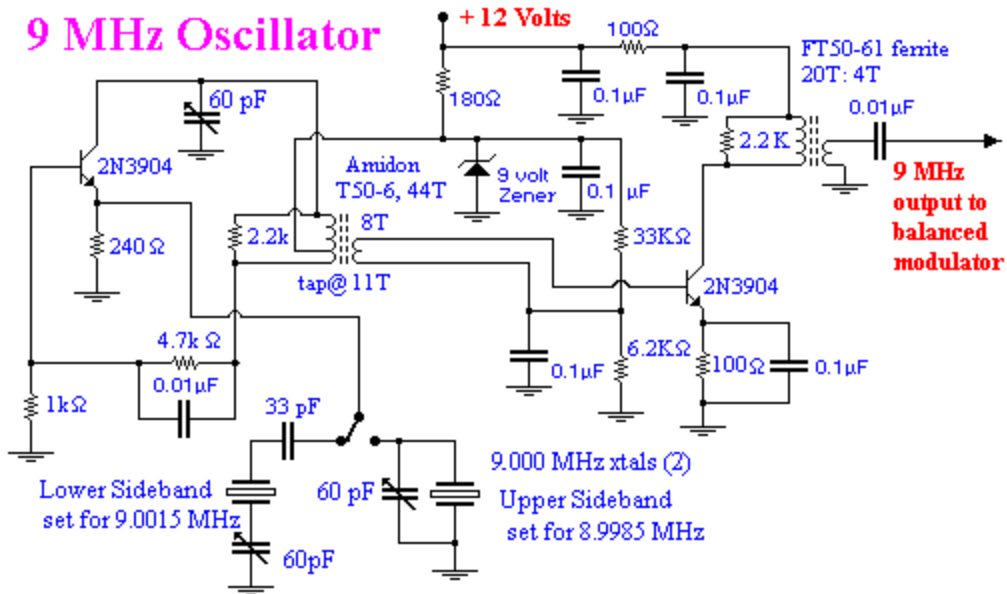
The circuits you've used in previous chapters are the audio amplifier, the crystal filter, the RF oscillator/ amplifier and the conversion modules to move the VFO signal to ham bands. The audio amplifier design is similar to the one in the homebrew receiver in chapter 13. The 9 MHz RF oscillator/ amplifier 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 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!

### How sideband 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 and one of the two sidebands is filtered out with a crystal filter. Let's begin with the crystal oscillator:

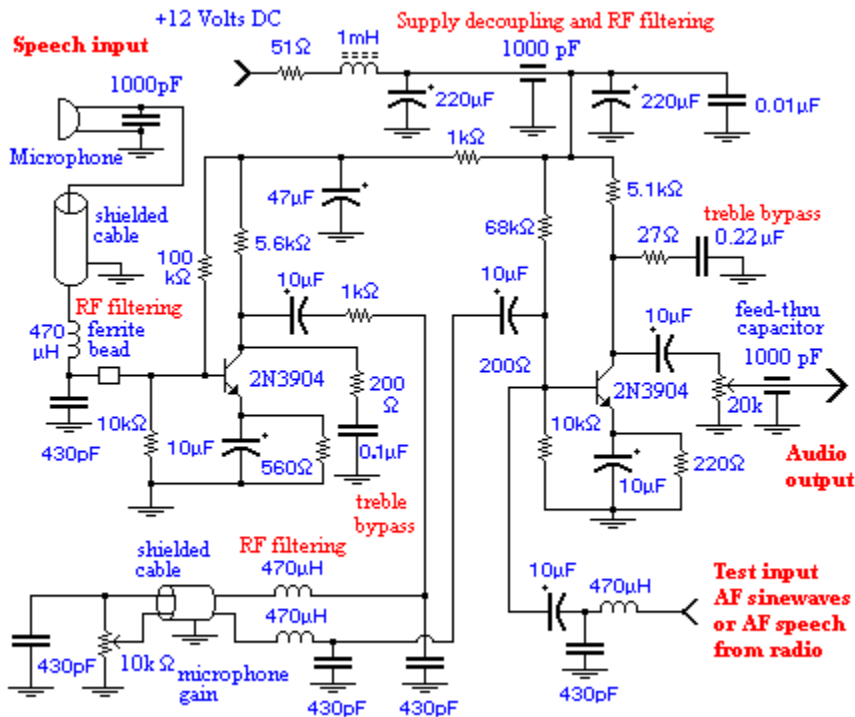


## 9 MHz sinewave oscillator / amplifier

A stable, fixed frequency RF sinewave signal is generated by a crystal-controlled 9 MHz oscillator and amplifier that resemble the 7 MHz QRP transmitter described in chapter 6. The crystal oscillator has two crystals. Each has tuning capacitors so that the frequency can be pulled about 1 KHz up and down. This allows the two AM sidebands to be lined up properly with the ladder-style crystal sideband filter that follows the balanced modulator. The filter shears off the unwanted upper or lower sideband.

A switch enables the oscillator to select two crystal/ capacitor pairs so that the operator can switch between upper and lower sideband. The crystal filter that removes the unwanted sideband is at 9.000 MHz, almost exactly. Notice that the upper sideband is generated by a sinewave 1.5 KHz below 9.000 MHz. The lower sideband is generated by a sinewave 1.5 KHz above 9.000 MHz. To pull the crystal above 9 MHz, the tuning capacitor is in series with the crystal. To push the crystal below 9 MHz, the tuning capacitor is in parallel with the crystal.

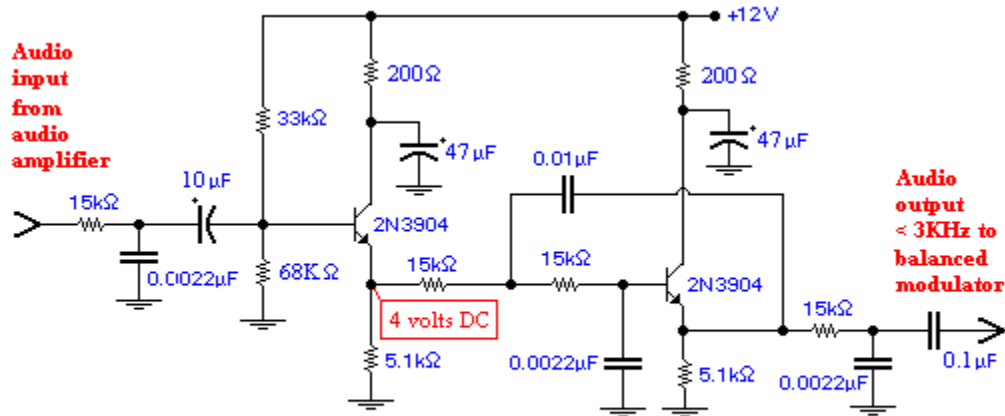
## The audio amplifier



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.



### AUDIO LOWPASS FILTER (< 3 KHz)

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 just help 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 that insures that the amplifier will not oscillate. Butterworth filters are usually implemented with operational amplifiers. Until this filter, I had never built one with transistors. Yup, 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 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.

#### Decoupling for the power supply lead

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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 feedthrough 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 falls 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.

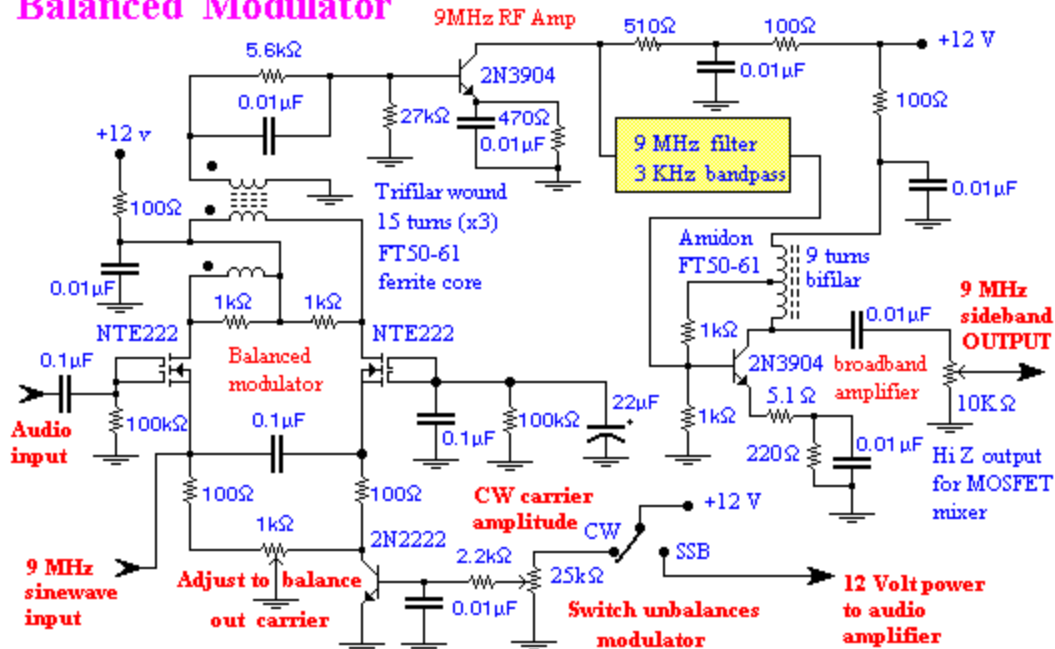
The final amplifier draws too much current for it to be practical to decouple the amplifier supply lead. In fact, it is the huge 10-ampere surges of current drawn by the final that cause the noise in the rest of the transmitter. In general, the less current drawn by a circuit block, the more extreme 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 3 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.

### **The balanced modulator**

## Balanced Modulator

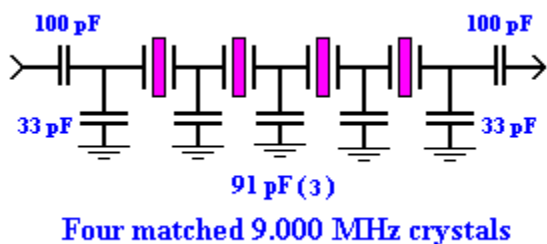


The balanced modulator is the “carrier cancellation circuit.” It is a kind of dual mixer in which an audio signal is mixed with the 9 MHz sinewave to produce a AM modulated signal, exactly like AM radio. An AM signal has a carrier signal just like the CW input plus the two RF sidebands caused by the audio modulation. What’s different about a balanced modulator is that it consists of two mixers in parallel. The second mixer has no audio input so its output is just another CW signal, just like its RF input. The two mixers share a common output transformer that has three windings - two primaries and one output winding. There is a primary for each mixer. The clever part happens when the primaries generate magnetic signals in the transformer iron. The windings are oriented so that the two primaries work against each other. The CW signals in both windings are “balanced” with an adjustment pot so that they exactly cancel. This means that the only signals that appear in the secondary winding are the two sideband signals. ***In summary, a balanced modulator produces a double sideband signal with no carrier.***

The transistors are dual gate MOSFETS with the gates shorted together. The idea is to use transistors without any P-N diode junctions. According to the handbook, P-N junctions act like varactors and distort the speech slightly. Dual gate MOSFETs are used simply because they are the most common small RF MOSFET available. A single gate small RF MOSFET is fine, but you probably won’t be able to find one. The above circuit was adapted from the 1986 Handbook.

To use this modulator for CW, there is a switch that unbalances the modulator and allows some carrier to pass through to the filter. This CW mode will be hard to use for actual CW contacts because the crystal filter will tend to remove 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 CW operation, you may bypass the SSB filter or use a separate 9 MHz oscillator. This sideband generator can also be modified to generate amplitude modulation. This is discussed in chapter 16.

### 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 generator. This filter seems to work, so I haven't had to experiment.

The homebrew way is to buy a bunch of 9.000 MHz microprocessor crystals from Mouser or Digi-Key for 86 cents 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.

### 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 & 9.0015 MHz), this CW signal will be far lower than the maximum power you will get on voice peaks.

## MECHANICAL CONSTRUCTION

### Sorry! You must shield sideband.

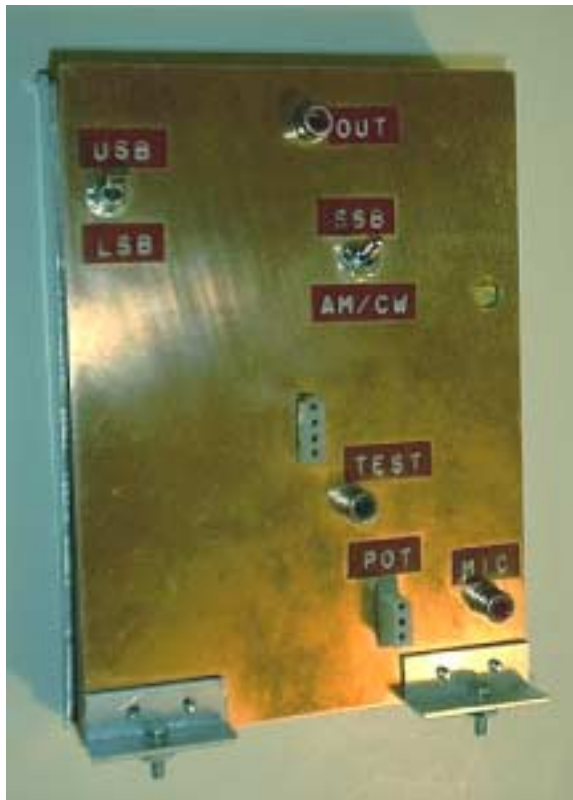
When building CW transmitters, some of us think it's cool to have the parts out in the open where we can see them. Unfortunately a huge problem with SSB is RF feedback. To prevent that, you must enclose all the modules of your SSB transmitter in metal. All the connections between modules should also 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 exposed wires.

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Actually, I still leave the linear amplifier out in the breeze, but all the low power modules and the power supplies are well shielded. 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 SSB generator.** An aluminum lid fits over the top of the box.



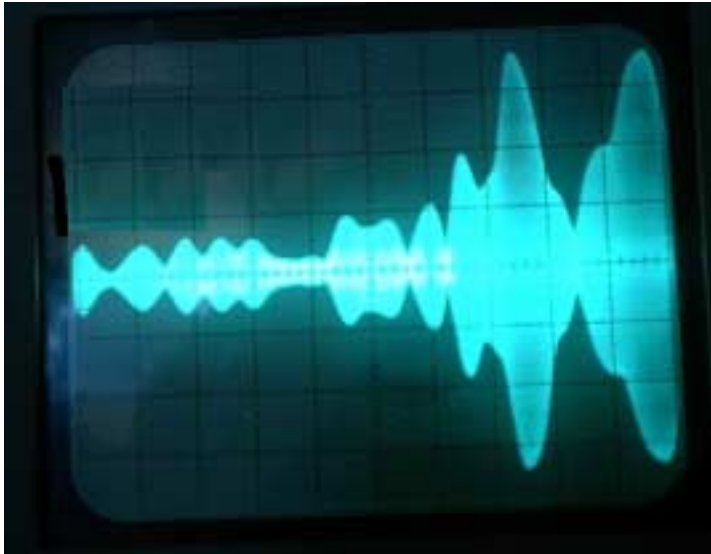
### **Tuning and testing the sideband generator**

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 circuit above generates 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 be perfectly understandable in your ham receiver. When you turn off the BFO and set up the receiver for AM modulation, speech should be 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 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. Or, we could all write to the WARC to ask them to establish a little 6 KHz hamband centered on 9.000 MHz. Maybe not.

Moving the SSB to a hamband is by far the most difficult part of sideband. However, if you don't make the mistakes I did, maybe it won't be so bad. Four 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.

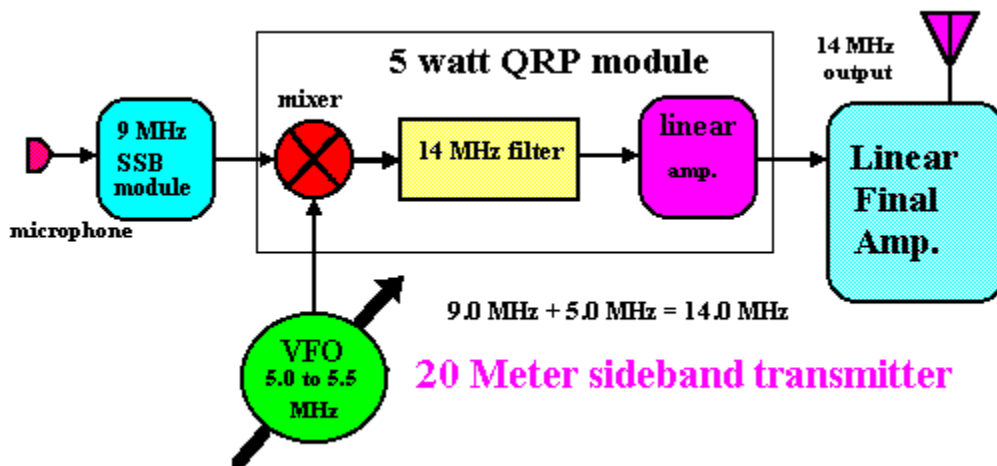
**\*Don't use tuned amplifiers and mixers.** When you stop talking, tuned amplifiers tend to oscillate by themselves at frequencies similar to where they were tuned. In fact, getting rid of the noise and oscillations when you're *NOT* talking is the harder than making the speech intelligible. Unlike CW, it is best to use broadband mixers and amplifiers and to put all your hamband 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.

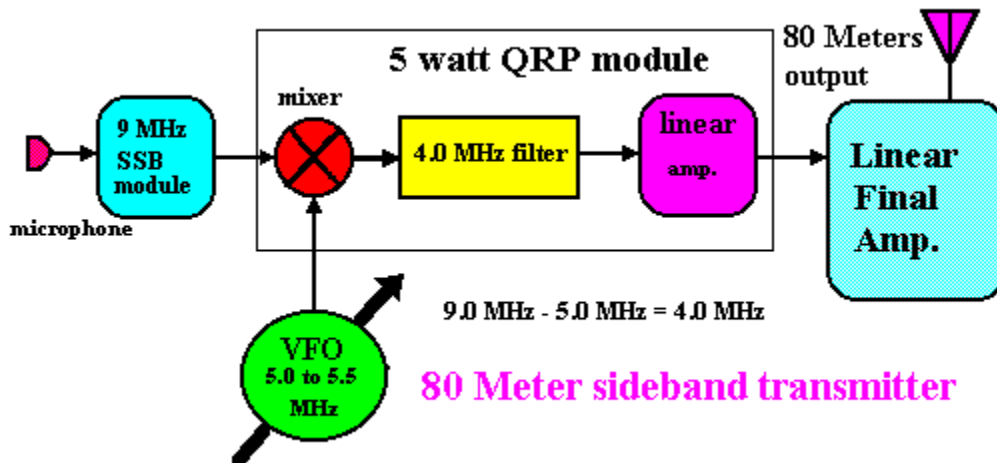
**\* It sometimes helps to connect all ground connections to the outside layer of your two-sided PC board.** The ground connections for all high current RF stages must be extremely low inductance. Otherwise, if your board layout isn't well designed, RF voltages on all the ground traces inside the PC 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 a wire 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 meters) 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.

### 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 hamband 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

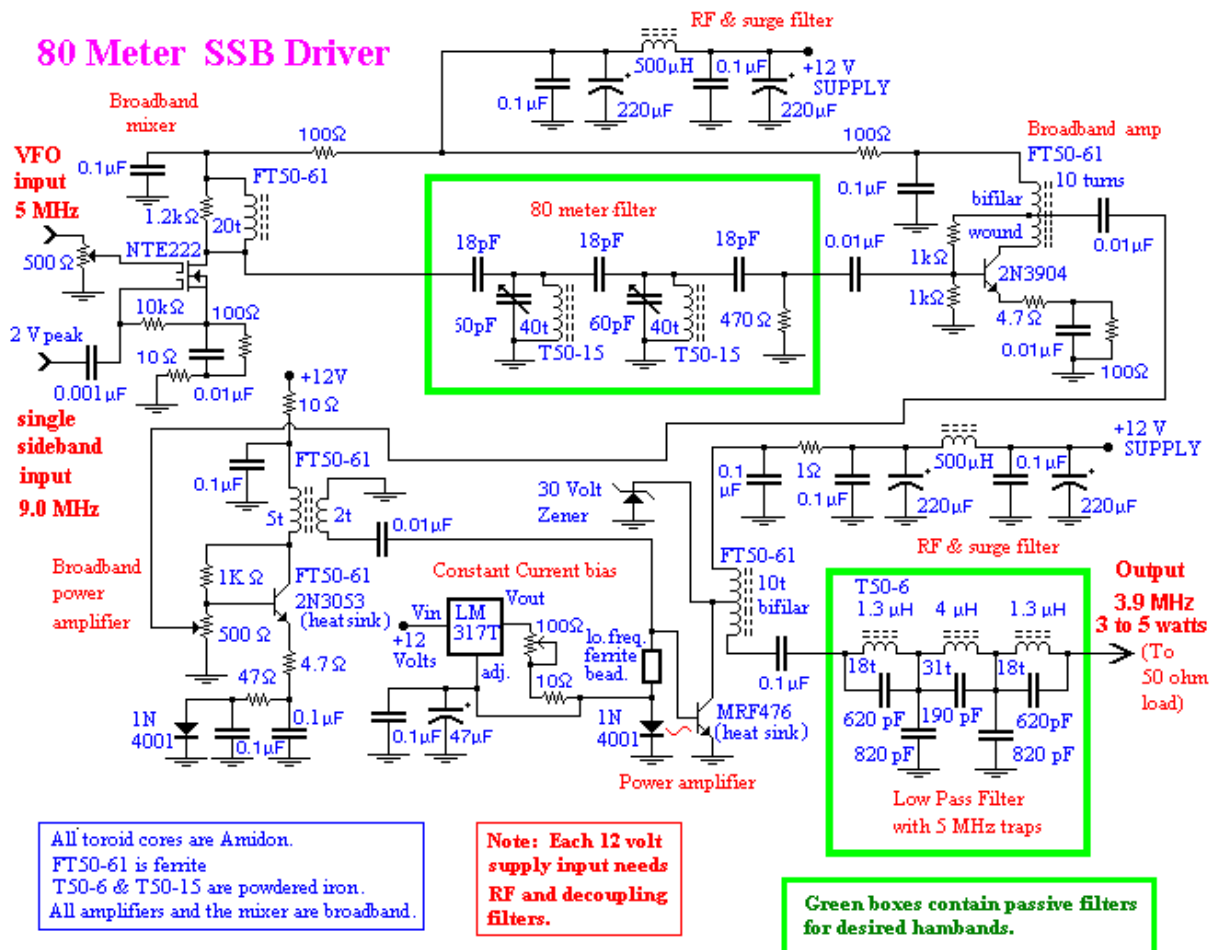
There is a great deal of similarity between a sideband receiver and a sideband transmitter. Once you've built a receiver, it dawns on you that the transmitter has most of the same modules and that you are building the same circuits twice. On the other hand, using the same circuit modules for both tasks 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 have intermodulation, noise and whistles it didn't have before. 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. Hmmm... Furthermore, the VFO band conversion oscillators in the receiver and transmitter must be aligned to within a Hz or two. Not so simple after all. The transceivers solve the problem by using the same oscillators for both tasks so alignment isn't a problem. As my high school textbooks used to say, these problems are left as exercises for the interested student.

### 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.



All transistor stages are broadband, including the mixer. Note the 2K resistor across the

primary of the first ferrite core transformer. Without this or other feedback, the broadband amplifiers tend to generate an uncontrolled signal whenever the SSB input drops to zero between spoken words. The un-bypassed 4.7 and 10 ohm emitter resistors in two of the amplifiers also help prevent oscillations. To reduce surging and RF feedback to the driver module I filtered my 12 volt input leads with RF chokes, big capacitors and small ceramic capacitors.

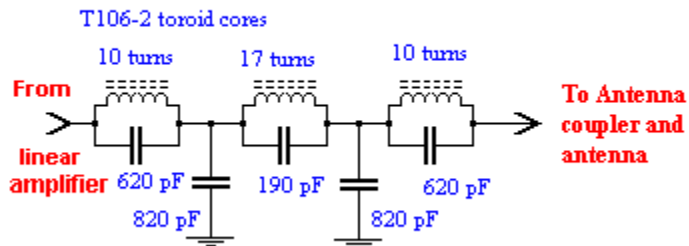
Unlike the CW QRP modules, the SSB module output stage needs forward bias to operate in linear mode. The LM317 circuit current source supplies the needed current. This temperature compensated circuit was used in the 50 watt linear in chapter 12 and is overkill for this 5 watt final, but what the heck! With experimentation I found that just 20 milliamperes of forward bias is plenty to operate linear and give good speech quality. In theory, a 560 ohm 1 watt resistor can provide this bias much more cheaply. However, I haven't tried this.

The passive 80 meter filter is placed between the mixer and the first broadband amplifier. The output filter is the usual Chebyshev low pass except that capacitors have been placed in parallel with the inductors. These make the inductors resonate at 5 MHz and provide extra attenuation to get rid of the 5 MHz VFO signal. Notice that 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 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.

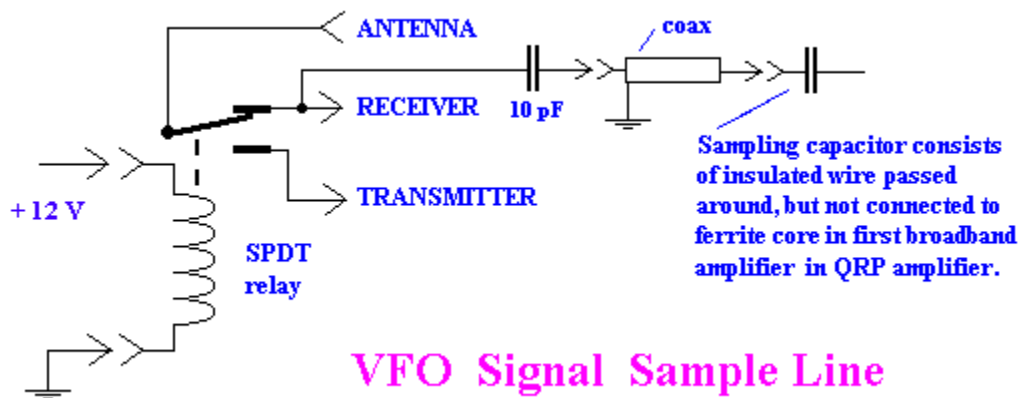
### 80 Meter lowpass Elliptical Filter for Linear



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 and 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. Persistence will win in the end!

### Hearing the transmitter VFO in your receiver

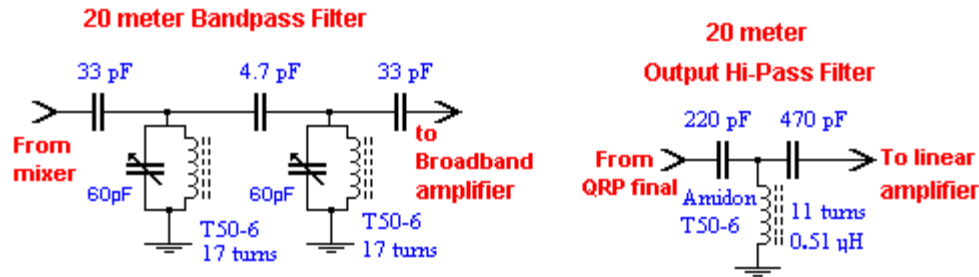
One consequence of shielding and filtering every low power module of my SSB transmitter was that I could not hear my own VFO signal. This made it impossible to tune the VFO to a station I might wish to talk to. Eventually I solved the problem by connecting a tiny capacitor, 10 pF, to the receiver antenna 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 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 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), and 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." So 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 complex.

### 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 noise problem is 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 two 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. Finally the voice quality was acceptable. The pot worked so well, I went back and installed one in my 80/ 20 meter driver module.

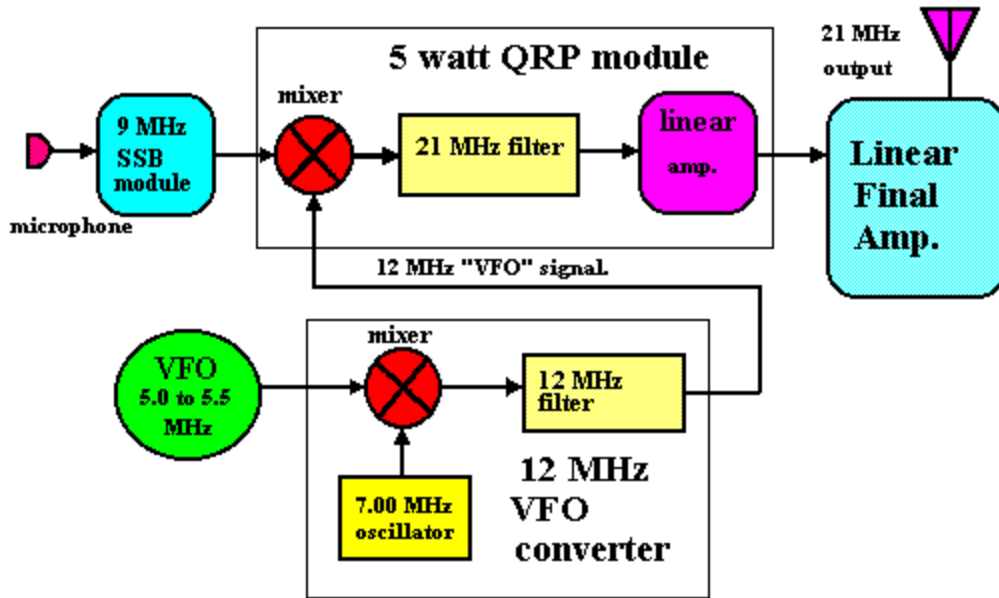
### Moving an SSB signal to the "difficult" hambands

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 2000 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 MHz + 9 MHz = 21 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 sounds really cumbersome... and it is! However, it uses technology you have already mastered. So, in the long run, I believe moving the VFO is the easiest way to go.





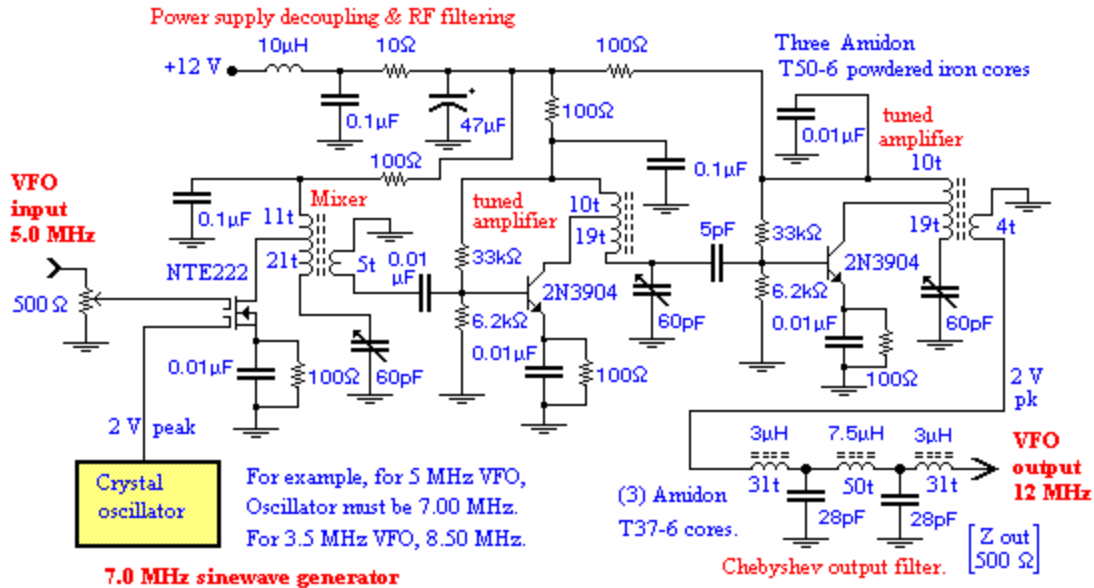
### Generating a 12 MHz VFO signal

The VFO signal is just a sinewave so moving it 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

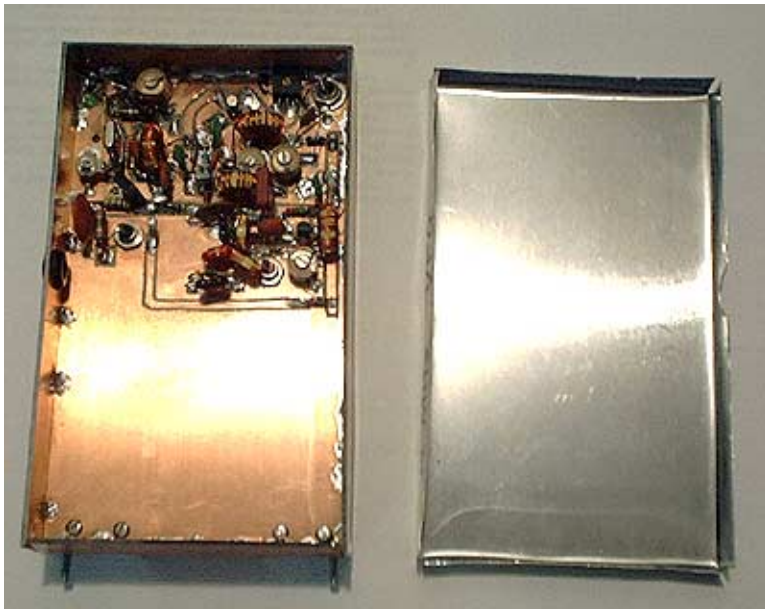
The frequency converter contains the same circuits I used in my HF QRP boards in which I used an 80 meter VFO to drive a CW signal on each HF band. I used the dual gate mixer because it was simpler than the bipolar transistor mixers I used in my first QRP boards. If you start with an 80 meter VFO, it 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 designs are more stable, more versatile and easier to adjust.

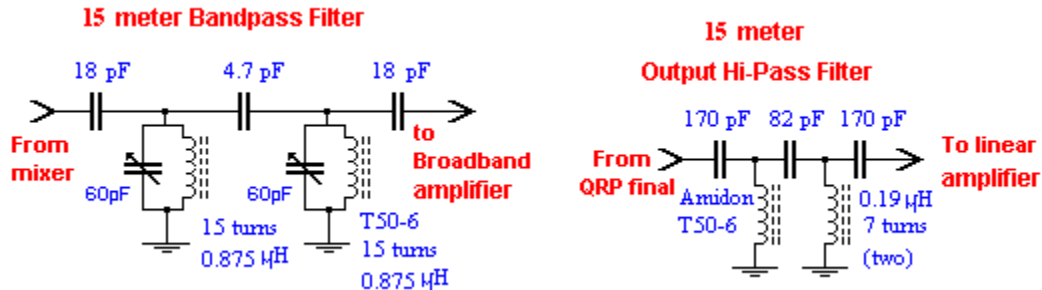


The 12 MHz VFO converter. I left room for a second VFO converter for some other band.

### A Linear sideband “QRP” 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 connector so that it is mounted on 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. However, 17 meters is also particularly troublesome 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

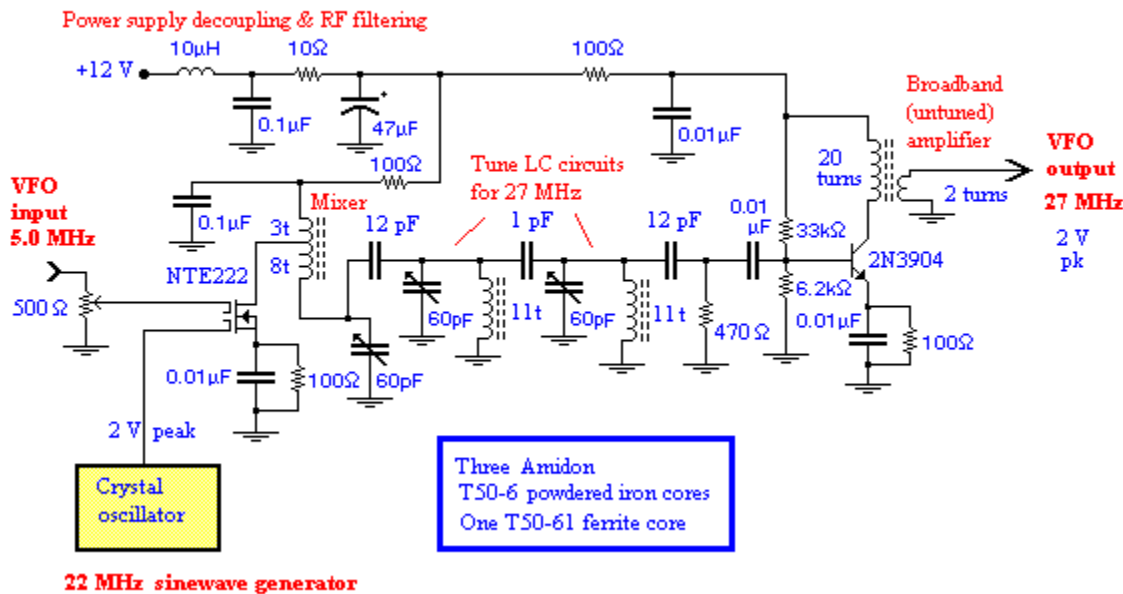
a good signal on 17 meters where it is supposed to be, (for example, 18.120 MHz), there will also be a small sideband-like signal on 18.000 MHz. Of course the frequency deviation of the unwanted signal will have twice the audio frequency modulation. In the old days it was routine to move low frequency 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 9.120 MHz VFO signal to add to the 9.000 MHz SSB to get 18.120 MHz, you will also be transmitting at the second harmonic of the 9 MHz VFO sinewave signal. That is, if the desired frequency is 18.120, there will also be another small sinewave transmitted on 18.240.

*To be honest, the best way to get on 17 meters is to start over with a different SSB generator frequency, say 6.0 MHz.* Then you can combine that with the same 12 meter VFO that you used for 15 meters. In other words, 12.15 MHz + 6 MHz = 18.15 MHz. With this approach you aren't using any 9 MHz frequency components and second-harmonic, out-of-band emissions are highly unlikely. I strongly recommend this approach.

**Pressing on with a 9 MHz SSB generator:**

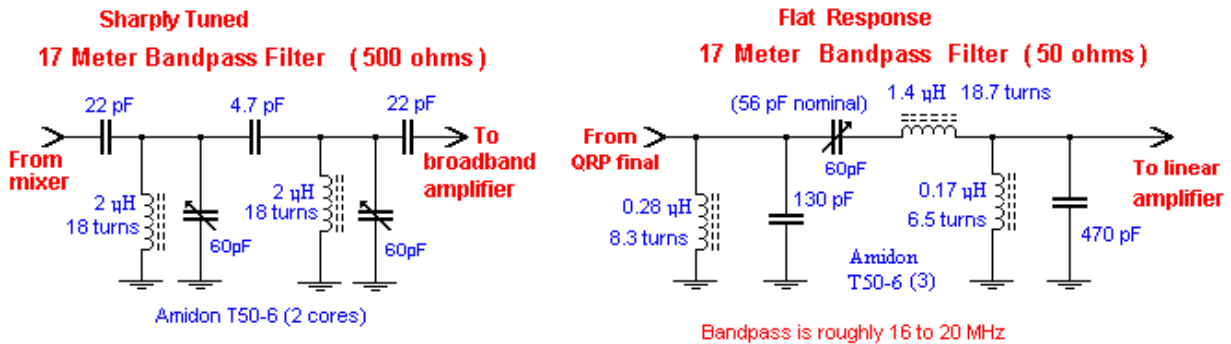
## 27 MHz VFO converter for 17 meters



To minimize the 17 meters/ 9 MHz pitfalls described above, I moved my 5 MHz VFO to 27 MHz as shown above. This circuit consists of a 22 MHz crystal oscillator, the 5 MHz VFO and the mixer/ filter. To suppress the second harmonic of the SSB generator, I filtered the output of the 9 MHz SSB generator with a low pass filter before the mixer. This reduces the 2<sup>nd</sup> harmonic before it goes to the mixer. Finally, I subtracted the 9 MHz SSB from 27 MHz to get 18 MHz. Notice that subtraction converts upper sideband to lower sideband and vice-versa. Whew!

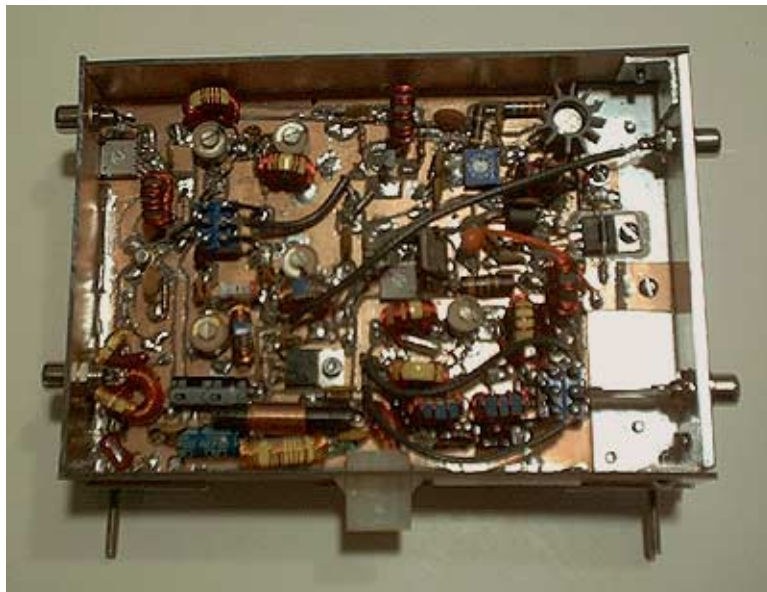
The output of the 5 watt driver needs both a low pass to get rid of the 27 MHz artifact and

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 9 MHz and 27 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 build, but it can't handle any power and the impedance is wrong.



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 LCs 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.

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.

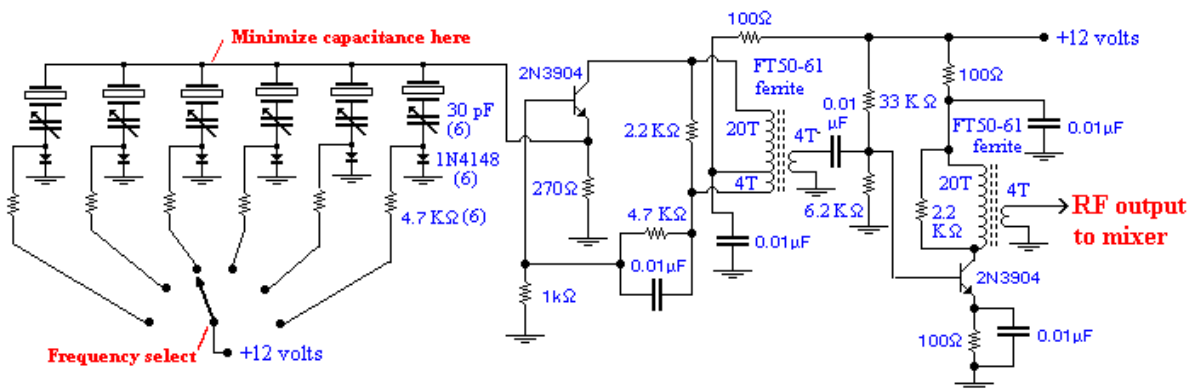


Even now that the 17 meter SSB is working, I still have to be careful. One morning I loaded up the antenna with the SSB generator set to CW. I got a big, fine sinewave and thought it was working perfectly. Then I looked at the counter, which read 18.003 MHz. Oops! How can that be? It turned out that the VFO cable to the driver was broken. With no VFO signal you will get a fine 17 Meter sinewave at twice your SSB generator frequency.

### 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 the rotary switch can be far away from the oscillator up on the front panel.

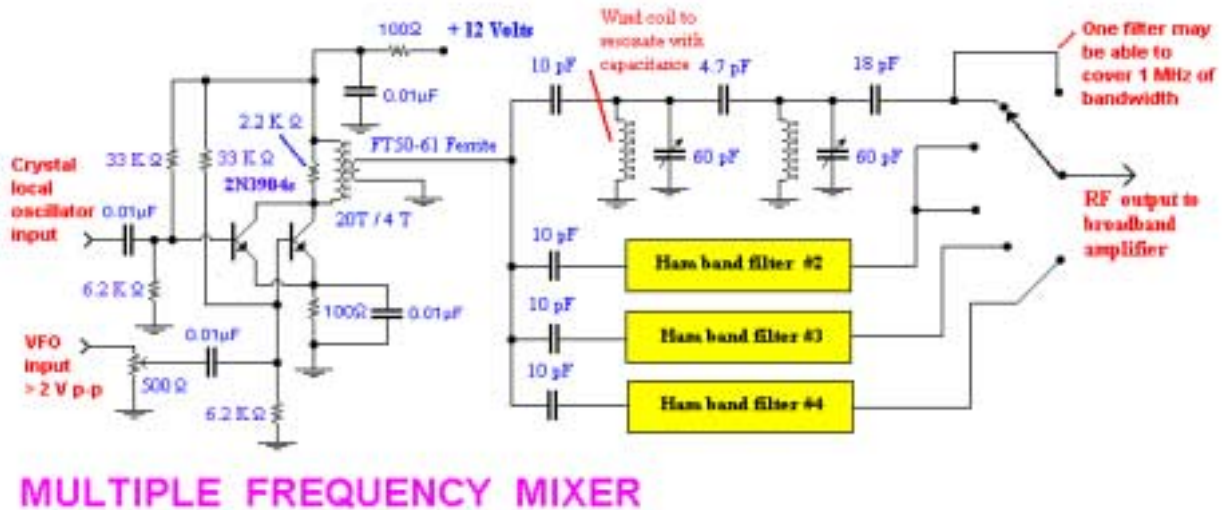
Be sure to minimize the capacitances between the oscillator emitter and ground. All those crystals connected to the emitter will be affected by the extra capacitance. This will tend to pull each crystal frequency away from its nominal value. Too much capacitance and it may not oscillate at all.



### MULTI - CRYSTAL OSCILLATOR

The 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 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.



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.

### 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 the 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 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.

### **Driving a 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 turned way, way down. Don't deafen yourself! When I speak into the microphone, my voice should sound clear, as though I 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 9MHz generator. You will probably find that speech sounds terrible at first. It may just be bursting, sputtering sounds.

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

You'll have to adjust the DC bias to the final 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 that is adequate for one band, may not be enough for another.*** That 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.

### **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 invent 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,



## 25. Chapter 15, Harris

KD6DCO in California. We failed to make contact. In that weak moment I thought I should stop messing around 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!!

