CRYSTAL SETS TO SIDEBAND

Chapter 15A

THE NOBEL PRIZE FOR SIDEBAND

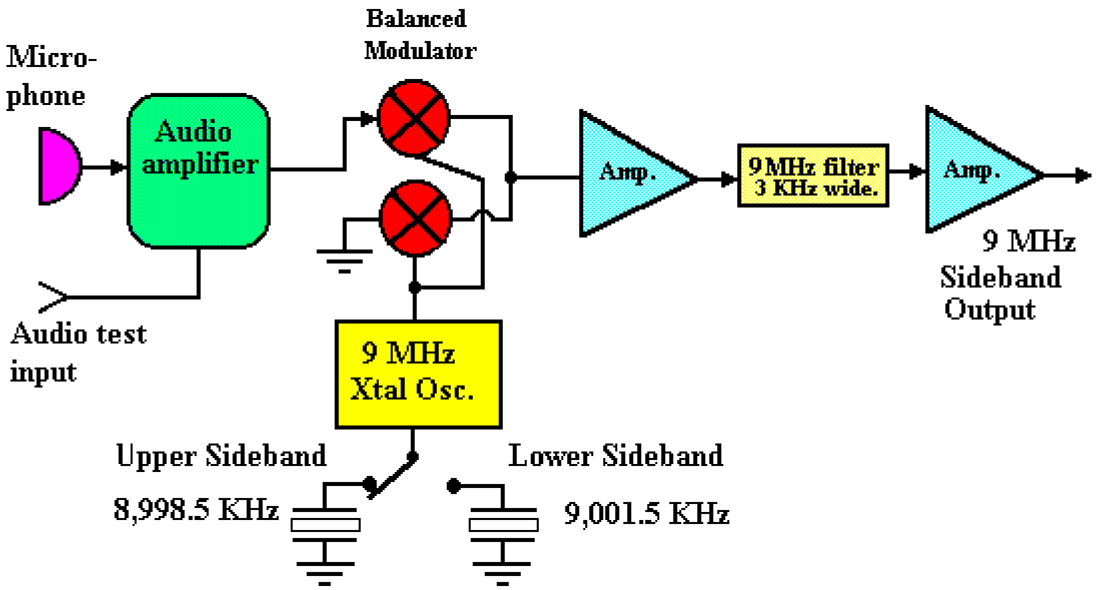
Generating the SSB speech signal

How sideband works

In the beginning of the book I mentioned that Glenn Johnson, WØFQK, was an elementary school principal who was on a crusade to recruit kids into ham radio. We were in the 8th 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 QRPs, VFOs and a receiver, then sideband is the next logical project. SSB uses most of the same basic circuits. Besides, you won’t really understand sideband until you’ve built one.

You begin with the sideband generator

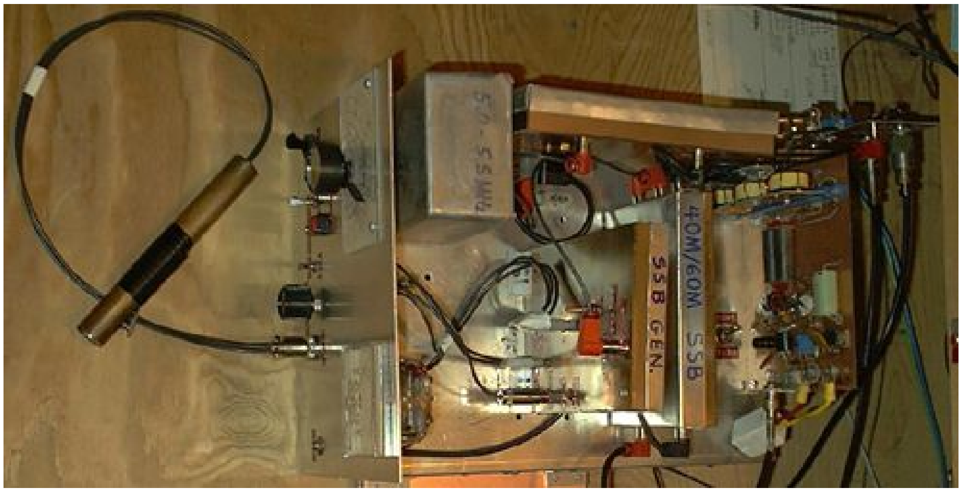


There are different ways of generating an RF sideband phone signal, but the most straightforward one I've seen is outlined above. The block diagram shows the five circuit blocks needed to generate a sideband signal on 9.000 MHz. This generator is similar to one found in the 1986 ARRL handbook. After 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 circuits 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 much harder than it appeared.

Don't burn your bridges

If you're thinking about modifying a working CW transmitter to sideband, don't do 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 broadband with no resonant circuits. The tuning is accomplished by separate, passive L-C filters place in between the broadband amplifiers. If you try to 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!

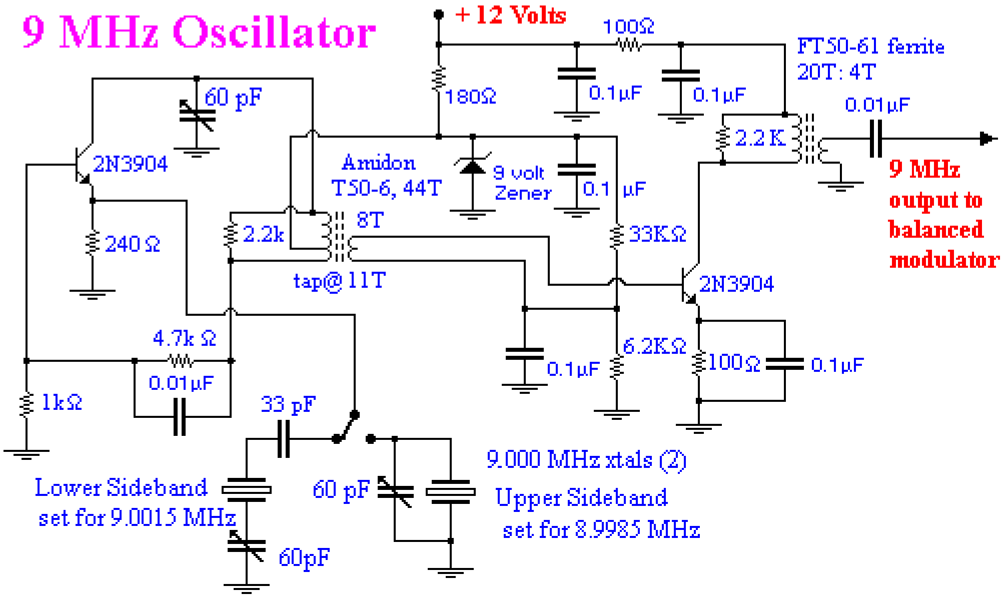


Homebuilt 100 watt SSB transmitter

No, it doesn't have to be this huge. However, I wanted loads of space so I wouldn't be forced to start over (again) when my prototype modules didn't fit on the chassis. The interior of the chassis is about 90% air. The remaining internal space is taken by the VFO and QRP driver power supplies and several inductor-capacitor low pass filters. The filters are needed to prevent RF feedback riding on wires entering the chassis.

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:



9 MHz sinewave oscillator / amplifier

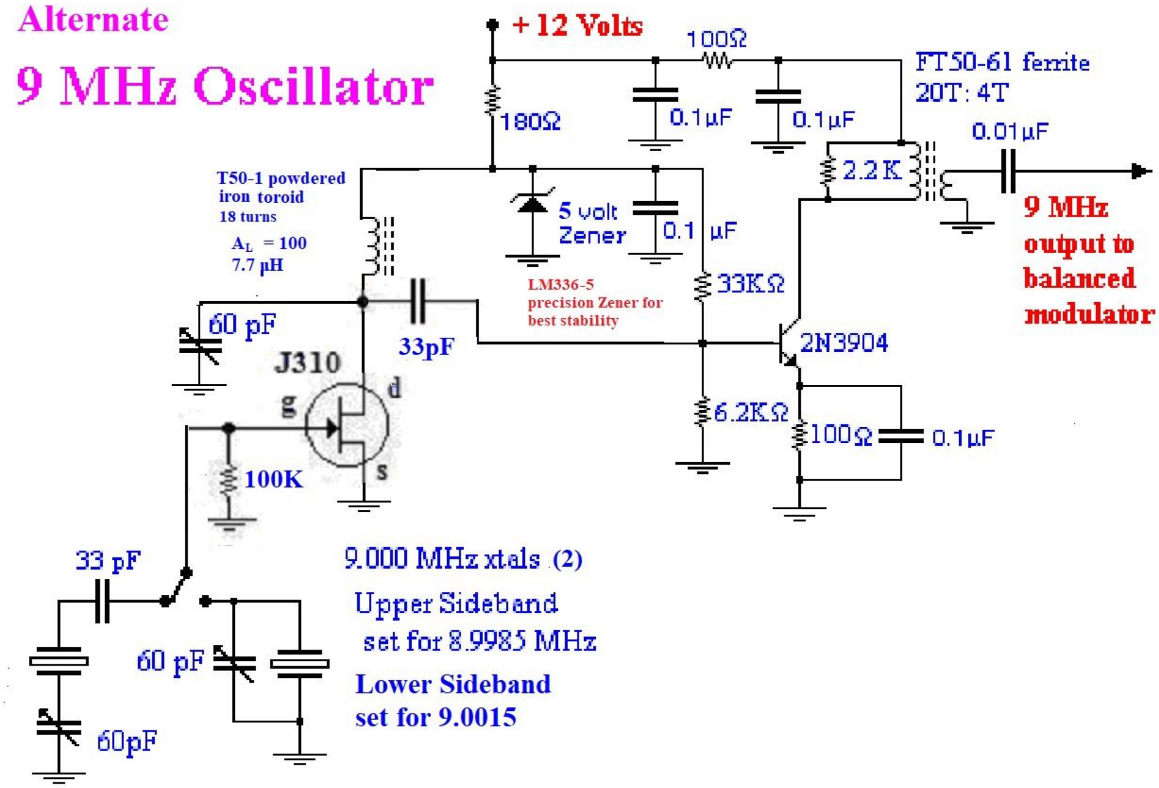
A stable, fixed frequency RF sinewave signal is generated by a crystal-controlled 9 MHz oscillator and amplifier that resemble the 7 MHz QRP transmitter described in Chapter 6. The crystal oscillator has two crystals. A switch enables the oscillator to select two crystal/ capacitor pairs so that the operator can switch between upper and lower sideband. Each crystal has tuning capacitors so that their frequencies can be pulled about 1.5 KHz up and down. This aligns the two AM sidebands with the ladder-style crystal sideband filter that follows the balanced modulator. The filter removes the unwanted upper or 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.

Just like the receiver project in Chapter 13B, you will need a bunch of inexpensive 9 MHz microprocessor crystals. How much capacitance is needed in parallel or series with a crystal depends on the individual crystal. The low side oscillator is the difficult one. Start by selecting the lowest natural oscillation frequency among your collection of crystals. Chapter 13B describes a homebrew universal crystal tester. Whatever oscillator you use for your tester, just pick the lowest frequency in your collection for the upper sideband filter. The frequency in the test oscillator doesn't matter, just pick the lowest frequency in your collection of 9 MHz crystals. Hopefully it will be low enough in the sideband generator.

For some crystals 8.9985 MHz might be reached with a relatively large capacitor in series with the crystal. For other crystals the parallel capacitance method is necessary and you may even need to pad the trimmer with an additional fixed capacitor. You may find that none of your crystals will go that low without becoming unstable and losing control of the frequency. You might even need to buy a custom crystal. As always, the oscillator collector circuit LC must be tuned to a compromise setting where the frequency will "lock in" to both crystals.

An alternate JFET oscillator



The advantage of both the JFET and Butler oscillator circuits is that, when first turned on, the output frequency does not drop significantly. As you know, tuning in SSB is not always easy. Having the frequency shift a 50 Hz or more would make your signal hard to copy. The LM336-5 precision 5 volt Zener also improves frequency stability.

The original version used T50-6 toroids which needed 44 turns to reach 7.7 µH. The wire had to be thin and the resulting toroids were loose and floppy. Using T50-1, the higher iron content used fewer turns and the coil was self-supporting on its leads.

Regulate the crystal oscillator supply

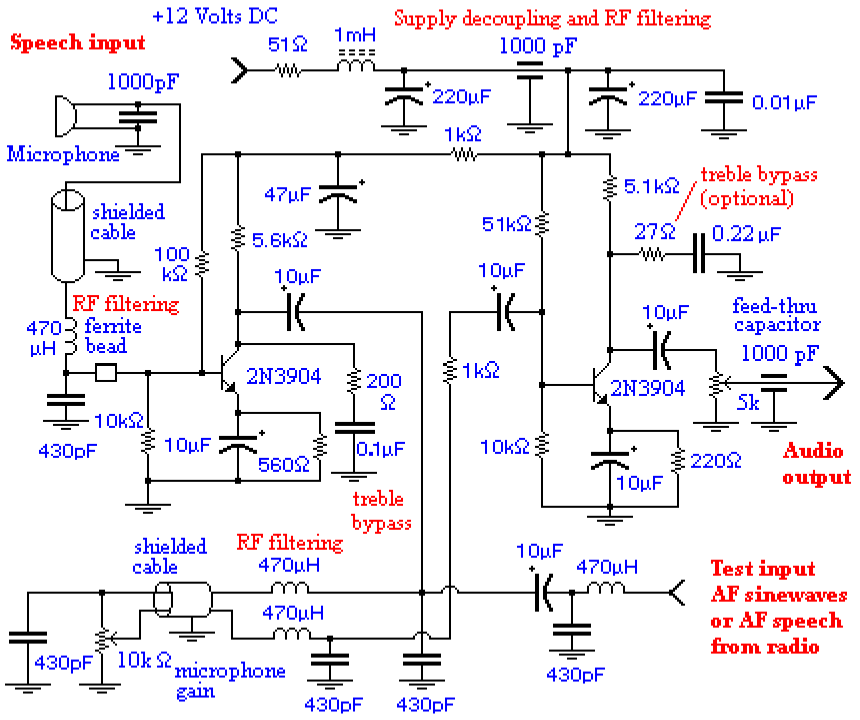
If you wish to use this transmitter for CW, the oscillator for the SSB generator also needs a precision regulated supply. In a CW-only transmitter the frequency was solely determined by the VFO and the crystal oscillator that was used to move the VFO to the desired band. A possible fault of any CW transmitter is "chirp," a change in frequency when the key is pressed. To prevent signal drift, the power supplies for the VFO and crystal oscillators were carefully regulated. In an SSB transmitter, the frequency is determined not only by the VFO and the premix oscillator crystal but also by the SSB generator module. Because any one of these three oscillators can cause drift and chirp, all three need to have regulated supplies.

SSB generator frequency drift is not noticeable with SSB because it would only change the pitch of the voice during the first moment that the transmitter is turned on. Drift is also unimportant if the SSB generator is used for CW at low transmitter power levels, that is, QRP. However, when the generator is driving a linear amplifier drawing 100 or more watts from the station power supply, the supply voltage may slump during that first second. If this drop in voltage is allowed to affect any of the oscillators, the result will be chirp.

Aligning the oscillator frequencies

The first step in aligning the oscillator frequencies is to test the oscillator and see that it will deliver a strong signal over at least a 3 KHz range. The variable capacitors for adjusting the frequency range shown above may not work for you. I found the JFET oscillator version had a wider range of frequency adjustment and it was easier to reach the required +/- 1.5 KHz.

The audio amplifier



An audio amplifier with test input

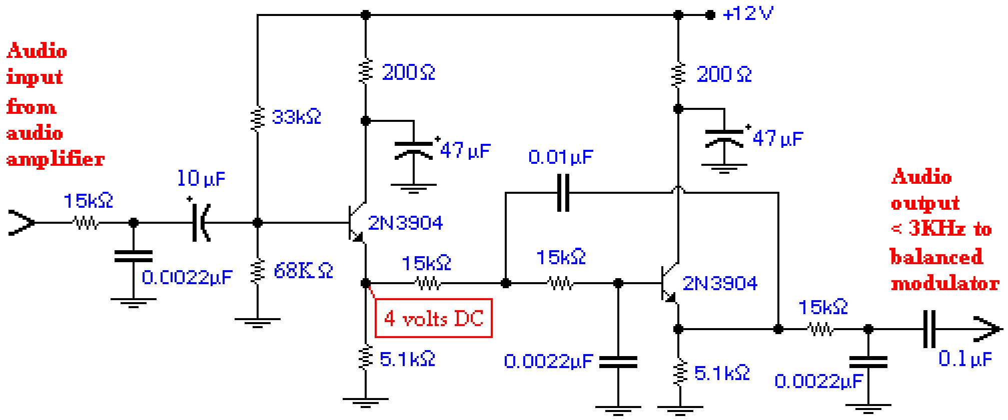
The microphone needs a high gain audio frequency (AF) amplifier before it can drive the balanced modulator. The audio amplifier is an ordinary design except that heroic effort is needed to shield it from RF. Notice the RF chokes, bypass capacitors and shielded cables on the two audio inputs, the audio gain pot and the +12 volt power input. Because crystal microphones 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 bypass filters*** on the collectors of both amplifier stages. That is, I shorted some of the higher audio frequencies to ground. 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.

Testing the amplifier

The first requirement of a audio amplifier stage is that the transistor bias is adjusted so that each transistor is turned half ON. In other words, audio amplifiers are biased to be "class A." With no input signal or microphone connected, measure the collector voltage of each transistor stage. If you are using a 12 volt supply, the collector voltage should be between 5 and 7 volts. That way, an amplified audio signal can be enlarged without the waveform being clipped or distorted by colliding with the supply voltage or ground. The 2nd stage is particularly critical.

Adjust the forward bias up or down to achieve a resting voltage of about 6 volts. You may have 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. After you check the bias, introduce an audio voltage, preferably using an audio sinewave generator on the test input. The output waveform should be a continuous, smooth sinewave with equal positive and negative peaks.

An optional 3 KHz audio filter



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 will just emphasize the lower frequencies. The filter uses two transistor amplifiers wired in the ***emitter follower*** configuration. Notice that the load resistors (5.1K Ω) for each transistor are wired between the emitter and ground, rather than between the collectors and the positive supply.

This audio filter is probably unnecessary because the crystal filter trims the bandwidth down to about 3 KHz anyway. So try the SSB generator first without the filter, then add it later if necessary. Even if you don't need this audio low-pass filter for this project, it is a useful circuit to know about.

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 feed back 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 µF audio output capacitor

Notice that the output from the filter circuit is not the usual big 10 µF capacitor but is only a 0.1 µF 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 µF 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

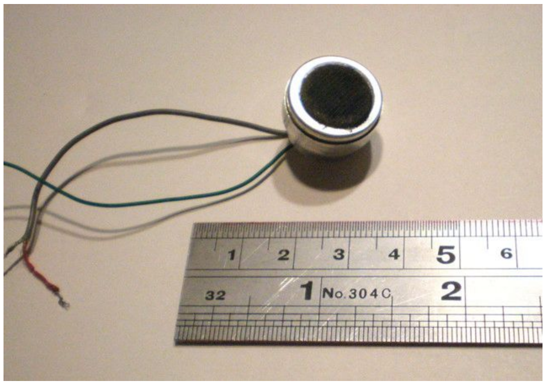
The 12 volt power supply lead for the audio amplifier also has a large RF choke (one millihenry) in series with the lead and passes through another feed-through capacitor bypass. In addition, the power supply lead is isolated or ***decoupled*** by means of the 51 ohm resistor and the large 220 microfarad 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 interference from RF feedback.

The final transmitter RF amplifier draws too much current to be practical for decoupling 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

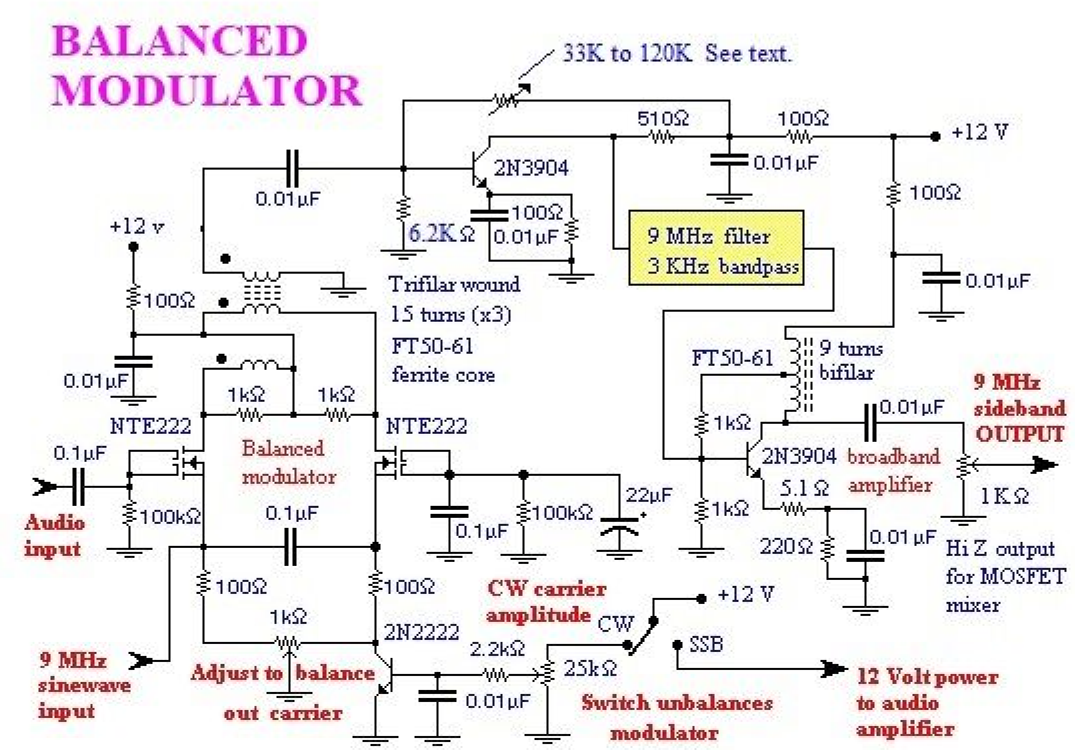
Radio Shack microphone cartridges gave a “tinny” sound. I was able to compensate with RC bypass networks on the collectors of both audio amplifier transistors to limit the high frequency components (treble) of the speech. For example, notice the 200 ohm resistor and 0.1 µfd capacitor combinations going to ground from the two transistor collectors. I also tried a 40 year old Hallicrafters crystal microphone designed for mobile radio. It worked well without the RC bypasses. Next I tried two tiny condensor-type electret microphones. One was too “bassy” and made a low frequency hum. The other, a Radio Shack PN # 270-092A, worked perfectly (to my ears) and is shown below. 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 1,000 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.

My microphone case/ copper pipe also contains a push-to-talk SPST button switch. This switch turns on the transmitter just like the switch mounted on my electronic bug. The switch lead-in has its own separate piece of RG-174 coax. So as you can see, my microphone cord is actually three parallel RG-174 coax cables. Obviously my mike cord should be a single, shielded three-conductor cable. But since I didn't have a cable like that, I used the three separate single-conductor shielded coax cables. To connect the mike to the transmitter, I used a (fairly) standard microphone connector that has 4 inner conductors plus the outer shield ring. I found this connector pair at Radio Shack and by some miracle it was the same connector used on my old Hallicrafters crystal mike.

The 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 an AM modulated RF 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 simply 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 winding 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 identical 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.*** Zero remaining carrier is optimistic. There were always be leakage onto whatever scope or measurement system you're using. My SSB generator reduces the scope image of the carrier to 1/50th of the original amplitude.

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. 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 ARRL Handbook.

An ideal SSB generator would produce zero carrier wave and zero unwanted sideband. Obliterating the unwanted sideband is relatively easy to do, but having absolutely no carrier is not so easy. Even though the generator circuit does a wonderful job of canceling the carrier, there is always a tiny carrier signal remaining. Notice that the broadband (untuned) amplifier preceding the sideband filter is biased class C. That is, it is not biased "ON" and this amplifier ignores signals smaller than 0.6 volts.

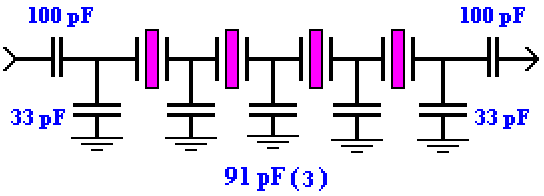
Generating a useful CW mode

To use this modulator to generate 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 remaining carrier. 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, I bypassed the entire balanced modulator modulator with another switch***.

Amplitude modulation

This sideband generator can also be modified to generate amplitude modulation. This is described in Chapter 17A. You may 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. In other words, it will transmit on upper and lower sideband simultaneously. DSB has a bandwidth of about 7 KHz.

The sideband filter



Four matched 9.000 MHz crystals

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 13B we made a 4-crystal CW receiver crystal ladder filter that is 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 crystal test oscillator shown earlier in Chapter 13B 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 50 Hz is good enough. I put in series trimmer capacitors on each crystal to make them all equal. This turned out to be unnecessary and I later removed them. This application is not nearly as critical as crystal filters for receiving CW in a receiver.

Using an RF 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 my 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 quite close to the nominal frequency.

Aligning the oscillator USB and LSB frequencies

Once you have the complete balanced modulator working, the first task is to find the exact central frequency that your 4-crystal filter will pass. First, detune the carrier balance pot so that there is always a strong carrier. Next, using the trimmer capacitors on the crystals, use a frequency counter to adjust the oscillator frequencies to find the exact central frequency. For example, you might find that it is 9000.20 KHz. This tells you that the USB oscillator needs to be set to 8998.70 KHz. Similarly, the LSB oscillator should be set to 9001.70 KHz.

I first used the usual class A amplifier in front of the filter which amplified even the smallest signals and resurrected the carrier wave from its grave. To cut out the carrier, I had to decrease the forward bias by increasing the resistance which connected the 12 volt supply to the base. The resistor was originally my (usual) 33K which I increased to 120 K. In that particular prototype, with no forward bias resistor at all, the low level part of the waveform was clipped off and the speech was distorted. Consequently, we need just enough low amplitude response to maintain the speech quality, but not so much that the tiny carrier wave is amplified. Maybe this is another place for a trim pot.

If your SSB speech is understandable with the receiver detector set to "AM" (the BFO turned off) you have too much carrier wave. On the other hand, if ***human communication*** is the goal, having modulation that is comprehensible using both AM and SSB detectors is a good thing. An article in Chapter 17A on narrow band AM demonstrates that having a little carrier wave only takes up 4 or 5 KHz of bandwidth. That is only about a KHz more than pure SSB.

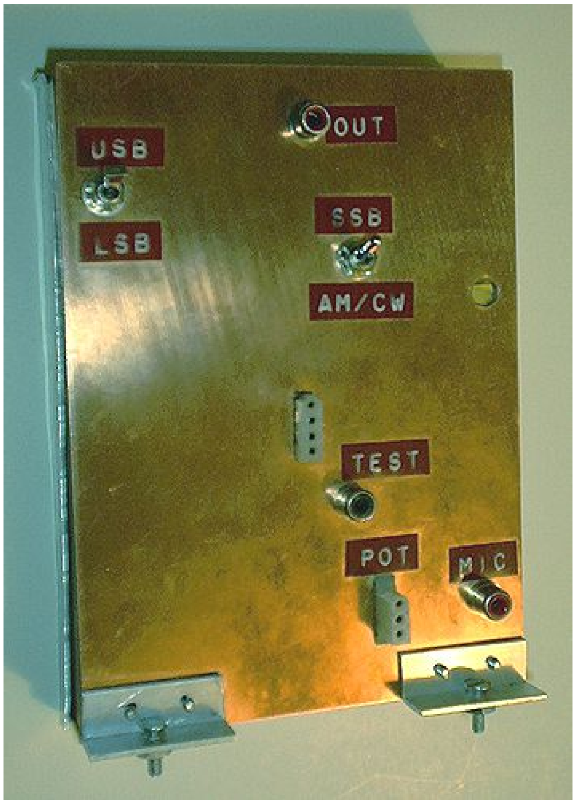
MECHANICAL CONSTRUCTION

Sorry! You must shield sideband.

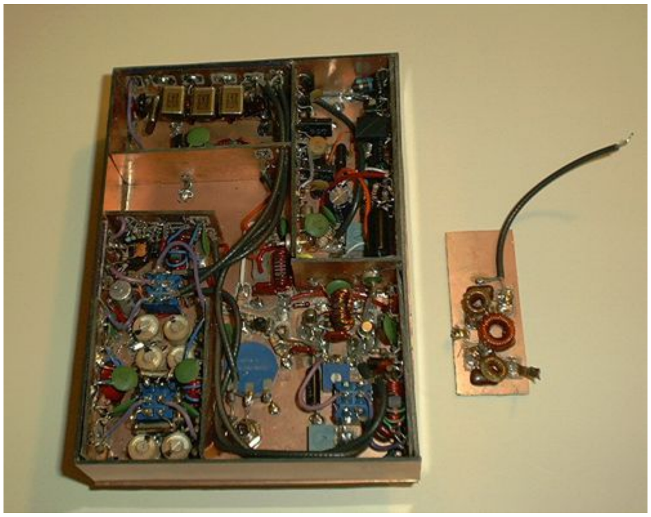
When building CW transmitters some of us think it's cool to have the pretty little parts out in the open where we can admire them. Unfortunately RF feedback can be a huge problem with SSB. Feedback is minimal with 5 watts output, but a serious problem with a 50+ watts output. To help prevent that, you 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 braided power cables to my RF modules, but eventually I worked out a way to mount the Molex DC input connectors directly to the shielded boxes. In this way I could plug the module directly onto the chassis with no exposed wires.

Actually, I still leave the 50 watt linear amplifier out in the open air, but all the low power modules and the power supplies are well shielded. If I were building a new 100 watt linear amplifier, I would design it to be shielded from the beginning. It is quite awkward to shield it later. 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

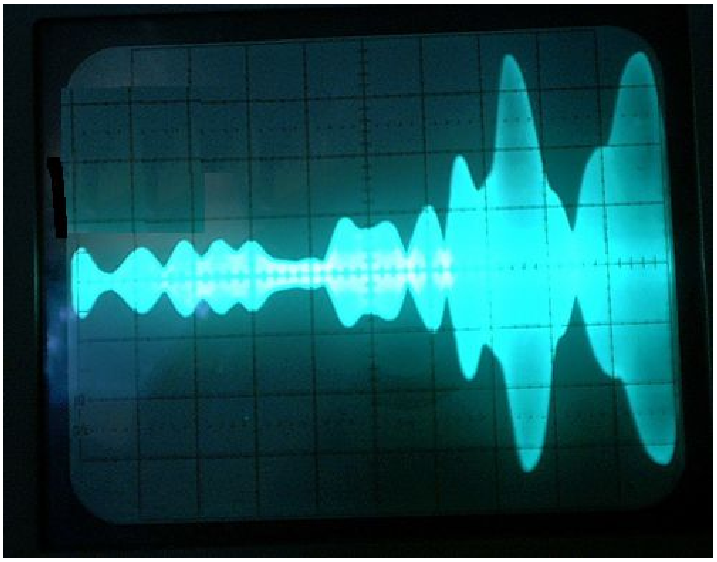
After learning that 9 MHz was impractical on 17 meters, I built a new SSB dual frequency generator. The 8 MHz crystals are in a row at the top left. The 9 MHz crystals are in a row just beneath them. The two frequency oscillators are at the bottom left. The balanced modulator is at the lower right. Notice 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 you can 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 should listen with one of those 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 RF 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 very low RF output.*** I define "low" as 1/20 the modulation peaks or less. If the resting power is much more than that, the modulation can be understood without a BFO. In other words, there is a significant AM component.

Checking out the microphone and microphone audio 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 another pair of 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 the audio input test jack. This input is shown on the audio amplifier diagram. 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.

In fact, modern SSB transceivers generate CW in exactly this way. A constant frequency audio sinewave is broadcast which produces a constant RF sinewave at a single frequency. The original carrier is gone, so only the one displaced RF frequency is present. This technique has the advantage that the upper sideband or lower sideband offset can be tuned by simply changing the frequency of the audio sinewave oscillator. The actual RF oscillator that generates the radio signal never has to change frequency.

Another way to think about single sideband is that it is a kind of 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 tone. That is, with SSB, you shouldn't see sinewaves impressed 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 1,000 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 poor low frequency power supply decoupling.

****

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. Unfortunately, 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 from 9 MHz to 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***. For example, 2 times 9 MHz is 18 MHz. This makes using a 9 MHz SSB generator and/or a 9 MHz VFO to generate 17 meters (18 MHz) extremely difficult. Notice that 6 MHz is also difficult because 3 times 6 MHz = 18 MHz.

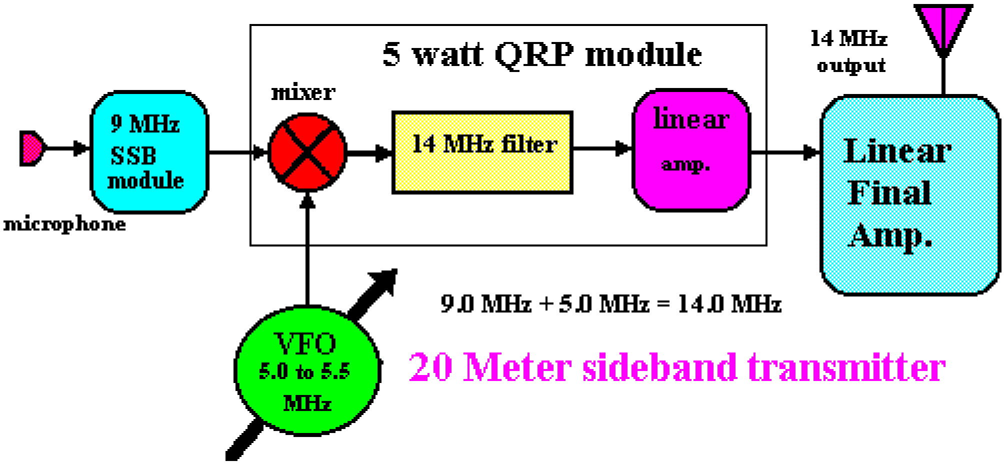
**** Don't use tuned amplifiers and mixers.*** When you stop talking, tuned amplifiers tend to oscillate by themselves at the frequencies to which they were tuned. Actually, getting rid of the noise and oscillations when you're *NOT* talking is harder than making the speech intelligible. Unlike CW, it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

**** Beware of having too much gain in your SSB generator and frequency converter.*** I originally had unnecessary broadband amplifiers in the generator output and also right after the converter mixer. These extra amplifiers amplified noise. Every moment 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 on the outer side of the PC board.

Getting on 20 and 80 meters

Hetrodyne converter for the SSB generator



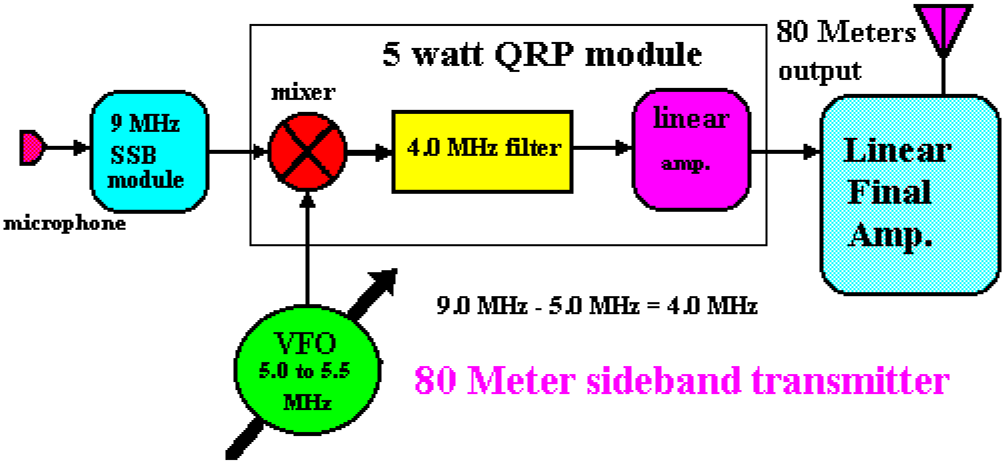
When starting with a 9 MHz sideband signal, 20 meters is the easiest hamband to reach. For 20 meters, a 5.00 to 5.35 MHz VFO signal is mixed with 9 MHz to give 14.0 to 14.35 MHz.

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.

What if you can't find affordable 9 MHz crystals?

Later: When I set out to build a VHF sideband transmitter, I discovered that cheap 9 MHz crystals were no longer available. I did find that even numbered frequencies such as 4, 6, 8, 10 and higher crystals were still easy to buy. If we were to build a sideband generator for one of these frequencies, we would still have to move the VFO to some frequency which had no hard-to-filter harmonics. For example, using an 8 MHz sideband generator to get on 20 meters, we could move a 3.5 to 4.0 VFO to 6.0 to 6.5 MHz. Then 6 MHz + 8 MHz = 14 MHz. Where there's a will, there's a way! As you'll soon see, many of upper bands will require moving the VFO. Sure, you can always build a 6 MHz VFO or even higher frequencies, but lower VFO frequencies will always be more stable.

Getting on 80 meters - a.k.a. 75 meters



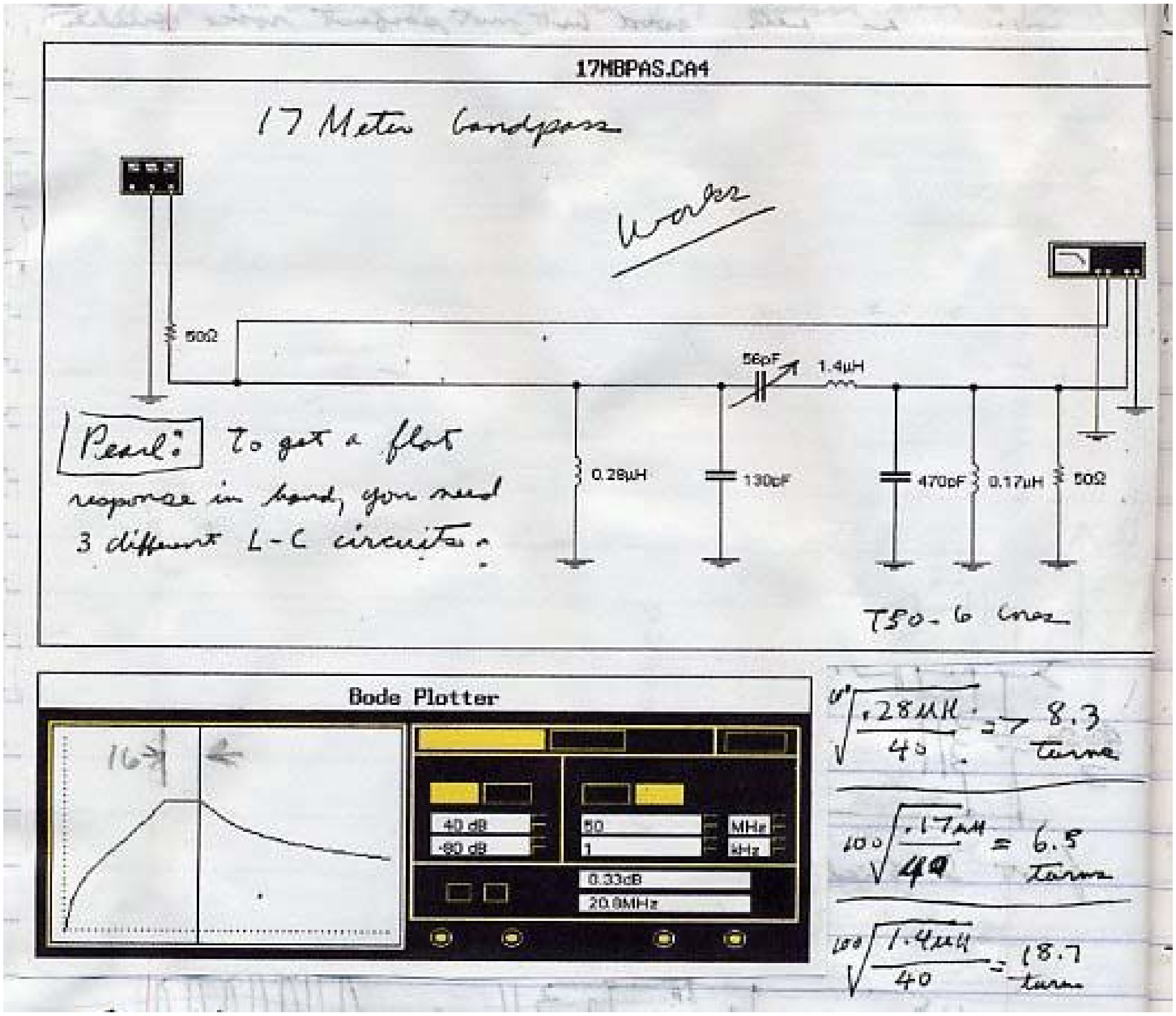
Now suppose that you wish to move the 9 MHz sideband signal down to 80 meters. 9 MHz minus 5 MHz is 4.0 MHz. The phone band extends right up to 4.0 MHz. So the 80 meter (75-meter) output signal can be as little as 20% different from the VFO signal. Filtering the 80-meter signal is almost twice as hard 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. Starting with a 3.5 MHz VFO, operation on 80 meters is almost impossible.

Spice makes filter design bearable

I found my Spice program essential for simulating filters before I built them. I first used a rather elderly program called Electronics Workbench, version 4. I now use a free student version of "5Spice" which I found on line. 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 was always far off from what I had intended. But then I could quickly plug in dozens of values into the simulation until I got the response I wanted. I get tired just thinking about building and testing those filters the old way and plotting the results at each frequency with real components.

In case you're wondering, how *REAL* engineers designed filters before Spice, they formerly solved for the L and C values with multiple, complex, algebra equations based on long polynomials. Even if they inserted all the numbers correctly in the equations, plowing through the arithmetic took forever and, for me, it usually resulted in useless nonsense. When I got to the real world, I quickly learned to do it with "Smith Charts," a graphical approach that lines up the resonances crudely, but effectively. In summary, modern computerized Spice is *WONDERFUL*.

Below is a copy of a page from my notebook showing the most difficult filter I built. It was a low impedance band pass for 17 meters. After it looked correct on the computer, I built a real one and it tuned up immediately using the variable cap in the center. The simulations for this project were 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 an RF 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, un-bypassed resistance, such as 10 or 20 ohms, 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 may 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, especially if you want it to work on more than one band.

Unfortunately we homebrewers have enough challenges 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. It really should be the same 9 MHz oscillator. 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 it as a transceiver from the beginning. It seems to be impractical to merge an SSB transmitter with an existing receiver.

The 2nd half of this chapter describes how to move the basic 9 MHz SSB signal to all of the HF ham bands, except for 160 meters.