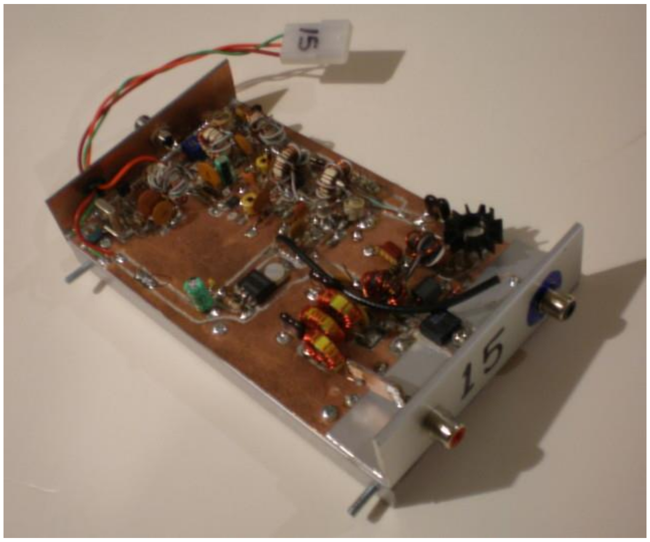
CRYSTAL SETS TO SIDEBAND

Chapter 11

Building a VFO and QRP for the higher bands



A QRP CW module for 15 meters is shown above. In some ways this module resembles the crystal controlled QRP module described in Chapter 6A. Instead of a crystal, it uses the low frequency VFO described in Chapter 10. A crystal-controlled premix oscillator (PMO) converts the low frequency VFO sinewave up to the desired ham band. This may seem overly complicated, but it's the best way to transport the stability of a low frequency VFO up to higher bands. The high frequency crystal oscillator drift is usually no more than 2 Hz per minute. This drift is added (or subtracted) from the low frequency drift and results in drift that is acceptable to modern hams receiving on their store-bought digital masterpieces.

If we had built a VFO for 21 MHz and we used all the tricks described in Chapter 10, the VFO drift would be at least 5 times worse. You may remember that the receiver described in Chapter 7C has a high frequency analog VFO. Unfortunately, if I used it to control a transmitter on 15 meters, I would receive howls of complaints. Other stations won't complain if your receiver drifts, but the Chapter 7C receiver drifts so much that I was not able to add multiple crystal filters or even sharp CW audio filters.

The 15 meter module receives an 80 meter VFO signal and converts it to cover the 21.000 to 21.450 MHz hamband. The VFO signal and DC power come in at the back. The 5 watts of RF output exits from the red phono jack at the left front on the heat sink. The telegraph key port on the right is marked with blue. The Chebyshev output filters are visible in the foreground. The PMO filter amplifiers are at the rear. It would be more professional if it were enclosed in a metal shield, but I like to see all the components.

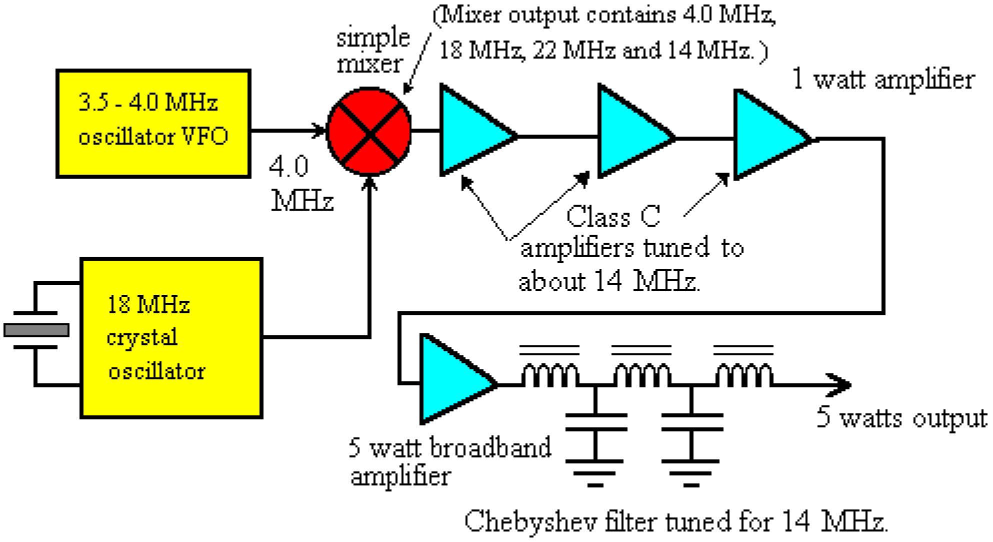
You can’t multiply frequency anymore

In the old days, it was customary to build a VFO for 1.8 to 2.0 MHz or 3.5 to 4.0 MHz.

Then for higher frequencies, we ran the signal through successive frequency multiplier amplifiers to get 7, 14, 21 and 28 MHz. A frequency multiplier was simply an amplifier tuned to the second or third harmonic of the input frequency. By using an amplifier tuned to multiples of the base frequency, the desired harmonic can be selected. For example, the tapped-coil tuned amplifiers described in Chapter 6A work well for this purpose.

If your driving oscillator is crystal controlled, then frequency multiplication is still practical. However, if your VFO drifts more than about 2 Hz /minute, you may get complaints on the upper bands. For example, if you have an 80 meter VFO you will have to multiply the frequency eight times to raise the frequency up to 28 MHz giving a drift of 16 Hz. But, if your VFO drifts 5 Hz, then the multiplied signal will drift 40 Hz at 28 MHz.

Fortunately, carefully built high frequency crystal oscillators can be quite stable even up to 30 MHz. The solution to the drift problem is to "add" a low frequency, wide band VFO to a stable high frequency crystal oscillator. These crystal oscillators are called ***Pre-Mix Oscillators*** or ***PMOs***. A ***mixer*** performs the frequency addition by literally combining two sinewave signals. The composite signal contains, not only the original signals, but also signals with frequencies that are the sum and difference of the original frequencies. Filters follow the mixer to extract and amplify the desired frequency component. The process is illustrated by the block diagram of a 20 meter QRP transmitter shown below:



20 Meter 5 Watt QRP Transmitter Block Diagram

PreMix Oscillator method of frequency translation

In the diagram above, an 80 meter VFO is "converted" to 20 meters. The 80 meter sinewave is mixed with the output from an 18.000 MHz crystal oscillator. When the VFO is set to 4.0 MHz, the output from the mixer is a messy looking waveform that contains four frequencies, namely - 4.0 MHz, 18 MHz, 22 MHz and 14 MHz. By tuning the next three amplifier stages to 14 MHz, the "contamination" goes away and we get a pure 14.0 MHz sinewave tunable up to 14.5 MHz. The Chebyshev filter attenuates frequencies above 15 MHz. Without it, there might be a significant signal broadcast on the second harmonic, 28 MHz. The crystal oscillator may contribute a Hz or two of drift, but basically, the drift on 20 Meters is the same as it was on 80 Meters. The mixer is comparable in function to those used in superheterodyne receivers, but PMO mixers are much easier to build. Low noise and extreme image canceling aren't necessary because both input signals can be as large as you like.

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CRYSTAL OSCILLATORS ARE STABLE, AREN'T THEY?

Several years ago I thought I had the VFO problem conquered. I had just enjoyed a nine-month "VFO vacation." During this time my signal was so stable that no one ever commented on it. I was quite proud of myself. Then I built QRP modules to get on 17 and 30 meters. Suddenly the complaints started up again and I was mystified. After all, I was using the same VFO. What had changed?

I checked out my VFO. I discovered that, when it was cold, it drifted downward 20 Hz the first minute. Then, after a few more minutes, it stabilized and the drift was plus or minus a 2 or 3 Hertz /minute. Of course, by definition, whenever I start sending, the VFO is cold. Therefore, unless I send for minutes on end, it will always be drifting. But even so, that didn't explain the 100 Hertz complaints.

Surely, it couldn't be the frequency converter crystal oscillators, could it? Crystals drifting!!?? Blasphemy! I checked out my 17 and 30 meter crystal oscillators. The 30 meter crystal oscillator drifted downward 50 Hz the first minute, 25 Hz the 2nd minute and eventually stabilized 150 Hz below the starting frequency.

Use HC-49 or larger crystals

The drifting of my 30 meter converter was caused by the crystal. The crystal was a teeny-weeny flat metal can, about 1/4" square and a 1/32" thick. It had come from my junk collection and I don't know what size number it was. However, I've since concluded that all the tiny ones in my collection aren't as stable as the HC-49 or larger crystals. Little bitty overtone crystals are particularly bad. Yes, eventually they settle down and become reasonably stable. But by then you have switched the QSO (conversation) over to the other guy. Now your oscillator is cooling off again so it will be ready to drift during your next transmission.

Not all tiny crystals are bad. I have some little half-size 9.00 MHz HC-49 crystals that work quite well in my receiver BFO and IF filters. The lesson I learned was that I need to check my oscillator stability during that first critical minute. The drift after 5 minutes is interesting, but not important for a ham transmitter.

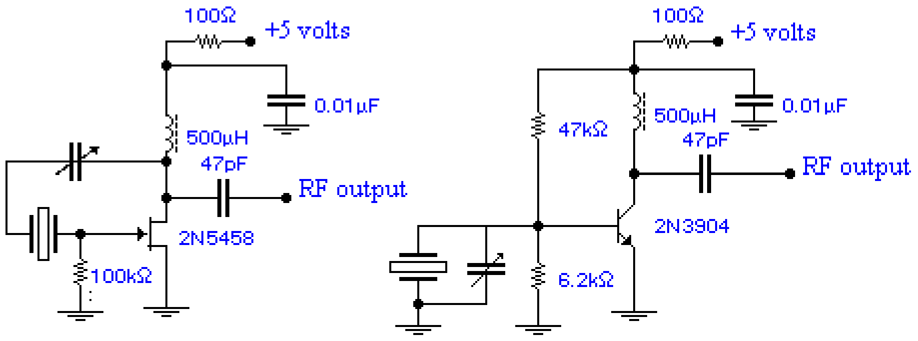
TTL oscillator blocks

The 17 meter board had one of those sealed-in-a-can, TTL oscillator blocks. They're like an integrated circuit with the crystal and oscillator sealed in the same package. I used one because it was the right frequency and I happened to have it in my junk collection. Yes, I remembered to run it at the correct 4.5 volts TTL voltage, not 12 volts. My oscillator started out at the right frequency, but it ran surprisingly hot. Then it dropped at 25 Hz per minute. Although the drift slowed, the frequency never stopped sinking. I had a big bag of various frequency oscillator blocks and they all did that. Every one I tried was terrible! All except the really high frequency ones - like 50 or 100 MHz. ... Those were really terrible. Some moved as much as 500 Hertz a minute. The only good news is that they're consistent - they all drift downward. It did not occur to me to try running the oscillator blocks at lower voltage, say 3 volts or lower.

Solutions to crystal drift

I could leave the crystal oscillators running continually. That could work with the ones that stabilize. There is no reason why crystal oscillators in a receiver can't be left running. The transmitter doesn't have to listen to receiver oscillators. However, I would probably be able to hear harmonics of a transmitter oscillator signal in the receiver. No, thanks. I already have some whistling artifacts in my receiver. Also, transmitter stability is more critical than receiver stability. If your receiver drifts a little, you're the only one who will notice. You could blame the drift on the fellow you're talking to. On the other hand, we homebrew guys shouldn't be quick to criticize others. The problem is probably ours, not theirs.

All oscillator circuits are not equal



Two common crystal oscillator circuits

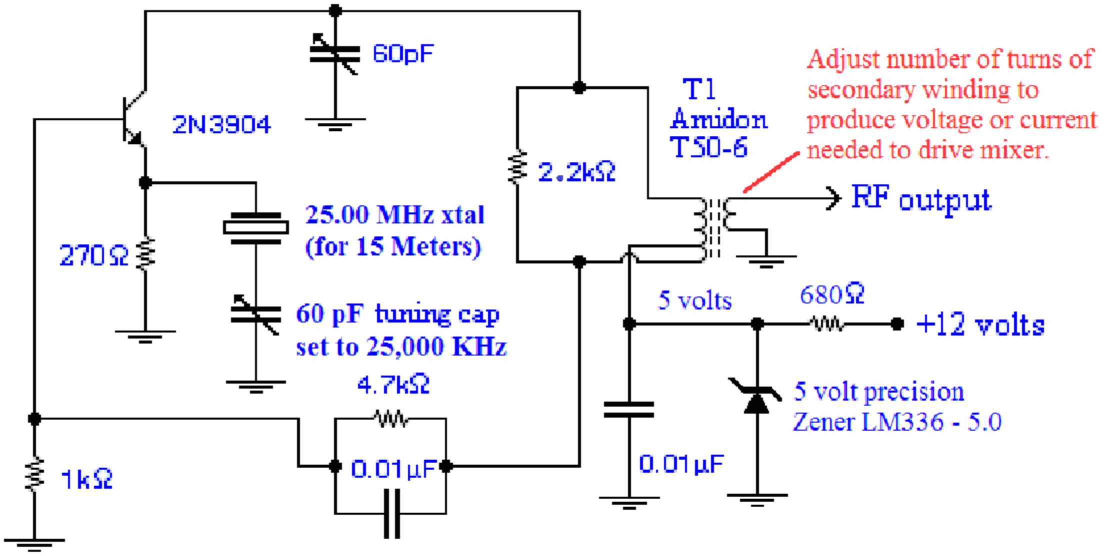
The drawing above shows two common crystal oscillator circuits that I used in some of my early QRP PMO converters. The variable capacitors are used to trim the frequencies to the exact Hertz. Both oscillators have the crystal connected to the base or gate. Remember that feature and you'll know which oscillators to be wary of. In my experience, ***these gate or base-connected crystal oscillator circuits drift downward when first turned on.*** Finally, after a minute or two, they stabilize.

Plan your frequency converters so the drifts cancel

Suddenly I understood why I received no complaints while using my 40-, 20- and 15-meter crystal-controlled frequency converters. They used oscillators with the crystals connected to the bases like those above, but the crystal frequencies were 4 MHz above the target band. As the oscillators drifted downward for the first minute, typically at 20 Hertz per minute, my 4 MHz VFO was also drifting downward at the same rate. For example, (25 MHz - 20 Hz crystal drift) minus (4 MHz - 20 Hz VFO drift) = 21.000,000 MHz. The result was a relatively constant frequency and no complaints. After a couple minutes the drifting stopped and the crystal oscillators were slightly more stable than the VFO.

Notice that if these converter crystal oscillators had been below the target hamband, then the drifts would have been added instead of subtracted. It turned out that my receiver was designed this way. Oops! Oh well, no ham has ever complained about my receiver during a QSO. Because I run my receiver oscillators non-stop, initial drift isn't important.

Butler is better



Adjust number of turns of secondary winding to produce voltage or current needed to drive mixer.

BUTLER OSCILLATOR WITH 5 VOLT PRECISION SUPPLY

A Butler crystal oscillator

I checked out every oscillator in my rig and discovered that some of them didn't drift when turned on. The stable ones used the Butler crystal oscillator above. Notice that the crystal and its capacitor are in parallel with the emitter resistor. This circuit is stable the moment you turn it on. Perhaps it's because the crystal has little voltage across it and receives little power to heat it. Anyway, Butlers typically drift no more than a hertz or two per minute. Two of my oscillators showed zero Hertz drift during the first minute. This is the same oscillator I recommended in Chapter 6. Depending on your application, Butler also has the advantage that the series capacitor can pull the frequency lower than the base-connected oscillators above.

You may be wondering about the purpose of the 2.2K ohm resistor across the primary winding: Without this resistor the oscillator will have maximum output. However, it will lock onto the crystal poorly and the frequency will be primarily controlled by the LC tank circuit. Also, the frequency will drift noticeably with changes in voltage or temperature. When the resistance is low, such as 2.2K, the frequency will always be controlled by the crystal. Unfortunately, the output amplitude may not be adequate. If your crystal isn't very active, you may have to increase the resistance to say, 10K ohms. Or you could try another crystal. As you can see, the resistor value is a tradeoff between stability and amplitude.

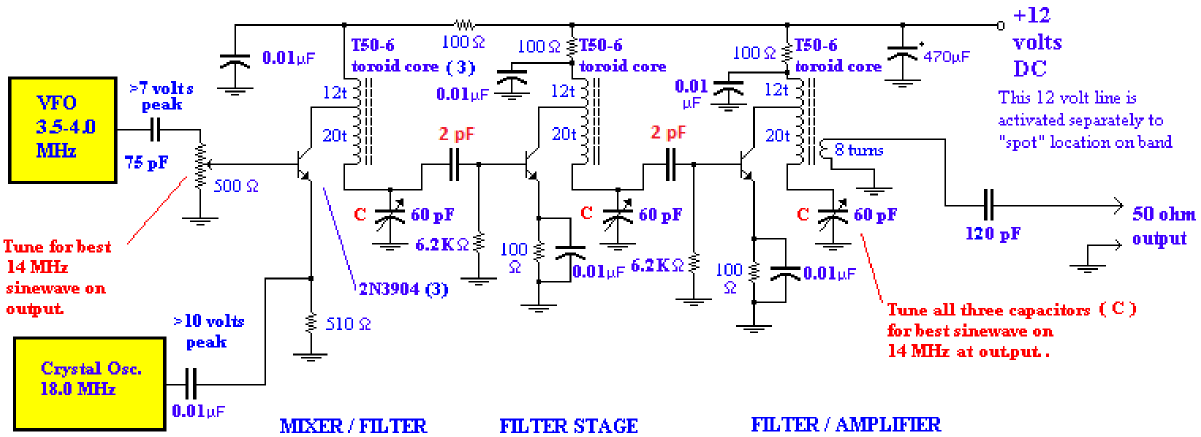
Drastic solutions to crystal drift

Suppose that you have done all of the above and your oscillator still drifts significantly. This is likely to happen with the higher frequencies, such as 25 MHz or 32 MHz. If necessary, the techniques in Chapter 10 for making a stable VFO can be applied to crystal oscillators. The simplest alteration is to run the oscillator on regulated 5 volts instead of 12 volts. This is illustrated above. This requires little board space and can be done without starting over with a new circuit board. Yes, I know. I've gone bonkers with the LM336 - 5.0 precision regulators. I started out just using them in VFOs and power supplies, but now I'm using them with crystal oscillators as well. Drifting is a huge problem and I've found that this is one of the few simple improvements that always makes an obvious difference.

The decoupling and voltage dropping resistor to the 12 volt supply is a 680 ohm resistor. A Zener diode is wired across the 0.01 µF "voltage reservoir" capacitor. The LM336 - 5.0 volt regulator can be used without the four diodes and trim pot. Without this fine adjustment it will still provide the stability you need to get you through those first 2 minutes of transmitting. If you measure the 5 volt supply during use, it will stay within a millivolt of where it started. This eliminates a big variable. Ordinary 5 volt Zener diodes do not work nearly as well.

Of course, when you reduce the oscillator supply from 12 to 5 volts, the oscillator output voltage will drop to 41% of its former level. If the crystal oscillator is driving a dual-gate MOSFET mixer, the mixer input impedance is extremely high. MOSFETs require very little drive current at only 1 or 2 volts. The oscillator will still function if you wind 2 or 3 times more turns on the secondary winding of the oscillator transformer. This will restore the 1 or 2 volts drive to the mixer. You will have to retune the oscillator because of the extra accidental capacitance the windings have added. However, the mixer will function as before. If you are using another style of mixer, a large secondary winding may demand too much current from the oscillator and stall it. In this case you will need to add an amplifier after the crystal oscillator. There may not be room on your circuit board, so this might be awkward. In short, build your crystal oscillator first and be sure it has the stability and voltage drive you need before you proceed.

A VFO controlled QRP



QRP DRIVER FOR 20 METER CW (14 MHz)

My first successful design for a CW QRP driver is shown above. Unfortunately each QRP driver covers just one band. However, once it's tuned and working, it covers the entire band without further tuning or fussing. Taken as a whole, the entire circuit shown above can be considered as "a 14 MHz VFO." It took me all those parts to generate a stable sinewave on 14 MHz! A simple crystal oscillator using 14 MHz crystals gives the same result, but of course it will only tune a few KHz at best. Life is hard for homebuilders in the 21st century.

I should mention that the same filter train can be designed so that it could be tuned up for several different bands, for example 20 meters through 10 meters. But of course, changing bands would mean changing the crystal oscillator and retuning the entire chain for the new band – not exactly convenient band switching.

Multi-band QRP modules

So far, I've built seven versions of this design covering 40 through 10 meters. My 80 meter QRP is just a simple amplifier that directly amplifies the VFO. Boy, was *that* easy! So why didn't I build one driver that works on every band? Each of the 7 difficult QRP modules are different and each one had to be tweaked and modified to get it working. By the time I had built the last QRP for 12 meters, my circuit was somewhat standardized. Unfortunately, I predict your versions will also need modifications in order to get 4 or 5 watts of clean sinewave out of each QRP module. I have only recently reached the confidence level where I might (again) consider attempting a multi-band transmitter. I did manage to build three different 2-band SSB QRP modules as described in Chapter 15. However, each 2-band module ended up unique and each needed many hours of troubleshooting and adjustment. Somehow, a circuit that worked on one band didn't work properly on another without changing the turns on a broadband secondary, changing transistor bias, different interstage coupling or using a transistor with lower or higher gain-bandwidth product (high frequency rating). A bandswitching CW transmitter that covers 160 through 10 meters is a formidable challenge for a homebuilder. A multi-band SSB transmitter is even harder.

Back in the vacuum tube days, multi-band transmitters were easy to build. That's because the spectral purity and stability of our signals back then was awful. Even the inexpensive commercial equipment was poor. I returned to ham radio after a 30 year absence. I brought my faithful old Heathkit DX-20 with the Heathkit VF-1 VFO down from the attic. The complaints about my signal quickly drove me off the air. I gave the these antiques to my local amateur radio club. The club sold them to raise money at a hamfest. Today I'll bet they slumber in someone else's attic. If you're a lightly-equipped tinkerer like me, you'll find that building even one band to work to modern standards is much harder than it looks. I suspect that's why hardly anyone does this kind of scratch-built homebrewing anymore. I strongly recommend that you start simple.

Changing the direction of tuning

In the 20 meter QRP driver above, the 80 meter VFO is mixed with an 18 MHz local oscillator. Note that the oscillator could also run at 10.5 MHz. As an experiment I ran my 20-meter QRP with both 18 MHz or 10.5 MHz crystals. All I had to do was change the crystal and it worked well. The 14 MHz filter remained properly tuned with no adjustment. The operational difference is that the direction of the VFO tuning reverses. As explained in the last chapter, this might be useful if you are using a varactor VFO and need to have the high frequency end of the VFO range tuning the lower end of a ham band.

The NPN transistor mixer needs a big local oscillator drive signal

The mixer stage in the 14 MHz converter shown earlier is just an RF amplifier made out of a bipolar 2N3904 transistor, much like the amplifiers in the filter train. This mixer is a class C amplifier stage with a 500 ohm emitter resistor. We can use class C because the input signals are much larger than 0.6 volts. One input, usually the VFO, feeds into the transistor base in the usual fashion. However, this drive level is adjustable with the input pot.

The local oscillator input is applied across the emitter resistor. I usually inject the higher frequency input across the resistor, but I've done it both ways. Unlike the input to the base, the input to the resistor has no amplification gain whatsoever. In order for the emitter signal to produce a big signal on the collector, all of the signal amplitude must be impressed onto the 500 ohm resistor.

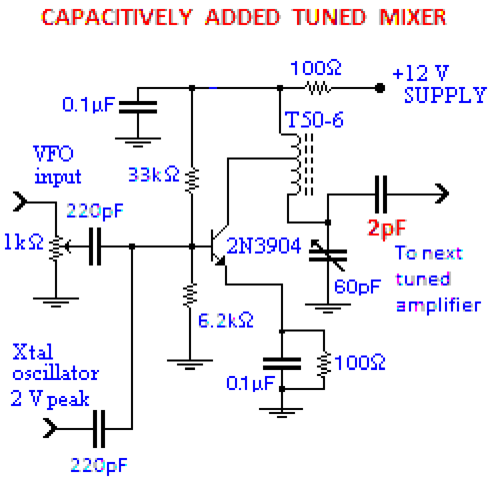
A lesson I learned the hard way was: ***Both input drive signals must be strong enough to turn the mixer stage full on and off like a switch, cycle by cycle.*** In the bipolar transistor design I needed at least a 20 volts peak-to-peak sinewave on the emitter resistor. A wimpy little 2 volt crystal oscillator signal will produce little difference-frequency component in the output and it will take many stages of filtering to extract the desired frequency. To get 20 volts pk-to-pk signal drive, I had to amplify the output of the crystal oscillator through an additional amplifier stage before it went into the mixer. I threw out two boards before I figured this out. I'm a slow learner.

On the other hand, the second input signal from the VFO, can be small because it is amplified by the transistor. Later, when you're tuning up the whole filter/ amplifier string for best output, you'll find that the maximum output and purity occurs at a specific setting of the input pot. The optimum VFO input level is not simply the maximum available amplitude.

The LC filter/ tank circuit on the mixer collector is tuned to the desired sum or difference frequency. Using the formulas in your CWS (Amidon) T50-6 core literature, calculate the inductance needed to go with your trimmer cap to resonate at the desired band, just the way we did in Chapter 6A. I found that T37 cores were too small and didn't produce the gain per stage that I got out of the T50s. In contrast, the T68 cores were unnecessarily large. Chapter 13B describes a superheterodyne receiver that uses band converters similar to these PMO QRPs. There is a table of coil specifications which can you guide you on the type of powdered iron core to use and the numbers of turns for the windings.

The simplest mixer of all

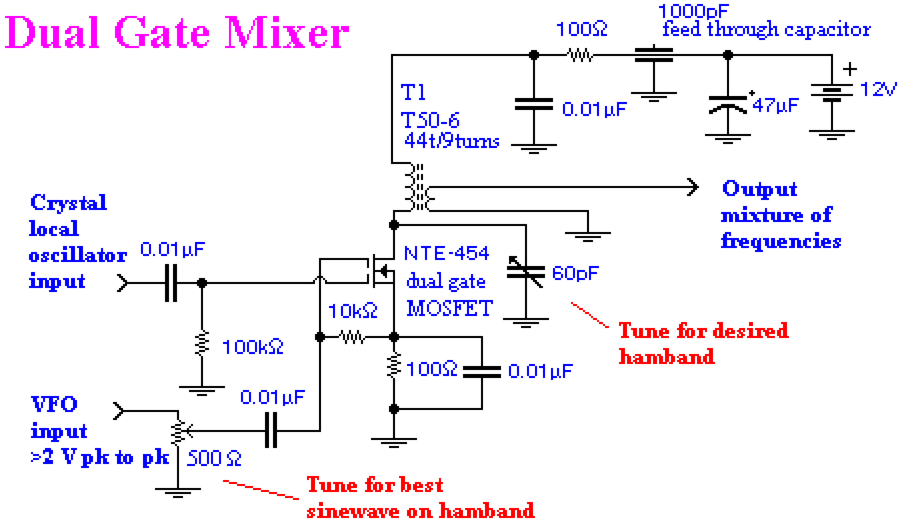
I can't believe I didn't try this sooner! Here is a single transistor class A amplifier just like my usual NPN hi-Q RF amplifier. Instead of the amplifier amplifying just one signal, it amplifies both the VFO and the high frequency crystal signal simultaneously. It is driven by two 220 pF capacitors connected to the base.



It worked perfectly in my rebuilt 40 meter QRP. One capacitor is driven by the VFO and the other is from the higher frequency crystal oscillator. The two signals are added across the one base-to-ground resistor. You need greater than 2 volts from both sources for this to work.

As you can see, mixers for this application can be quite simple. I have since learned that the following mixer designs are more complex than needed. The dual gate MOSFET mixer is suitable for superheterodyne receivers and is an expensive extravagance for this application. On the other hand, it works well and, because I hadn't yet tried the dual capacitor input mixer, I used MOSFET mixers for most of my QRP drivers.

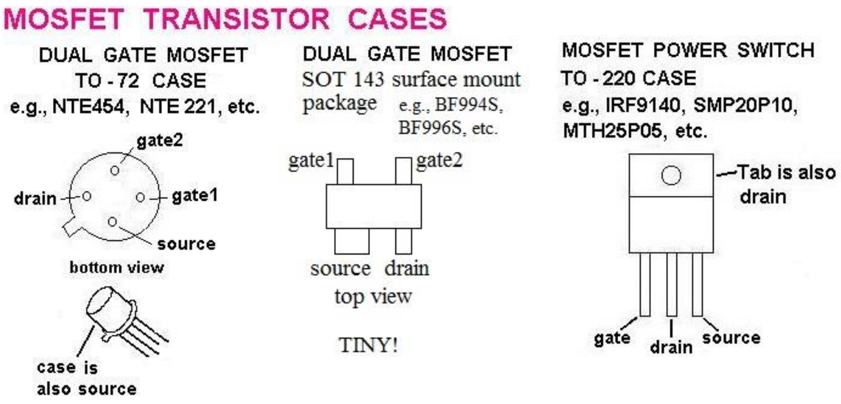
Dual gate MOSFET mixers



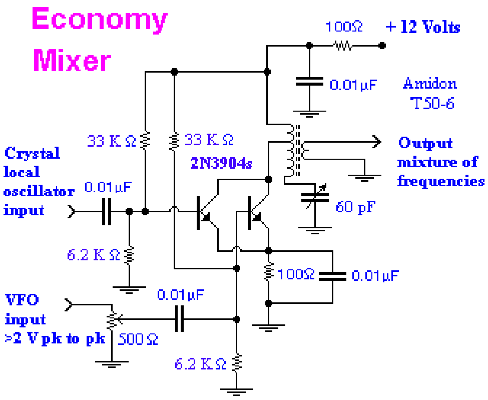
I began using dual-gate MOSFET transistor mixer stages in a receiver project and found them superior in several ways. A dual gate MOSFET is a small RF transistor with *TWO* input gates. Otherwise, in principle a dual gate works just like the power MOSFETs described in Chapter 6. Since both gates have lots of voltage gain, small signals may be used on both inputs. I found that each gate only needs 2 volts peak-to-peak and the output is much easier to tune and filter. Dual-gate MOSFETs formerly cost $7 to $10 each. Consequently, I didn't use them everywhere I would have liked. However, in 2012 dual gates such as the 3N140 became more widely available again and cost $3 or $4.

Even better, the surface mount versions such as the BF994S or BF996S cost about 70 cents each. The bad news about surface mounted dual-gates is that they are the size of a grain of sand with 4 tiny pins projecting from the corners. Using a knife, I cut an "X" in the PC board making 4 electrically isolated quadrants. The transistors are so tiny that the cuts to form the center of the "X" must be very fine, no more than about 0.5 mm wide. Solder a tiny drop of solder to one quadrant. Under a jeweler's loupe and holding the transistor steady with a pencil point, place the transistor in the center of the "X" and press the point of your sharpest soldering iron onto the pin over the solder droplet. After it sticks in place, you may solder the 3 other tiny pins in the remaining quadrants. Finally, go back and properly solder the first pin.

Steel tweezers work poorly to hold surface mount transistors because the magnetism in the steel sticks to the nickel in the transistor leads. These miniatures work as well as the "gigantic" old style TO-72 transistor case versions and, needless to say, they take up far less room on the board. I believe any dual gate will work well in the VFO frequency converter application. Mixers in superheterodyne receivers are not so uncritical, and some types may work better than others in your circuit.



The economy dual gate mixer



It turns out there are many ways to build QRP mixers. Two bipolar transistors in parallel can produce gain like the dual-gate MOSFET. If both input signals are small, both transistors will need forward bias, the 33K resistors. If one of the inputs is large enough, say 5 volts peak or larger, you won't need the forward bias for that input. This circuit would be plenty sensitive for a receiver mixer. However, because it has PN junctions, it will be noisier than the dual-gate MOSFET mixer and not recommended for receivers.

Tuning the mixer

When you first apply the two input frequencies to the mixer stage, the scope will show a messy, complicated waveform on the collector (or drain). It will be impossible see what setting of the trimmer capacitor on the drain is best. The first step is to disconnect the input frequency that is farthest from the desired output frequency. Now it will be easy to tune the trimmer for maximum gain. For example, in the 20 meter filter train shown earlier, tune the first mixer/ amplifier to the crystal frequency of 18 MHz. When it's peaked at 18 MHz, look to see if the trimmer is at or near maximum or minimum capacitance. If it is near minimum capacitance, but not quite there, the mixer stage should tune up well at the lower frequency, 14 MHz. If the gain at 18 MHz is maximum while the capacitance is tuned to either minimum or maximum, then you know that your toroid coil has too many or too few turns. Trimmer capacitors usually rotate freely around and around, so minimum and maximum are not obvious. ***When your mixer coil and capacitor are correctly matched to your desired frequency, there will be two optimum settings in each 360 degree rotation of the adjustment screw***. If there is only one best setting, it means that your coil has too much or too little inductance and the mixer is not working as well as it could.

Later in the receiver Chapters 13A and 13B and the sideband Chapter 15 there are examples of un-tuned, broadband mixers that could also be used. Broadband mixers don't need tuning and they are less likely to self-oscillate. However, they have less gain and for PMOs you will need more stages to reach the same degree of frequency purity.

Filtering the desired frequency from the mixture

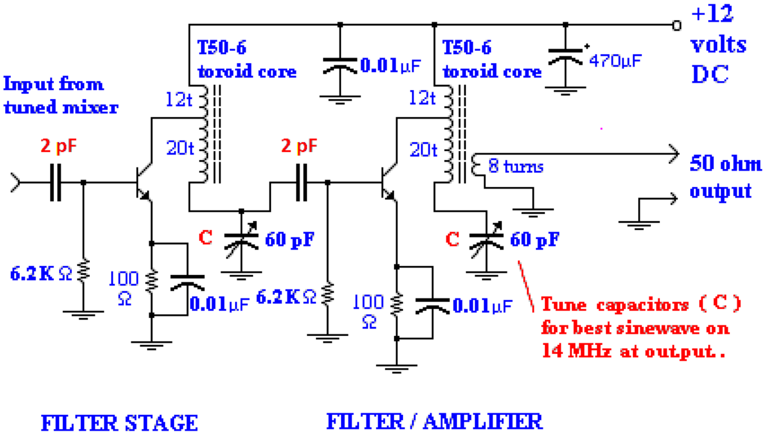
At the mixer drain (or collector) there are four frequency components and you must filter the one you want into a pure sinewave. I first considered using complex Chebyshev filters as described in the ARRL Handbook. I was discouraged by the many inductors and capacitors needed to achieve the desired "pure" output. Besides, my first attempt worked poorly. Eventually I realized that Chebyshev filters have the advantage that they can be designed for arbitrarily low impedances - in other words, high power signals. In the PMO application here the signal is extremely high impedance (low power) and relatively simple parallel LC filters are adequate. Chebyshevs are not needed. Using LC filters between broadband RF amplifiers for frequency conversion is illustrated in the SSB transmitter in Chapter 15.

My CW transmitter uses two sharply tuned amplifiers as filters, just like an IF amplifier in a receiver. The ease of filtering depends on how far the desired frequency is from the local oscillator and other mixer products. For example, on 14 MHz, the 4.0 MHz VFO is 28% of the desired frequency. 14 MHz compared with the 18 MHz crystal oscillator is 77% of the desired frequency. 18 MHz is pretty close but isn't a problem. Now suppose we use a 32 MHz crystal on 10 meters (that is, 28 MHz). With a 4.0 MHz VFO, the desired frequency is 88% of the crystal frequency. You will find that tuning this is much more "tweaky," difficult, but still practical. In general, having the crystal oscillator *BELOW* the desired frequency makes tuning the filters easier.

In summary, the tuned amplifier approach is reliable for CW and is extremely hi-Q. It can separate frequencies that are quite close. However, it is not suitable for use in an SSB transmitter because the hi-Q amplifiers tend to self-oscillate during pauses in the speech signal.

Bandpass "filter amplifiers" - they just filter and don't amplify

Each filter/amplifier stage is essentially like the bipolar transistor mixer shown earlier. However, the emitter resistor is bypassed with a capacitor so that, from the point of view of the RF, the emitter is connected to ground. The purpose of the parallel RC connected to the emitter is to stabilize the gain and reduce the DC current drawn by the stage. You may use either class A or class C amplifiers. I often use class A amplifiers, meaning the stage is biased “ON” at all times with a 33K resistor, just as we did back in Chapter 6A. Class A amps draw more current than class C amplifiers that are basically the same circuit. However, they handle wave components of any amplitude. To say it another way, class As work over a wider range of input amplitudes and don’t introduce harmonics that must be filtered out.



FILTER FOR 20 METER CW (14 MHz)

An RF filter/ amplifier stage

Two stages of filter/ amplifiers are shown above. Including a tuned mixer stage, three stages of tuned amplifier were enough for any HF band using an 80 meter VFO. However, as explained earlier, when you are trying to separate two frequencies that are only 10% different, having only 3 filter stages is just barely practical. If you are having trouble getting a pure sinewave, just add another tuned stage. As shown above, the above stages are class C. If desired, you could forward bias these amplifiers on with 33K ohm resistors and convert them to class A amplifiers. In this way, they could handle smaller signal levels.

Use tiny interstage coupling capacitors

The ***BIG SECRET*** to making “filter amplifiers” work is to use tiny coupling capacitors between amplifier stages. Notice the **2 PF** capacitors between stages in the diagram above. The purpose of these amplifier stages is filtering, not power gain. The LC circuit “rings like a bell” when the input contains a frequency that resonates with the LC. This ringing exaggerates the desired frequency component. If you load the LC circuit by trying to couple significant power to the next stage, it’s like putting your hand on a ringing bell. The ringing will be damped and the filter effect dies. To avoid damping the ringing, use tiny 2 pF capacitors. OK, on 80 Meters maybe 5 pF is acceptable. And on 10 meters 1 pF works well. However, 2 pF works over the entire HF spectrum. If you use large coupling capacitors, say 50 pF, that 50 pF becomes part of the LC resonance and will dominate the tuning and lower the Q. Also remember that your scope or counter probe contributes another 15 pF or more. ***To make a final adjustment of a filter***

***stage, you must put the oscilloscope or counter probe on the output of the stage FOLLOWING the one you are adjusting*.**

With one stage of filtering after the mixer, the waveform will still look “messy” on the scope. But after two stages of filtering it should be possible for your frequency counter to lock onto the correct frequency. As you tune the VFO, the reading on the counter should track solidly with no drifting and dancing digits. When properly tuned, the sinewave will look nearly perfect on the oscilloscope after two stages of filtering. When you first try to tune up all three stages at once, you may be frustrated, but keep trying. When your counter “locks” onto the desired band, look at the ringing on the trimmer of the last stage with the scope while tweaking all the previous stages for the best sinewave. Notice that perfection occurs when you trim the input level of the VFO on R1. Now you understand why the input is applied through a trim pot.

If you own an RF signal generator, you have a simple way to tune up filter/ amplifiers. Unplug the VFO and replace that signal with a test signal from the generator set to the desired ham band frequency, i.e., 30, 20, 15 meters, etc.. If your L-C tuned circuits are designed correctly, they will peak up in the right ham band immediately. Your circuit will appear to ignore the signal from the crystal oscillator. Then, when you plug the VFO back in, the L-C circuits will be tuned correctly with little or no adjustment.

In general, QRPs for 40 meters are easy. But if you use an 80 meter VFO, your filters will easily tune up on twice the VFO frequency. That means the tuned amplifiers could ignore the 11 MHz input and tune up on double the VFO frequency. For instance, if you want 7.040 MHz and you use an 11 MHz crystal, the VFO must be set to 3.960 MHz. I found it easy to tune the filters out of the band to 7.920 MHz.

An advantage of the filter-amplifier design is that the 2 pF interstage coupling capacitors are extreme high pass filters. This means that the filter produces a clean sinewave with few or no low frequency artifacts. In other words, when you look at the waveform on the oscilloscope, there will be no tall waveform cycles and no short ones that occur periodically. A messy waveform makes it difficult for your frequency counter to lock and produce a stable, reliable frequency reading. If you use the filter method described in Chapter 15, it will produce more low frequency artifacts and the final amplifier stages may have to be modified with low pass filters to get rid of these impurities.

Running low on 2 pF capacitors?

Tiny 1 pF or 2 pF fixed capacitors are rare. If you don't have any, simply solder a couple inches of insulated wire to the base of the transistor of the following stage. Then pass the free end of the wire through the transformer core of the preceding stage and wind one to 3 turns. Do *NOT* solder the free end to anything. (If you ground one end, it will short out the DC bias resistors.) The wire is merely "a conductive object" that makes a small capacitance with respect to the primary winding. For instance, I measured 2.5 pF of capacitance with two turns on a T50-2 core.

The capacitance between the center conductor of coax to the outer coaxial shield can also be used to make small ***homebrew capacitors***. Here is a terrific example: I used to work with an electronics engineer, Bob Anderson. Before I knew him he had worked on the Apollo command module spacecraft, the moon ship. Bob's job was to design and build the manual joystick control system used by the pilot. The only time the manual system was ever used while re-entering the atmosphere was during the Apollo 13 mission. The crew capsule was crippled and frozen, the batteries were nearly dead and the crew was exhausted. As you can imagine, the joystick servos had to be fast and tight with a precise response. A slow or sloppy response might have allowed the crew module to tumble during re-entry causing them to burn up in the atmosphere.

At that time NASA insisted that analog parts in electronic designs could not be adjustable. Trimmer pots and trimmer caps were specifically forbidden. NASA didn't want technicians to diddle with trimmers after the electronics left the factory. Unfortunately a servo system with this speed and precision required little trimmer caps, exactly the kind we use in our QRPs. Bob managed to make his servos meet specifications easily enough, but he was stumped by how to tune the damping and overshoot without variable capacitors.

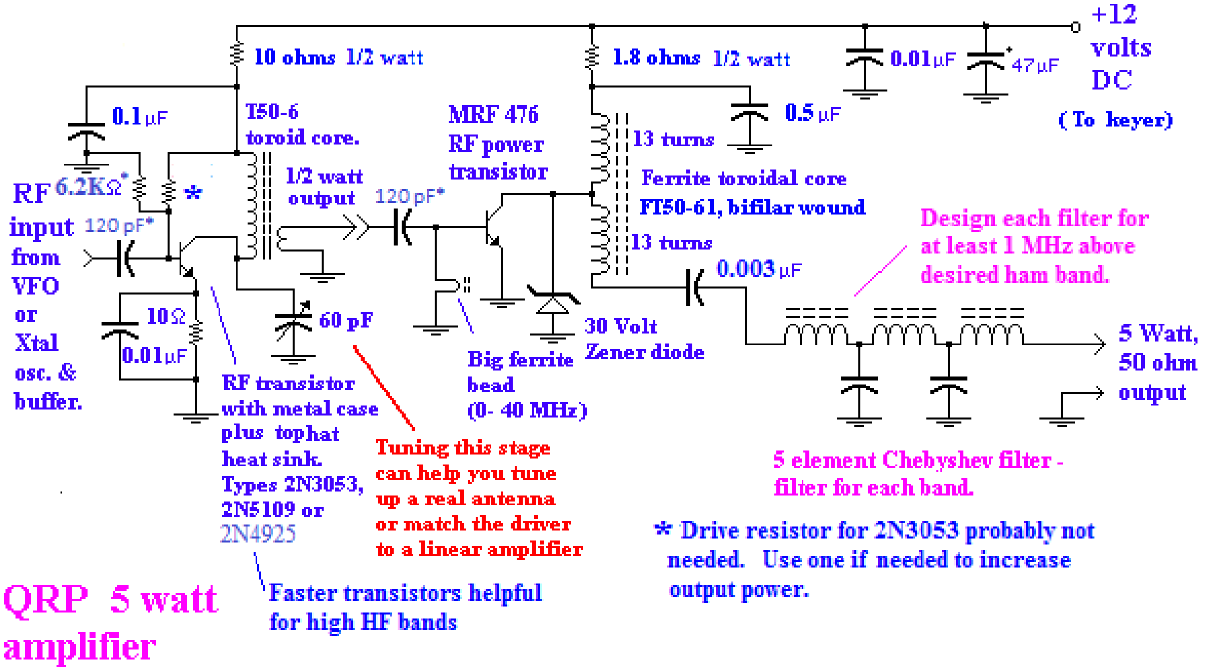
It was a Friday and he was supposed to demonstrate his finished servos to NASA engineers Monday morning. He struggled all weekend, living rough in the lab. Late Sunday night he had the brainstorm. He soldered one end of short lengths of thin coax, (such as RG-174), across the points where trimmers were needed. He used his diagonal cutters to clip the loose ends of the coax shorter and shorter until the servo stabilized. If he cut off too much, he soldered on a new, slightly longer piece of coax and then carefully pruned it to the ideal length. Monday morning arrived and NASA was satisfied. The servos never failed on a flight.

Where to get crystals for your local oscillators

Yes, you need a separate crystal for each band. Fortunately, when using an 80 meter (4 MHz) VFO, standard microprocessor frequencies can cover the major ham bands. The 40, 20, 15 and 10 meter bands can be covered by standard crystals for 11 MHz, 18 MHz, 25 MHz and 32 MHz respectively. Mouser Electronics and Digi-Key sell these for less than $1 each. For WARC bands and 160 Meters you may have to spend some money or be creative. As explained earlier, don’t use those TTL oscillator blocks. Cheap ceramic resonator “crystals” are also a poor idea. Significant drift is not worth saving a few dollars. I simply surrendered and ordered custom crystals for 30 and 17 meters, 13.7 MHz and 21.9 MHz, respectively. For 12 meters I used an 86.15 MHz VHF overtone crystal (case size H-49) I happened to have. I tuned the oscillator to the crystal primary frequency, 28.72 MHz, and it worked well. $86.15 \div 3 = 28.72$ MHz. I haven't built a QRP for 160 meters because my largest antenna is inadequate for that band.

The QRP power amplifier stages

Your VFO now tunes the HF band of your choice. To increase this signal up to 3 to 5 watts, you will need two or three stages of power gain as described earlier in Chapter 6A. My QRP boards use two power amplifier stages. The first is a tuned stage. The second is a broadband amplifier followed by a Chebyshev lowpass (or high pass) filter designed for 50 ohms. This scheme seems to combine the advantages of both systems. For example, suppose I connect the QRP output to a non-inductive 50 ohm dummy load. All the CW QRP boards I have built have no trouble delivering a clean sinewave into a dummy load. Tuning is easy, *until* you have to connect it to a real antenna or to a final amplifier. A tuned stage gives you a way to adapt to loads which have some reactance.



I recently built a prototype 10 meter AM modulated walkie-talkie that used this circuit for the second amplifier following the crystal oscillator. I began by using a tapped inductor tank circuit like the inductors in the oscillator and buffer. However, I got better performance and more power output by using a simple L-C parallel tank as shown above. The L-C circuit simply becomes an inductor essentially in parallel with the tuning capacitor. For 10 meters the walkie-talkie used 15 turns primary and 4 turns output secondary on a T50-6 toroid.

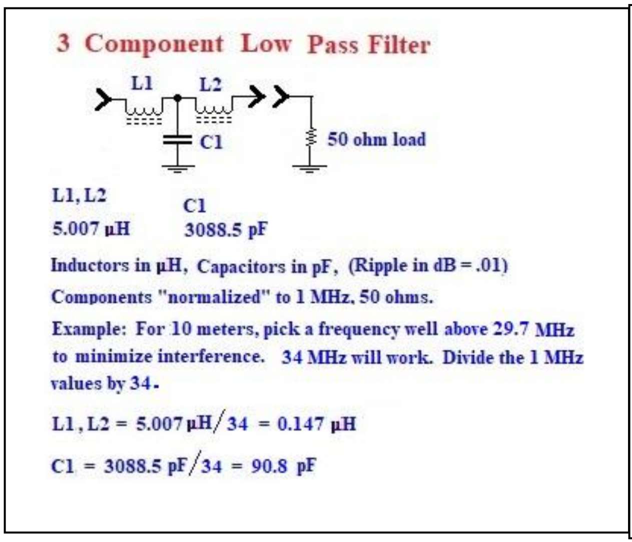
The driver stage above is tuned and resembles the buffer stage following the crystal oscillator stage. Depending on the number of turns on the coils in the tuned amplifier stages, these stages can tune two or more bands. For example, with 27 turns on the primary using a T-50-6 toroid, you can (barely) cover 20 to 10 meters assuming your capacitor tunes widely enough. The secondary would be about 4 to 6 turns. The input of a grounded emitter transistor amplifier is a low impedance. Therefore the transformer lowers the voltage and raises the current to “match” the impedance.

The driver transistor 2N3053 or other type may need a metal heat sink "hat" clamped on top to help keep it cool. The smaller 2N2222 transistor will also work, but will be damaged easily because it lacks the mass and surface area to dissipate the heat. I worked a fellow with a homebrew QRP who was using three 2N2222s in parallel to achieve sufficient cooling for his two watt output stage. Be sure to design the printed circuit traces to be as short as possible on all power stages. Notice the big ferrite bead with a loop of wire through it that connects the base of the MRF476 transistor to ground. This is an example of a low pass filter needed to shunt low frequency artifacts to ground. The MRF476 transistor is hard to find these days. Fortunately the 2SC2166C is a direct (and inexpensive) replacement. I tried some and confirmed that they work OK. Because they are relatively cheap, you might also use a 2SC2166C in place of the 2N3053. It can share the heat sink used for the MRF476. Unlike small, free-standing transistors, heating won't be a problem.

Chebyshev output filters

Some readers complained about the design method for designing Chebyshev 5 component Low Pass filters that was described in Chapter 6A. That method looks confusing and requires *MATH!* I sympathize. I also find math annoying because, as soon as it gets complicated, the equations usually don't simulate the real circuit and *DON'T WORK*. However, ***simple equations***, like the ones used in this book for inductors and filters, are often a Godsend. If an equation accurately predicts circuit values, it can save you a day of trial and error. Have faith and try it!

Here is an easy method for designing 50 ohm output filters. The data is from page 15.11 in the 1986 ARRL handbook. The downside of the formulas shown below is that the tables only cover 50 ohm loads and a certain level of ripple - noise. If you want a higher impedance load, like 500 ohms, you'll need the other method.

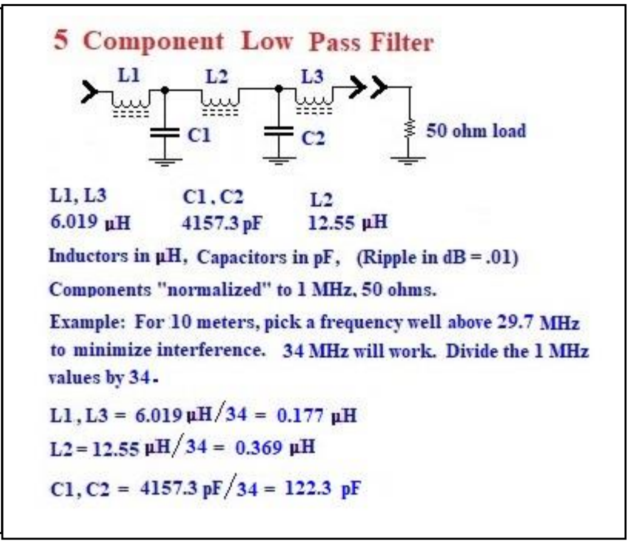


3 Component Low Pass Filter

L1, L2	C1
5.007 µH	3088.5 pF

Inductors in µH, Capacitors in pF, (Ripple in dB = .01)
Components "normalized" to 1 MHz, 50 ohms.
Example: For 10 meters, pick a frequency well above 29.7 MHz to minimize interference. 34 MHz will work. Divide the 1 MHz values by 34.

L1, L2 = 5.007 µH/34 = 0.147 µH
C1 = 3088.5 pF/34 = 90.8 pF



5 Component Low Pass Filter

L1, L3	C1, C2	L2
6.019 µH	4157.3 pF	12.55 µH

Inductors in µH, Capacitors in pF, (Ripple in dB = .01)
Components "normalized" to 1 MHz, 50 ohms.
Example: For 10 meters, pick a frequency well above 29.7 MHz to minimize interference. 34 MHz will work. Divide the 1 MHz values by 34.

L1, L3 = 6.019 µH/34 = 0.177 µH
L2 = 12.55 µH/34 = 0.369 µH
C1, C2 = 4157.3 pF/34 = 122.3 pF

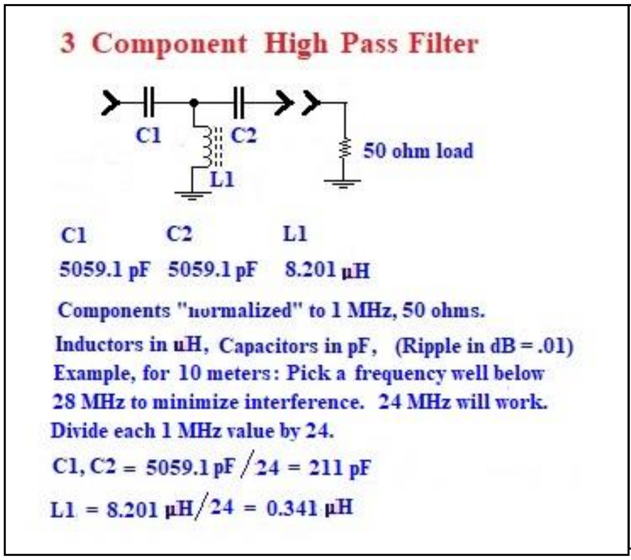
High pass output filters

Higher frequencies like 15 meters and above are often plagued by low frequency components. If the output capacitor from a stage is a tiny capacitor, it can often reduce low frequency noise. Naturally there is a trade off between low frequency noise and attenuation of the output from the stage. The QRPs described here tend to produce low frequency noise that makes the output appear in bursts or even chaos. Low capacitances such as 120 pF can serve as high pass frequency filters which can remove low frequency distortion from the output sinewave. The capacitance value is a compromise between distortion and loss of power. 0.01 µF may work in the final stage instead of the 0.003 µF "high pass" coupling capacitor shown above. The values shown above settled my 40 meter QRP into a stable sinewave with just a tiny trace of low frequency, AM-like, modulation. A T-type antenna coupler removed the last of it.

High Pass 50 ohm output filters

For upper HF bands and VHF bands, like 10 meters and above, a simple small output capacitor and the ferrite bead on the MRF476 base may not be enough. The 50 ohm output filters shown below will help get rid of the low frequency contamination and improve the quality of your CW tone. In Chapter 15 they were necessary to the remove the audible rough noises and produce clear SSB speech. Yes, there will probably also be higher frequency components that might interfere with TV or UHF frequencies. A TVI preventing filter like the one in Chapter 9 may solve your harmonic problem. Alternatively ... MORE FILTERS! You're the engineer - fix the problems one by one as they attack you.

Here are the equations for calculating high pass output filters:



3 Component High Pass Filter

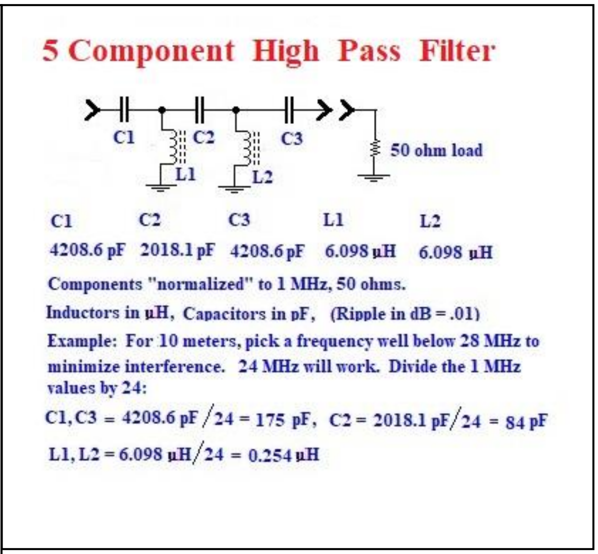
C1	C2	L1
5059.1 pF	5059.1 pF	8.201 µH

Components "normalized" to 1 MHz, 50 ohms.

Inductors in µH, Capacitors in pF, (Ripple in dB = .01)
Example, for 10 meters: Pick a frequency well below 28 MHz to minimize interference. 24 MHz will work. Divide each 1 MHz value by 24.

C1, C2 = 5059.1 pF / 24 = 211 pF

L1 = 8.201 µH / 24 = 0.341 µH



5 Component High Pass Filter

C1	C2	C3	L1	L2
4208.6 pF	2018.1 pF	4208.6 pF	6.098 µH	6.098 µH

Components "normalized" to 1 MHz, 50 ohms.

Inductors in µH, Capacitors in pF, (Ripple in dB = .01)

Example: For 10 meters, pick a frequency well below 28 MHz to minimize interference. 24 MHz will work. Divide the 1 MHz values by 24:

C1, C3 = 4208.6 pF / 24 = 175 pF, C2 = 2018.1 pF / 24 = 84 pF

L1, L2 = 6.098 µH / 24 = 0.254 µH

Noise mode

A common problem when checking out the completed QRP is that it may work properly at low supply voltages, like 6 or 8 volts, but when you raise it to 12 volts, the output turns into a roar of random noise and overlapping blurs on your oscilloscope. You may even hear the static in your FM radio. This is usually caused by feedback through the power supply between the output stage and previous stages. This is why you need the RC decoupling circuits on the +12 V DC supply line which go to each transistor stage. Increasing the resistor values, starting close to the final and working back toward the mixer, may fix the problem. Another cause can be the coupling capacitance between stages discussed earlier.

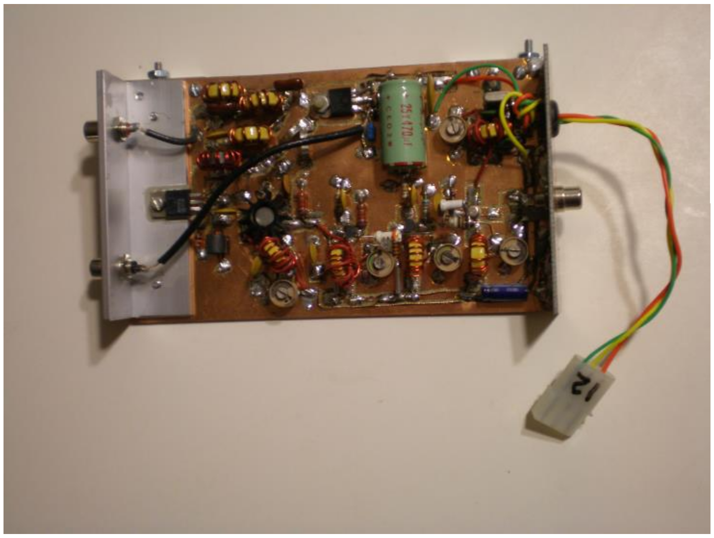
The last tuned stage in the amplifier/ filter chain

Notice that the capacitors and resistors surrounding the last tuned stage have asterisks next to the component values. When I examined each of the high band modules to re-write this section, I realized that ***no two of my modules were alike!*** I apologize, but this circuit is finicky. The best operation is achieved when you experiment with the bias and coupling to the tuned stage. Forward bias, the 33K resistor, may not be needed.

I recently built a 10 meter AM modulated walkie-talkie prototype. I discovered that I got more power out of the tuned stage by not using the tapped output coil. Consequently in this stage of amplification the L-C circuit is simply an inductor in parallel with the tuning capacitor. Because the power supply has big capacitors and little ceramic capacitors across it, the RF passes through it as though it was simply a wire - an impedance of zero ohms. That means that soldering the tuning capacitor to ground is equivalent to connecting it to the supply voltage. The advantage of connecting it to ground is that the adjustment screw on the trimmer is now at ground voltage and it may be touched with a metal screw driver without effecting the tuning.

In this stage of amplification the L-C circuit is simply an inductor in parallel with the tuning capacitor. Because the power supply has big capacitors and little ceramic capacitors across it, the RF passes through the supply as though it was simply a wire - an impedance of zero ohms. That means that soldering the tuning capacitor to ground is equivalent to connecting it to the supply voltage. The advantage of connecting it to ground is that the adjustment screw on the trimmer is now at ground voltage and it may be touched with a metal screw driver without effecting the tuning. If the metal screw were connected to the transistor collector, a metal screw driver would change the capacitance across the inductor.

A related problem with this QRP design is that it's sometimes difficult to get the full 5 watts, even at relatively low frequencies like 20 meters. Also, when you do get your 4 or 5 watts, the output may not be stable and will tend to go into noise mode. A sign of the cause can be that, when you adjust the last tuning capacitor, it only has one optimum point. This optimum point is usually at **minimum** capacitance and doesn't tune sharply. The can happen when the secondary of the transformer is coupled to the final stage with a large capacitor, like 0.01 µF. (0.01 µF = 10,000 pF.) This capacitance may be coupled back to the primary and swamp the little 60 pF trimmer. That is why the output of the QRP driver circuit shown above has a 120 pF capacitor at the output, not a 10,000 pF capacitor. When the minimum coupling capacitor is used, you can tune the last stage and get optimum power output. On the other hand, 0.01 µF may work well for you. I was just examining my 3 highest frequency QRP modules. Two of them have the 0.01 µF cap. If it works well, it's good enough!



The 12 meter PMO QRP module. The last tuned stage is on the lower left.

12 Meters and higher frequencies need compact circuitry

At 10 and 12 meters it was impossible to get 5 watts out of my QRP drivers. At first, 2 watts output was the best I could do at 10 meters with the design described above. Moreover, the linear amplifier described in Chapter 12 could only increase this power level 4 or 5 times. So, although my linear delivers 100 watts at 80 meters, I could only get 10 watts on 10 meters. I tried adding a broadband "booster amplifier stage" between the QRP output and the linear amplifier input to increase the power. The booster made absolutely no difference in the power delivered to the antenna.

The light dawned when I discovered that I could mistune the tuned filter/ amplifier stages in the QRP so that they resonated at 14 MHz instead of 28 MHz. The slope of the rising portion of the sinewave on the oscilloscope screen was the same as it had been before, but now the voltage had time to rise twice as high before it had to turn around and descend to the bottom of the 14 MHz sinewave. That is, the same rate of change on the voltage sinewave produced twice the voltage and 4 times the power. Suddenly my 2 watts QRP output on 28 MHz became 8 watts on 14 MHz. Wow!

This experience teaches us that, the higher the frequency, the better the craftsmanship must be. All component leads and printed circuit traces must be as short as possible to avoid stray inductance and capacitance. Every bit of extra wire is an inductor that must be magnetized before a surge of sinewave current can flow through it. Every component or wire that is close to its neighbor is a tiny capacitor that must be charged before the voltage on that component can rise or fall. It's like a mechanical clock filled with viscous molasses. The higher the frequency, the thicker the molasses. Needless to say, I am in awe of guys who homebrew UHF rigs.

I eventually improved the 10 meter QRP to 4 watts by rebuilding the output stage so that the printed circuit trace between the emitter and the previous stage and the trace between the collector and the output filter were as short as possible. That is, I redesigned it until there was hardly any exposed trace distance at all. Whenever a trace must carry high current at a high frequency, the trace becomes a significant inductor and reduces the potential power it will deliver.

VHF transmitters mean careful planning and construction

The 1986 ARRL handbook has a design for a 3 watt 6 meter (50 MHz) transmitter that uses the same MRF476 and 2N5109 transistors that I used in my higher band QRPs. The final and its driver are stuffed into a tiny module in which every part is strategically positioned like a jigsaw puzzle. There are only a couple inches total of circuit board traces. They are entirely covered by circuit components soldered to the traces at right angles. There is ZERO extra trace distance. Obviously this design had to be exactly right the first time. Modifications are nearly impossible. In spite of this perfection, they only get 3 watts at 50 MHz.

For the high HF bands it helps to use transistors rated with a ***gain bandwidth product*** much higher than the frequency you're building for. As examples, the 2N4925 is rated at 500 MHz bandwidth product. The 2N5109 is rated up to 1200 MHz. In contrast, the otherwise similar 2N3053 can work at 28 MHz, but it is only rated at 100 MHz bandwidth product. A circuit board design using a 2N3053 must be superior to get the same power at 28 MHz that the 2N5109 will deliver. On the other hand, the 2N5109 is more likely to go into noise mode on lower bands.

Tuning the QRP output to an antenna or amplifier

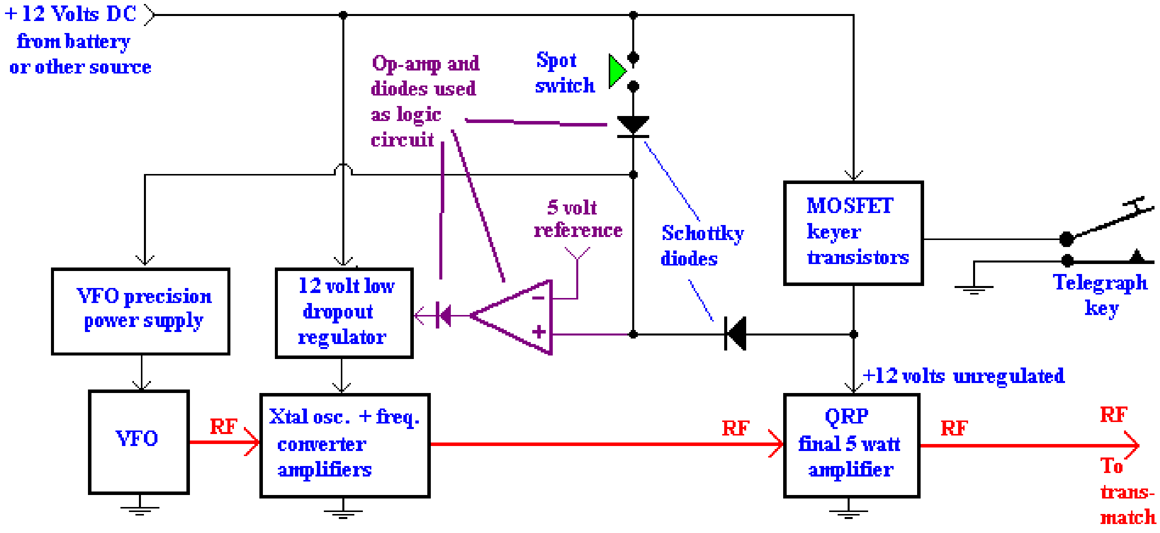
Suppose after tuning it up with a dummy load, I connect the QRP to a high power final amplifier or to an antenna tuner. Suddenly I discover that the QRP output is badly distorted. The output stage broadband amplifier may even go into “noise mode.” If I had designed both QRP power amplifier stages as broadband, I wouldn’t have anything to adjust. Strange as it seems, tweaking a tuned stage will usually match up the broadband output stage to my final amplifier. The most extreme example of this I have observed was on 10 meters. I loaded my antenna with the 10 meter QRP driving a 40 watt linear amplifier (power gain of ten) in series with the TVI low pass, the antenna tuner and the antenna. The "T-type" antenna tuner (Chapter 9) was not able to produce a clean sinewave output. I had to re-tune the last tunable stage of the QRP in order to match the antenna! In contrast, the lower ham bands like 40 and 80 are extremely easy to match to the linear and the antenna.

I assume that the ability of early stages to effect the tuning of an antenna has to do with "***phase shift***." The phase of a sinewave is the instantaneous relationship of the voltage sinewave to the current sinewave passing through the circuit. Because of the way capacitance slows the rate of change of a voltage waveform and inductance slows the rate of change of a current waveform, the current and voltage sinewaves in the output of a transmitter are rarely perfectly synchronized. Or to say it another way, a real antenna rarely looks like a perfect resistance without any capacitive or inductive component. Think of water sloshing back and forth in a cattle watering trough. The length of the trough and the frequency of the waves must be aligned perfectly or the waves quickly become chaotic. In other words, they go into noise mode!

In summary, when you build an amplifier input that is nominally designed for “50 ohms resistive load,” you may find that it has lots of reactance (accidental capacitance and/ or inductance) and is quite different than planned. Notice that Chebyshev filters are designed for specific input and output impedances. To say it simply, filters don’t filter when they are mismatched.

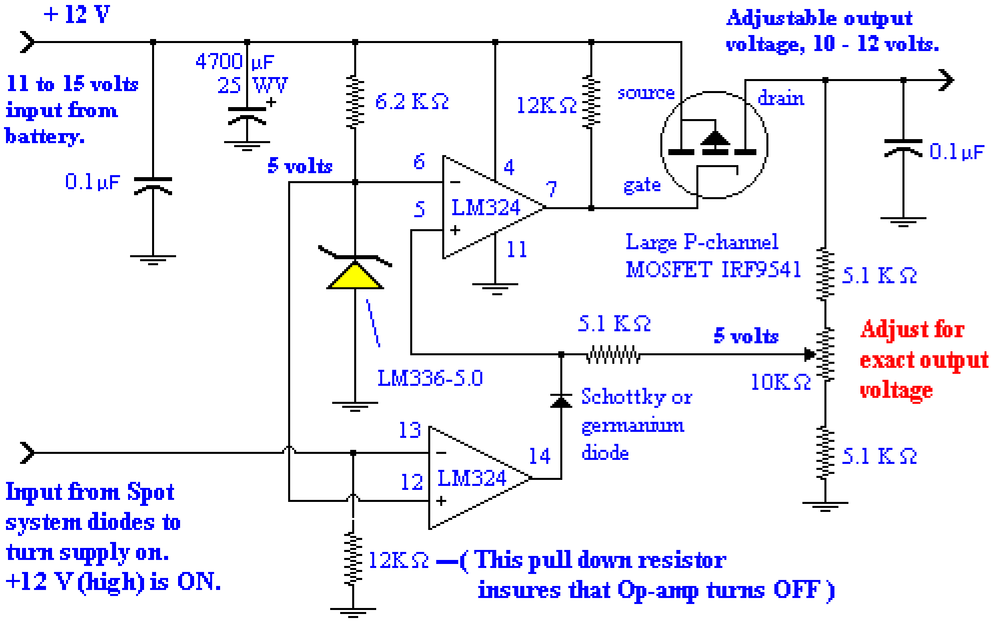
"Spotting" with a VFO

Now suppose you are on an upper band using your new VFO driven QRP. You hear a station calling CQ. But if you key your transmitter and adjust the VFO to the same frequency as the station, you will be sweeping the band with your transmitter and making yourself unpopular. Besides, you have probably wired the antenna and power supplies so that the receiver shuts off while transmitting. In order to hear your own QRP in the receiver you need to turn on those parts of the QRP that generate the desired frequency, but not the power amplifiers. You also want the antenna to remain connected to the receiver and you don’t want the receiver to shut off. To hear the VFO we need to direct power from a “Spot” switch to the VFO power supply. But we also need to turn on the QRP PMO sections that generate the desired frequency.



QRP KEYER WITH "SPOT" BUTTON

If you are running your transmitter on battery power as I usually do, then the low dropout supply only has to run the crystal oscillator and the filter/amplifiers. The power amplifier (or amplifiers) can run directly off the battery and that unregulated 12 volt line can be activated by the MOSFET keyer circuit. Now when you push the spot switch, the VFO and the low power sections of QRP will turn on without shutting down the receiver. Below is the low dropout regulator with the turn-ON control line from the Spot diodes.



Low Dropout 12 Volt Power Supply with Remote

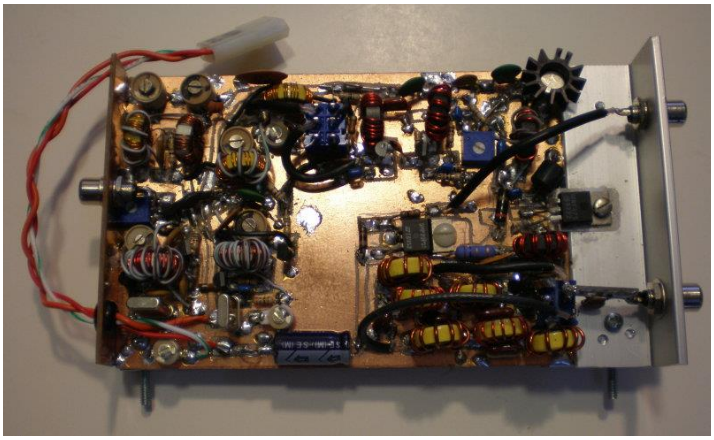
Multi-band QRPs

When I began trying to get on the air with my first CW QRP, my goal was simply to reach 15 meters. This chapter summarizes what I learned on that journey. Since one band was plenty of challenge, I didn't worry about expanding the QRP to cover multiple bands. After a while I began to wish I could operate on 40 meters, so I just built another version of the same QRP design. Because soldering is such fun, I eventually cloned the unit for every HF CW band. This was grossly inefficient. In retrospect, it's a bit embarrassing, especially since I included a separate keyer MOSFET on every band module. Surely you can improve on that!

If you are an experienced builder and want to make a multi-band QRP, then check out the Single Side Band (SSB) QRP modules in Chapter 15. In that system the amplifiers are wide-band/linear and are separate from the passive band filters. If everything works as planned, arrays of oscillators and filters for each band can be switched in with only one set of linear amplifiers. The CW PMOs described above use filters that are tuned amplifiers that are easier to make work, but confined to just one band. One limitation of the broadband/separate-filter approach is that there are no tuned amplifiers to adjust to help you match the QRP to an antenna or to a linear amplifier. Beginners beware. Multi-band units are comparable to flying submarines. Flying submarines will almost certainly be poor airplanes and lousy submarines. It is difficult to build one machine that performs multiple functions well.

Don't scrap a prototype that works - until you have one that works better!

The first QRPs for 15 and 20 meters I built used the original filter-amplifier design. They were extremely ugly with lots of patches and crude soldering, but they worked well. ***My big mistake was scraping the old QRPs*** and using the parts to build the inferior 2-band version shown below.



This QRP covers both 20 and 15 meters using passive tuning networks and broadband amplifiers. Two DPDT switches swap the filters and crystal oscillators for the two bands. It works, but it was difficult get 4 or 5 watts. Also the waveforms had low frequency artifacts, so the frequency counter didn't always lock. A crude solution to this was to place a 120 pF capacitor in series with the output. In other words, I added a simple high pass filter. When I still had loading difficulties, there was no tuned amplifier stage in front of the final to tweak. So in desperation I tuned the "broadband" amplifier just following the passive filters. I hoped I could at least get it to work well on one band. Strangely enough, a single tuned setting worked adequately for both bands. The final 2-band QRP was much more likely to go into noise mode than the original separate units, but with vigilance I managed to make it work.

Eventually I tired of struggling to make the 2-band unit work reliably and exiled it to the junk pile. I replaced it with brand new, separate 20 and 15 meter QRP modules. The single band QRPs work well, of course. So much for progress!

Now the big mystery is why my single sideband (SSB) 2-band modules work so well. 2-band CW modules should have been easier than the SSB modules. The SSB modules produce the final frequency with two frequency conversions, not just one. (See Chapter 15)

Watch out for frequency drift

After you have used these VFO driven QRP boards for a few years, you may suddenly hear complaints about frequency drift. The cause is almost certainly in the VFO (Chapter 10). Before you attack your VFO, it is worth checking your crystal oscillator to confirm that it is stable. Also, after some years the little trim capacitors become "set" where you left them. This is seen as an initial stiffness, almost like a detent, when you first re-tune them. Because of this subtle mechanical alteration, the tuning of your tuned stages may no longer be optimum.

Another kind of frequency drift is "chirp," a change in the musical tone of CW while you are sending a dot or a dash. I have almost never had a chirp problem when using a QRP module barefoot without an amplifier. The exception occurred when I ran my QRP on weak flashlight batteries. In general, the more power you draw from your power supply or batteries, the more likely you will have chirp. As explained in Chapter 12, a poorly tuned antenna can also produce a subtle chirp at the end of a long dash, presumably because the amplifier is drawing higher current surges. Unlike vacuum tube transmitters (Chapter 14), the transistorized transmitters described here are unlikely to chirp.

The next Chapter discusses building an amplifier to increase the QRP output to 40 to 100 watts, depending on the band and the power output of your PMO QRP.