

CRYSTAL SETS TO SIDEBAND
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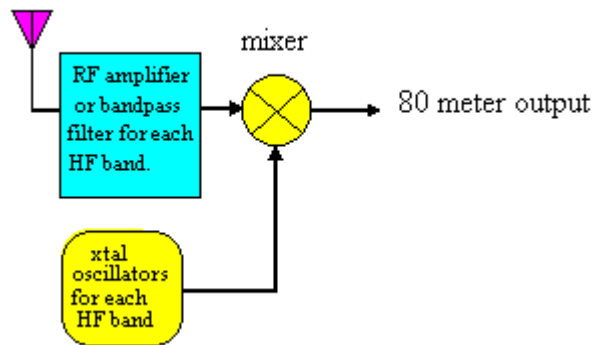
Chapter 13B

BUILDING AN ALL-BAND HF RECEIVER (continued)

Building HF converters and extra features for the 80 meter receiver

As explained in the last chapter, each additional frequency band needs its own converter module. On the bright side, the converters are physically small and 8 or 9 of them can be crammed into one big module or several smaller ones. I decided which bands were most interesting to me and built those first. It was many months before I finished them all.

Converters for the other HF bands



Block diagram of a converter for an HF hamband

I used the RF amplifiers and crystal oscillators out of the W7ZOI / K5IRK receiver. I built most of these modules close to what was described in the handbook and they worked right away. For my mixer module I used the same dual gate MOSFET circuit I developed for the 80 meter receiver. It was difficult to build low frequency preselector filters that actually worked, so I used other designs as will be described.

In my receivers all the converters for bands other than 80 meters are switched so that they share the same dual gate MOSFET mixer transistor. Each band needs its own crystal-controlled oscillator and a pre-tuned bandpass filter or “preselector” to limit the input to the desired band. Bands above 30 or 40 meters need an RF amplifier. Below 20 or 30 meters, the signals and noise are stronger and an RF amplifier on the antenna input shouldn’t be needed. In my first receiver the signals on 30 meters were rather weak, so in my second receiver, I added an RF amplifier on 30 meters as well. Now I have more gain on 30 meters than necessary - a nice problem to have.

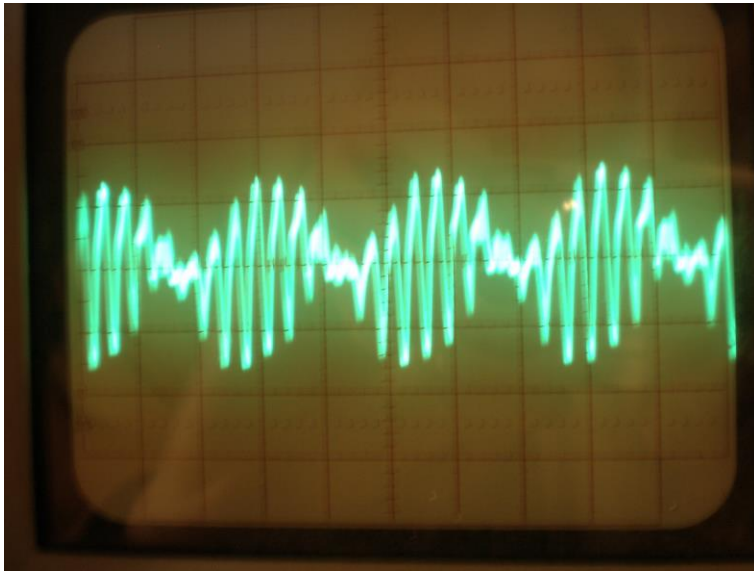
In the old vacuum tube days, tubes were physically large and it would have been extravagant for a homebuilder to use a separate converter for each band. My 1967 homebrew

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vacuum tube receiver had a single multi-band converter that had to be tuned manually for each upper band. In other words, after I switched bands, I had to adjust 3 variable capacitors - not exactly convenient.

Transistors and powdered iron cores are tiny, so today we can easily house a complete HF converter in a few cubic inches. Moreover, each converter runs on just one low DC voltage. This simplicity means that the power can be routed to the converter using the same coaxial line that receives the output from the converter. Since each converter is optimized for just one band, it can be tuned up once and forgotten.

How converters work



In the converter mixer, the incoming signal is combined with a crystal oscillator signal. Sum or difference frequencies are extracted and filtered to produce an 80 meter signal which is passed on to the 80 meter core receiver. Instead of producing a smooth single curve, the 80 meter frequency waveform is approximated by bursts of short, high frequency sinewave cycles. In the example above, the output of the 10 meter converter moves the 28 MHz signal down to 4 MHz by subtracting 28 MHz from the 32 MHz crystal. The mixer produces the 4 MHz difference. Since 32 MHz divided by 4 MHz equals 8, there are eight 32 MHz sinewave cycles in each big 4 MHz burst. The 28 MHz component is modulated producing bursts of 32 MHz. Audio, low frequency amplitude modulation on the 10 meter signal varies the amplitude of the whole pulse train and can't be seen in this brief sample.

Converter mixers

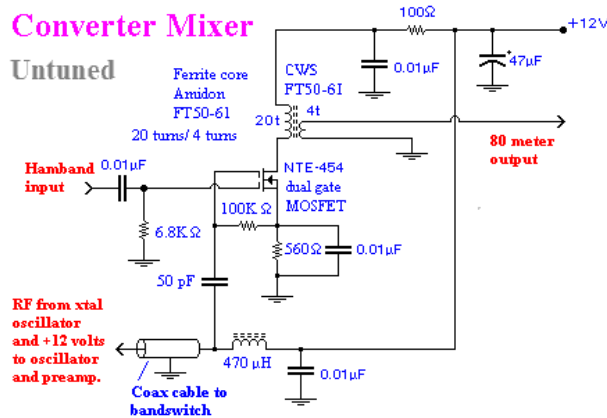
The mixer for a band converter and a mixer for the core receiver have slightly different functions. The converter mixer must transpose the entire ham band to the frequency range of the core receiver. That is, 3.5 to 4.0 MHz in this receiver. In contrast, the core receiver only generates one specific IF frequency, 9.000 MHz in this case. Logically, an un-tuned, broadband mixer would be ideal for the converter, as shown below. However, in the second receiver, the un-tuned converter mixer produced several oscillating "birdies," large and small, up and down the band. So I reluctantly modified it to a mixer tuned for 80 meters and the birdies disappeared. The down side is that now tuning can only be optimum for one portion of the band, while the signal

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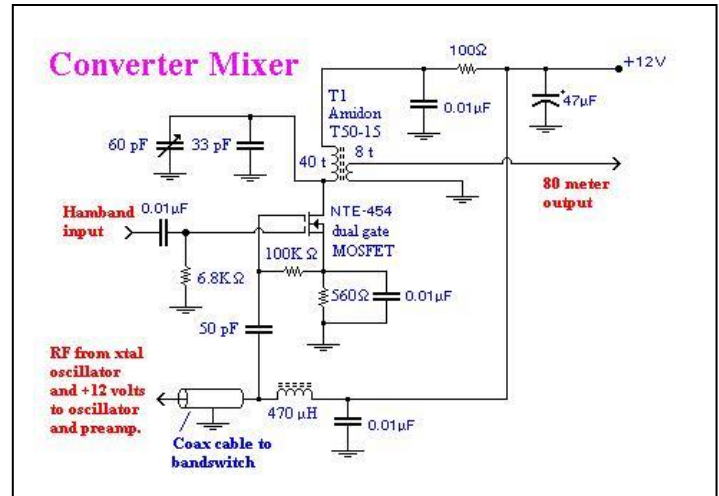
voltage may only be half or a third as high at the opposite end of the band. I recommend starting with an untuned mixer then switch to the tuned version if birdies are a problem.

Converter Mixer

Untuned



Converter Mixer



All my converters share a common, single, converter mixer shown above, either tuned or untuned. You don't need a separate mixer for each band. A rotary bandswitch brings in the filtered and amplified hamband RF signal on the upper input. The lower input takes in the RF from the local crystal oscillator for each band. In addition, the lower "input" is also an output that delivers 12 volt power to the oscillator and the preamplifier for that band.

In my first receiver, a broadband converter mixer worked fine. Eventually I got the 2nd receiver to behave and was able to return the converter mixer from tuned back to broadband. If the birdie problem persists, you can reduce the gain by removing the .01 µF capacitor in parallel with the 560 Ω resistor. If this sacrifices too much gain, you could replace the 560 Ω with two 270 Ω resistors in series and put the capacitor across just one of them.

As a rule, try to limit the function of your mixer to "mixing" and achieve the gain elsewhere. As usual, this birdie-versus-gain problem was far worse in my second receiver. The important characteristic of mixers is *LOW NOISE*, not gain. Once the desired signal is above the noise level, it can be amplified later, even in the audio amplifier if you like. Electronics often seems mysterious. Keep attacking until it surrenders.

Use a choke rated for much higher current than you need

Notice that the power to all the converters is delivered through the 470 µH choke, one band at a time. When connecting modules or probing a circuit, it is surprisingly easy to short this power line to ground. Use a high current rated version of this choke, say 50 or 100 mA. Otherwise a momentary slip of your hand can short the choke to ground and fry it. So far I've burned out two of them.

Eliminating 80 meter signals from the other ham bands

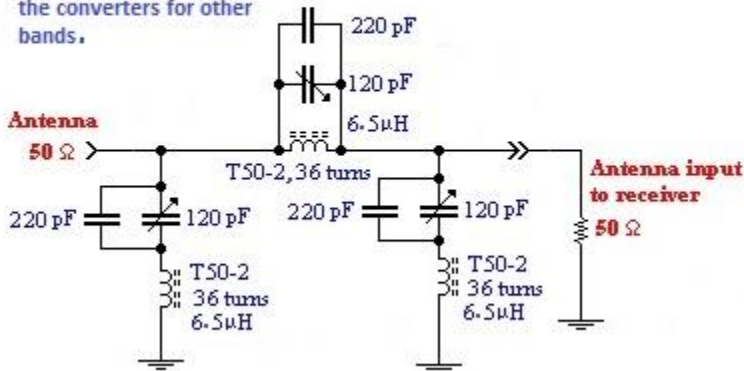
A disadvantage of having the core receiver operate at 80 meters is that strong, actual 80 meter signals may leak through the other band converters. This is particularly likely at night on 160 meters and on the high HF bands, 15 meters and above. During the day 80 meters is usually

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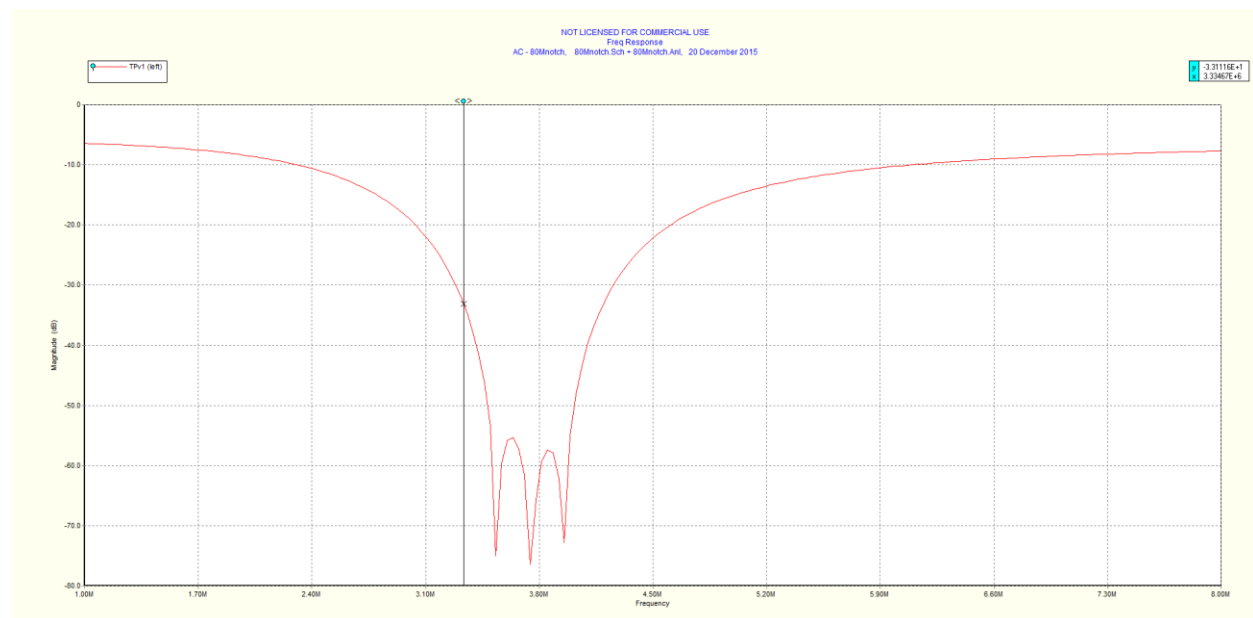
quiet with few signals. But by evening it usually has many strong stations. In contrast, the high HF bands are usually "dead" at night with no distant signals and a low noise level. You may switch to 10 meters and be surprised to hear SSB stations. You investigate and discover they are actually on 80 meters and they have somehow leaked through your 10 meter converter. ***This problem may or may not appear in your receiver.*** In my first version of this receiver, the 80 meter leakage was minimal. In my second receiver it was much more pronounced. If this is an annoyance for you, a converter input notch filter can eliminate the 80 meter artifacts.

80 Meter notch filter

Keeps 80M signals out of the converters for other bands.



This is an interesting circuit. It consists of three L-C resonant filters using the same L and C components. Two L-Cs are arranged as series filters which have a near zero impedance and shunt 80 meters signals to ground. The third L-C filter is wired as a parallel 80 meter resonant filter and provides a high impedance barrier for any 80 meter signal that attempts to travel from the antenna side to the converter inputs.



Understanding decibels

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This filter reduces all 80 meter signals by about 70 dB. Remember that decibels, which are abbreviated as dB, are not a linear multiplier. Also, keep in mind that dB power levels are not the same as dB voltage levels.

Decibels = $10 \log (P_2/P_1)$, where **P_1** and **P_2** are the two power levels.*

This means that the signal strength of an 80 meter signal will be reduced, not by 70 times, but by $10^{70/10} = 10^7$ = ten to the 7th power, or 10,000,000 times. (You can calculate dB power change quickly by dividing by 10 and counting out the zeros, 7 zeros in this case.)

* The "Bel" is named after Alexander Graham Bell, the telephone guy. Tenths of a Bel are a more useful measurement, so hardly anyone uses Bels. This explains why the $\log P_2/P_1$ formula is multiplied by 10.

70 dB attenuation sounds more extraordinary than it is. Our ears and radios operate over a gigantic power range. The overall power increase of any good short wave receiver can be as much as 100 decibels. This is the increase in power from a tiny RF signal on the antenna up to the sound booming out of your loudspeaker.

You can test this filter by placing it in series with the antenna input of any receiver tuned to 80 meters while the band is active. The filter will obliterate all the unwanted signals except the static noise from the mixer and IF strip. To install it in your receiver, it needs to be located so that antenna signals going to any of the band converters pass through it.

Notice that the graph shows that there is a 10 decibel penalty (9/10 power loss) while using this filter in front of a 160 meter converter. All the other HF ham bands are farther away from 80 meters and there is less loss, but it is still significant. I placed my filter directly in series with the antenna input and added a bypass switch. That way, I only incur the attenuation on those rare occasions when I am bothered by those 80 meter signals appearing on other bands.



Converter filters and preamplifiers

As you know, the mixer process produces 4 different frequency signals. The mixer output contains the desired frequency band signal, local oscillator signal and the unwanted sum or difference frequency. If you want the band that is the *sum* of the two frequencies, a filter is

needed to remove the *difference* frequency, the local oscillator sinewave, plus any other strong signals that may be on the antenna. As you can see below, a broadband amplifier is preceded by a low pass filter and followed by a high pass filter.

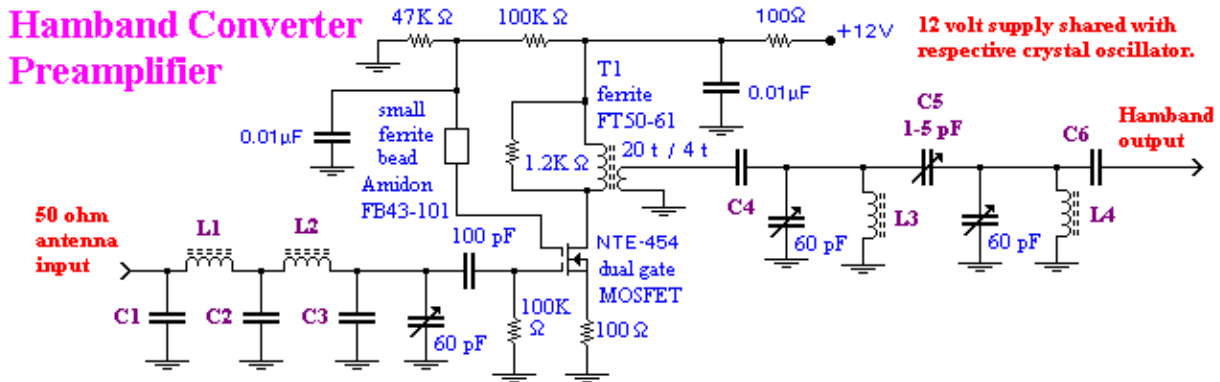


Table of values for converter preamplifier and filters

| Hamband | C1 | C2 | C3 | C4 C6 | C5 | L1 | L2 | L3 L4 |
|-----------|-----------------------------------|------|------|----------|------|--------------|--------------|--------------|
| | (pF) | (pF) | (pF) | (pF) | (pF) | (μH) | (μH) | (μH) |
| 30 meters | 300 | 680 | 33 | 33 | 4.1 | 0.68 | 3.36 | 1.16 |
| | T50-6 CWS (Amidon) toroids | | | | | (13t) | (29t) | (17t) |
| 20 meters | 220 | 500 | 22 | 27 | 4 | 0.58 | 2.50 | 1.16 |
| | T50-6 | | | | | (12t) | (25t) | (17t) |
| 17 meters | 180 | 390 | none | 22 | 3.9 | 0.40 | 1.94 | 1.44 |
| | T50-6 | | | | | (10t) | (22t) | (19t) |
| 15 meters | 150 | 330 | none | 20 | 3 | 0.40 | 1.60 | 1.44 |
| | T50-6 | | | | | (10t) | (20t) | (19t) |
| 12 meters | 120 | 200 | none | 12 | 2.1 | 0.26 | 1.44 | 0.58 |
| | T50-6 | | | | | (8t) | (19t) | (12t) |
| 10 meters | 110 | 250 | none | 12 | 4.7 | 0.26 | 1.16 | 0.40 |
| | T50-6 | | | | | (8t) | (17t) | (10t) |
| 6 meters | 50 | 66 | none | 6 | 4.7 | 0.14 | 0.6 | 0.22 |
| | T50-6 | | | | | (6t) | (12t) | (7t) |

Recently I built a converter which has 4 crystal frequencies to cover the entire 10 meter band in 0.5 MHz increments. Each of the 4 crystals is selected by a rotary switch. In this

prototype I couldn't get the input gate filter to tune properly on 10 meters using the above values. I modified it as follows:

| Hamband | C1 | C2 | C3 | C4 C6 | C5 | L1 | L2 | L3 L4 |
|----------------|-----------|------------|-----------|------------------------|-----------|-------------|--------------|------------------------|
| 10 meters | <u>91</u> | <u>120</u> | none | 12 | 1.6 | <u>(6t)</u> | <u>(14t)</u> | (10t) |

The 30 meter band needs a crystal filter

The 30 meter CW band is just above the WWV time station at 10.00 MHz. Also, there are some strong AM religious stations just below WWV. The 30 meter band needs at least one 9 MHz crystal in the 9 MHz IF strip to filter out these nearby stations. For 30 meters the tuned LC circuits in the IF are not selective enough without a crystal to filter out those nearby bellowing elephants. When I bypass the crystal filters, I can hear the WWV clock ticking superimposed on a sermon from the loudest religious station. Because the IF is 9 MHz, it doesn't matter where I tune the VFO. This is distracting to say the least. With one crystal switched in, the background interference disappears and it performs like the other bands.

A pervading whistle on 20 meters

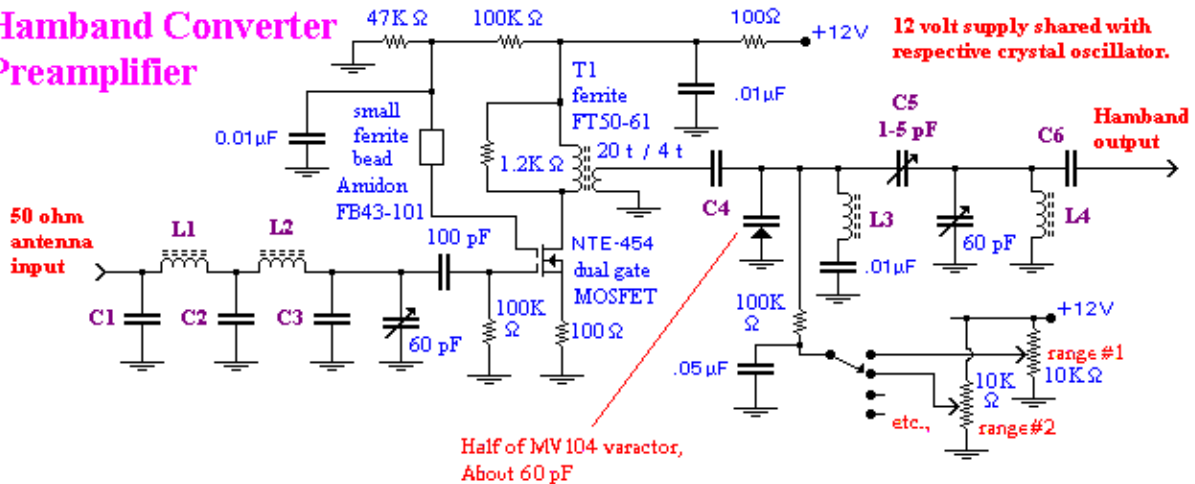
The 20 meter converter in this design may have an annoying, odd glitch. On 20 meters an 18 MHz crystal is used to convert the 4 MHz core receiver to 14 MHz. (18 MHz - 4 MHz = 14 MHz.) This means that your 9 MHz BFO oscillator is operating at the same time as an 18 MHz crystal oscillator. In order to make the calibration perfect, the 18 MHz oscillator should be adjusted to 18,000,000 Hz. If you can do that, there will be no glitch. But if it is misadjusted to say, 18,000,**500** Hz, you will hear a continuous 500 Hz tone in the background whenever the noise and signals are at low strength. In other words, the 18 MHz signal is acting like a 9 MHz signal. Alternatively, the 2nd harmonic of 9 MHz is 18 MHz. The difference between 18,000,**500** Hz and 18,000,**000** Hz is an audible whistle that you'll hear in your headphones. The solution is to tweak the capacitor in series with the 18 MHz crystal and move it out of the audible range.

That will change your calibration by 1 or 2 KHz, but that probably will not be significant for you.

Covering the entire 10 meter band

In early 2012 the 10 meter band was becoming active with the return of significant numbers of sunspots. I built the new converter in hopes of working stations on phone with just a few watts. So far, it appears to me that all the activity happens between 28.0 and 28.5 MHz. So if you don't add the 3 more mixer crystals (32.5, 33.0 and 33.5 MHz) and the extra filters to cover up to 29.7 MHz, you probably won't miss much. To cover those 3 upper ranges using this design, you could build 3 more converters. Or, you can use a single crystal oscillator with a 4 position rotary switch to select the proper crystal. A single RF preamplifier can use a varactor capacitor "programmed" with 4 preset voltages to peak the amplifier in each of the 4 ranges. A second section of the rotary switch selects the needed DC voltage to program the varactor. Each pre-adjusted voltage is determined by a tiny trimmer resistor as shown below:

Hamband Converter Preamplifier



The trimmer capacitor next to C4 has by far the largest effect on the overall signal strength of the entire preselector. Adjusting *ALL* of the capacitors, would be nice, but isn't necessary. I suggest that you first tune all 3 variable capacitors for best performance in the 28.0 - 28.5 range. For the other three ranges let the varactor do the best it can. The differences in performance will be small. The varactor is controlled by a DC voltage delivered by the 100K resistor. The resistor is bypassed to ground by the .05 μ F capacitor, so the RF ends there. The rest of the DC control circuit, including the rotary switch, may be as remote from the preselector as you like. Notice that ***L3 must not be connected to ground directly*** or it would short out the varactor control voltage. A 0.01 μ F capacitor grounds the coil at radio frequency, but insulates the DC control voltage from ground.

6 meter converter

I built this by scaling the values from successful lower frequency converters. It makes lots of lovely tunable static, but I have yet to hear a ham on 6 meters. According to my frequency counter, RF generator and oscilloscope, it seems to work properly. Time will tell. When using a scope on 50 MHz and other high frequency signals, it may be advantageous to put a 1 pF capacitor in series with the probe. 1 pF will interfere with the tuned circuits much less than a directly-connected 15 pF probe. This decreases the amplitude on the screen, but will still allow you to tune LC circuits for maximum resonance.

After my experience with unintended capacitance and inductance lowering the resonance frequency of previous converters, I used fewer turns than calculated. Wouldn't you know it? It turned out that the calculated turns were correct after all. I had to rewind all the coils to their original turns. It would be difficult to do this work without an RF generator, frequency counter and scope.

Tune up each converter using real ham signals

When I initially got my 2nd receiver working, the bands above 17 meters were dead. By that I mean there were few sunspots and no signals to hear. Eventually 15, 12 and 10 meters became mildly active in my old receiver, but all I could hear in the new receiver was static. It

turned out that my converters were poorly adjusted. My tuning procedure using the RF generator apparently wasn't optimum. Sure enough, when I plugged the receiver into an antenna, took off the converter covers and tweaked them, signals emerged from the usual hiss. Unless these upper bands are booming, the signal strengths are often barely above the noise. To hear them at all, the converters must be precisely tuned. I'm still waiting to hear someone on 6 meters. By the way, remember that you won't hear a darn thing on 6 meters if your antenna has a 30 MHz low pass TVI filter on it!

Converting 6 meters to 10 meters

In the (old) ARRL handbooks the homebrew VHF converters always convert the signals to 10 meters rather than the IF frequency. They do this because the 6 meter band is huge, 50 to 54 MHz. Our 0.5 MHz VFO tuning range only covers the very bottom of the band, but does include the CW portion of the band. If you wish to cover the lower 2 MHz of 6 meters you could use a 22 MHz crystal oscillator and route the 6 meter converter output to the input of the 10 meter converter. ($28 \text{ MHz} + 22 \text{ MHz} = 50 \text{ MHz}$.) I'm assuming, of course, that you have built the quadruple crystal version of the 10 meter converter.

To receive the upper 2 MHz of 6 meters, use a 24 MHz crystal. ($28 \text{ MHz} + 24 \text{ MHz} = 52 \text{ MHz}$.) Notice that the 50 MHz input filters and amplifier remain the same, but would have to be retuned for the upper half of this gigantic ham band. In fact, my guess is that the portion of the filter after the amplifier will have to be retuned at least 4 times to cover the whole band. If you use the same scheme I used for 10 meters, that implies more switching and varactor tuning. I get tired thinking about it! What 6 and 2 meters need is a VHF VFO to drive the converters. No, I have never built one.

Simulation of band filters using "Spice" network design software

If you wish to confirm, design or modify these complex LC filters, I strongly recommend buying (or downloading) a circuit simulation software program. Trial and error works poorly on these complex circuits. I am presently using the free on-line student version of "5Spice." After some frustrating trial and error while learning to use this software, it seems to work reliably and I have no doubt that the results are mathematically correct. Unfortunately, when I actually construct my computer-simulated filter, I often find that it doesn't work correctly. Sometimes it doesn't work at all. As I learned earlier while building 80 meter preselectors, real filters usually have more capacitance than the pure, simulated version. Also, the toroid inductors sometimes don't have the exact inductance I calculated. (How to wind custom inductors is discussed in Chapter 6.)

Troubleshooting preselectors

You could just install your new band filter into the receiver and start tuning the trimmer capacitors until the desired signals peak. This approach usually worked on my first receiver, but it didn't on my second receiver. On my second receiver, ALL the preselectors needed component value changes. As discussed earlier, ***This phenomenon is called "beginner's luck."*** Now I align each preselector outside of the receiver and introduce a signal using an RF generator. I monitor the mixer output across a 6.8K ohm resistive load which simulates the input to the mixer. When I don't obtain an output from the filter, I try tuning the RF generator below the desired frequency range. The unintended capacitance in the circuit often moves the filter peak down a

megahertz or two. If you find a lower resonance frequency, you can remove excess capacitance (or inductance) and move the response up to the desired range.

After you have tuned each trimmer capacitor to produce the best response, examine the trimmer to be sure it is not at either maximum or minimum capacitance. Remember that, if a trimmer has the right range, the best response will occur at *two points* as you rotate the screw 360 degrees. If it only peaks once, then it is at maximum or minimum. If the capacitance is at maximum, add a parallel fixed capacitor so that the best performance will peak twice. If the capacitance is at minimum, replace the trimmer with one with a much lower capacitance range, reduce any parallel fixed capacitance or you might have or reduce the relevant inductance. If no signals at any frequency emerge from the filter, probe each circuit node of the filter using your oscilloscope. Usually the signals will stop abruptly at a particular circuit node. This usually reveals a short to ground or a cold solder joint.

Preselectors for the lower hambands

As explained earlier, hambands lower than about 30 meters should not need an RF preamplifier. The basic purpose of the preselector is to limit the input signals to the particular hamband. This design shown below is the one recommended by W7ZOI and K5IRK. Examining the filter circuit below, notice that L1 and L2 are the same size in the version without the amplifier, whereas in the amplified version L2 is about 5 times larger than L1. The large inductor is an impedance raising feature to match the 100K ohm input resistance of the MOSFET amplifier.

Hamband Preselector Filter

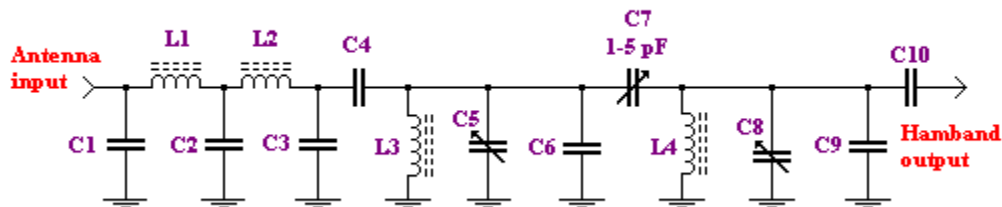


Table of values for preselector filter (without amplifier)

| Hamband | C1 C3 (pF) | C2 (pF) | C4 C10 (pF) | C5 C8 (pF) | C6 C9 (pF) | C7 (pF) | L1 L2 (μH) | L3 L4 (μH) |
|-----------|------------------|----------------|-------------------|------------------|------------------|------------|------------------|------------------|
| 30 meters | 300 | 600 | 32 | 180 | 50 | 4.1 | 0.68 | 1.16 |
| | | CWS (Bytemark) | | T50-6 toroid | | | (13 turns) | (17 turns) |
| 40 meters | 430 | 860 | 42 | 180 | 50 | 4.6 | 1.16 | 2.50 |
| | | CWS (Bytemark) | | T50-6 toroid | | | (17 turns) | (25 turns) |
| 60 meters | 570 | 1150 | 56 | 260 | 68 | 60 | 1.55 | 3.35 |
| | | CWS (Bytemark) | | T50-2 toroid | | | (19 turns) | (28 turns) |

160 meters 1720 3440 47 120 470 20 4.64 10.0

CWS (Bytemark) T50-15 toroid (19 turns) (27 turns)

My 160 meter filter is similar to the original handbook design and was extrapolated from the 40 meter values.

160 meters is difficult

160 meters presents two problems. First, standard broadcast signals are stronger than loud and just below 1.800 MHz. If you don't attenuate the broadcast band signals, you may be plagued with the loudest local AM stations appearing in your IF. Even if you can't actually hear their modulation, these stations may be saturating your mixer and keeping you from hearing anything except IF noise. You may find the AM broadcast filter described in Chapter 7A useful. I had this problem with my first receiver. The filter worked best when placed in between the 80 meter preselector and the input to the 80 meter receiver mother board. It was not noticeably helpful in series with the antenna jack outside the receiver. My first 160 meter preselector was primarily a high pass filter.

The second problem with 160 meters is its proximity to 80 meters. When I got my 160 meter converter working in my first receiver, I immediately heard hams and thought I was successful. It was several evenings before I discovered that some of those hams were actually on 80 meters. Oops. When I tuned in a ham, I then switched to 80 meters to see if he was still there. If he disappeared, then I knew he was on 160 meters. Not really up to snuff. Since my core receiver is designed for 80 meters, the bandpass filtering on the 160 meter converter must be quite selective to keep out both the broadcast signals and the 80 meter signals. The 2nd receiver has the filter design listed above and seems to work much better. As discussed elsewhere, 80 and 160 meters work best when you listen to them through your transmitter "T-match" antenna tuner. The 80 meter notch filter discussed earlier can also keep 80 meters out of your 160 meter reception.

It can be hard to find an appropriate, cheap crystal for 160 meters. 5.5 MHz is available as a standard frequency and looked ideal. Unfortunately, this produces a large whistling artifact on 2.00 MHz. 5.6 MHz worked OK because the artifact is now on 2.1 MHz, completely out of the 1.8 to 2.0 MHz ham band.

Still another difficulty with 160 meters is that, if you build a multistage filter like those shown for 40 and 30 meters, the variable trimmer capacitors might be physically quite large. To scale the 40 meter filter to 160 meters, I multiplied the value of each capacitor and inductor times four. This implied large variable capacitors, like 500 pF or more. In my first receiver, I used physically large trimmers but they didn't leave room for a complete filter. This is why 80 meter signals seeped through my first 160 meter preselector. For my second receiver, I found some tiny trimmers that were 120 pF maximum. I put them in parallel with 470 pF fixed capacitors and was able to trim the filter in the correct range. I "guessed" what the variable capacitance range was needed using Spice simulation. The simulation was fairly accurate for change!

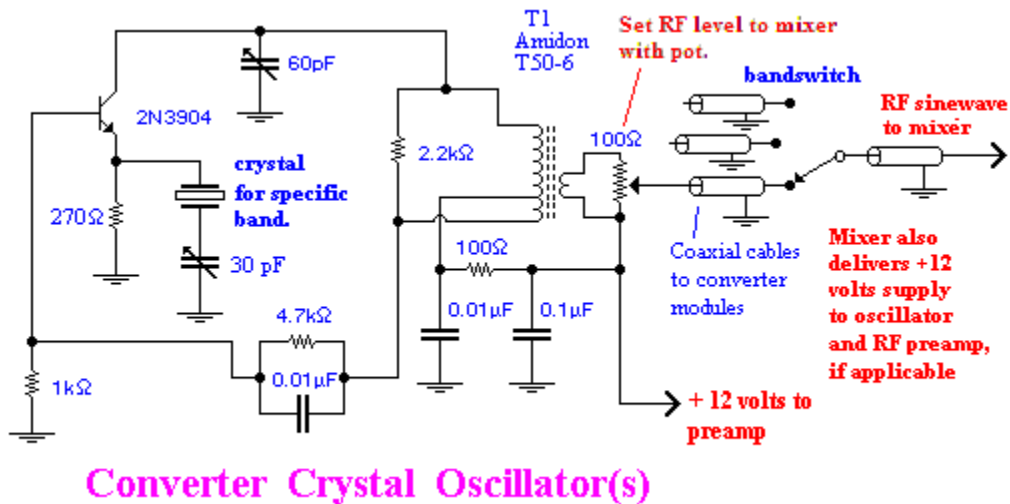
Crystal oscillators for the converters

These oscillators are nearly identical to the BFO oscillator described earlier. The 12 volt power for each oscillator is delivered via the cable from the bandswitch. On two of the lower band oscillators, the 30 pF capacitor in series with the crystal was insufficient to make the crystal

oscillate on its nominal frequency, so I increased the capacitance. You can even put a few picofarads in parallel if needed. Just be sure the oscillator is locking onto the crystal frequency. When you adjust the trimmer capacitor, the frequency should remain locked. It is desirable for calibration, but not essential, to have the oscillation frequency come out on round numbers such as "28.800 MHz." Also, sometimes I needed more than the 60 pF trimmer capacitance on the collector.

Sometimes a Butler oscillator refuses to oscillate with the exact circuit shown. One variable you might change is the emitter resistance. 150 ohms often produces a larger signal than 270 ohms, but is more likely to fail to lock onto the crystal frequency. Another possible change is to increase the transistor base resistance from 1K to 2K. If they are run open circuit with no load, they may oscillate with the frequency solely under the control of the LC circuit instead of the crystal. To test for this, vary the capacitor in the drain LC circuit to be certain that the frequency is stable. For example, if tuning this capacitor causes the frequency to vary and the trimmer capacitor cannot reach the desired crystal frequency, you will need to add capacitance or subtract inductance. When the LC oscillation approaches the crystal frequency, it will usually lock in properly.

The RF level delivered to the mixer can be adjusted with an optional 100 ohm trim potentiometer across the output winding of the oscillator transformer. As with the core mixer, the ideal level for the sinewave local oscillator produces the maximum signals with the minimum noise and birdies. This is usually about 0.6 to 1.0 volts peak. On the upper bands 2 or more volts peak is way too much and reduces signal strength. On the lower bands, I haven't noticed a disadvantage to large oscillator signals. Notice that having 10 to 100 extra ohms in series with the 12 volt supply will make no measurable difference in oscillator or pre-amp performance. I had a severe birdie problem on 160 meters and just adding the 100 ohm load on the oscillator output winding helped end the birdies. I had a minor birdie problem on 40 meters, but the pot did not eliminate birdies without also eliminating the ham signals. Fortunately, the 40 meter birdies were outside the ham band, so they weren't important to me.



Data table for crystal oscillators

| Hamband | Crystal freq. (MHz) | T1 primary total turns | Primary tap turns | Secondary turns |
|------------|------------------------|---------------------------|----------------------|--------------------|
| 160 meters | 5.600 | 34 on T50-15 | 7 | 7 |
| 60 meters | 9.100 | 18 on T50-15 | 4 | 4 |
| 40 meters | 11.000 | 32 on T50-6 | 7 | 6 |
| 30 meters | 13.800 | 26 on T50-6 | 6 | 5 |
| 20 meters | 18.000 | 28 on T50-6 | 5 | 4 |
| 17 meters | 21.900 | 20 on T50-6 | 4 | 4 |
| 15 meters | 25.000 | 20 on T50-6 | 4 | 4 |
| 12 meters | 28.800 | 17 on T50-6 | 4 | 4 |
| 10 meters | 32.000 | 14 on T50-6 | 3 | 3 |
| 6 meters | 54.000 (see text) | 10 on T50-6 | 2 | 2 |

Toroids are CWS (Amidon) T50-6 powdered iron, except for 5.6 and 9.1 MHz.

Choosing crystal frequencies

Since I am converting to 80 meters, my receiver uses the same local oscillator frequencies I used in my CW transmitter which has an 80 meter VFO. For most bands I used (cheap) microprocessor crystals cut for frequencies 4.0 MHz above the bottom of the desired ham band. For example, I used 11.0 MHz for 40 meters, 18.0 MHz for 20 meters, 25.0 MHz for 15 meters and 32.0 MHz for 10 meters. The WARC bands are only 100 KHz wide. This allows you to use crystals that are any convenient frequency covered by the 3.5 to 4.0 MHz frequency range of the core receiver. To make your choice, you might consider what other interesting bands are close by. For example, if your 30 meter choice allows you to hear 10.00 MHz, you can check your UTC clock setting from the WWV time station. Ham communications are recorded in logbooks using UTC time (Greenwich Mean Time) so that everyone in the world is on the same time standard. You may also enjoy the 31 meter band shortwave broadcasts stations below 10.0 MHz. For wide bands like 15 meters and especially 10 meters, you will have fewer choices about which crystal frequencies to use.

You could also use local oscillator frequencies below the desired band. For example, to cover 15 meters, you might use a 17.5 MHz crystal oscillator. This will convert the 15 meter band to 80M spanning 3.5 MHz to 3.95 MHz. Notice that the *direction* of VFO tuning is reversed from using local oscillator frequencies above the desired band. Whatever you do, it's good to be consistent so that direction of tuning and the calibration can be consistent. Also, if the local oscillator frequencies are round numbers, like 11.0, 18.0, 25.0 and 32.0 MHz, then the decimal calibrations on the VFO will be identical.

Ordering custom crystals

To get quality crystals for the WARC bands that didn't drift, I eventually had to have custom crystals ground for me from the ICM company. Sadly, ICM has gone out of business. They were probably too inexpensive and provided service that was much too speedy! I recently

ordered some crystals from Bomar Crystals in New Jersey. They cost three times as much and took over a month to arrive. But other than that, the crystals work well.

How to order custom crystals

To order you must specify the desired frequencies, plus what parallel or series capacitance you plan to use and what physical crystal size you prefer. I recommend HC-49 or larger, since big crystals produce larger oscillations and are more stable. You might also tell them what your application is. If you are buying a replacement crystal for old manufactured equipment, many of these crystal companies have the data needed to reproduce the exact original crystal. If it's a high frequency, above say 20 MHz, you might specify whether you prefer an overtone crystal (cheap) or a primary frequency crystal. If the crystal is overtone, your L-C circuit is vital for determining the higher frequency which will be 3 or 5 times the frequency of the primary. With a broadband tank circuit on the drain, (just an RF choke, no L-C) a crystal oscillator will oscillate at the primary frequency, not its overtone frequency.

For my 6 meter oscillator, I used an 18 MHz crystal and built a frequency tripler and filter. Producing a clean 54 MHz sinewave required far more circuitry than I expected and it was a nuisance to perfect. I should have just ordered a 54 MHz overtone crystal!

Trouble-shooting high band converters

Unlike my first receiver, in my second receiver the 20 meter converter was the only upper band that worked properly. They were the same circuits. They just worked poorly the second time I built them. The 17 through 10 meter converters were too insensitive to hear ham stations. One explanation seems to be that I had too much converter oscillator signal as discussed above. Decreasing the oscillator signal with the 100 ohm pot cured my 17 meter converter. I reduced the oscillator RF signal down to about 1 volt peak and it suddenly produced lots of loud ham signals. This modification didn't help the 12 and 15 meter converters.

Testing converters when the sunspots are few and the bands are dead is difficult. Before you do anything drastic, such as increasing converter gain, listen to the dead bands with a known, quality receiver. If you don't own a first rate receiver, call up a friend and have him listen. Is 15 meters really dead? Increasing the gain of an amplifier may just be increasing the noise, so that isn't a panacea.

Boosting preselector amplifier gain

The following gain improvements should only be tried after you have failed to hear signals on the upper bands. My first receiver used the original W7ZOI/K5IRK circuit and produced great signal strength, low noise and few birdies without these modifications. In the 2nd receiver I made the 15 through 10 meter band converters work by increasing the gain of the RF amplifier. First I tried changing the surface mount BF996S to some NTE454 and 3N140 dual gate MOSFETs, but there was no change.

Notice that the output from the broadband transformer is a low impedance winding. This winding is driving a high impedance parallel circuit. It dawned on me that more output voltage was available by removing the transformer output winding and simply connecting the drain of the amplifier directly to the output filter with a small capacitor. 10 pF was enough for 10 meters and proportionately larger capacitors for lower bands. The value doesn't seem to be critical but it

does become part of the first LC circuit, so use a small capacitor. This change made the major improvement.

Gain can also be increased slightly by removing the 1.2K resistor across the broadband capacitor. Be sure the amplifier is not oscillating after you do this. Look at the amplifier output on a scope and, with no antenna attached, you should *NOT* see a high frequency sinewave. Similarly, a small amount of extra gain can be achieved by placing a 0.01 μ F ceramic capacitor bypass across the 100 ohm emitter resistor. Again, check to be sure the amplifier is not oscillating. These last two changes may introduce more birdies into the band and may not be worth doing. In total, the voltage gain of each converter was raised from about 3 times the input voltage to about 15 times the input voltage.

Tunable birdies

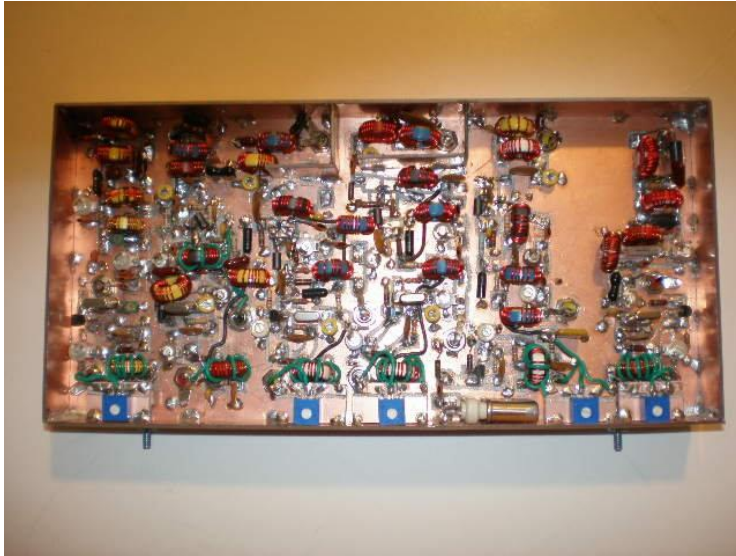
If you get carried away with preselector gain, you may encounter loud birdies that can be tuned up and down the band by adjusting your transmitter transmatch. In other words, the C-L-C circuit in the antenna tuner will interact with the amplifier in the high gain preselector and cause it to oscillate. If this happens to you, the only cure is reduce the gain by reversing the changes you made earlier.

Mechanical construction of converters

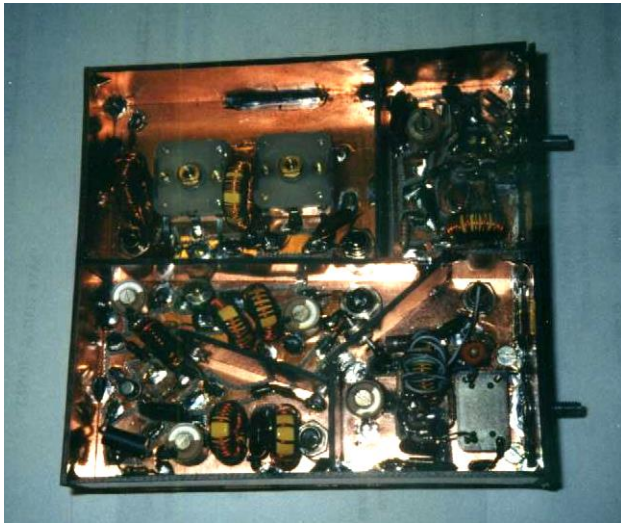
I built my converters on two-sided PC board material. In my first receiver, I soldered strips of PC board onto the main board to provide walls and partitions in the egg carton construction. In my second receiver it dawned on me that only one converter is active at a time. Therefore, the inactive converters are just inert metal and the egg carton shielding isn't needed. I did use a couple shield "cubicle-like" barriers where the output from the preamplifier was close to the input. A folded aluminum, press-on cover keeps out most stray RF. As I said, building all these converters looks overwhelming, but spread out over several months, it wasn't so bad.



Converter modules for 20 meters, 30 meters, 40 meters and 12 meters in the first receiver are shown above. Notice how the side walls were soldered nearly continuously to the base sheet. This warped the sides and pulled them inward. Perhaps it's better to just tack the sidewalls to the base as I did on the second receiver.



Six of the converters in my second receiver. The 160 meter converter is on the far right.



The module directly above contains converters for 160 meters and 17 meters in my first receiver. Notice the large trimmer capacitors in the 160 meter converter at the upper left. The rectangular digital oscillator block in the 17 meter converter oscillator can be seen at the lower right. As explained earlier, these components were poor choices. In my second receiver I used custom crystals where necessary. For 160 meters I used 120 pF trimmer capacitors in parallel with fixed 470 pF capacitors. The complete second filter as shown earlier in the schematic eliminated (nearly all) the 80 meter signals that were leaking into my ears when I was trying to receive 160 meters. That's why I built the 80 meter notch filter described earlier in this chapter.

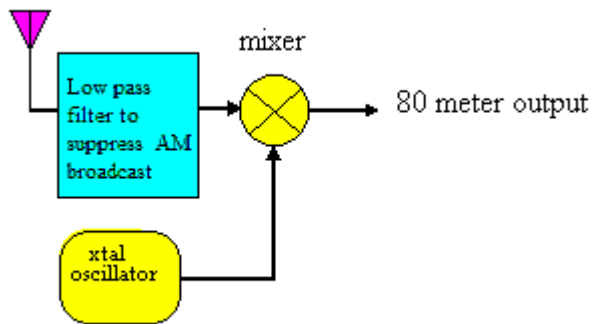
Limbo Radio - How Low Can You Go?

In the early days of radio, guys like Marconi and Tesla hung out at or below what is now AM broadcast radio. As we all know, until the 1920s, all frequencies higher than AM radio were considered worthless. Nowadays the world is obsessed by frequencies *ABOVE* VHF, let alone

standard broadcast. Once I had my all-band HF receiver working reasonably well, I began to look for new worlds to conquer. Occasionally in QST I read about hams given special experimental licenses to try out communication on 138 KHz and 452 KHz. David, VK6DI in Australia, has been communicating with a fellow in Cleveland, Ohio, USA with 100 milliwatts on 138 KHz! Of course the signal is so far down in the noise it takes his computer ages to sort out the ultra-slow CW. Supposedly 452 KHz may soon become a standard little ham band and I'm told there are already some ham beacons there.

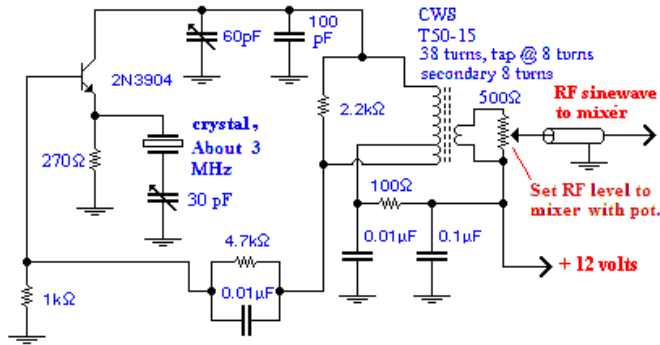
Building a low frequency converter - 50 KHz to 550 KHz

Notice that, if I convert the entire low frequency spectrum to 80 meters, I would need to have the tuning range cover from Zero Hz up to 550 KHz. That's just 50 KHz wider than the 80 meter band.



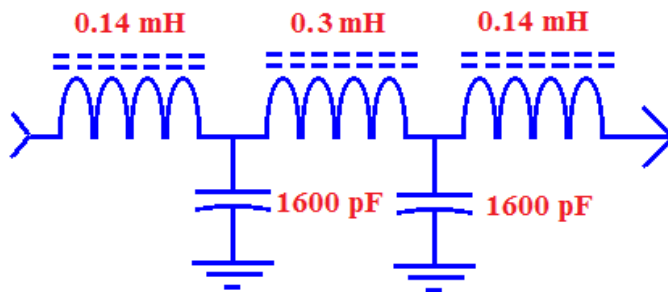
My converter is just a broadcast band low-pass filter, a mixer and a 3.27 MHz (cheap) microprocessor crystal oscillator running just below the 80 Meter band. The low frequency signals are added to the 3.27 MHz sinewave to produce signals within the 80 meter band. I suppose the ideal crystal frequency would be 3.45 MHz. For example, 50 KHz plus 3.45 MHz is about 3.5 MHz. And 550 KHz plus 3.45 MHz = 4.00 MHz. However, my VFO tunes below 80 meters down to 3.29 MHz so a cheap 3.27 MHz microprocessor crystal can tune from about 20 KHz to 710 KHz. The purpose of the low pass filter is simply to prevent my nemesis, the local broadcast KBUF rap music station, from overwhelming the IF. After a couple iterations on the filter system, I took out the dedicated mixer, wired it into the bandswitch and now use the existing broadband converter mixer in the receiver. The working converter is shown below. The "X" in the center is the mixer/ dual-gate MOSFET transistor that I'm no longer using.





L. F. Converter Crystal Oscillator

I initially had troubles with birdies so that I didn't know what was a signal and what was just a local artifact. Most of those troubles were related to having too much IF gain in the core receiver. The amplitude of the sinewave sent to the mixer is adjusted by the 500 ohm pot for maximum gain with the fewest artifact whistles.

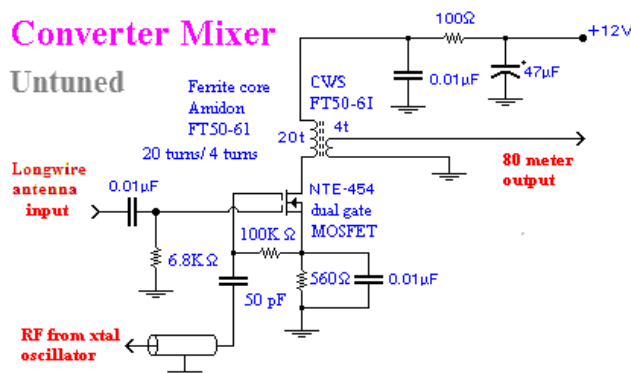


Low Pass CHEBYSHEV FILTER

This low pass can be tweaked by increasing the 2 capacitances to emphasize the LF band near 452 KHz - 500 KHz. The inductors are FT-50-43 *ferrite* cores with 16, 24 and 16 turns, respectively. I had never used ferrites for resonant circuits before. If you need big inductances measured in **milliHenries**, ferrites require far fewer turns than powdered iron cores.

Converter Mixer

Untuned



Similarly, instead of the broadband design shown above, the LC tank circuit of the mixer could be

tuned to emphasize a particular region of the low frequency spectrum.

To hear anything you will need a *REALLY LONG LONGWIRE*. Perhaps not-so-large loops will also work, but I'm not a loop expert. I used my entire 40 meter dipole as a long wire by shorting the coax to the center conductor. Don't forget to bypass any T-match antenna tuner you may be using. C-L-C "T-matches" are high pass filters that will remove low frequency signals.

The first evening I heard the following stations:

| LF Stations & Description | Frequency |
|--------------------------------------|-----------|
| Data with random, slow, pseudo-Morse | 530 KHz |
| Data with Morse "LA" | 420 KHz |
| Data with Morse "FN" | 410 KHz |
| Loud data, no ID | 320 KHz |
| Data with random, slow, pseudo-Morse | 280 KHz |
| Data with Morse "AP" | 270 KHz |
| Lowest frequency data heard, no ID | 210 KHz |

The above list is typical of what I hear. Some data stations have a 2 character Morse code identification. Others are random "pseudo-Morse." By that I mean that most characters are real, but many are oddities like 4 dashes or a "1" with 5 or 6 dashes. The Morse translates to nothing I understand. At the high end of the band there are lots more weak data signals which usually sound like distant buzz saws and don't identify themselves. So far, below 200 KHz I only hear power line noise. It gets louder the lower I tune.

So that's the wonderful world of L.F.! Maybe when there are official LF ham frequencies, it will be more interesting. Of course, like all new bands, when you want to try it out, you don't need to build your own converter. Just push the right buttons on your Yeasu, and voila! You're done! Modern technology sure has a way of converting adventure into boredom. As for me, I'm going to have a go at listening for whistlers down below 5 KHz. I plan to simply connect the audio amplifier to the antenna instead of to the RF detector. Yeasus can't do that, can they? How low can *you* go?

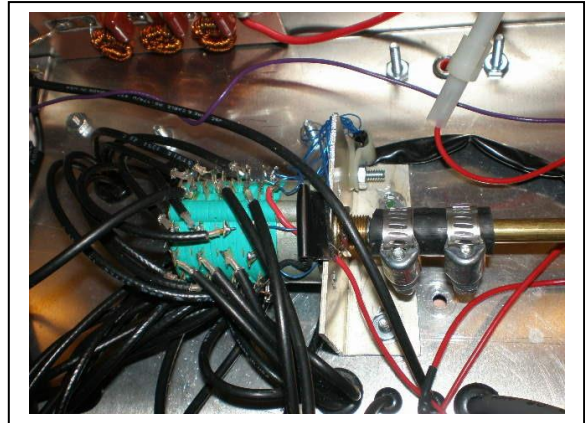
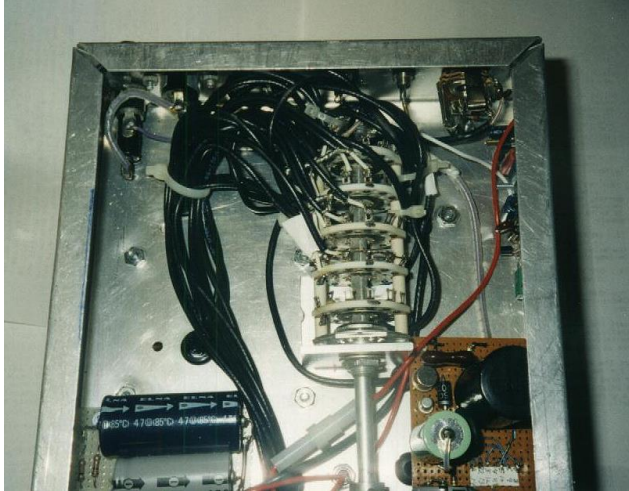
Chapter 17B has an article about listening for whistlers. It turns out that an audio frequency RF receiver is overwhelmed by 60 Hz hum from the power lines inside a house. Consequently the receiver must be battery powered and hand-held so you can carry it outside.

2019: Since this was originally written there are now two official LF ham bands at 135 KHz and 472 KHz. The lower band is 135.7 KHz to 137.8 KHz with 1 watt maximum. The 2 KHz band width is tiny so only CW and slow digital modes are possible. The LF challenge isn't building the transmitter, it's building the antennas and computerized receivers capable of extracting modulation from background noise.

The higher band covers 472 KHz to 479 KHz, 5 watts maximum. It's at least possible to

fit an SSB signal into this 5 KHz wide band, but I imagine nearly all LF guys concentrate on antennas and signal processing. I doubt there is much rag-chewing (conversation) down there. If signal processing turns you on, **go for it!**

Band switching



The very first module in my first receiver that worked properly was the converter for 15 meters. I checked it out by using it with my 1967 vacuum tube homebrew receiver tuned to 80 meters. I immediately noticed that I heard more stations with less noise than with the old receiver tuned to 15 meters. Later, when the new 80 meter receiver began to work, I was able to listen to 15 meters by plugging the 80 meter receiver into the 15 meter converter directly with phono plug cables. Next I built converters for 10 meters and 40 meters. Whenever I switched bands, I moved my cables around like plugs on an old-fashioned telephone switchboard.

Eventually, as I built more and more converters, changing bands became increasingly cumbersome. Finally I gritted my teeth and spent a Saturday wiring up the bandswitch shown on the left, above. To switch from one band to another, a rotary switch selects the desired input filter/ RF amplifier and local oscillator for each band. A minimum of a triple wafer switch is needed, although the 4th wafer can be used for bypassing the mixer used for all the converters on 80 meters. An unused wafer can also be used to light LEDs for each band on the front panel. Or, a voltage signal could turn on a digital sign such as "15" for the 15 meter band. Like the BFO design described earlier, the 12 volt power for each local oscillator and RF preamplifier arrives riding on the local oscillator RF signal to the mixer. In other words, a single switching circuit carries both the local oscillator signal and the 12 volt power. Even with this reduction in complexity, the 10 to 12 band rotary switch becomes a confusing pile of RG-174 coax spaghetti. Be sure to label each plug and socket. I used a fold of plastic tape on each cable and labeled it with a fine-point permanent marker pen.

RG-174 coax quality problems

I've had trouble buying quality RG-174 coax. One 100 foot roll I bought was mechanically and electrically excellent. Unfortunately, the insulation had a chemical stench that was quite obnoxious and, for all I know, carcinogenic as well. The smell did not dissipate with

age. I even tried hanging it on a fence post in the backyard and letting the sun and rain work on it for a few months. It still stank, so I threw it out. Another roll of RG-174 had no smell, but the inner multi-strand conductor was so fragile, that the slightest bending on a solder joint broke the wire. To use it, I had to strain relief each connection with a drop of 5-minute epoxy - what a nuisance! In summary, if possible, sniff your coax and examine it closely before buying it.

Although I had a rotary switch with 5 decks available, I only needed 4 decks to route the converter modules to the mixer. I used the entire 4th deck simply to bypass the converters and connect the antenna directly to the basic 80 meter receiver. If you prefer, this can be simplified by simply connecting the antenna to the input of the 80 meter mixer on the 80 meter switch contacts.

Obviously there is no oscillator input, so the signal passes directly to the 80 meter receiver. This functionless mixer adds an unnecessary stage of amplification but (surprisingly) it doesn't seem to have an obvious disadvantage. If you have a unused switch deck in your switch, just as I did above, you could use it to annunciate which band you are on. The switch can turn on an LED light for each band or activate digital numbers.

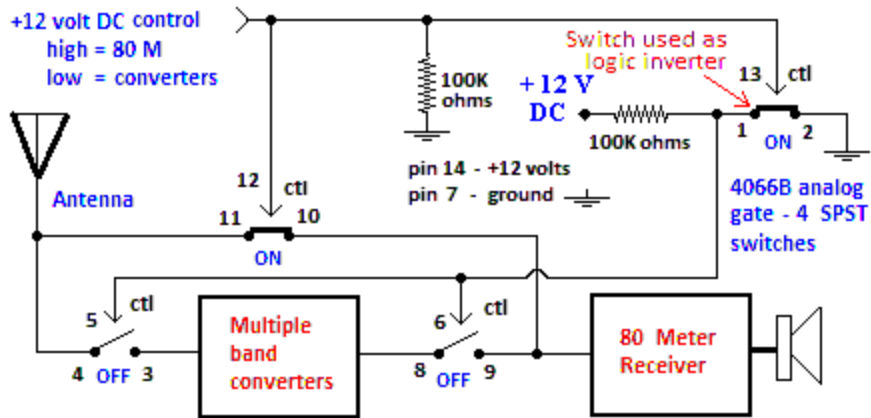
Consider digitally-controlled analog switches

Multi-gang, high-quality rotary bandswitches are quite expensive. Suppose you have a 3 gang switch and need just one more gang to add an additional band function. For example, rather than run the 80 band antenna signal through the converter mixer when the receiver is set to 80 meters the way I did, perhaps you should bypass the mixer to get rid of un-needed gain or extra noise.

RF can be switched digitally instead of using a mechanical switch. "Analog switches" are integrated circuits that function like an ordinary switch. Instead of your finger flipping a paddle, a DC logic signal turns the switch ON or OFF. Analog switches consist of MOSFETs that pass any signal ranging between zero and your circuit voltage, V_{cc} . Each SPST switch has about 100 ohms resistance. When turned on, the switches conduct like a $100\ \Omega$ resistor at any voltage between the V_{cc} and ground. When OFF, the switch has infinite resistance. It also has capacitance to ground, which might be an annoyance. If you have a DC control signal available that represents "80 meters," you can use this to turn on a combination of analog switches in the chip to bypass the mixer.

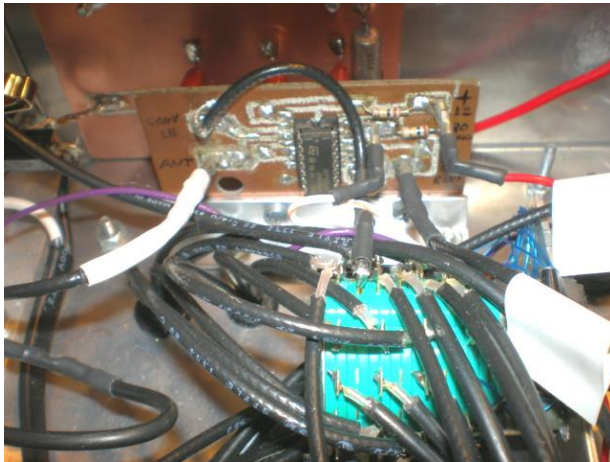
In my usual fashion I tried to design my own digital analog switch out of MOSFETs. I couldn't figure out how to do it, so I studied the chip schematic more critically: It turns out that the MOSFETs inside the chip have an accessible floating drain-source contact that is wired separately from the drain and source! In other words, they are strange 4-lead transistors. Somehow, the switched signal propagates down these "isolated central/ components" while the gates steer it high or low. These are weird transistors which can't be simulated with normal transistors. Or at least I don't know how to do it.

The CD4066B analog switch is available in good old DP (large pinned) chips which sell for 48 cents in the dip version or 14 cents in an SO surface mount version. It contains 4 separate SPST switches. The 4066B can switch RF up to 65 MHz, so it's good for 6 meters. The DG611DJ is also available as a dip chip and works up to 540 MHz.



ANALOG GATES USED TO BYPASS CONVERTERS

Eventually I got around to building this 80 meter converter mixer bypass circuit and installing it in my receiver. Maybe 80 meters is a little less noisy, but it is hard to say. The performance of the converters seems unaffected. In any case, analog switches are useful circuits to know about.



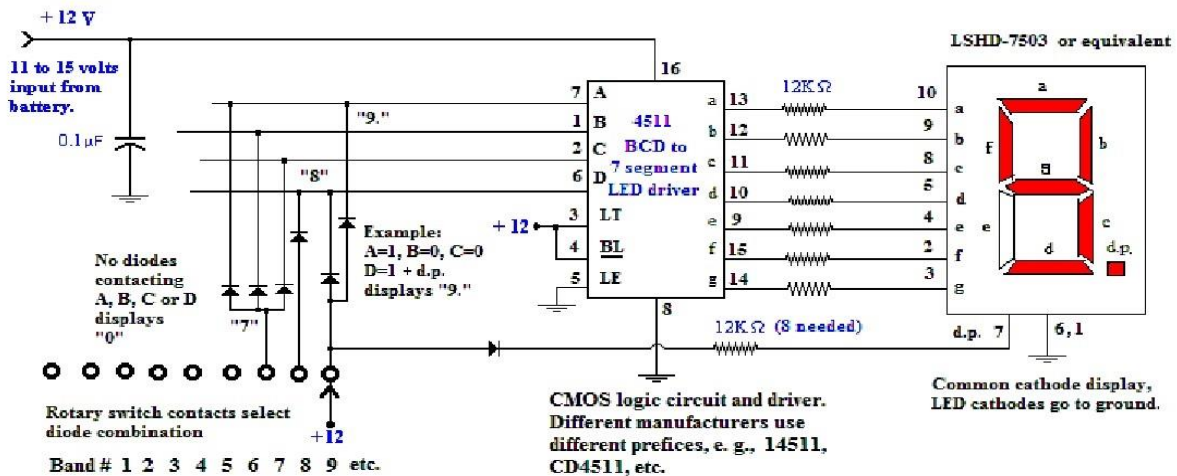
An LED digital band enunciator

Here's a way to label each band: Ideally I would like to build a frequency counter display. But so far, digital radio noise interference has always frustrated me. I compromised with a 2 digit numerical display that shows the first 2 digits of each frequency band, 1.8, 3.5, 5.0, 7.0, 10, 14, etc.. This circuit is static - unchanging. In other words, it isn't incessantly switching transistors on and off. It makes no radio noise because it has no clocks or micro-controllers.



The LED digits are the 7 segment variety that also have a decimal point. I used modern versions that are super bright when each segment of the numbers is lit with less than 1 milliampere. My first breadboard prototype used ancient LED digits that looked exactly the same but drew as much current as the rest of the receiver! The enunciator assembly is powered by unregulated 12 volts from the battery. The DC signals to select each band are 12 volts from one layer of the multi-ganged band switch. At each switch position 12 volts DC is passed to the enunciator through one of 12 separate wires. Each wire goes to one or more ordinary 1N914 diodes that select which of the 7 LED segments turn on. Since there is a decimal point as well, many of the numbers might need 8 separate diodes to select each of 2 numbers - 16 diodes per 2 digit band display! Fortunately, that much complexity isn't necessary.

Numerical Band Display (One digit shown)



The 4511 CMOS logic chip is designed to drive 7 segment displays. One 4511 is needed for each digit. This chip is called a "BCD-to-7 segment driver." BCD refers to the binary code, although "ABCD" would be more accurate. Each number, zero through nine, is coded by a 4 bit binary number. Specifically:

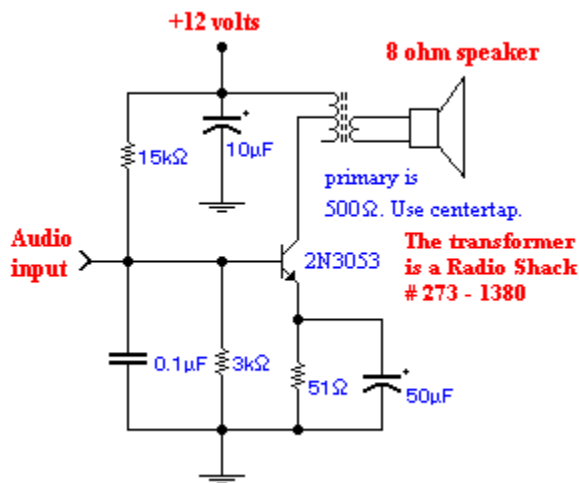
Zero = 0000
 one = 0001
 two = 0010
 three = 0011
 four = 0100
 five = 0101
 six = 0110
 seven = 0111
 eight = 1000
 nine = 1001

Each "one" in the binary number needs a diode to set the correct combination of ones in the number. Also, another diode is needed to turn on a decimal point. For example, if you label 80 meters as "3.5" MHz, an extra diode is needed to light the decimal point. The decimal points are wired directly to the LED display, rather than passing through the BCD-to-7 segment driver. The good news is that zeros are assumed by the 4511 chip, so an "8" only needs one diode to select it, e.g., 1000, not 7 separate diodes to light each segment. However, it still requires a bunch of wires and diodes to code ten or more channels. Welcome to digital circuitry!

Driving a speaker

If you don't need a speaker, you probably don't need a third amplifier stage. On the other hand, an 8 ohm speaker plugged into the 8 ohm headphone output is much too faint. Amplifiers to drive a pair of headphones are relatively easy. The main difficulty I've had with earphone amplifiers was making sure the sound wasn't too loud. Also, I have had to filter the amplifier stages to get rid of obnoxious high frequency noise.

In the original W7ZOI/ K5IRK receiver AF amplifier design, the third stage was an emitter-follower for driving either a speaker or low impedance headphones. The advantage of this design was that the emitter-follower drove the speaker directly and there was no need for a high-to-low impedance transformer. Unfortunately it distorted the audio waveform and I was never able to fix it. In frustration, my first receiver used the following simple amplifier. It can drive a small speaker, but is barely loud enough to be useful.



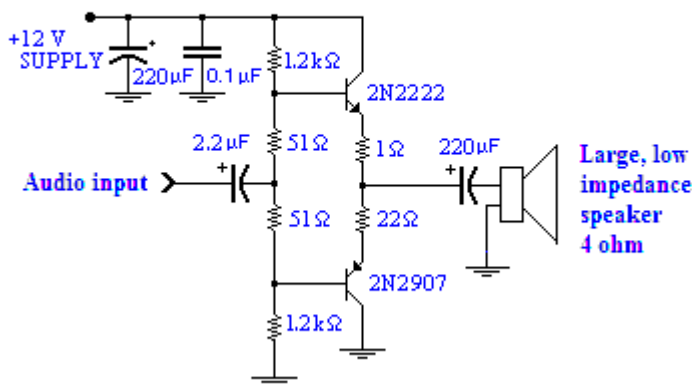
A simple amplifier for driving a small speaker

You'll find that a big speaker sounds much better than a little one. A speaker small enough to fit in the receiver itself will probably sound "tinny." It turns out that half of the sound volume and much of the sound quality from a speaker can be attributed to having a large

resonating chamber behind the speaker. If your receiver is like mine, the unfilled empty space is criss-crossed by various modules, shafts and wires. Moreover, there is no "roof" over the chassis to enclose a resonating space.

The following push-pull amplifier has enough gain to drive a large speaker. I have a 12 inch wide 4 ohm speaker in a cabinet which I use like a table for my old Collins receiver. I use a DPDT switch to select audio from the Collins receiver or my homebrew receiver. Since my earlier little speaker amplifier was too feeble, I had assumed that way more power would be needed to get adequate volume. It turned out that ordinary 2N2222 and 2N2907 transistors can produce more quality sound than I can tolerate.

Push-Pull Complementary Transistor Speaker driver



A push-pull complementary 1 watt amplifier

This amplifier uses complementary NPN and PNP power transistors to avoid using input and output transformers. Because of the complementary transistor arrangement, the "pull down" resistor that insures that one transistor will turn off, is also serving as the "pull up" resistor that turns the opposite transistor on. In other words, each of the two output transistors delivers half of the sinewave output to the speaker load. The push-pull design is reminiscent of the 50 watt RF linear amplifier discussed in Chapter 12. Unlike the Chapter 12 radio frequency design, the input to both output transistors doesn't need to be positive. The PNP transistor can be turned on with negative drive so no center-tapped transformers are needed.

I started out using 33K ohm resistors for the pull-down/pull-up function. These worked OK at ear splitting sound levels, but at low levels, the transistors did not turn fully on. The result was a coarse noise on the signal that sounded like static. When viewed on a scope, the output voltage on the speaker was zero much of the time with positive and negative blips of signal poking up and down from the zero line. In contrast, the input waveform was a continuous wavy line with no obvious horizontal lines. I kept reducing the pull-up/pull-down resistance until the output waveform was continuously wavy. This occurred at 1200 ohms and the sound became noise free. I increased the 2N2907 emitter resistor from 1 ohm to 22 ohms to make the + and - audio sinewave halves more equal and symmetrical.

This double 1200 ohm bias drive takes 40 milliamperes. This means that 1/2 watt is

expended just to keep the transistors ready to turn on! These transistors are both rated for 0.4 to 0.8 watts each without a heat sink, depending on the specific transistor version. Consequently, 0.25 watts each doesn't hurt them, but they do run hot to the touch.

When you think about it, driving a 4 ohm impedance speaker with a 12 volt power supply implies surges of $12 \div 4 = 3$ amperes. If I had used a transformer output, it would have converted a given amount of AC power from 12 volts AC at a small current to roughly one volt AC at a very large current. Unfortunately, I couldn't find any small input and output transformers for an audio push-pull circuit analogous to the radio frequency design in Chapter 12. The complementary circuit accomplishes the voltage-to-current conversion by dropping the voltage across the large output capacitor. Big surges of current enter the positive end of the output capacitor at 6 volts and are delivered to the speaker at 1 volt. The trick is balancing the transistor gains so that the capacitor discharges with every audio sinewave cycle.

If you would like to save some current and run the transistors cooler, there is no reason you can't run the output using an impedance step-down audio transformer. Again, I couldn't find one with the right specs. Simply connect the output capacitor to say, a 100 ohm to 4 ohm transformer. That way, the pull-up/pull-down resistors can be increased up to some economical level like 10,000 ohms. If the transformer is too small it may saturate its iron and cause distortion. You'll have to experiment to get the values right so that the output will be smooth, wavy and high fidelity. A scope picture of the output waveform will be smooth and not in pulses when you have a hi-fi waveform.



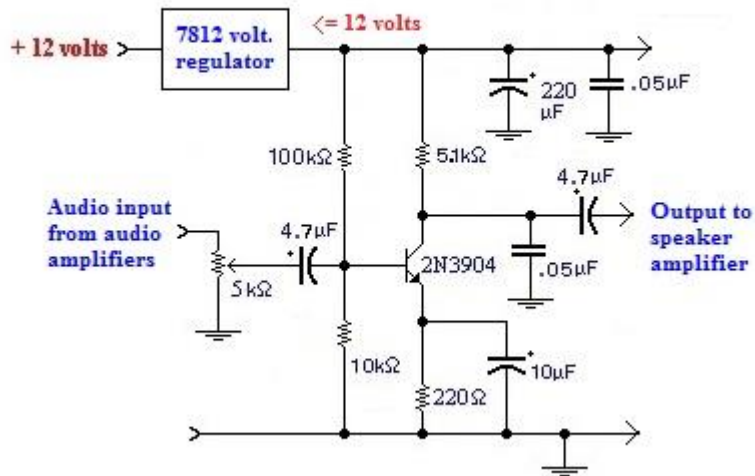
The push-pull circuit worked so well in my second receiver, I built the one above for my old receiver. I built exactly the same circuit, turned it on and it was silent as a tomb. I noticed that, when I first applied power, I sometimes heard a little "pop" coming from the speaker. It dawned on me that the output capacitor (the big green cap on the right) was fully charged and wasn't discharging during the negative halves of the sinewave cycle. Sure enough, the capacitor voltage measured +12 volts DC. The 2N2907 was not turning on to discharge the capacitor. The DC voltage from its base to emitter was only -0.2 volts and should have been over -0.6 volts.

I substituted 2K ohm trimmer resistors for the 1200 ohm resistors. Next I applied the 12 volts supply voltage, but no audio. I balanced the two trimmers until the + end of the output capacitor measured exactly 6 volts. Voila! It worked. The sound quality was best when I moved

the balance a bit off center so that the NPN 2N2222 took more of the load. I tried various combinations of emitter resistors, but I never improved on the 1 ohm and 22 ohm resistors shown in the schematic.

How much gain do we need?

Optional auxiliary audio amplifier to drive speaker amplifier



A major challenge difficulty with building receivers is that there always seems to be too much or too little gain. Putting in trimmer pots can help, but it's a challenge deciding how many stages of IF or AF amplification are needed. The above circuit is an audio driver amplifier for my speaker amplifier stage which, on my amplifier, is on the same PC board as the output amplifier. You may not need this. Build the final stage first and see how it sounds. On my little speaker amplifier module, the 7812 voltage regulator takes power directly from battery and insures that the amplifier doesn't see voltages greater than 12 volts. The input pot helps me equalize the sound in the headphones with the speaker. I needed this amplifier because it receives the speaker audio from the stage ahead of the amplifier for the headphones. I did not want to use the 0.6 volt clipped headphone version of the audio to drive the speaker.

My present attitude is that having both high IF and high AF gain available are desirable. High gain from both simultaneously is rarely needed but you need to be able to turn them both down to nearly zero when necessary. My front panel AF and IF gain controls are 100K multi-turn precision pots, so there is plenty of control of both ends of the gain spectrum. Also, high quality pots are not scratchy. More sources of static are NOT desirable in this project.

Receiver muting

While transmitting, it is extremely distracting to hear your own signal blasting your ears in the receiver. Even with the antenna switched over to the transmitter, the receiver will be overwhelmed by your own loud signal. A CW signal will sound distorted and will interfere with your sending. I have found it best to turn the receiver off altogether while transmitting. That's

why I built a Morse code sounder into my electronic bug so I would hear a clear tone while I am sending. (See Chapter 9)

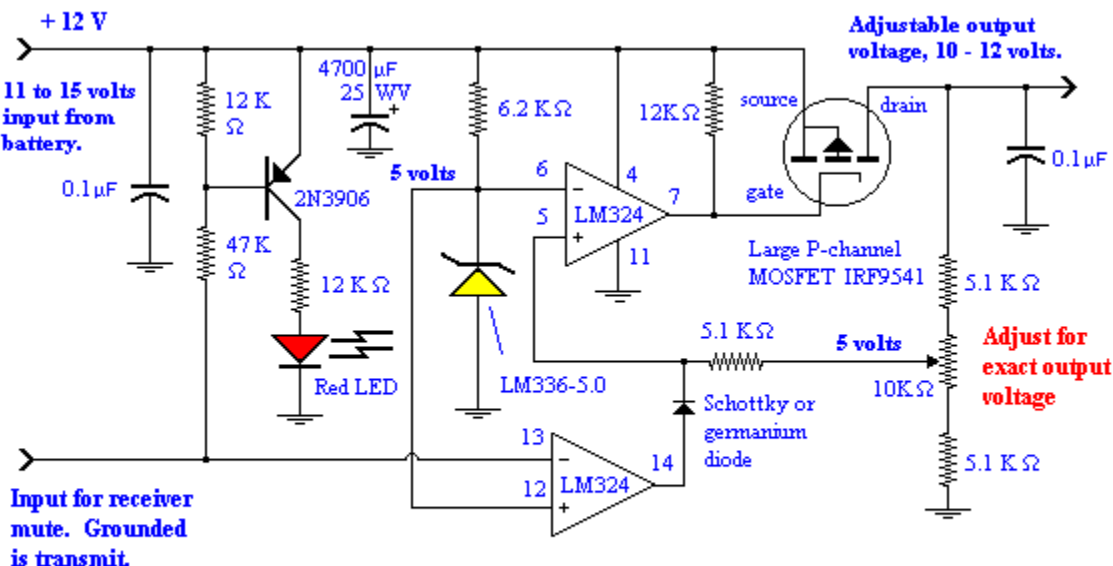
Turning the receiver off by hand is too slow, so you will need to build a muting circuit. I trigger mine with the same transmit/ receive signal line used to turn on the transmitter. I have found that the simplest solution is turning off some of the power supply lines. I first tried just turning down the audio and IF gain pots by pulling the pot wipers down to ground using the collectors of transistors. This was inadequate. Now I switch the receiver main power supply on and off, just as I did in the transmitter. I leave the receiver VFO supply on continuously to prevent frequency drifting due to the VFO circuitry cooling and warming.

Receiver power supplies

The +12 volts input to the receiver as a whole could be supplied by a line powered regulated supply such as the one(s) described in Chapter 8. I often run my station on a 12 volt battery, so I just needed the low drop-out regulator shown below. This isn't essential, but insures that the voltage never exceeds 12 volts and is consistent. The power supply requirements for the receiver are similar to the low power stages of the transmitter. I used the same supply that I developed for use with my QRP modules in Chapter 8. This supply is over-designed for a receiver and can supply at least a few amperes. The VFO power supply used in the receiver is the same one described in Chapter 10.

Mute capability

The mute function was implemented using an unused op-amp as a comparator. The mute input lead comes from the transmitter. Or in my case, it comes from the transmit/ receive switch on my homebuilt bug. During transmit the mute line is pulled low to ground. During receive, the 12K and 47K resistors pull the mute line up to +12 volts.



Low Dropout 12 Volt Power Supply with Mute Capability

Referring to the lower op-amp, the positive input is wired to the 5 volt reference.

Whenever 5 volts is higher than the input mute voltage, the op-amp output, pin 14, rises up to 12 volts. This causes current to flow down through the Schottky diode to the positive input of the upper op-amp, pin 5. When the positive input (pin 5) is higher than the 5 volt reference on pin 6, the upper op-amp output (pin 7) rises to 12 volts, thereby turning the power MOSFET off and shutting off the current supply to the receiver.

Red mute indicator light

While the receiver is being muted, the base of the 2N3906 PNP transistor is pulled down to ground, thereby turning on the transistor and lighting the red LED. The LED is on the front panel of the receiver and alerts me that the receiver is in standby mode for transmit. My LED is an extra bright type that needed less than 1 milliampere to be adequately visible. You may need a resistor smaller than 12 K for good brightness.

After building this, it occurred to me that I should have used another unused op-amp to turn the LED on instead of the transistor. There are 4 op-amps in each chip and I only used 2. As drawn, the 12K resistor and 47K resistor are the pull-up resistors for the transmit/receive line. This worked OK in my first receiver, but I needed to add a 10K resistor from the T/R line up to 12 volts in my 2nd receiver.

Use linear regulators, not switching regulators

I originally tried to use a switching power supply for this receiver, but reception was always impaired by switching supply noise. My switcher caused buzzing and hissing on every ham band. RF filtering was a great improvement, but it was never good enough. Building a low-noise receiver is hard enough without fighting a built-in noise generator. For me, one of the great mysteries of modern commercial receivers is how they incorporate all those digital displays and processors without producing a hash of noise that would make the receivers insensitive to weak signals on the upper bands. Sometimes I can even hear my Hewlett Packard digital frequency counter, which is located 2 feet from the receiver and operates from a different power source!

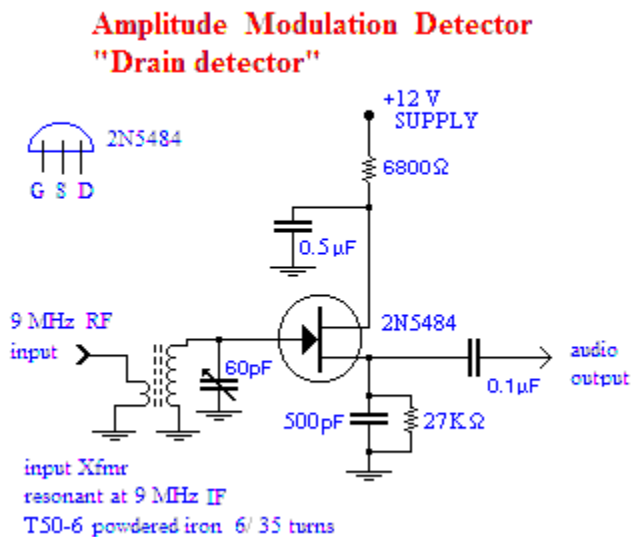
AM detectors

My new receiver has three detectors; a product detector for CW and SSB and detectors for AM and FM. All three detectors are housed in a separate module. A product detector can detect AM modulation, but the tuning must be precise to avoid hearing an annoying whistle on top of the speech or music. An AM detector makes listening to shortwave broadcast stations much more pleasant. Also, who knows, some day you may talk to a ham using "Ancient Modulation."

Scanning a ham band with the usual product detector, then repeating the scan with the AM detector is interesting. It sounds utterly different. The CW and most data signals vanish. The band has few signals and there is far more background noise. Strong SSB signals can be heard, but they are just unintelligible squawking. Curiously, *REALLY* loud SSB signals, the kind that pin the S-meter, are quite intelligible. Some shortwave AM broadcast stations on the 31 meter band are so powerful, they overwhelm the 30 meter band converter. On AM, when I turn up the IF gain up high, I can often hear a religious sermon over the entire band. To receive the sermon on its actual frequency, 9.95 MHz, I have to turn both the AF and IF gains to near

minimum. I learned from these sermons that Armageddon will happen any day now and I should move to South Carolina and await the rapture.

I first tried an ordinary crystal set AM detector, much like the one discussed in Chapter 4. It produced a surprisingly weak signal. When I switched from the product detector to the AM detector, the signal vanished. Both the IF and AF gains had to be cranked all the way up to hear anything at all. My next AM detector was a form of source follower. That is, it resembles a bipolar transistor "emitter follower" amplifier. In old-time vacuum tube technology this design was called a "plate detector." So I guess we should call this a "drain detector." As you can see, in this case the diode is the gate of a JFET.



This circuit produces much more signal than a simple diode detector, but it's still far short of the signal strength produced by the product detector. Therefore, I added another stage of audio amplification to make the output more equal to the product detector. This extra stage of amplification is also mounted in the detector module.

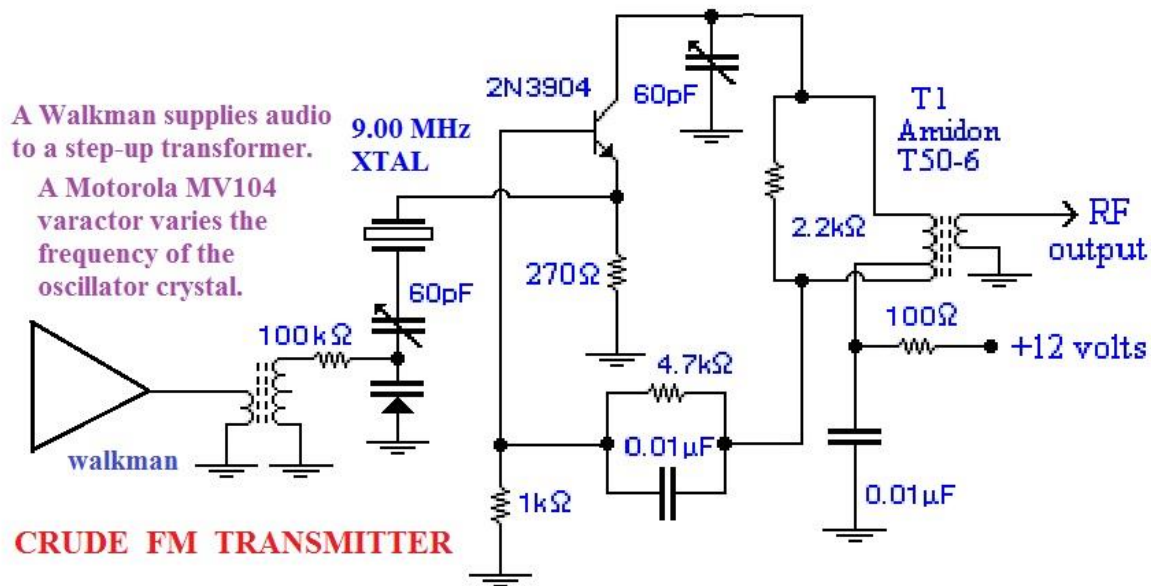
This receiver was built some years ago. As of 2018 my newest receiver is the relatively "simple" superheterodyne described in Chapter 7C. One "simplification" I discovered was that AM detection doesn't need a special "detector" at all. I fed the IF output directly into the audio amplifier. The audio amplifier is full of huge capacitors that short out all the RF signals. All that remains are the amplitude variations, the AM signal. Like the detector described above, you may need to add another stage of audio amplitude to compensate for the loss of gain normally provided by the product detector. Experiment!

FM detection

Why FM? Frequency Modulation is permitted on 10 meters, although I may not live long enough to hear a ham on ten meter FM. I have read that 10 meter FM is popular in Japan. If we ever have sunspots again, we might hear some Japanese stations. I had never built an FM detector, so just for fun, I did. First let's review how frequency modulation is generated: FM is

produced by making the transmitter frequency vary up and down in proportion to an audio signal. In other words, instead of directly varying the amplitude of a single transmitter frequency, the FM modulator just varies the frequency of the transmitter in proportion to the amplitude of the speech. The signal amplitude remains constant. When the signal is higher than the noise level, it can be separated from the noise and produce clean static free sound. In contrast, an AM signal that isn't extremely strong, will dip its amplitude down into the noise and be vulnerable to static.

In theory a tiny audio speech signal from your microphone can be used to modulate the DC signal that tunes a transmitter varactor VFO. This only needs very small amounts of audio signal. In principle, FM makes single sideband modulation look ridiculously complicated. In case you're wondering, I built such a crude FM modulated oscillator to test my detector. Yes, it worked, but the sound quality was only poor to fair and the modulation deviation was much too wide for the 10 meter ham bands. Obviously my FM research had barely started.



2019 update: Product detectors can detect narrow band FM

If the frequency deviation matches the audio frequencies being transmitted, a product detector can produce quite good audio. I discovered this when I was building a 2 meter FM transmitter. (See Chapter 16B) The transmitter circuit I was copying FM modulates an 18 MHz crystal oscillator. The transmitter uses the same basic principle described above, an audio voltage applied across a crystal. The frequency deviation of the modulation can be varied with a pot. Because 18 MHz is near the 17 meter band, I could receive the signal using the receivers described here in Chapter 13. By varying the deviation I could change the audio pitch of the speech up or down. In other words, I could give the voice or music too much treble or too much bass. Speech became unintelligible when I switched in even one crystal filter into the IF amplifier strip.

In my 2 meter transmitter, the 18 MHz signal is doubled to 36 MHz, doubled again to 72

MHz and finally doubled to 144 MHz. The frequency deviation impressed on the signal increases every time the RF frequency doubles. Therefore, the deviation at 2 Meters is 8 times the actual frequency range of speech. The speech from my prototype sounds as good as commercial transmitters when received by a commercial 2 meter handheld transceiver. Of course, if this wide band FM were received by a product detector, speech would not be intelligible. 500 Hz would become 4 KHz and so on.

Ironically the crystal controlled discriminator described here in Chapter 13B could not detect the narrow band 18 MHz FM. I believe my discriminator is too insensitive to narrow band frequency deviation and my test signal was too feeble. With a true FM detector, FM deviation = loudness, in other words, audio volume.

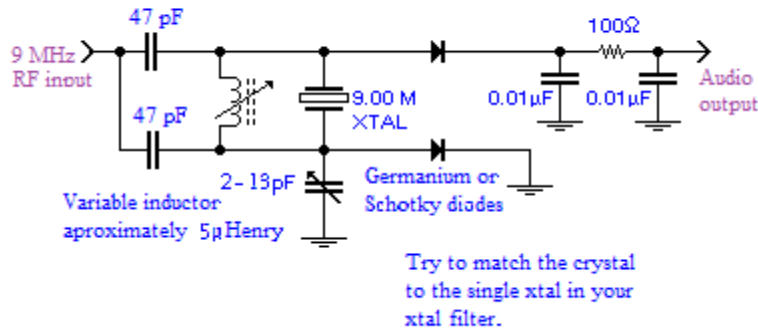
In contrast, product detectors are the most sensitive type of detector I have encountered by far. The AM detector presented above produced a noise free spot, a carrier, at 18 MHz. As you would expect, there was no audio modulation audible on the carrier, no matter how high I turned the gain.

Conventional FM detectors

The essence of FM detection is detecting rapid frequency changes and converting them into a varying amplitude audio signal. There are three kinds of conventional FM detectors - the **discriminator**, the **ratio detector** and the **Foster-Seeley** detector. These detectors are designed to react to frequency changes, not changes in signal amplitude. After studying the ARRL handbook essays on these subjects, I concluded that most discriminator and ratio detector circuits involve carefully balancing multiple windings on a transformer so that signals cancel and reinforce. Maybe I missed something, but the circuits for all these detectors seemed rather similar, even if the operating principles aren't. A discriminator uses diode detectors to produce positive and negative DC voltages when the frequency rises above or below the center of the IF. These rapidly changing DC voltages can be used as an audio signal, much like an ordinary AM detector.

After thinking about the complexity of building multi-winding transformers and making them cancel precisely, I was attracted to the simplicity of a discriminator circuit that uses an IF frequency crystal. If you have built the rest of this receiver, you are bound to have extra 9 MHz crystals. When the signal frequency rises above the crystal frequency, it produces a negative voltage. When the frequency drops below the crystal frequency, the diode pair produces a positive voltage.

Crystal Discriminator



You have surely tuned up your IF frequency amplifiers to match the frequency of your crystal filters. Therefore the discriminator should also be tuned to the IF amplifiers, even though the *discriminator will be used without a crystal filter* in the IF.

How the discriminator works

To me, the theory behind this detector is rather abstract. I think of the crystal and its trimmers as a series LC circuit with the one end grounded. As you learned way back in Chapter 4, when the frequency perfectly matches the crystal resonance point, the crystal impedance is **minimum** and the DC output voltage signal goes to nearly zero, a couple millivolts. When it is not on the center frequency, an RF voltage appears on both sides of the crystal. These voltages are rectified to produce two low frequency (audio) signals. The variable trimmers are tuned until the two sides of the output are equal and cancel each other. At frequencies above the IF center, the crystal looks like an inductor. At frequencies below the IF center frequency, the crystal looks like a capacitor.

The current-to-voltage phase relationship between the two signals reverses as the center frequency is passed, so the voltage polarity of the two signals reverses. One of these signals is shunted to ground by the diode. The ungrounded diode delivers the low frequency output audio signal. Whenever the frequency drops below the center, a positive voltage appears. When the frequency rises above the center frequency, a negative voltage appears because the audio output includes the connection between the two diodes and ground. The farther the frequency deviates from the center frequency, the more voltage it produces. The best reception usually occurs without the usual 9 MHz crystal filters.

Because of the stray capacitance in the rest of the circuit, the trimmer capacitor and trimmer inductor are needed to zero out the DC signal when the frequency is constant. I happened to have the tiny variable inductor in my spare parts, so I don't know where to buy another one. You'll just have search your junk box and parts catalogs. My coil is a small, molded plastic tube with a powdered iron core in the shape of a set screw. The threaded powdered iron core is screwed in and out to adjust the inductance. The maximum inductance of my coil is about 5 microhenries. The actual coil is 11 turns, 0.21 inches diameter and 0.21 inches long.

How to measure inductance

How did I measure 5 microhenries? I don't have a fancy bridge inductance meter, but I

do have a capacitance meter. First I measured the capacitance of my oscilloscope probe. It was 15 pF between the probe and ground lead. Next, I connected the RF generator across the coil. I connected the probe across the inductor and swept the HF frequency bands until I found the frequency where the RF voltage peaked. This is the frequency at which the probe and coil form a parallel LC circuit. The inductance was then calculated according the formula:

$$\omega^2 = 1/LC. \quad \omega = (2 \times \pi \times \text{frequency}) \text{ and } \pi = 3.14159$$

$$\omega^2 = 1 \div \text{microhenries} \times \text{picofarads}$$

Solve for microhenries. See? Math is occasionally useful.

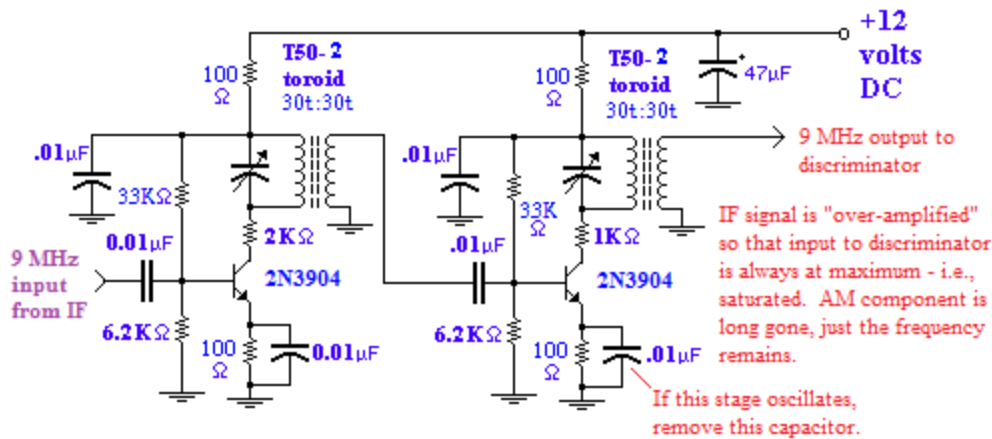
FM "Limiter" circuits

The raw IF signal from a receiver varies in amplitude due to noise and interference. Unfortunately, the discriminator circuit will respond like an AM detector as well as a frequency detector. Therefore, when the FM signal is weak or strong, the discriminator output will be proportionately weak or strong. As a result, the discriminator itself is vulnerable to AM noise. The reason Edwin Howard Armstrong originally developed FM was to eliminate the static and noise inherent in amplitude modulation. Obviously the amplitude component must be eliminated and this is done with the inaccurately named "limiter" circuit.

Limiters remove the AM component by amplifying the IF signals again and again until the FM signal is as large as possible. That is, the peak-to-peak amplitude of the RF sinewave is almost as large as the supply voltage, 12 volts. In this way, even relatively weak signals are supposed to become maximum and constant amplitude. In practice, when tuning in a signal using the FM detector, I find the *IF gain must be set quite high*. This contrasts with a low IF gain setting with AM and CW signals.

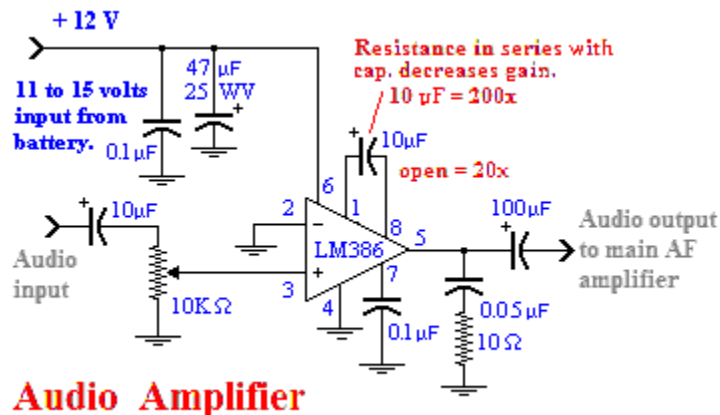
The circuit below is simply two class A RF amplifiers in series. Notice the 2K and 1K resistors in series with the L-C circuits. These resistors "throw away" unwanted signal strength so that the next stage will have something to amplify. In the circuit that I copied, the first collector resistor was 15 K, but for my amplifier, that was too extreme and 2K worked better. Also, my second amplifier self-oscillated until I removed the bypass capacitor across the emitter.

FM Limiter to Remove AM Components



After all this trouble, the resultant audio signal from the discriminator is still rather weak. It depends of course on the frequency deviation of the transmitter. Commercial FM music stations vary ± 75 KHz! No wonder they produce gorgeous hi-fi audio. But on the ham bands we are only allowed to vary ± 5 KHz, roughly 3 times the width of sideband audio signals. This means that ham FM audio signals are inherently puny. The new narrow band FM that the police use is even more narrow so that they can cram more channels into the same spectrum.

An extra audio stage to boost discriminator output



An integrated circuit audio amplifier

Because the resultant audio is so weak, I had the same feeble audio that I had with the AM detector. I could have just fed the output from the FM detector into the amplifier I used for the AM. Instead, I built yet another audio amplifier stage. I was tired of building discrete component audio amplifiers, so I used one those sinful LM386 integrated circuits. They have adjustable voltage gain, 20x to 200x. This is far more gain than a single stage of a transistor amplifier. You'll get more gain than you need and you may have to throw away some of the gain with yet another trimmer potentiometer, as shown.

If you have 3 different detectors, having a wide of range of IF and AF gain becomes important. A product detector for CW and SSB is extremely sensitive and usually works best with low AF and low IF gain settings. In contrast, the FM detector described here is quite **insensitive** and works best with wide open IF gain and high AM settings. The AM detector usually needs moderate settings of both gain controls. As mentioned earlier, multi-turn control pots makes it easy to fine-tune IF and AF gain settings.

Notice the input 10 μ F capacitor: This cap is removes any DC bias from the previous stage. If the preceding stage has a capacitor output, you don't need this. DC on the input drives the output line, pin 5, high and severely limits the audio output voltage swing.



This module houses the CW/SSB product detector, the AM and FM detectors plus separate audio amplifiers for the AM and FM detectors. The FM crystal discriminator can be seen at the lower left of the floor of the box. The limiter amplifiers are on the lower right side. The AM and product detectors are on the back wall. The rotary switch selects which detector is in use. The folded-out side of the box has the two audio amplifiers for the AM and FM detectors. The little light-blue squares on the audio board are the trim pots for the AM and FM outputs.

I just tacked the folded sides of the box in place with solder joints at the corners. The 5 separate PC boards are grounded together with flexible multi-strand wire. That way, in the future I won't need dynamite if I need to disassemble the box. The usual bent sheet aluminum top clips onto the box and is held in place by friction.

Automatic frequency control

Now if I were *REALLY* competent, I would have worked out a feedback system to insure that my FM detector locks onto signals and prevents drifting, just like commercial FM radios. Because frequency deviation from the center frequency causes positive and negative output voltages, these signals can be averaged into slowly changing DC voltage and used to bias the receiver varactor VFO. As the receiver drifts off frequency, the feedback could bias the VFO to pull the signal back into the center of the IF passband. Nothing to it! ... Right.

What's an FM detector good for?

It has been fun comparing reception with the 3 kinds of detectors. The only actual FM I

have listened to so far has been my crude, homemade FM transmitter which works but has poor fidelity. The best practical use for it so far has been listening to noisy AM shortwave broadcast stations. If they have enough signal strength, the limiter circuit does its job and the signal is far less noisy than when using either the AM detector or the product detector. Moreover, the quality of the sound from the FM detector is far better than either the CW or AM modes. This is an application for which high IF gain is essential. The discriminator needs all the IF gain it can get in order to eliminate the noise. Also, the discriminator works best with all the crystal filters switched out. This gives the maximum frequency change and the biggest signal.

If you think about it, SSB is a combination of AM and FM. In SSB the one remaining sideband rapidly changes both its frequency and amplitude simultaneously. There is no carrier. When I tune in SSB with the usual product detector, the musical pitch of the distorted voice drops toward a low point and suddenly the voice becomes intelligible and even good fidelity. When I switch to the FM detector, I hear distorted "Donald Duck" quacking, just as I do with the AM detector. But when I tune *very carefully* toward the center of the sideband, the modulation abruptly becomes intelligible and clear. Unlike the product detector, there is no change in tone to tell you when you are getting close. Consequently, tuning in SSB with a discriminator is quite hard to do, but it's *interesting*. And that pretty well sums up FM detection in an HF receiver!

Sharp audio filters

Many HF receivers have audio filters that limit the audio frequency of signals passed onto the headphones. This is useful for separating CW signals that are nearly on the same frequency or covered by atmospheric noise. Even though I have multiple crystal filters, I would still want an audio frequency filter. The two filters can work well together for separating noisy, crowded signals. Unlike IF crystal filters, audio filters may be added external to the receiver.

Extracting DX from the noise

I have discovered that my 700 Hz audio filter is great for super weak CW signals. For example, you will routinely hear "DX storms" of hams on your continent calling some exotic station on another continent. How often can you hear the actual DX station? I can usually hear the DX, but rarely copy it easily. For one thing, those popular DX expeditions usually send at 25 or 30 words per minute. But also, the DX signal is often weaker than the atmospheric noise.

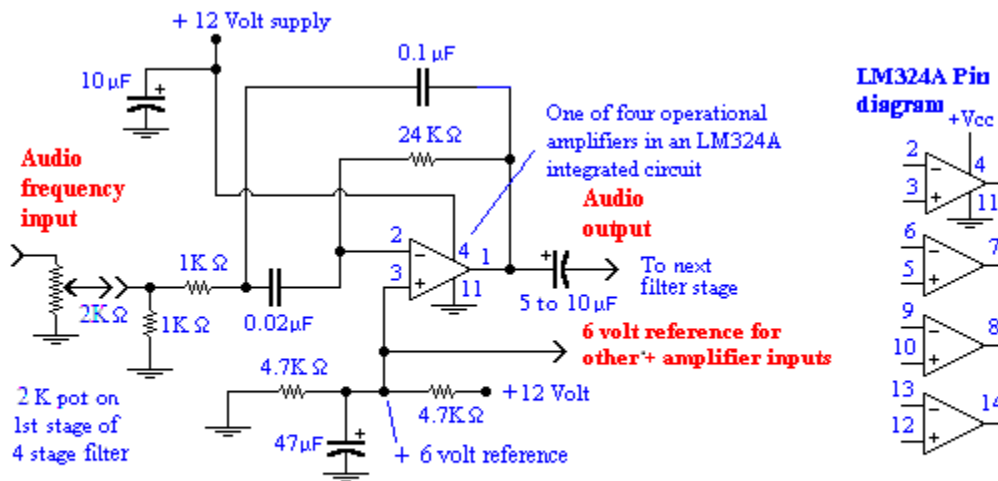
Suppose you are hearing a faint suggestion of CW under a roar of static. As you switch in more stages of crystal filter, the static will decrease dramatically as the bandwidth decreases. In theory, the AGC should compensate, although my AGC is insufficient. You'll probably have to increase the IF gain. Now turn on the 4 stage audio filter. The signal will usually disappear in the noise. But when you adjust the fine bandsread, the frequency offset can match the 700 Hz filter and the CW will appear, extremely strong and easy to copy.

When there is no apparent signal at all, sometimes it's possible to extract it from the atmospheric or severe power line noise. It's like fishing in a deep pool for fish you can not see. First, turn off all the crystal filters. This makes the receiver as sensitive as possible but it also admits a cacophony of atmospheric noise. Next, switch in the 4 stage audio filter and sometimes the 8 stage filter. Next, tune carefully with your main tuning vernier dial. Hopefully you'll hear faint suggestions of CW under the static. Now rotate the bandsread and voila! There are faint

stations, loud enough to copy. With the 8 stage filter, you'll always hear an annoying 700 Hz tone in the background, but it's better than no signals.

Filter design

There are two examples of 700 Hz audio CW filters in Chapter 7A. The first 4 stage audio filter I built for the DCR worked OK, but recently I built a better 700 Hz filter for the new receiver. I went back to Chapter 7A in revision 13 and updated the filter with the new design. I developed the new filter on Spice and it worked just like the simulation. Spice is quite reliable at low frequencies because stray capacitance and inductance are insignificant. The basic diagram of the improved filter is below:

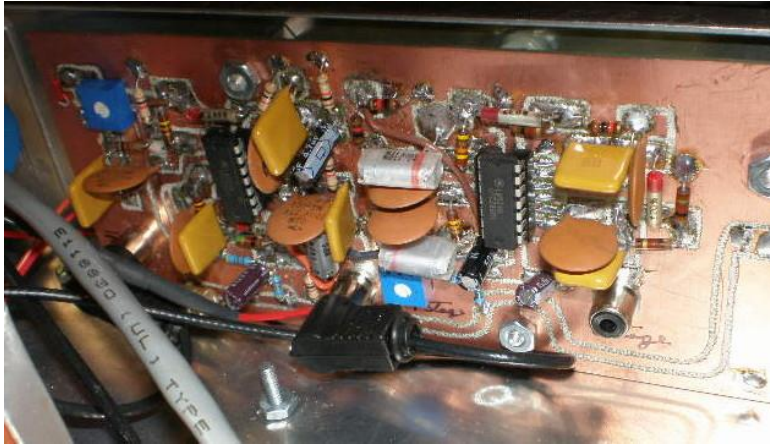


Single Stage 700 Hz Resonant Bandpass Filter

This filter can be thought of as an audio frequency series L-C circuit. As you know, when signals pass through a series L-C circuit, only one frequency is passed efficiently and all others are attenuated. The 0.02 µF capacitor serves as "the Capacitor" in this L-C circuit. At 700 Hz an inductor would ordinarily be a large chunk of iron and wire. However, the 0.1µF feedback capacitor together with the operational amplifier can work together to simulate an inductor.

The operational amplifier continually adjusts the output voltage in order to hold the two input pins at the same voltage. Whenever the output changes, the feedback capacitor must charge before the voltage across it can change. As you know, the voltage across a capacitor can't change instantly. Similarly, the current through an inductor can never change instantly. Because the other end of the capacitor is connected to the input, the output voltage changes the input voltage and the output can't keep up with the changing voltage. Consequently it must supply current continuously to charge the 0.1µF capacitor. This constantly changing current is analogous to an inductor charging. Because all the resistances and capacitors are fixed in size, there is a certain optimum frequency at which the sinewaves present at the input will appear at the output. All others are transferred inefficiently. The 24K feedback resistor determines the amplification, but is also a vital part of the frequency determination. If you change the value of ANY of these components, the resonant frequency will be different than 700 Hz. Also, the amount of gain will change. In short, if you wish to modify the frequency, change the value of the 0.02 µF cap. For

example, 0.04 μF will give you roughly 500 Hz.



A double 4 stage 700 Hz filter

For my new superheterodyne, I built a double 4 stage filter - a total of 8 stages. Both 4 stage filters need an input pot to prevent the filter stages from overloading. Well, it sure does limit the audio to 700 Hz! Turn up the volume and even the static whistles at 700 Hz. It's disconcerting when everything you hear has the same monotonous tone. I had a large supply filter capacitor on the far right but it delayed turning the filter on and off so I removed it.

Occasionally the QRM (interference from other stations) is so severe that this filter does separate the desired CW station. But, as you might expect, tuning in a signal is extremely sensitive and difficult without the bandspread. Eight stages is rarely helpful or necessary. Consequently I added a phono jack output to the first 4 stages and another phono jack to the 8 stage output. Now I can switch in either.

And finally,

Tuning in CW and SSB signals with your new receiver

By now you are familiar with class A audio and RF amplifier stages. They are biased "ON" to be in the center of their operating range. This insures that the signals will not be clipped by being too close to zero or too close to the supply voltage. By the time the signals travel from the antenna input to the loudspeaker in your receiver, they will pass through 6 or 10 different class A amplifiers. Any one of these amplifiers can distort the signal by having too much gain or too little. Use the IF and audio gain controls to keep the signals in the center of the operating range of each amplifier stage. The 80 meter preselector and the crystal filter selector can minimize noise and focus the receiver on the desired signal. The following summarizes tuning in signals:

External Antenna Tuner If you are using an antenna tuner to couple a transmitter to the antenna, the same settings will also produce the best signal reception. The antenna tuners shown in Chapter 9 are examples. When switching to a new band, begin tuning for any signals by first adjusting the antenna tuner. when you peak the tuner controls, you will immediately notice actual signals or an increase in atmospheric noise provided that the band is active. If the band is "dead,"

like 6 meters is most of the time, the optimum listening setting will not be obvious.

80 Meter Preselector Next, use the 80 meter frequency adjust as an attenuator to maximize signals or minimize noise. If you tune precisely on top of the desired signal, it will sometimes admit far too much static. In the amplification stages that follow, the static will be amplified along with the desired signal. By mistuning the preselector frequency toward either 3.5 MHz or 4.0 MHz, the signal will have as little noise as possible when it is passed on to the next stage.

IF Gain Adjust the IF gain control to the minimum needed - often near zero - to produce an adequate signal. If the IF is too high, the sound coming out of loudspeaker will be distorted, noisy or both.

Audio Gain The audio gain control needs the optimum setting for the least distortion. For example, on CW too much audio gain will make the CW harsh instead of a clear whistle. Too much IF or too little attenuation will cause the whistle to be accompanied by too much background static.

Crystal Filter Multiple crystal filters are most useful to separate *CW* signals. A sharp setting also serves to limit atmospheric noise. With no crystal filter, the maximum bandwidth will admit noise into the receiver from a wide segment of the band. Personally, I rarely find a use for the no-crystal setting. *AM* stations are wide band, often as much as 10 KHz or 20 KHz wide. Therefore, when listening to AM music stations, no crystal filter should sound the best.

For *SSB*, one crystal in series will help remove QRM (neighboring stations) with no apparent loss of speech clarity. SSB signals are only supposed to be about 3 KHz wide, so admitting more KHz bandwidth will add nothing but noise or QRM. When you add 2, 3 and 4 crystals, less and less Hz of bandwidth are admitted. Multiple crystals are only useful for CW or perhaps some digital data modes. 4 crystals eliminates the most noise and tunes extremely sharply. Every time I add an additional crystal filter, I usually have to turn up the IF gain to maintain signal strength. Ideally, the AGC should do this automatically and perhaps if I worked on it, I could improve mine.

700 KHz Audio filter for CW Adding the audio filter to a sharp crystal filter will often make CW signals noise-free and easy to copy. Sometimes a sharp 4 or 8 stage audio filter can extract a CW signal from extreme power line static that totally obscures it.

How to tune in CW signals

CW stations are the easiest to tune. First, your beat frequency oscillator tuning knob should be calibrated so that you can select about 700 Hz above or below the 9.000 MHz IF. For 40 meters and below, set the BFO to 700 Hz *above* 9.000 MHz. For 30 meters and above set the BFO for 700 Hz *below* 9.000 MHz. This will insure that you are listening to the lower and upper sidebands, respectively. If you have built a multi-stage crystal filter, this function will be obvious as you tune up and down the band. With just one crystal filter or no filter you will find you can adjust the IF gain as high as you like. Ideally the Automatic Gain Control will raise the gain automatically to compensate exactly for the attenuation of the crystals. If not, increase IF gain. If your AGC has too much gain - overcompensates - the sound may begin to motorboat, that is, oscillate.

In general, the minimum IF gain will give you the least noise. At high IF settings, the amplifiers will appear to preferentially amplify the noise, rather than the signal. When listening to faint CW signals, I often have the audio gain to maximum and IF gain set to near minimum. I'll bet your receiver is different than mine. Experiment!

If you need more IF gain, it's usually better to add extra gain in the audio amplifiers. When planning your receiver, you might consider building extra stages of audio and IF amplification from the beginning. The extra stages can be equipped with trim pots.

Tuning in Single Sideband

Tuning in weak **SSB** is much more difficult than CW, so it helps to have a strategy. First, set your BFO to 9.000 MHz, zero Hertz offset. Think of the BFO as replacing the carrier that was removed from the original AM (amplitude modulated) signal. I usually add a single crystal filter since that helps separate the signal from the QRM. The two crystal filter is usually too narrow for the speech to be intelligible. For upper sideband modulation, the modulation will enter your IF in the range of 9.000 to about 9.003 MHz. By beating with your BFO signal, the difference will recreate the original audio signal, roughly 300 Hz to 3 KHz.

When tuning across a band looking for upper sideband SSB (20 meters and above), I like to tune UP the band. It seems to be easier to make the signal intelligible in this direction. When looking for lower sideband signals I find it easier to tune DOWN the band. I asked Bob, NØRN, if he ever had difficulty tuning SSB with his high quality commercial ham transceiver. He admitted that tuning in lower sideband was sometimes difficult.

The main trick to tuning in SSB is to use the absolute minimum RF and IF gain that will allow you to hear the voice. As you know, the 80 meter preselector control can be used as an attenuator. To make the voice loud enough, you may have to crank the AF gain quite high to compensate. As explained earlier, use the 80 meter preselector variable capacitor as an attenuator to reduce the RF input signal to a minimum. For example, if the SSB RF signal from your converter peaks at 3.8 MHz, you'll often find the speech most intelligible when you mistune the preselector to, say, 3.5 MHz.

Tuning with the BFO control

To make SSB sound exactly like your friend's normal voice, tuning must be precise. You may find it helpful to tune the last few Hz using the BFO control knob rather than the local oscillator (main) tuning knob. In Chapter 10 there is a varactor tuned VFO that has an op-amp controlled "bandspread" pot that can pull the frequency up and down a few kilohertz or so. This bandspread is useful for tuning SSB signals. Tune in the signal with the main tuning until the "Donald Duck" voice is approximately centered in your 3 KHz pass band, then finish the tuning with the bandspread or BFO control. Rock-steady fingers will not be required and you can usually produce natural sounding voices.

The RFI filter and antenna tuner must be appropriate for the desired band

My receiver antenna signal first passes through the transmitter antenna tuner and the RFI low pass filter discussed in Chapter 9. The RFI filter is designed to suppress all signals above 30 MHz. Consequently, if you plan to listen or transmit on 6 meters, 50 MHz, you must remove the RFI filter. Similarly, frequencies below 160 meters like AM radio and VLF will always be

suppressed by the high-pass antenna tuners described in Chapter 9.

In summary,

The difference in capability between these Chapter 13 receivers and the Chapter 7C "simplified superheterodyne" is dramatic. If the signal is loud and the atmospheric noise is low, the 7C receiver works fine. But when the band becomes crowded, the signals are weak or there is power line noise or other static interference, the 7C receiver has no way to compensate. I either have to give up listening or move over to the Chapter 13 receiver. Personally, I enjoy manipulating all the knobs and switches to extract difficult signals.

If you've already built homebrew transmitters, you'll find that building a receiver is much easier than building a multiband, VFO-controlled CW transmitter. The hardest modules to get working are the 80 meter pre-selector, the 80 meter mixer and the IF amplifier. After that, it's relatively straightforward. Unlike transmitters, receivers don't need RF power gain stages, so the currents are low and the circuit board layout is not critical. Happy soldering!