in above circuit performs better than leaving the transformer out. In other words, this implies that the crystals look like roughly 50 ohms, but must be matched to the high impedance output of the MOSFET transistor. There's a design in my ARRL handbook that uses impedance step-up transformers to match the filter. I find it hard to believe that design is optimum unless the crystals they used behave differently than mine.

The second input gate in the above amplifier is used to set the DC bias and make the amplifier class A. A voltage divider delivers about 4 volts DC to the gate. The "***ferrite bead***" is a tiny inductor (RF choke) that helps insure that the MOSFET doesn't oscillate. The ferrite bead is literally a 1/8 inch cylinder with a tiny hole through the center. For example, you could use a CWS type (Amidon) FB43-101 bead. The type isn't critical. I used several different kinds of beads and have had no trouble with oscillation. If does oscillate, remove the 0.01 µF bypass cap from the 100 ohm source resistor. The resulting negative feedback should kill the oscillation at the expense of a small amount of gain.

### The IF amplifier

The IF amplifier is another tricky part of a superhetrodyne. It's a high-Q amp that must handle signals with a range of 100 dB or more without oscillation or noise. This is a huge dynamic range. The gain on the IF amplifier stages should be adjustable using an IF gain control. Too much gain and you will have noise and squeals. Too little gain and you can't hear those feeble DX stations.

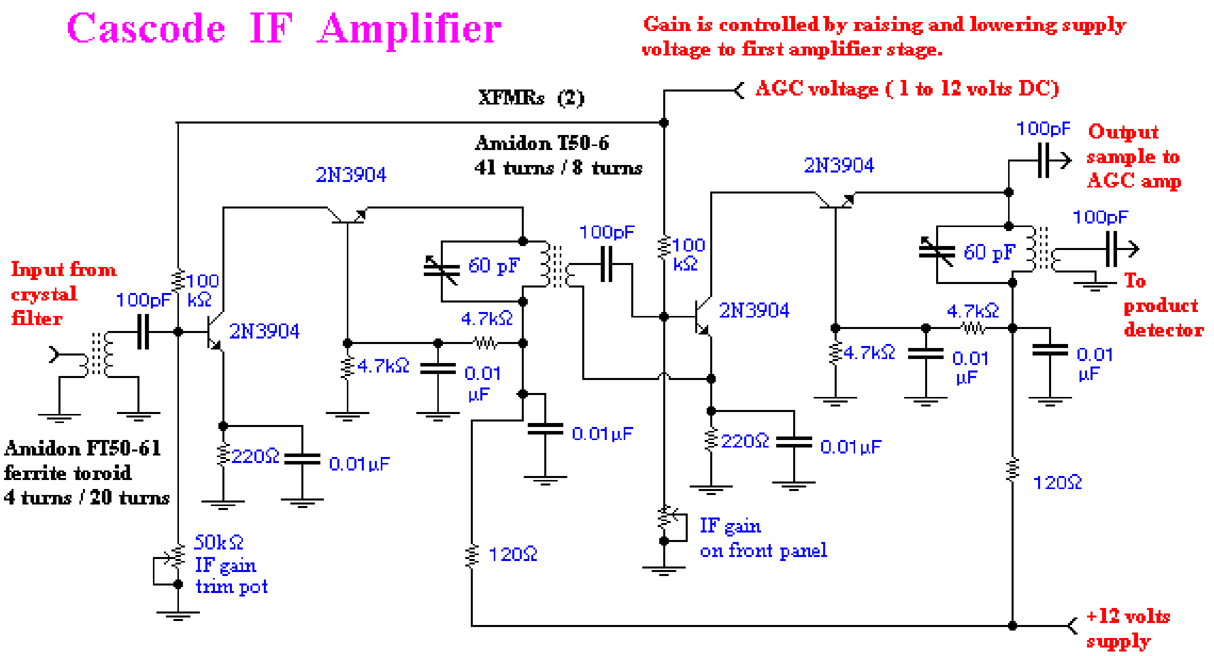
Moreover, if you used miniature half-size HC-49 crystals to build your bandpass filters, you will need even more gain to stuff signals through the significant attenuation of the filters. In the last section I described a simple RF amplifier that can be placed between the mixer and crystal filter to overcome this difficulty.

Oscillations in an IF amplifier come in several flavors. As you tune the LC circuit of an IF amplifier stage you will hear squeals, harsh roaring, silent dead spots, and gentle static. The setting that brings in the loudest signals is surprisingly noise free. The first time I turned on my receiver, I quickly learned that ***most of the receiver noise is coming from the mixer and IF amplifiers***, not from the outside world. The noise comes from a maladjusted mixer or too much IF amplifier gain.

Although I was able to tune up my 80 meter receiver using a signal generator, real 80 meter ham signals worked the best for me. There's no point in simulations when you have the real thing. A problem with tuning up the IF on 80 meters is that 80 may be dead during the day. During the summer, 80 may not be so hot in the evening either. As a result, you might consider building a converter for 20 meters early in the project. 20 meters is usually full of signals anytime, day or night, all year long. Since your 80 meter receiver may not yet be working, you can adjust your converter by feeding the output into a commercial receiver tuned to 80 meters. Then, after you have the converter working, you'll be confident that there are lots of real signals for your 80 meter receiver to hear.

### Impedance matching the crystal filter to the IF amplifier

Looking at examples on crystal filter circuits in handbooks from various years, I found circuits that seem to assume the filters are low, medium or even high impedance. In most of my attempts, I seemed to get the best gain when my filters were assumed to be relatively low impedance, say 50 to 100 ohms. That's why the optional amplifier described above used a step down transformer output. I tried step-up, step-down and no transformer to feed the signal into the IF amplifier shown directly below. Step up worked best as shown.



An IF amplifier using bipolar cascode amplifier stages

### Cascode amplifiers - variable gain with constant Q

I had heard of ***cascode amplifiers*** but didn't have a clue why they were wonderful. I built two other IF strips before I settled on the circuit shown above. The previous versions used dual gate MOSFET amplifiers, similar to the crystal filter preamplifier described earlier. The gain of each MOSFET transistor could be controlled by varying the DC bias on one of the two control gates. This control voltage can be generated by either the IF gain knob or by the automatic gain control circuit. In short, the dual gate MOSFET looks ideal for IF stages. Unfortunately, I had lots of trouble with squeals and noise and I always had insufficient gain.

Reading in an old handbook, I spotted the IF amplifier shown above. The handbook said that simple transistor amplifiers were poor for IF amplifiers because, when you tried to change the gain of a single transistor, the Q of the output tank circuit changes and you get squeals and noise. "Yes!! Yes!!" I hollered. "That's my problem!" The above circuit uses two bipolar transistors in each stage in a "cascode" configuration.

The input transistor is wired as an ordinary grounded emitter amplifier with its high input impedance. The clever part is that the second transistor is wired to the first in a grounded base configuration. This gives the amplifier a super-high output impedance which supposedly makes it immune to changing the DC bias on the first stage. Besides the phrase "cascode amplifiers" sounds cool and I wanted to use some. This cascode amplifier worked well for me. It produces more signals and less noise and oscillation than my previous efforts.

It’s interesting to see what happens when one tunes up an IF amplifier with a scope probe on the IF amplifier output. As expected, the audio signals ride on the IF frequency signal, much like amplitude modulation. When the amplifier is tuned for optimum signal reception, the scope shows that the amplifier is producing <u>the most modulation</u> on the IF signal. But when the output is tuned slightly differently to produce the largest 9 MHz signal, the reception is OK, but not the best. I had not realized that these two attributes aren’t the same thing.

### Automatic Gain Control (AGC) is not a luxury

The automatic gain control is a receiver feature that holds the signal level relatively constant while tuning in signals of varying strength. Before I built one, I thought an AGC was in the same category with digital readouts and beautiful cabinets. Why do I need one? Am I too lazy to turn the IF gain up and down? It turns out that an AGC has many advantages. The main one is that it helps you achieve the gigantic signal strength dynamic range (100 decibels) that you need in practical ham receiver. After I built an AGC, I realized it was it was also a big help in getting rid of the noise and oscillations.

Although I had been happy with the performance of my IF without an AGC, I could never get rid of the “noise zone” in my IF gain control. That is, I had to keep the IF gain below a certain level, or it would produce a roar of receiver-generated static. Apparently, IF amplifier stages are only happy when they are processing signals of a limited range of amplitude. Noise and oscillations happen when the signals in the final IF amplifier are too large. With an automatic gain control, it was easier to tune the IF so that the IF gain control acts like a “volume control” without a noise zone.

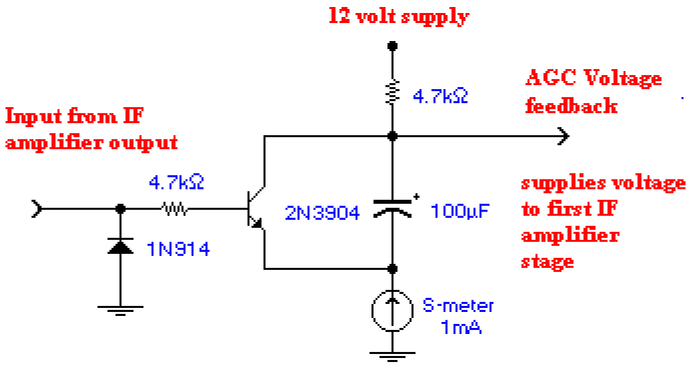
### The S-meter and other uses for the AGC

A benefit of an AGC is that, when I switch in higher selectivity crystal filters, the AGC compensates for the filter attenuation to a large degree. Also, when you put a meter on the AGC signal level, you have made an ***S-meter*** - in other words, a “strength meter.” The S-meter taught me that what you hear in the headphones doesn’t always correlate with the signal strength in the IF strip. In other words, the S-meter is reacting to big IF frequency signals, not the level of modulation on those carrier signals.

One nifty use for an S-meter is to tune the transmitter VFO to match the receiver. In other words, if you are answering a CQ, you can tune your transmitter right in on top of the fellow you want to call. First, you need to switch in a 3 or 4 crystal filter. Then, as you slew your transmitter VFO across the frequency, the S-meter will soar when you are lined up right on top of him. Without using this technique, “zero beating” the VFO is time consuming. Modern transceivers don’t have this synchronization problem because the receiver and transmitter and using the same VFO.

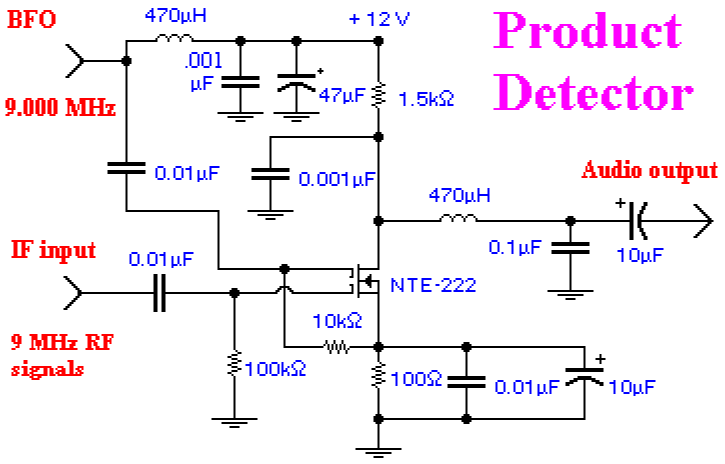
I originally used a digital bargraph S-meter that looks very racey. Unfortunately, like almost everything digital, it makes a hissing radio noise when it changes level and I don’t need that. I tried hard to filter the bargraph circuit, but as usual, I couldn’t get rid of the hiss. I finally replaced it with an old-fashioned analog meter and the noise vanished.

### Automatic Gain Control (AGC)



An AGC works by sampling the output level of the last IF amplifier stage. Signals are detected like a crystal set using a diode and averaged with a capacitor to produce a DC level proportional to the IF signal strength. This DC level is then amplified and used to bias the IF amplifiers. For example, the above circuit can deliver the positive voltage bias on IF amplifier stages made from dual gate MOSFETs. Or if the IF amplifiers are made from bipolar transistors, the same circuit can put Class A bias current into the bases of the transistors. For big signals, the AGC automatically turns off the bias and runs the transistors "Class C." Then when signals become weak, the bases are biased "ON" so that the signals don't have to exceed the 0.6 volt input barrier.

## The product detector



My product detector is basically the same circuit I used as my mixer. Product detectors are "direct conversion mixers" that mix an RF "beat frequency" (BFO) signal with the IF frequency to produce a difference frequency which is the audio signal. A 470 microhenry RF choke keeps the RF out of the audio output. To say it another way, the choke keeps the .1 µF cap from shorting out the RF while letting audio frequencies pass on to the AF amplifier.

Notice that the 12 volt DC power supply for the BFO oscillator passes through another choke and goes out to the BFO oscillator box on the front panel. That is, the DC power input for the BFO and 9 MHz RF output from the BFO share the same wire. The 470 microhenry choke prevents the 9 MHz signal from shorting to the power supply line.

Product detectors are exactly what's needed for CW or SSB. However, when you tune in an AM broadcast station, it will have a whistling overtone on it until you tweak the BFO perfectly to get rid of the whistle. If you plan to listen routinely to short wave AM broadcast stations, you'll probably want to replace the IF crystal filter with a short circuit. Otherwise, the 2 KHz width of a single crystal will be too narrow and the sound will be "low-fidelity." Another change you might consider is to put in a switch to bypass the product detector and use an ordinary diode detector for AM signals. Any of the four dual gate MOSFET transistor types mentioned earlier will work fine, including the NTE221.

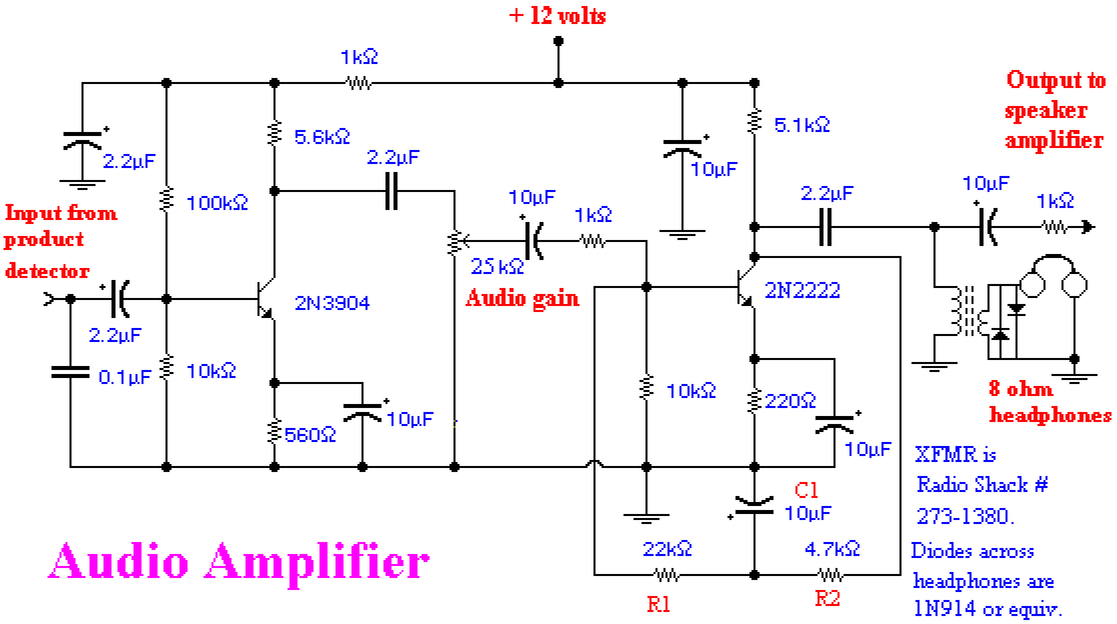
### With product detectors, anything works at least a little

In my experience, receiver RF mixers that produce an IF output are extremely finicky and are often plagued with low sensitivity and oscillations up and down the band. In contrast, a product detector is amazingly uncritical. I haven't tried to make one out of wood shavings or pebbles from the driveway, but I wouldn't be surprised if I would still hear signals.

For example, I built a new IF strip and product detector in hopes of improving the noise problem. It worked, but I was disappointed with the sensitivity. I was inspecting my dual gate MOSFET product detector when I realized that I had soldered the MOSFET in $90^o$ out of alignment. In other words, the drain was connected to the RF input gate, the source was connected to the drain circuit and the BFO input was connected to the source. Delighted that I had discovered my problem, I correctly soldered in a new transistor. When built properly, it worked better - but not dramatically better.

In another experiment I disconnected the RF input so that the input to the product detector was just stray coupling from the IF strip. Signals were weak, but it still worked amazingly well! Finally, I disconnected the BFO input. I was relieved to confirm that it no longer tuned and received ham-band signals. Instead it worked like a crystal set and received the loudest signals on or near the ham band input. For example, on 17 meters, it brought in the Deutshe Welle (Radio Germany) loud and clear.

### The AF amplifier



The output from the product detector is an audio signal that needs to be amplified before it goes to the earphones or speaker. Most ARRL designs use integrated circuits marked "audio amplifier." The LM386 is a typical one-chip audio amplifier. I've used these and they usually work great. But of course I didn't learn anything from the experience. So this time I built my audio amplifier out of discrete parts from an example in my 1986 handbook. It looked like two straight-forward "R-C coupled amplifiers" in series. But the design had extra filter components I didn't quite understand. Every part that I didn't understand, I left out. That was my education. The audio amplifier was dead as a doornail when I first turned it on.

## An audio Automatic Gain Control (AGC)

I was particularly puzzled by the low frequency feedback link, R1, R2 and C1. I couldn't understand what sort of "low frequency filtering" the designer was trying to accomplish. But, when the amplifier seemed completely dead, I put these mysterious components back in the circuit. Voila! The earphones came to life. It turns out that this loop biases the amplifier "on" for weak signals and biases it "off" for loud signals. It's a sort of audio AGC circuit.

Remember that for a bipolar transistor to turn on, the input signal must be greater than 0.6 volts or no current will flow into the base. In a "Class A" amplifier a DC signal is added to the base. This increases the base voltage above 0.6 volts so that it's always turned on. In this way a class A amplifier can amplify signals much smaller than 0.6 volts. The low frequency feedback adjusts the bias for weak and strong signals. When the signals are weak, the second transistor is turned off, so it's collector voltage is high and unchanging. This big collector voltage is leaked into C1 to provide a forward bias for the same transistor, biasing it on and raising its sensitivity. Conversely, when the signals are strong, the collector has a big current flowing but a low average voltage from the collector to ground. This lower voltage biases the transistor more "off."

## Protecting your ears from strong signals

The audio amplifier is able to blow your ears off when you encounter a strong signal.

Therefore it's essential to add a clamp circuit to limit the voltage to the headphones to less than about a volt. I first did this with back-to-back 5 volt Zener diodes across the headphone jack. In practice, with sensitive, modern 8 ohm headphones, I found that less than one volt peak is plenty of volume for me. Eventually I put in two ordinary silicon 1N914 diodes "shorted" across the headphones. This limits the positive and negative sound peaks to just +/- 0.6 volts and my ears haven't been blasted since.

### How Hi-Fi should it be?

The original circuit was also sprinkled with 0.1 microfarad bypass capacitors as if the designer were trying to kill all higher frequency sounds and shunt most of the audio to ground. Since I was always trying to get more gain, I left out the bypasses. The amplifier worked well without them, but the sound of the static had an obnoxious, piercing, high pitch that irritated my ears. I put the bypasses in and, as I expected, the audio sounded more "base" and became somewhat weaker. However, getting rid of that piercing, hissing static was well worth the loss of gain. Experiment!

The original design also had no emitter bypass capacitor, the 10 microfarad capacitor across the 220 ohm resistor. Not having this bypass capacitor reduces the gain because some of the audio voltage signal is wasted across the 220 ohm emitter resistor. Since I needed gain, I put in the capacitor and my gain jumped up noticeably. This bypass has no disadvantage that I could detect.

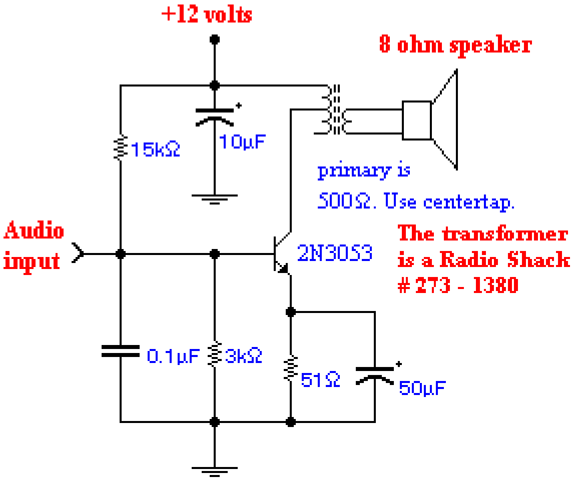
### Audio filtering

Many receivers have audio filters that limit the audio frequency of signals passed onto the headphones. This can be useful for separating CW signals that are nearly on the same frequency. If I didn't have my multiple crystal filter selections, I would definitely want audio filters. But in practice, when QRM (interference) happens to me, the guy that is interfering usually has the same audio tone pitch as the fellow I'm trying to listen to. Obviously in this case an audio filter would not help. But if you want to add one later, it is never too late. Unlike IF crystal filters, audio filters can be added later, external to the receiver.

### Driving a speaker

If you don't need a speaker, you don't need a third amplifier stage. By the same token, an 8 ohm speaker plugged into the 8 ohm headphone output is much too faint. Also, 0.6 volts peak is not nearly enough to drive a loudspeaker.

In the original handbook 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 needed no high-to-low impedance transformer. The speaker was located between the emitter and ground while the collector was connected to the positive supply. It looked straightforward to me, so I tried it. Unfortunately the emitter-follower distorted the sound and "motorboated" on strong signals. That is, the sound ran in "putt-putt" bursts. I tried several modifications to solve these problems but was never able to fix it. I gave up on the emitter-follower and used another impedance stepdown audio transformer to drive the low impedance earphones. I happened to have a handful of tiny speaker transformers in my transformer junk box, so for me this was an easy solution.



An optional extra amplifier for driving an external 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 sound "tinny." I eventually wired my speaker output to a remote, 12 inch wide speaker.

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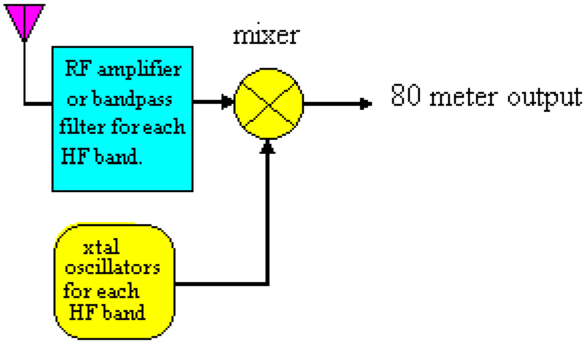
# Converters for the other HF bands



Block diagram of a converter for an HF hamband

I used the RF amplifiers and crystal oscillators out of the W7ZOI and K5IRK receiver. I built these modules close to what was 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. I had some difficulty with the low frequency preselector filters, so I used other designs as will be described.

In my receiver all converters for bands other than 80 meters share the same dual gate MOSFET mixer. Band switching would be easier if each converter had its own mixer. On the other hand, those dual-gate MOSFETs are pricey transistors, so do what you like. 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