DESIGN TIPS for SIMPLE SUPERHET RECEIVERS

The performance limitations of direct-conversion (DC) receivers can be overcome by constructing a bare-bones superheterodyne receiver with an equivalent number of component parts, or nearly so. The advantages of single-signal reception are enjoyed inexpensively with simple superhets. The problems of common-mode hum and receiver microphonics tend to vanish when changing to a superhet type of circuit. This paper describes short cuts you can take to make your receiver easy to build at minimal cost.

Eliminating the Extras

There are numerous superhet features that can be left out of the circuit without causing an impairment of basic performance. Certainly, we need not have an S meter in order to communicate. Likewise with an RF gain control. AGC is still another "extra" that we can live without. After all, DC receivers do not have an AGC circuit!

There is no design dictate that says we need to include IF amplifiers in a simple superhet. They increase the overall receiver gain and provide stages to which AGC can be applied, but the lost gain can be made up in the audio-amplifier chain. As is the situation with DC receivers, a superhet should have an overall gain (antenna to phones) of 75-100 dB. This is easy to achieve without having one or more IF amplifiers.

Additional modern-day features that can be left out of the circuit are passband tuning, IF shift, digital readout and notch filtering. These things are merely "window trimming" that we need not have for QRP operating or casual monitoring of the ham bands. Other unnecessary "bells and whistles" are frequency synthesis and noise blankers.

What About Dynamic Range?

There is much emphasis today on receiver DR or dynamic range, and rightfully so. The better the DR the less prone the receiver is to overloading and generating spurious signals within the tuning range when a strong signal enters the receiver. Some commercial receivers have DRs in excess of 100 dB, but a small homemade receiver for general use in a normal environment can do quite well with a DR as low as 80-85 dB. A simple superhet receiver can have a high DR if the design is done right, but such elegance can complicate the circuit in terms of additional stages needed to ensure sufficient overall gain, especially when lossy diode-ring (DBM) mixers and product detectors are used.

Selectivity and Single-Signal Reception

In order to rid ourselves of the unwanted sideband we must use an IF filter that has relatively steep skirts. The BFO signal is set approximately 1.3 kHz above or below the filter center frequency, depending upon the sideband we wish to copy (USB or LSB). Many builders shy away from building superhets because the IF filter is so costly ($50 or more for a decent filter). We need not expend that amount of money if we build a homemade ladder filter from surplus computer crystals. These are often available (new) for as little as $1 each. An excellent article that offers the experimental approach to designing ladder filters for CW and SSB with surplus crystals was written by W. Hayward, W7ZOI, for **QST** in 1987 (July issue, 1987, p. 24). This is recommended reading for those who build simple or complex superheterodyne receivers or SSB generators. You should be able to build a good 4-pole ladder filter for under $10. Additional poles, up to eight, will improve the filter skirt selectivity and greatly reduce the unwanted sideband response in a transmitter or receiver. A single series crystal between the mixer and IF amplifier or product detector will offer up to 16 dB of unwanted-sideband rejection, assuming the crystal is a high-Q type. The lower the Q the poorer the rejection. But, even this simple filter circuit is useful in a bare-bones receiver circuit! Fig. 1 shows a block diagram of a simple superhet to illustrate how few stages are needed to provide good sensitivity.

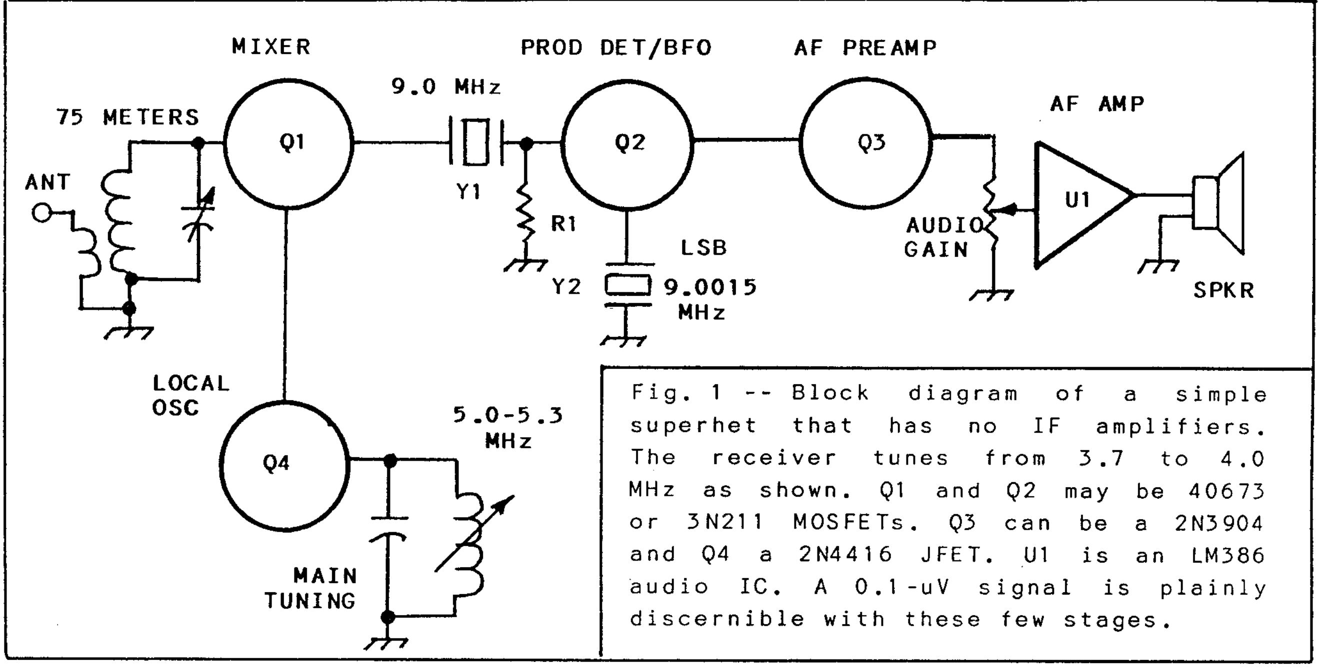

Fig. 1 -- Block diagram of a simple superhet that has no IF amplifiers. The receiver tunes from 3.7 to 4.0 MHz as shown. Q1 and Q2 may be 40673 or 3N211 MOSFETs. Q3 can be a 2N3904 and Q4 a 2N4416 JFET. U1 is an LM386 audio IC. A 0.1-uV signal is plainly discernible with these few stages.

Audio preamplifier Q3 may be eliminated if only headphone use is planned, thereby reducing the number of active stages to four. R1 is selected to provide the best load for IF filter Y1. Values from 1000 to 3300 ohms are typical. A 3-pole RC active audio low-pass or bandpass filter may be added between Q3 and U1 to further improve the receiver selectivity. Note that the BFO frequency is above the IF for LSB reception when the incoming mixer signal is below the IF. The reverse is true (BFO is lower in freq. than the IF) when the incoming signal is applied above the IF. Thus, for USB reception with this circuit it is necessary to have the BFO operate at 8998.5 kHz. With the same local oscillator frequency shown in Fig. 1, but with the mixer tuned to 20 meters, the reverse is true of the BFO frequency for the required USB mode. Many surplus computer crystals above 9 MHz may be used successfully for Y1 and Y2. A series capacitor between Y2 and ground can raise the frequency as much as 1.5 kHz. A parallel capacitor can lower Y2 sufficiently for BFO use. A 60-pF trimmer may be used for this. HC-6/U plated crystals appear to have higher Q than those in small HC-18/U types of holders. The lower the crystal frequency the smaller the frequency change when using series or parallel capacitors. The crystal frequency may be lowered substantially by adopting a VXO arrangement, whereby a small inductance is added in series with the trimmer that is between the crystal and ground. The coil reactance (XL) should be on the order or 1300 ohms for best results.

ICs versus Single Devices as Mixers

Arguments exist pro and con concerning the use of mixer ICs as opposed to discrete devices in this part of the circuit (Q1, Fig. 1). DBMs (doubly balanced diode-ring mixers) are perhaps the best in terms of performance (IMD and cancellation of signal energy that enters the LO and RF-input ports), but they require a fairly high LO injection level (+7 dBm), which is approximately 8 mW of oscillator output energy, or 0.63 RMS volts across a 50-ohm termination (1.8 V P-P). This requires an LO chain that is stronger than is needed for most active mixers. Also, a DBM has an insertion loss of 7-8 dB, which usually creates a need for an additional gain stage to compensate for the mixer loss. Active mixers, on the other hand, provide unity or greater gain, depending upon the device used and the particular mixer circuit employed. Diode DBMs are, therefore, ignored by those who design very simple superheterodyne receivers.

ICs, such as the NE602 and MC1496, are very popular among receiver designers because they are active, doubly balanced types that require very little LO injection power. The circuit-board layout is somewhat more challenging when using ICs of this kind, but performance is excellent. I prefer discrete devices for my experimental work, mainly because I can change the operating parameters easily. We can't get into the innards of ICs! I find PC layout less difficult when using discrete transistors, and that is a plus also. This same discussion applies to balanced modulators and product detectors, since each circuit functions in a similar manner.

Use the Correct LO-Injection Level

What happens if the LO injection voltage or power is too high or too low for the mixer of your choice? This is a critical consideration, and we should strive to set the injection for optimum performance. Generally, too little LO injection causes low conversion gain in a mixer. The dynamic range of the mixer may suffer also. Too great an injection level can cause mixer damage and may also degrade the dynamic range. Dual-gate MOSFETs, for example, should have between 5 and 6 volts P-P on gate 2 when operating as mixers. Values greater than 6 volts can destroy the gate insulation. I find that 4 to 6 volts P-P is a good range for 40673s and 3N211s in mixers and product detectors. IC mixers are specified for an optimum LO injection level. This information is given in the device data sheets. Mixer circuits are discussed in detail in ARRL's **Solid State Design for the Radio Amateur**. LO injection levels are measured best by means of a VTVM and an RF probe, or when using a scope. It is important that the measuring device or probe does not load the LO test point and cause incorrect readings.

Homemade IF Filters

The crystal ladder filter is perhaps the easiest one to build and make operate properly. This is because all of the crystals are on the same frequency, and the filter capacitors are the same value. An excellent article on an experimental approach to ladder-filter design was mentioned on page 1. Fig. 2 shows how these filters are arranged, along with a practical example of a CW-bandwidth filter.

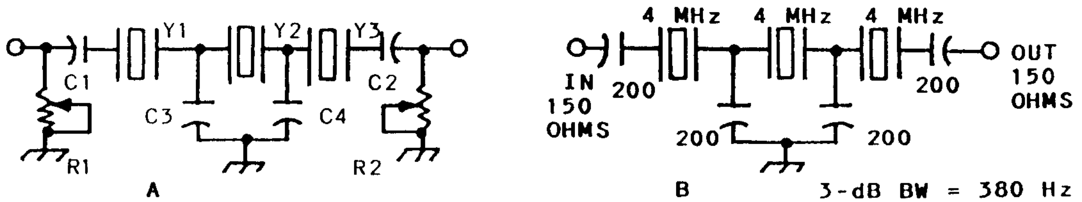

Fig. 2 -- Experimental 3-pole filter (A) and a practical one (B). See text.

As few as two and as many as eight filter poles (crystals) are practical for the amateur experimenter. The setup of Fig. 2A may be used to determine the best value for the capacitors and the terminations. The smaller the capacitor value and the higher the termination resistance, the greater the filter bandwidth. Actual values are dependent upon the Q, frequency and series resistance of the crystals used. In any event, the crystals should be matched closely in frequency with a test oscillator and counter (or receiver). They should be within 100 Hz (max) of one another. Fig. 2B shows a practical CW filter that uses 200-pF silver-mica caps and has a characteristic impedance of 150 ohms. HC-18/U surplus 4.0-MHz crystals are used. Matching to the mixer and IF amplifier stages may be done by way of broadband toroidal transformers (see Note BBT-1A). R1 and R2 of Fig. 1A, along with the values of C1-C4, are varied until the filter bandwidth is the desired value, and with minimum passband ripple. A sweep generator and scope may be used for this exercise, or you may install the test filter in a receiver IF strip and slowly sweep an input signal to the receiver while observing the change in audio-output level while using an ac VTVM.

A Practical 4-Stage Superhet

Fig. 3 shows the circuit of a 75-meter simple superhet that I built. It is sensitive enough to provide a plainly discernible signal in the headphones when a 0.1 uV signal is fed into the mixer. A 0.35-uV signal is 3 dB above the noise floor, and a 0.55-uV signal is 6 dB above the receiver noise floor.

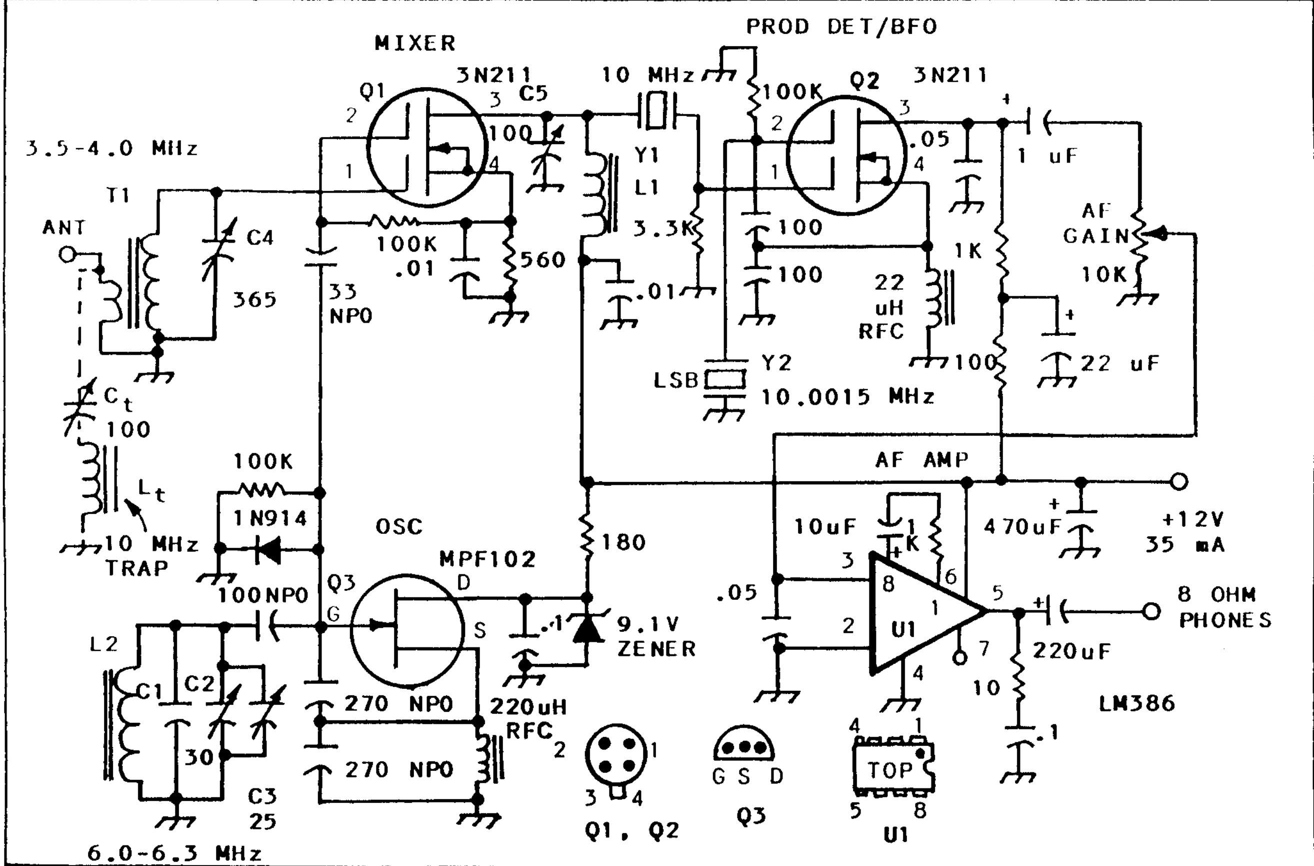

Fig. 3 -- Circuit of a practical 75-meter receiver. Coverage is from 3.7 to 4.0 MHz, lower sideband. Decimal-value capacitors are in uF. Others are pF. Resistors are 1/4-W carbon composition. Polarized caps are tantalum or electrolytic. K = 1000. C1 is a 100-pF NPO capacitor.

The receiver in Fig. 3 may be modified for use with other crystals. It may be changed also for operation on other bands by modifying the oscillator and the inductance of the T1 secondary. It represents a good foundation for QRP receiver experimentation. For example, it can be made to drive a speaker by simply adding a 2N3904 or 2N2222 audio preamp between Q2 and U1. An RC active audio bandpass filter may be included between Q2 and U1 for improved selectivity. T1 may be replaced with a two-pole, fixed-tuned bandpass filter. This would eliminate the need for a series wave trap at the receiver input (see ARRL **Electronics Data Book**).

C2 of Fig. 3 is the main-tuning control. It is a 30-pF air variable (preferably the double-bearing type). C3 is a 25 or 30 pF ceramic trimmer. C4 may be a broadcast radio tuning capacitor. C5 is a 100 pF mica compression trimmer. Ct and Lt are resonant at 10 MHz, should you experience WWV feedthrough in the receiver output. L1 has 4.2 uH of inductance (32 turns of no. 26 enam. wire on an Amidon Assoc. T50-6 [yellow] toroid). L2 has an inductance of 3.5 uH (29 turns of no. 26 enam. wire on a T50-6 toroid). Coat this inductor with two layers of polystyrene Q Dope or equiv. for best stability. T1 has a secondary inductance of 9 uH (42 turns of no. 28 enam. wire on an Amidon Assoc. T50-2 [red] toroid). The input link has 5 turns of no. 28 enam wire. Y1 and Y2 may be in HC-6/U or HC-18/U holders, but plated crystals in HC-6/U holders may provide higher crystal Q, and hence better selectivity for Y1. Unwanted sideband (upper) suppression with my model of this is 16 dB, based on 10-MHz HC-6/U crystals.

You may use polystyrene capacitors at those points in Fig. 3 where NPO ceramic capacitors are indicated. Oscillator stability will not be as good, however, as when NPOs are employed. Silver-mica capacitors may also be used, but I do not recommend them.

Reception on Other Bands

The receiver in Fig. 3 can serve as a mainframe for a multiband receiver by building small, crystal-controlled converters for use ahead of it. The converters can be band-switched in and out of the circuit as needed. A single 3N211 mixer and an MPF102 crystal oscillator will suffice in converters for 40, 30 and 20 meters. An RF amplifier and overtone oscillator will provide the desired performance on 12, 15, 17 and 10 meters. The RF amplifier will aid the noise figure and sensitivity. A grounded-gate 2N4416 JFET would be suitable for the RF amplifier stage (see **Solid State Design** [ARRL] for design info on rcvr RF amps and overtone oscillators). Fig. 4 shows a suggested circuit arrangement for a converter.

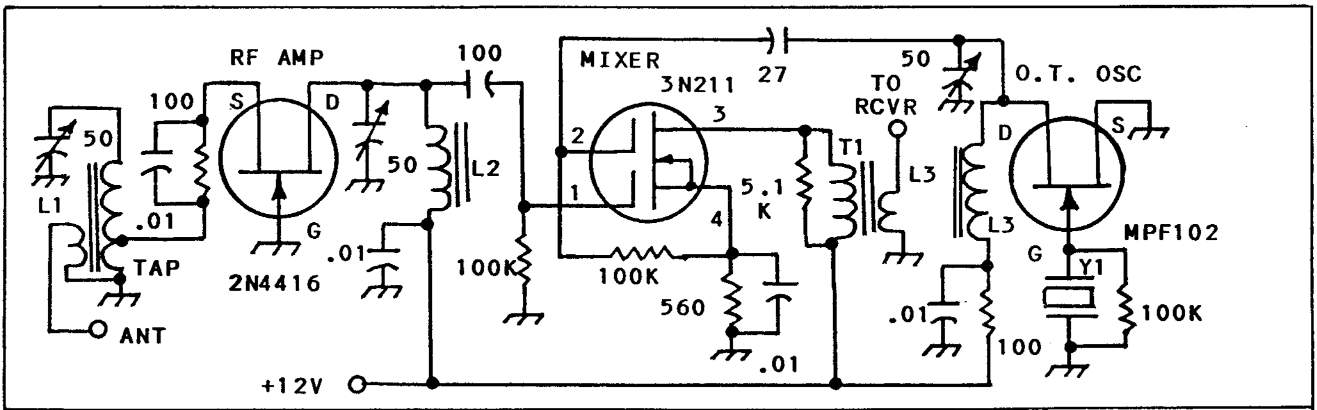

Fig. 4 -- Suggested converter circuit for 12, 15, 17 or 10 meters to be used with the receiver in Fig. 3. Eliminate RF amp for 30 and 40 meters.

The RF amplifier in Fig. 4 yields 10-12 dB of gain typically. Mixer conversion gain is roughly 10 dB, providing a grand total of approximately 20 dB for the converter. L1 and L2 are wound for the same inductance, and the link at L1 has 10 percent the total number of L1 turns. The L1 tap is made at 25% of the L1 turns, counting up from the grounded end. L1, L2 and L3 are resonant at the desired frequencies when their respective trimmers are 3/4 meshed (38 pF). T1 is a broadband toroidal transformer. It has a 5:1 impedance ratio, or 2.24:1 turns ratio. The 5.1K drain resistor sets the impedance transformation from 5K to 50 ohms while improving the mixer IMD. The T1 primary has 15 turns of no. 26 enam. wire on an Amidon FT-37-43 ferrite toroid. The secondary winding has 6 turns of no. 26 wire. The noise figure of this converter is approximately 2.5 dB at 30 MHz.

The RF amplifier in Fig. 4 can be eliminated for use below 14 MHz. If this is done an input link may be wound over L2 for the antenna (50 ohms) connection. The 50-pF mixer and oscillator trimmers can be increased to 100 pF for use on 30 and 40 meters. This will reduce the number of L2, L3 turns needed to establish resonance.

Two BFO crystals (Y2 of Fig. 3) are desirable when down-converters are used ahead of the 75-meter receiver. This will provide both USB and LSB reception. One crystal is 1.5 kHz above the IF and the other is 1.5 kHz below 10.0 MHz. A SPDT switch may be used for Y2 selection.

Other Considerations

If you choose to use a ladder filter (Fig. 2) instead of the single IF-filter crystal in Fig. 3, it will be necessary to include an IF amplifier after the ladder filter in order to compensate for filter insertion loss (2 to 5 dB). A single 2N2222A RF amplifier will be suitable. If the amplifier is not added, the overall receiver sensitivity will decrease significantly. My experience when inserting a 4-pole ladder filter was that the minimum discernible signal level degraded from 0.1 uV to nearly 1 uV! Addition of the bipolar IF amplifier cured the problem.

You may wish to convert Q1 of Fig. 3 to a singly balanced 3N211 mixer. This may be done by operating the FETs with their gates (1) and drains (3) in push pull. Gates no. 2 are joined (parallel) and the oscillator injection is applied to them. An MC1496 IC mixer may be substituted for Q1 if you desire a doubly balanced mixer.

If you place the Fig. 3 circuit on a PC board, avoid using double-sided board material. The oscillator will exhibit increased long-term drift when built on double-sided board, owing to unwanted capacitors with poor dielectric being formed between the PCB foils and the ground plane.

My version of the Fig. 3 circuit is built on an open PC breadboard with point-to-point wiring. It works just fine, so don't hesitate to use "ugly construction" or perf board for your project. Keep all RF leads short and direct!