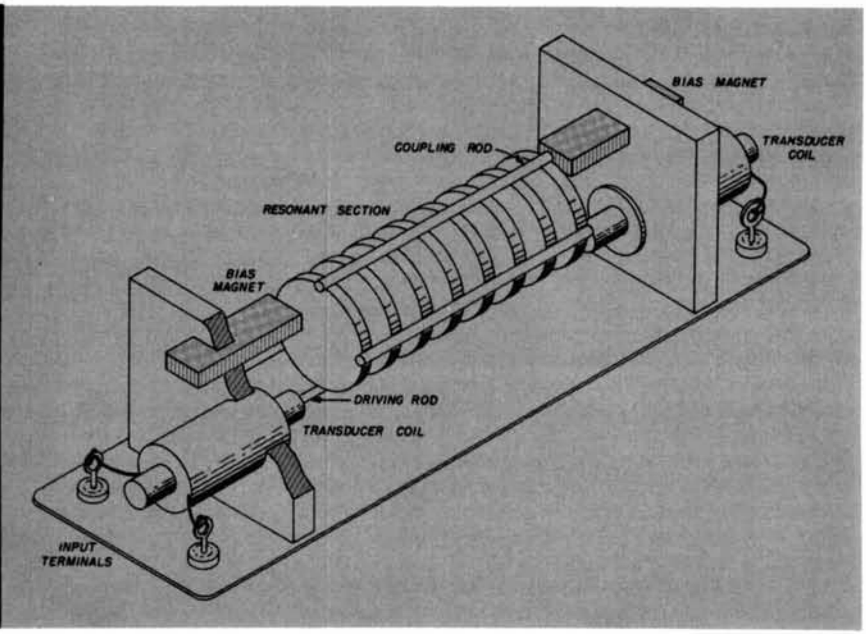

single-sideband filters

The filters required for generating a ssb signal fall into two general categories, crystal and mechanical; here is a description of both

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In a single-sideband transmitter, the signal coming from the balanced modulator is not yet an ssb signal; it still has both sidebands. Although the carrier has been suppressed, it is called a double-sideband suppressed-carrier signal. The job of removing the unwanted sideband is left to a device known simply as a **filter.**

In a communications receiver, incoming signals must be sorted out by the tuned circuits of the rf and i-f sections. These coil-capacitor combinations may allow adjacent signals through almost as well as the desired ones; their response is too broad. Removing those unwanted "side" frequencies is the job of a filter.

In a single-sideband receiver, every conversion the signal goes through generates an unnecessary extra sideband because of the nature of the heterodyning process. To recover the modulation, the ssb detector needs only the original sideband. The job of eliminating the unwanted sideband is turned over to—you guessed it—a filter.

On the schematic diagram of a modern ham receiver or transmitter, the filter is identified merely by a box labeled F1, F2 or FL1, FL2, etc. The filter circuit is almost never shown. Nor is the type of filter indicated. If you look inside the enclosure, you learn very little more. The filter is a sealed "black box" that has been plugged in or wired into the circuit. What's in it remains a mystery.

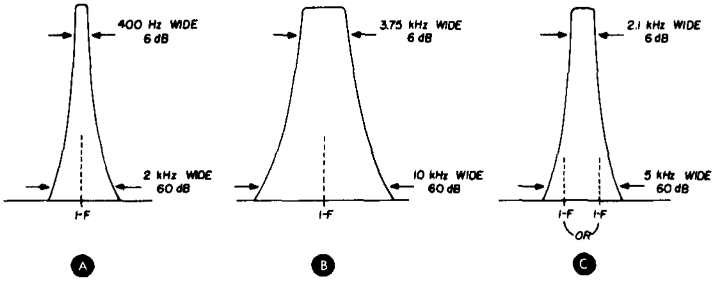
More important, of course, is what it does. From that standpoint, you can think of a filter as a three- or four-terminal device which certain signals are fed into, and out of which they come in some altered form. It is only a "black box" for all practical purposes. First, then, let's examine what filters do in ham receivers and transmitters; then we can explore what's in them.

shaping the curves

An important characteristic of any communications receiver is its **selectivity.** That is its ability to reject signals on either side of a desired one, while passing it freely. The selectivity you need depends on the kind of signal—that is, the modulation it carries.

A CW signal, for example, has no modulation. It therefore has no sidebands on each side of the carrier. It consists of the carrier alone. A receiver with very, very narrow selectivity can pick up the CW carrier (keyed, probably, for code transmission) and avoid interference from other, nearby carriers. One of the best ways to attain such selectivity is with a special filter in the i-f amplifier. The curve in **fig. 1A** graphs the response of an i-f section using a very narrow CW-only filter.

fig. 1. Response curves for typical filters used in ham radio equipment. A for cw reception; B for a-m and C for ssb reception. 2.1-kHz bandswitch is standard.



Filter characteristics are rated by their response at two points: 6 dB and 60 dB below maximum. The response in **fig. 1A** is 400 Hz wide at the 6-dB point and 2 kHz wide at the 60-dB point. The ratio between the two bandwidths is called the **shape factor.** The filter in **fig. 1A** has a shape factor of 5. A low shape factor means the skirts are steep, making the filter respond strongly to the desired frequencies—within the passband—and deeply reject signals on either side. A shape factor of 1 is, of course, ideal; the skirts are vertical. In practice, a shape factor of 2 or 3 is acceptable.

Consider the selectivity required for an a-m signal. Since both sidebands are needed for proper demodulation, the receiver must pass a bandwidth of at least 3.5 or 4 kHz—enough for intelligibility. That width passes sideband products for voice signals up to 2 kHz. The filter represented by the response graph in **fig. 1B** is for a-m reception. It has a 6-dB response width of 3.75 kHz and a 60-dB response of 10 kHz. The shape factor is about 2.5—giving fairly steep skirts.

Both curves in **fig. 1A** and **1B** represent responses centered in the i-f passband. For example, if the i-f is 3.395 MHz, the filter in **fig. 1A** responds well to frequencies from 3.3948 to 3.3952 MHz. The 400-Hz response is spread 200 Hz to each side of the i-f center. The i-f section with the filter of **fig. 1B** (3.75 kHz wide) responds well from 3.393125 to 3.396875 MHz. The filter rejects frequencies above and below; nearby signals cannot get through.

For single-sideband reception, the selectivity of the receiver can be narrower than for a-m, since only one of the sidebands is present. A bandwidth of 2.5 kHz is plenty. The curve in **fig. 1C** shows the response of the filter in one commercial ssb receiver. Its 6-dB response is 2.1 kHz; 60-dB response is

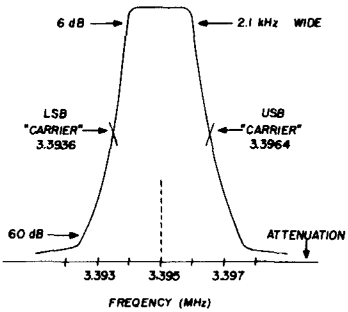
5 kHz. The shape factor is about 2.4.

There's something else special about the ssb filter in **fig. 1C.** Its response is not centered on the i-f. The "center" of the filter's bandwidth is off to one side or the other of the i-f, placing any i-f signal down on either skirt, below the 6-dB point. Which skirt is chosen depends on which sideband must fall within the bandpass. If the upper sideband must be amplified, the i-f is placed on the lower-frequency skirt of the filter response. The rejection characteristic blocks the lower sideband.

filters at work

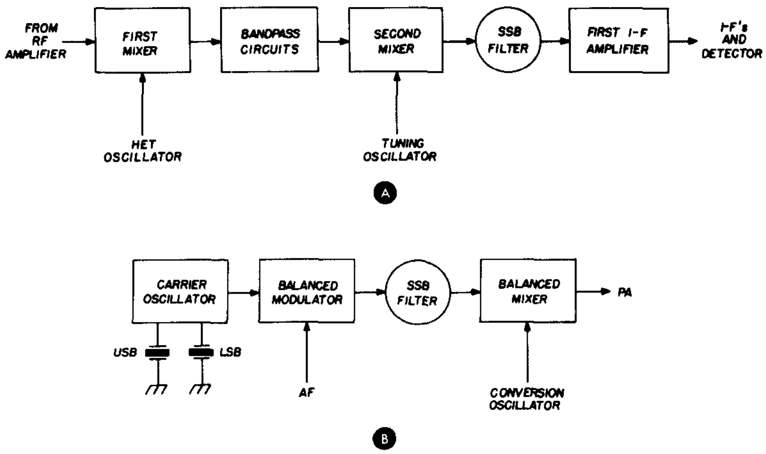
For ssb, a filter like the one in **fig. 1C** can be used in a transmitter or receiver. In modern transceivers, a single filter is used for both. Let's see how and why.

fig. 3. If the dsb "carrier" (which is suppressed) is placed in either position shown, one sideband is eliminated.



In a *superheterodyne ssb receiver*, every frequency conversion creates two sidebands from the single-sideband signal. That's because the local oscillator signal beats with the incoming sideband and produces both sum and difference frequencies. Following the i-f amplifier stage, only one sideband is needed for demodulation. The frequency of the filter (**fig. 2A**) is offset from the i-f as already described, to eliminate the extra sideband that has joined the desired one.

fig. 2. Ssb filters in receiver (A) and transmitter (B).



In the ssb transmitter, the chief job of the filter (**fig. 2B**) again is to eliminate the unwanted sideband. If well designed, it also removes any vestige of the carrier that might be left by the balanced modulator. Succeeding stages of frequency translation re-create a double sideband, but the two are far enough apart that it is easy to get rid of the unwanted one with ordinary tuned circuits.

In a transmitter, there is also a need to switch from one sideband to the other. With a single filter, this is done by shifting the frequency of the carrier oscillator. Then, the signal that reaches the filter is on the other skirt. The sketch in **fig. 3** gives you some idea how this works. If an upper sideband is desired, the 3.3964-MHz USB carrier-oscillator crystal (**fig. 2B**) is activated. Even though the carrier is eliminated by the time the signals reach the filter, the upper and lower sidebands fall on each side of the position shown (**USB "carrier"**) on the upper skirt of the filter response curve. The sideband frequencies higher than the "carrier" are attenuated drastically; those below are amplified. (Don't be alarmed that this is called the upper sideband; when the signal passes through a stage of conversion after the filter, the heterodyning process will "flip the sideband over," *making it an upper sideband in* the transmitter output.)

For a lower sideband, the other crystal is activated, generating the 3.3936-MHz carrier. The sidebands fall on both sides of the position indicated as **LSB "carrier."** The sideband on the upper side is amplified, and that on the lower is attenuated. Again, the ensuing frequency conversion flips the signal over and produces a lower sideband at the output frequency.

commercial circuits

There are about as many ways of using filters in ssb equipment as there are designers who develop the gear. A few of these are diagramed in **fig. 4.** They are merely examples of different ways filters are used in ssb receivers.

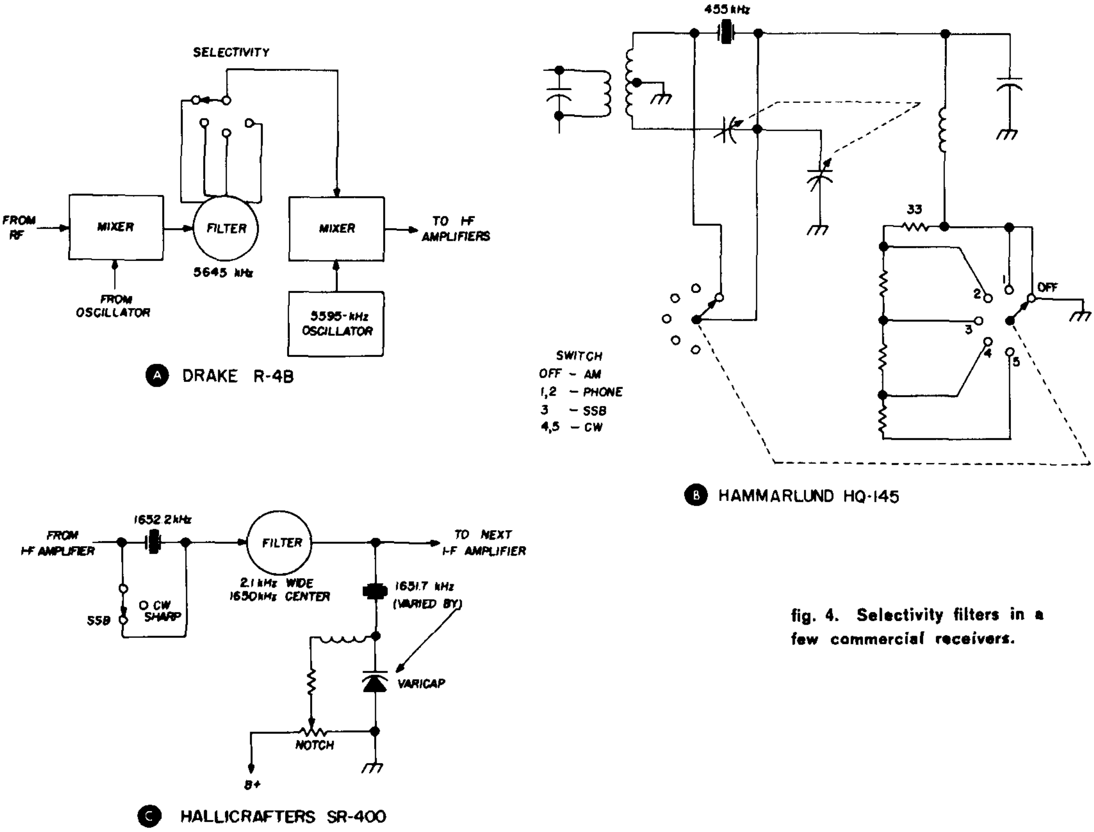


fig. 4. Selectivity filters in a few commercial receivers.

The circuit from the Drake R-4B has a variable-selectivity filter, with its center at 5645 kHz. The filter can be switched to four different bandwidths: 400 Hz, 1.2 kHz, 2.4 kHz, and 4.8 kHz. The first is for CW; the last is for a-m; the others are for various ssb reception conditions. Not shown is an additional phase control that affects ssb reception.

Another way to obtain variable selectivity with a single filter is shown in the diagram from the Hammarlund HQ-145 receiver. The filter in this case is the simplest imaginable —a series-resonant crystal *centered at the* i-f. The widest bandpass is obtained with the crystal shorted out—the OFF position of *the switch; it is for a-m reception. In posi-*

tion 1, the crystal is in the circuit, but the response of the output tuning coil is at its broadest, thus loading down the crystal. In successive positions, additional series resistance is switched in, reducing the loading effect of the output circuit and making the crystal's effect sharper. At the 4 and 5 positions, selectivity is too sharp for ssb reception, but is excellent for "notching out" interference on CW.

A fancier notch-filter circuit, combined with a conventional selectivity filter, is used in the Hallicrafters SR-400. The filter centers at the i-f, 1650 kHz. For CW reception, the CW-SSB switch is opened, inserting a 1652.2-kHz crystal in series with the signal path to the main filter. The relationship between the two frequencies narrows the over-all bandwidth to less than 1 kHz; the series crystal bucks the filter's repsonse near the upper skirt. The notch filter, which places a deep notch or dip in the pass band of the main filter, is a 1651.7-kHz crystal. The notch crystal's frequency is varied by a varicap (voltage-variable capacitor), which permits moving the notch back and forth. A NOTCH potentiometer applies voltage to the varicap to control its effect on the crystal.

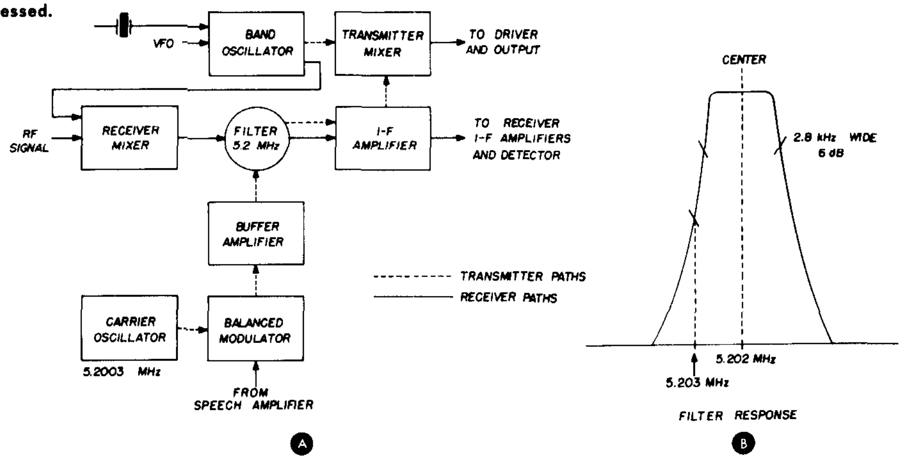
one filter, two jobs

In ssb transceivers, a single filter is frequently used for both transmit and receive. The National 200 transceiver contains a good example of this, diagramed in **fig. 5.** The filter is centered on 5.202 MHz. The local oscillator frequency differs from the incoming signal frequency by that amount, thus creating an approximate 5.2-MHz i-f. The specifications for the filter, which is a type called **crystal lattice,** list its 6-dB bandwidth as 2.8 kHz. The solid lines show the signal paths during ssb reception.

During ssb transmission, shown by dashed lines, the same filter and one of the receiver i-f amplifiers are used. Sideband elimination comes from feeding the double-sideband suppressed-carrier signal (produced by the balanced modulator) through the filter. The graph of filter response in **fig. 5** shows how. The carrier oscillator operates at 5.2003 MHz. The two sidebands coming from the balanced modulator are on each side of that frequency. With the filter bandwidth 2.8 kHz wide, and its center at 5.202 MHz, the 6-dB point on either skirt is 1.4 kHz away from center. The 5.2003-MHz carrier is 1.7 kHz below the center of the filter response, placing it below the 6-dB point of the lower-frequency skirt. This position assures additional suppression of any remaining carrier, and complete obliteration of the lower sideband. The upper sideband, on the other hand, is at the peak of the filter response, and passes through unattenuated.

As you can see, the ssb signal is then amplified by an i-f stage before it is applied to the final mixer for translation up to the output frequency.

fig. 5. Using one filter for both receive and transmit. Filter response curve shows how the sideband is suppressed.



inside the black boxes

There's a natural curiosity about what is in a filter. Truly, there need be no mystery. Hams have been building their own filters for many years. Nowadays, the shortage of cheap surplus crystals has slowed down that sort of experimentation; also, commercial units are less costly. Nevertheless, it's nice to know what goes on inside your equipment and what makes it happen.

There are three kinds of filters in ssb rigs: **LC, mechanical,** and **crystal.**

The **LC filter** is, as its name suggests, a coil-capacitor combination. Several high-Q tuned circuits, cascaded, can have a response with very sharp peak and steep sides. At frequencies around 50 or 60 kHz, such filters may suffice. Below that, component size is a problem. Special designs overcome some limitations. For example, Barker & Williamson has a model—the 360—that uses toroid inductance windings and silver-mica capacitors; the center frequency is 18.5 kHz, with a 3-kHz pass band.

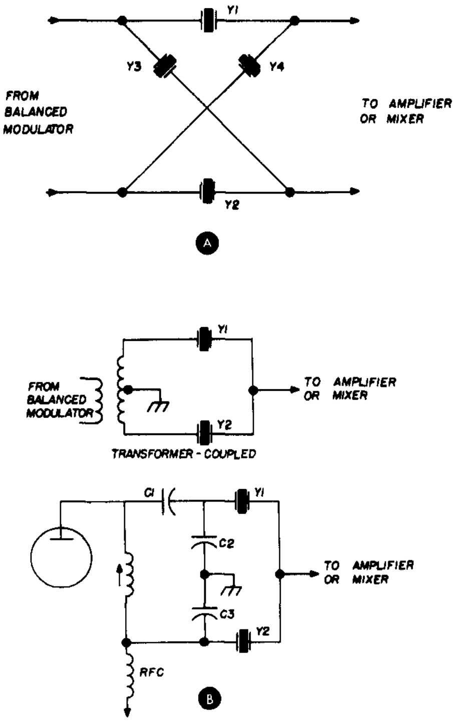
Above 100 kHz, the Q of LC components may not be high enough for practical filters. Commercially available LC filters are usually in the 50-kHz region. The Hammarlund HX-500 transmitter, which generates its primary carrier at 60 kHz, uses an LC sideband filter following the balanced modulator. Burnell's model S-15000 LC-type filter has its steepest slope at 50 kHz.

At 100 kHz and above, the **mechanical filter** becomes practical. Technically, it is electromechanical. A mechanical filter consists of an input coil tuned to the center of the i-f; a magnetostrictive transducer that converts i-f signal energy to mechanical energy; a "stack" of plates, rods or discs which are mechanical resonators coupled together by a coupling rod in their center or along their edges; an output transducer that converts the mechanical vibrations back to signal energy; and an output tuned circuit to couple the output signal to the next stage. A sketch of a mechanical filter is shown at the beginning of the article.

The best frequency for mechanical filters is around 250 kHz, although models are available from 50 kHz through 600 kHz. Almost never do you find one above 1 MHz. The response shape and center frequency depend on the size and shape of the resonator elements. At frequencies below 100 kHz, the elements are too large for practicality; above 600 kHz, the close physical tolerances that are necessary become too expensive to achieve.

By careful selection of the sizes of resonating elements, the bandwidth of a mechanical filter can be sharply controlled. Also, the very nature of this kind of resonant shaping insures extremely steep response skirts—almost vertical, which means an extremely low shape factor. One of the better-known mechanical filters is the Collins F455Y-31; its center frequency is 455 kHz, its 6-dB bandwidth is 3.1 kHz, and its shape factor better than 2.

fig. 6. Lattice-type crystal filters for ssb. Full lattice, or ring, circuit in A and two forms of half-lattice filters in B.



crystals in lattice networks

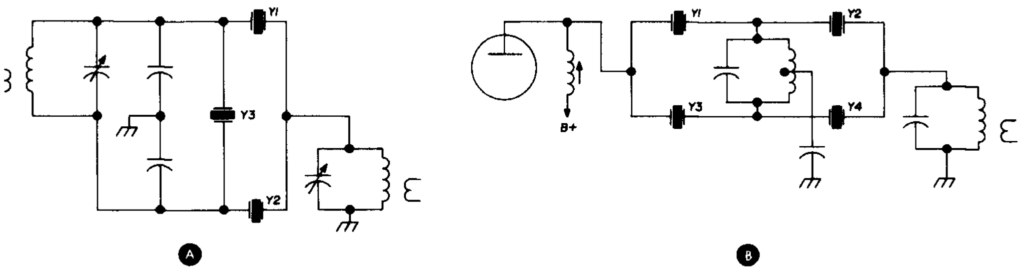
From 1 MHz up, ssb filters are most likely to be of the crystal variety. As you've seen already, crystal types are available below that, but most are above 1 MHz. They are costly, but offer excellent performance.

One unit that has become popular in commercial equipment lately is the 9-MHz crystal-lattice filter. Its cost ranges toward $50. For single sideband use, the bandwidth is standard: 2.1 kHz. The 9-MHz filter is used in the Galaxy V Mk2 transceiver, in the Hallicrafters SX-146 receiver and HT-46 transmitter, and in the Gonset 910-series transceivers –that I know of. In the transceivers, a single 9-MHz filter is used for both transmit and receive. One commercially available 9-MHz crystal filter is the McCoy 32B1; it retails for $35.00.*

Two basic circuits are the foundation for all crystal filters (other than simple series crystals already described). Both are called **lattice networks,** and are shown schematically in **fig. 6.** The one in **fig. 6A** is called a **full lattice** and the two in **6B** are called **half-lattice.** The full lattice has also been called a ring filter, due to its resemblance in configuration to the well known ring diode modulator. The two half-lattice crystal filters in **fig. 6B** differ only in the manner of coupling signal energy to the crystals.

In **fig. 6A,** crystals Y1 and Y2 are a matched pair, series-resonant at the center frequency of the filter. They pass along the signals at resonance, but not signals on either side. Broadening the response of the filter are Y3 and Y4. In some filters, they are parallel-resonant at the center of the filter pass band; in others, they are series-resonant at frequencies to either side; in a few, they are chosen to impart special skirt characteristics. The shape factor of most full-lattice crystal filters is down to 2 or better.

fig. 7. Variants on half-lattice configuration. With a shunt crystal (A), back-to-back for single-ended input (B).



The crystals in half-lattice filters, like those in **fig. 6B,** are chosen so that the parallel-resonant frequency of Y2 is the same as the series-resonant frequency of Y1. The result is the bandpass curve needed for ssb operation. Occasionally, a capacitor is added across one crystal to warp its frequency for exactly the spacing needed to produce the correct bandwidth. Half-lattice crystal filters exhibit shape factors around 2 or a little higher—adequate, but not so sharp as full-lattice filters.

The differences in coupling in the two half-lattice filters in **fig. 6B** deserve brief comment. The half-lattice configuration depends on the crystals being fed in push-pull, with the output taken in parallel. The transformer-coupled circuit does this easily; with a grounded center-tap, the secondary winding feeds the crystals in push-pull. To accomplish the same thing with the single-ended output from a tube is not that easy. With C2 and C3 across the plate coil, and a ground between them, the crystals are effectively fed in push-pull, after all. The rf choke keeps the bottom end of C3 from being grounded through the power-supply capacitors. C1 is merely a dc-blocking capacitor to protect the crystals.

There are several variations on the half-lattice configurations; two of them are shown in **fig. 7.** Another variation, not shown, is a cascaded series of half-lattice filters. This is seldom used in commercial filters because of the extra coupling transformers needed.

In **fig. 7A,** Y1 and Y3 are chosen for the same frequency, the center of the i-f pass

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* McCoy Electronics Company, Mount Holly Springs, Pennsylvania

band; Y1 is series-resonant, though, while Y3 is parallel-resonant. Y2 is series-resonant at a frequency offset by the bandwidth desired. In one design, for example, Y1 and Y3 are picked for 455 kHz, and Y2 for 453.2; bandwidth is 1.8 kHz. Shape factor is 2.3, but one skirt is much steeper than the other. That's the side the signal is placed on.

The back-to-back configuration in **fig. 7B** exhibits a better shape factor than two cascaded half-lattice stages merely cascaded. This is also an excellent way to feed the signal from a single-ended stage. Y1 and Y2 are chosen to match in frequency. Y3 and Y4 match each other, but are 1.5 to 1.7 kHz away from Y1 and Y2 in frequency. This arrangement is used in one commercial ssb filter in the 5-MHz range.

checking filters

There isn't space to go deeply into testing ssb filters. Briefly, though, there are three methods. One is to use an oscilloscope, sweep generator, and marker generator to display an exact curve and examine its bandwidth, shape factor, etc.[1] Another is to use a signal generator and a VTVM with an rf probe; you can plot a response curve in just a few minutes, one point at a time. The third is to test the filter's operation with signals; if the receiver or transmitter cannot be aligned to receive or generate an ssb signal with proper modulation, suspect the filter.

In most cases, you'll be able to do nothing about filter trouble, beyond buying a new one. The sealed black-box nature of ssb filters precludes any repairs. At least, however, you know what should be going on in them.

references

1. M. J. Goldstein, VE3GFN, "Instrumentation and the Ham," *ham radio*, July, 1968, p. 28.
2. C. E. Weaver, W2AZW, J. N. Brown, W4OLL, "Crystal Lattice Filters for Transmitting and Receiving," *QST*, June, 1951, p. 48.
3. B. H. Vester, W3TLN, "Surplus-Crystal High-Frequency Filters," *QST*, January, 1959, p. 24.
4. D. J. Healey, W3HEC, "High-Frequency Crystal Filters for SSB," *QST*, October, 1960, p. 35.
5. B. Roberts, W0IEU, "Mechanical Bandpass Filters for I-F Ranges," *QST*, February, 1953, p. 22.
6. R. A. Genaille, K4ZGM, "Ferrite Coil and Crystal Sideband Filter," *Electronics World*, June, 1967, p. 46.

ham radio