A Detector for Single-Sideband Reception

Eliminating the Unwanted Sideband by Phase-Shift Networks

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• We're so used to getting our selectivity by tuned circuits that it may be startling to most of us to find that there are other ways of getting it — maybe better ways. This article describes a single-sideband detector circuit that inherently eliminates the unwanted sideband, entirely independently of the selectivity of the receiver with which it is used. The experimental model described here can be simplified considerably, as the authors point out.

In an earlier paper the basic principles of a.m. and single-sideband detection were reviewed.[1] It was pointed out that a change to s.s.s.c. transmission makes possible a considerable increase in the effective selectivity of present-day a.m. receivers, whose ability to reject interfering signals leaves much to be desired. To take full advantage of the benefits of s.s.s.c., a balanced detector (which eliminates interference attributable to rectification) may be added to existing sets, and this may be followed by a sharp cut-off low-pass audio filter for additional selectivity. The only disadvantage of such an arrangement is the audio "image" — the audible output produced by an incoming radio frequency on the side of the beating oscillator opposite to that of the desired signal. There will be described in this article a method of eliminating this "image" which makes possible the design of an inexpensive single-sideband receiving attachment for standard amateur receivers. The effective selectivity of a receiver equipped with this attachment is surpassed only by the most elaborate commercial installations. Single-sideband transmission, plus this receiving technique, now makes possible for the first time a truly complete utilization of the spectrum available in the amateur 'phone bands — something which is hardly possible with conventional a.m. and present-day equipment.

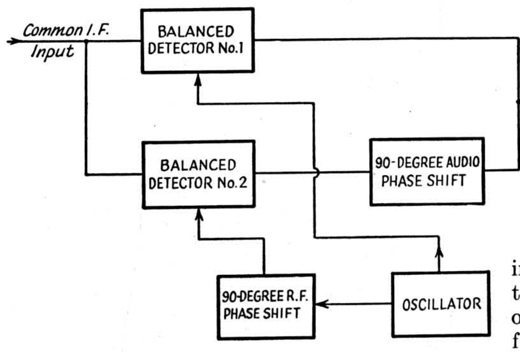

Fig. 1 — **Block diagram of single-sideband detector utilizing 90-degree r.f. and a.f. phase shifts.**

The method is based on the relatively recent development of simple 90-degree wide-band phase-shift networks.[2] A typical network of this sort, consisting of 6 resistors and 6 condensers, is capable of dividing a common audio input into two parts whose magnitudes are nearly equal, and whose relative phases are nearly 90 degrees, over a band of frequencies extending from 300 to 3000 cycles. One of the many applications of the networks mentioned in the referenced article is the generation of single-sideband radio signals. It is therefore not surprising that these same networks may be used in a somewhat analogous manner to make possible single-sideband reception.

A block diagram of the basic system is shown in Fig. 1. Two balanced detectors are connected to a common i.f. input. Oscillator voltage is fed to one directly, and to the other through some means for obtaining a 90-degree r.f. phase shift. The audio output of the second balanced detector is delayed 90 degrees by means of a suitable network, and is then combined with that of the other.

The method of operation may be visualized with the aid of the vector diagrams of Fig. 2. It is assumed for simplicity that the incoming signal is pure c.w. The reasoning is equally valid, however, if more than one incoming c.w. signal is present, or if (which is the same thing) the incoming signal is a modulated wave consisting of carrier and sidebands. A vector diagram may be likened to a high-speed flash photograph: it is a way of viewing the situation when all action is "stopped." We may tag each a.c. voltage being studied (no matter what its frequency) and examine its instantaneous relationship to the

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[1] O. G. Villard, jr., "Selectivity in S.S.S.C. Reception," *QST*, April, 1948.

[2] R. B. Dome, "Wide-Band Phase-Shift Networks," *Electronics*, December, 1946.

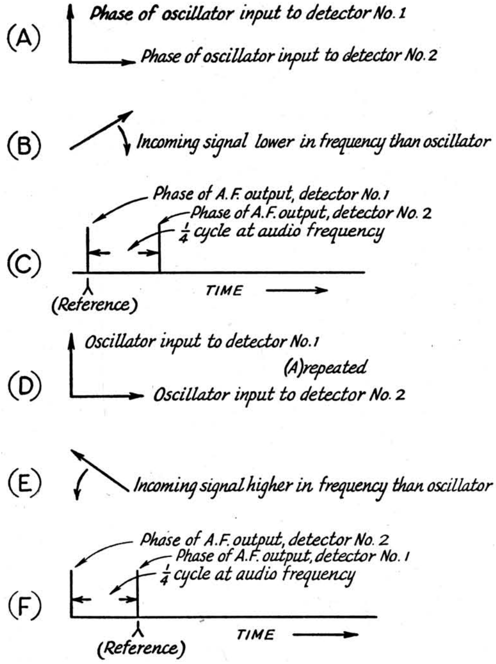


Fig. 2 — **Vector diagrams illustrating the operation of the single-sideband detector.**

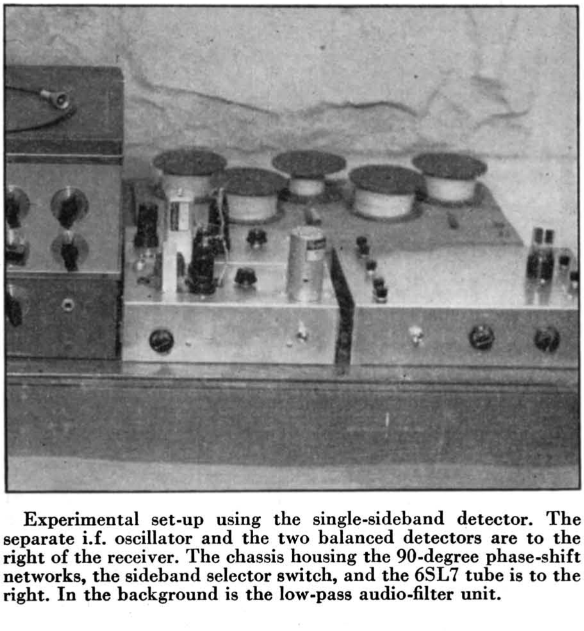
others. A succession of vector diagrams resembles a stroboscopic view: If we flash the lamp in synchronism with one of the a.c. voltages, that particular one will appear to be stationary. Voltages of a frequency slightly higher than our reference will appear to rotate in one direction, while those lower in frequency will rotate in the other.

Fig. 2-A is a representation of the relative phases of the oscillator voltages being fed to Detector 1 and Detector 2. These two voltages will be taken as reference — i.e., our stroboscope is flashing at the oscillator frequency and these vectors will always appear stationary. The vector in B, however, represents an incoming signal lower in frequency than the oscillator; consequently it would be found to be rotating clockwise if a succession of vector diagrams were drawn. This motion is indicated by the curving arrow. It can easily be seen that this rotating vector will be parallel to that of the oscillator input to Detector 1 *before* it becomes parallel to that of the input to Detector 2.

We may consider the instant in time at which these vectors are in phase as a reference point in the audio output of the two detectors, since it is a characteristic of frequency translation of this sort that audio phase relationships are exactly determined by radio-frequency phase relationships. Fig. 2-C represents the audio outputs of the two detectors plotted as a function of time. The vertical lines represent the instants in time at which the incoming-signal vector is in phase with the two oscillator voltages, and therefore will equally well represent the relative phase of the audio output of each detector. It is quite apparent that the output of Detector 1 has a phase which is 90 degrees ahead of the output of Detector 2.

In E, the counterpart of B, the incoming frequency is higher than that of the oscillator, and therefore its vector rotates counterclockwise. Under these conditions this vector becomes exactly in phase with that of the input to Detector 1 *after* it has become in phase with that of Detector 2. The audio output of Detector 1 now has a phase which is 90 degrees behind that of Detector 2.

Now let us suppose that we delay the audio output of Detector 2 by one-quarter cycle, as shown in Fig. 1, by means of a 90-degree wide-band audio phase shifter. The output of Detector 2 will wind up one-half cycle behind that of Detector 1 in C of Fig. 2 (i.e., the two voltages will be 180 degrees out of phase), whereas in F the delayed output of Detector 2 winds up exactly in phase with that of Detector 1. This is the basis on which the scheme works — for c.w. or single-sideband signals lower in frequency than the conversion oscillator, the two detector outputs cancel; for signals higher in frequency, they add up in phase. By reversing the polarity of the oscillator voltages (or that of the detector outputs) the detector may be made to respond to



Experimental set-up using the single-sideband detector. The separate i.f. oscillator and the two balanced detectors are to the right of the receiver. The chassis housing the 90-degree phase-shift networks, the sideband selector switch, and the 6SL7 tube is to the right. In the background is the low-pass audio-filter unit.

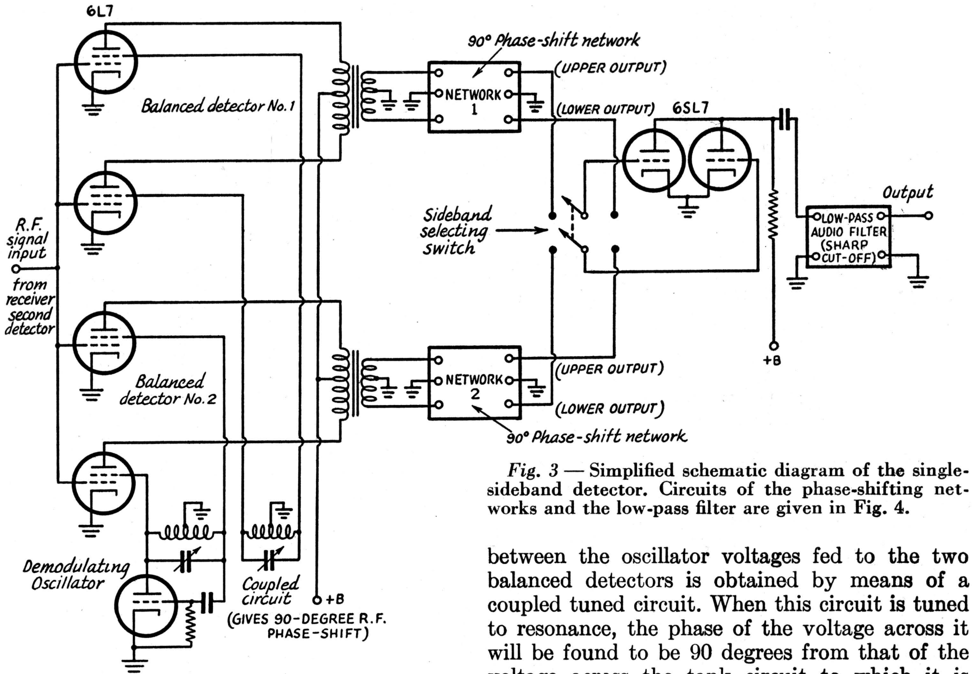


Fig. 3 — Simplified schematic diagram of the single-sideband detector. Circuits of the phase-shifting networks and the low-pass filter are given in Fig. 4.

signals either on one side of the beating oscillator or the other.

Practical Circuits

Fig. 3 is a simplified schematic showing how two balanced detectors, two 90-degree phase-shift networks, and a low-pass filter may be combined to make up a single-sideband detector. The circuits of the phase-shift networks and of the low-pass filter are shown in Fig. 4. A complete schematic of the entire unit is given in Fig. 5. This unit is by no means the best way to carry out the functions indicated in the block diagrams — it merely represents a first experimental model whose only merit is that it does work! It is hoped that it will serve, however, to illustrate the principles involved.

Referring to Fig. 3, the 90-degree phase shift between the oscillator voltages fed to the two balanced detectors is obtained by means of a coupled tuned circuit. When this circuit is tuned to resonance, the phase of the voltage across it will be found to be 90 degrees from that of the voltage across the tank circuit to which it is coupled.

It will be noted that *two* 90-degree audio phase-shift networks of the type shown in Fig. 4 are required. The reason for this is that while each network produces two output voltages 90 degrees apart in phase, the relative phase of these two voltages bears no fixed relationship to that of the input voltage. Therefore two identical networks must be used in order to get the necessary 90-degree audio delay between the outputs of the two detectors. Fig. 6 gives vector diagrams illustrating the action. A c.w. input signal is assumed; therefore the audio output is sinusoidal. In A, the relative phase of the audio output of the first balanced detector is shown. This is split into two portions, 90 degrees apart in phase, but bearing no fixed phase relationship with the input voltage. It is assumed that at the particular

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Top view of the balanced-detector chassis. The i.f. tuning control for r.f. phase shifting is brought out to the front by means of a flexible shaft. The large knob is the oscillator tuning control.

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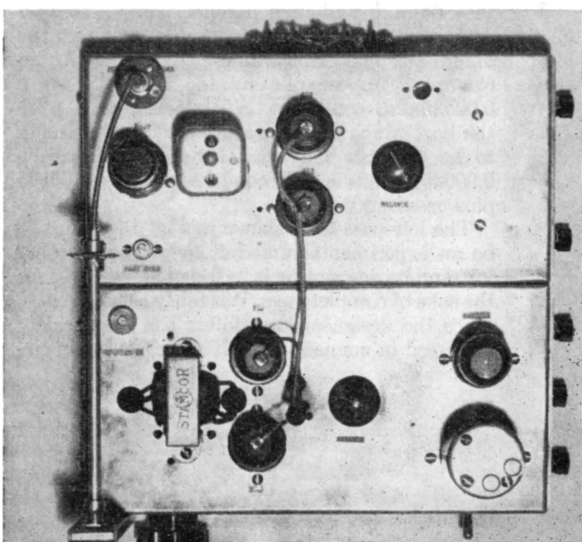


audio frequency chosen for the example, the phase shift between input and output happens to be that shown. Fig. 6-B shows the output of the second balanced detector, and it will be seen that the upper output voltage of Network 1 is of just the right phase to cancel the lower output of Network 2. C and D show how the situation is reversed when the incoming signal is on the other side of the oscillator frequency.

Two other characteristics of the phase-shifting networks should be mentioned. It will be observed that each requires a push-pull input; this is essential for their correct operation. The output impedance of the two networks is very high, and as a result it does not appear to be possible to connect them in series or in parallel without upsetting their normal operation. For this reason their outputs are combined in the 6SL7 twin triode.

The "sideband selecting switch" in Fig. 3 makes it possible to listen to c.w. and s.s.s.c. signals either higher or lower than the oscillator frequency, the others being rejected. The reason for this can be seen by following through the vector diagrams of Fig. 6.

Notes on Circuit Details

Construction of the phase-shift network of Fig. 4 offers only one difficulty. The values actually used should be as close to those shown as possible. It has been found that reasonably good performance is obtained if the values are matched to within plus or minus 5%; but the closer the match, the better the network may be expected to perform. Since the condensers and resistors most commonly used have a tolerance of the order of plus or minus 10%, it is very desirable to check the actual values on both resistance and capacity bridges. Most well-equipped radio service shops have both types, and the job of picking values close to the desired is not an especially tedious task when a large assortment is available.

If picking items from an assortment is too time-consuming, an alternative method is to measure a condenser or resistor accurately (no matter what its value, provided it is less than that desired) and then parallel or series it with additional units whose rated values make up the difference. The error will then be small. As an example, suppose one wanted to make up a 0.00535-μfd. condenser. A 0.005 is picked from the box, which when measured is found actually to be 0.00510. This may be paralleled with a 0.00025 10% tolerance condenser to give 0.00535 plus or minus 0.2%.

The low-pass filter shown in Fig. 4 happens to be an experimental unit left over from another job, and its description is included here merely for the sake of completeness. It is fairly easy to make. Since the design of such filters has been widely discussed in connection with speech-clipping circuits,[3] no comment is needed here, other than that filters of this type are now commercially available. Since the phase-shifting networks are good up to 3000 cycles, a filter cut-off frequency of 2500 cycles may seem unnecessarily low; however, it is found to be perfectly satisfactory in practice from the standpoint of intelligibility, and gives greater effective selectivity.

Fig. 5 looks quite a bit more complicated than Fig. 3, but most of the extra details are circuit components added for the sake of convenience in the experimental model. Much could have been cut out if economy had been the primary consideration. Coupling to the last i.f. stage of a standard communications receiver (in our case a National NC-200) is accomplished by means of

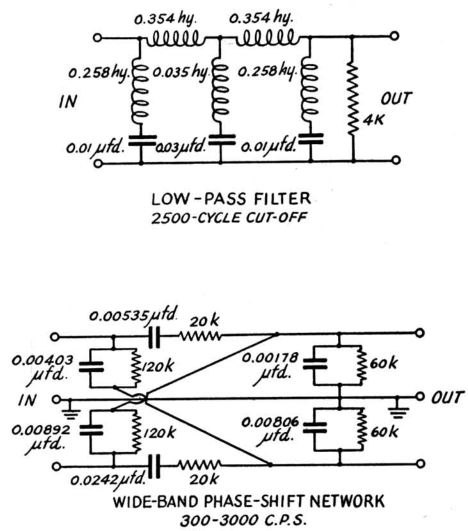


Fig. 4 — The low-pass filter and wide-band phase-shift network. In the phase-shift network the values shown should be matched as closely as possible. The filter coils used in the experimental unit shown use No. 25 s.c.c. enamel wire scramble-wound on wooden spools 1⅜ inches in diameter and 2 inches between sides. The 0.354-henry coils have 1.74 pounds of wire each, the 0.258-henry coils 1.5 pounds, and the 0.035-henry coil 0.64 pound. The sides of the spools are 4⅜ inches in diameter.

a 6C4 cathode-follower tube built into a plug-in adapter. The second detector of the receiver is removed, the adapter containing the 6C4 plugged in, and then the detector tube is plugged into the adapter. The 6C4 derives its filament and plate currents (which are negligible) from the receiver, and provides a low-impedance i.f. output of several volts for connection to the single-sideband

[3] W. W. Smith, "Premodulation Speech Clipping and Filtering," *QST*, February, 1946; W. W. Smith, "More on Speech Clipping," *QST*, March, 1947; J. W. Smith and N. H. Hale, "Let's Not Overmodulate," *QST*, November, 1946; Galin, "Audio Filters for the Speech Amplifier," *QST*, November, 1947.

detector. The grid of the 6C4 connects to the secondary of the last i.f. transformer, the other side of which is grounded. Addition of the 6C4 necessitates only a very slight retuning of the i.f transformer to restore perfect alignment.

The i.f. signal from the 6C4 is attenuated by means of a small variable condenser to approximately 1 volt r.m.s. (for full NC-200 r.f. gain) before being applied to the paralleled control grids of the 6L7s. Connected to the plates of each pair of 6L7s is a small step-down transformer of the Class AB driver type (turns ratio primary to ½ secondary = 3:1). The step-down is needed to provide a low source impedance with which to feed the networks. To prevent resonances in the transformers, swamping resistances of 10,000 ohms are connected across each half of the primaries. Their use is essential. The 50,000-ohm

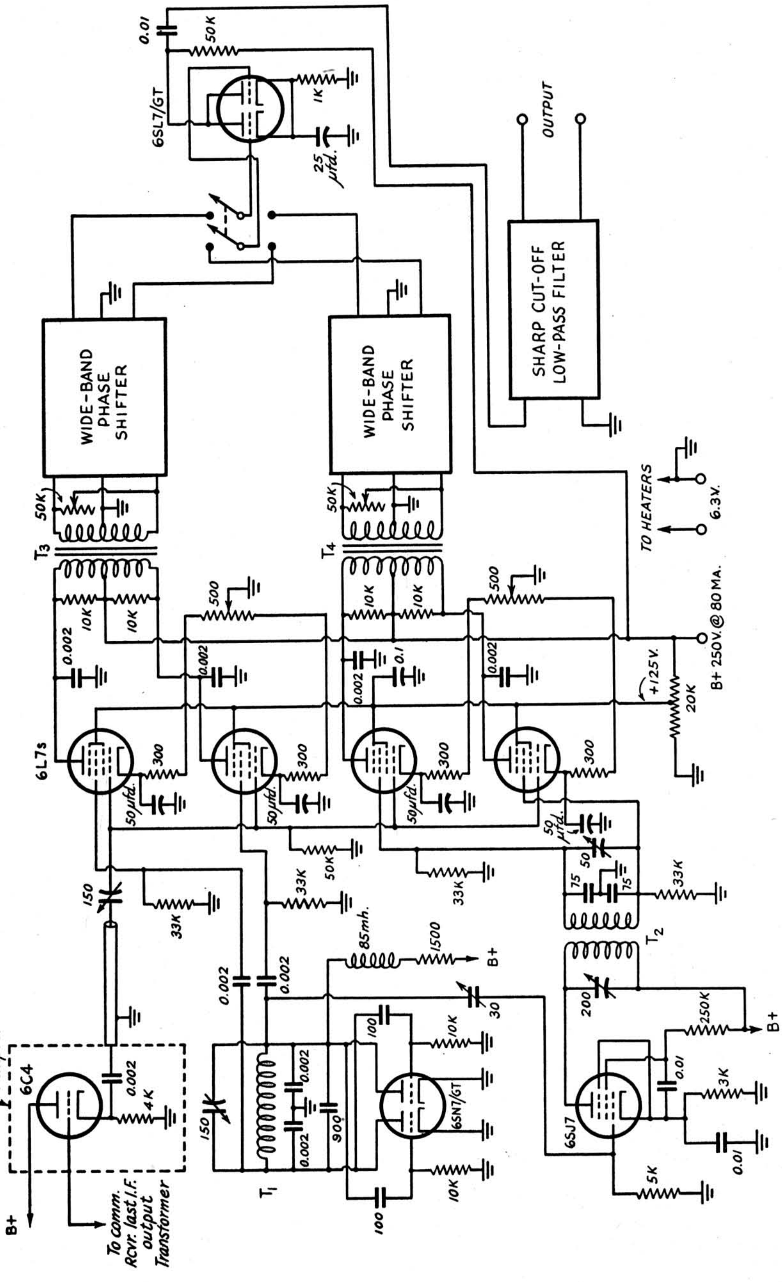


Fig. 5 — Complete circuit of the experimental single-sideband detector unit. The circuits of the phase-shift networks and low-pass filter are given in Fig. 4. Transformers in the diagram shown above are as follows:

T_1 — Approx. 65 µhy. (broadcast-band antenna coil with primary and some secondary turns removed).

T_2 — 450–475-kc. i.f. transformer (Miller 512-C11) with secondary condenser removed and 75-µµfd. condensers substituted, as shown.

T_3, T_4 — Audio transformer, turns ratio primary to ½ secondary: 3:1 (Stancor A-4712).

variable resistors connected across the transformer secondaries may be adjusted to equalize the outputs of the two detectors so that complete cancellation can take place when the correct phase relationships exist.

The oscillator was made push-pull, although it could equally well have been single-ended. Both balanced detectors require oscillator voltages of opposite phase, however. A 6SJ7 buffer tube is used between the oscillator and the phase-shifting coupled circuit, in order to prevent any reaction on the frequency of the oscillator caused by tuning the secondary of the phase-shifting i.f. transformer. (By connecting the coupled circuit to the plate of an electron-coupled oscillator, it would have been possible to eliminate the buffer tube while still providing isolation between this circuit and the oscillator tank.) The 6SJ7 is not required to produce any gain; therefore its input from the oscillator is cut down by use of a small coupling condenser. Resistance loading of the i.f.-transformer secondary can also be used to reduce the gain and has the advantage that the circuit *Q* is thereby reduced, making the tuning less critical. The desired phase shift is obtained by tuning this circuit, and when it is at resonance, the phase shift will be approximately correct. However, at resonance the rate-of-change of phase with tuning is greatest, and is proportional to the circuit *Q:* hence it is desirable to make the tuning less critical and the phase setting easier by reducing the secondary *Q*.

Testing & Adjustment

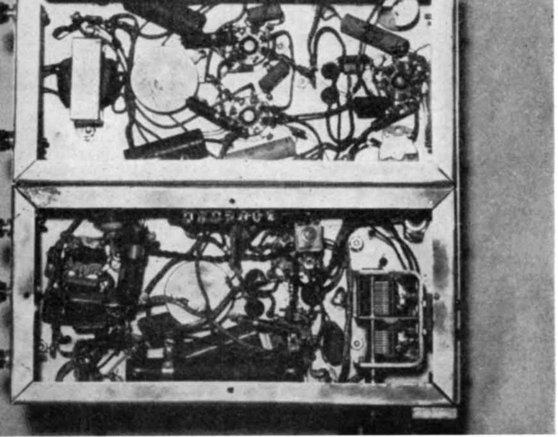
Testing and tuning up the circuit is quite straightforward. The first step is to see that the correct oscillator voltages are applied to the 6L7s. (A 20,000-ohm-per-volt voltmeter plus a crystal rectifier makes a convenient substitute for a vacuum-tube voltmeter, as suggested by WØTQK.)[4] The injector grids may have up to 15 volts r.m.s. applied, in accordance with conventional converter practice. It is desirable that all four tubes receive roughly the same oscillator voltage. Maximum voltage at the signal grids should be held to one or two volts r.m.s. The balanced detectors are balanced by applying a strong a.m. signal with the oscillator detuned. The cathode resistors are then adjusted for minimum audio output.

If the phase-shift networks have been constructed with accurately-measured components, they may be relied upon to operate as planned. To test them, only a variable-frequency audio oscillator and an oscilloscope are required. For best results, the networks should be fed from the oscillator via a push-pull audio transformer of fairly good quality, preferably of the step-down variety. The horizontal and vertical amplifiers of the oscilloscope are then connected to the two network output terminals, and the relative gains adjusted until the pattern becomes as nearly circular as possible. The audio frequency may then be varied from 300 to 3000 cycles; if the pattern remains approximately circular over this range, the network is functioning properly. It is important that both networks behave as nearly alike as possible. Actually, even if the network design values are duplicated exactly, the patterns will not remain precisely circular over the range because in a simple network of this sort both phase and amplitude deviate somewhat from the ideal condition. However, the phase should hold within a few degrees and the amplitude within a few per cent.

While set up for this test, it is interesting to feed a voice signal into the network and observe the result. A complex voice wave produces a remarkable pattern of curlicues and circles within circles — a pure "pear-shaped" tone, of course, always produces a circle no matter what the frequency, provided it is within the range of the network. It is possible that patterns of this sort might be useful for voice training, or in connection with teaching the deaf to speak.

With the detectors balanced, the networks connected, and the oscillator at the correct frequency, the radio-frequency phase shift must be set. Tuning the i.f.-transformer secondary to resonance will give approximately the correct setting. An easy way to find the correct setting exactly is to connect the horizontal and vertical plates of a 'scope to the outputs of the two balanced detectors. With a c.w. signal applied to the input and adjusted to a frequency that produces, say, a 1000-cycle beat note, the tuning is adjusted until

[4] A. H. Nichols, "A Single-Sideband Transmitter for Amateur Operation," *QST*, January, 1948.



Bottom view of the balanced-detector chassis.

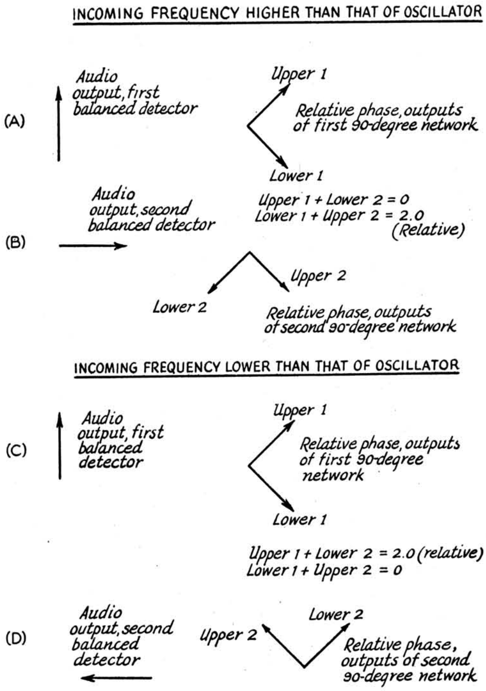


Fig. 6 — Vector diagrams showing operation of the practical detector circuits of Figs. 3 and 5.

the pattern on the oscilloscope is a perfect circle. It should be a perfect circle when the incoming signal is on either side of zero beat, and its shape will not be dependent on the exact frequency of the beat note. If the incoming signal is modulated with speech or music, it may be possible to see the direction of rotation of the 'scope pattern reverse as the incoming signal slowly passes through zero beat!

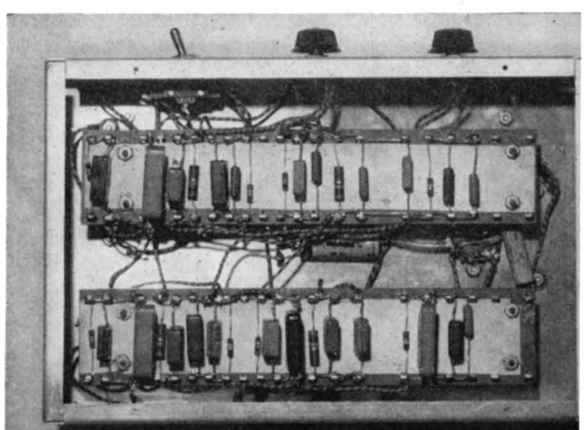
Once the correct r.f. phase has been found, it should be possible to observe a noticeable difference in output when the sideband selector switch is thrown. (It is assumed that a steady c.w. signal on one side of zero beat has been tuned in.) With the switch thrown to the position at which the signal is weaker, the two amplitude-balancing resistances (across the audio-transformer secondaries) may be adjusted for greatest rejection of the incoming signal. These resistors could be ganged in such a way that when one opens the other closes, and one control would thereby be eliminated.

The single-sideband detector is then ready to go. Its output may be fed back to the audio input of the receiver, or it may be fed to a separate amplifier. By touching up the r.f.-phase as well as the amplitude-balance controls, it is possible completely to eliminate a signal on the wrong side of zero beat. The procedure is much like balancing a bridge. Changing the r.f.-phase setting, as well as the amplitude balance control, compensates for any deficiency in the audio-phase-shift networks, both as to output phase and amplitude. However, it should be realized that these deficiencies can only be compensated for at one audio frequency; at all others, the balance will again be imperfect and some signal will be heard. Therefore it is best to choose a frequency of roughly 1000 cycles, where the ear is most sensitive, for perfect cancellation; at other frequencies, some signal will leak through because of imperfect operation of the phase-shift networks, but the leakage will then not be quite so noticeable.

The solid curve in Fig. 7 is the ratio of the input to the output voltage of the low-pass filter as a function of frequency. The dip at 5200 cycles represents the frequency at which the shunt M-derived end sections are series-resonant. It is seen that signals 10 kilocycles away from the beat-oscillator frequency are attenuated 1000 times by this filter — in other words, its selectivity is equivalent to that of the i.f. stages of, say, an NC-200 receiver! For reference, the selectivity curve of this receiver is plotted as the dotted curve in Fig. 7. The over-all response curve of an NC-200 followed by this filter would, of course, be the product of these two curves.

An idea of the image-signal or unwanted-sideband rejection made possible by the two 90-degree networks, whose R and C values are within plus or minus 5%, may be gained from the following typical measurement:

Frequency	*Ratio, Desired to Undesired Sideband (Voltage)*	*(db.)*
300 c.p.s.	10	20
500	17	24.6
600	50	34
650	100	40
900	100	40
1000	65	36.2
1500	17	24.6
2500	20	26



Underneath the phase-shift network chassis. The two networks side by side are electrically the same, although the components are not always identical.

The shape of this curve is to a large extent dependent on the exact frequency chosen for perfect balance — in this case somewhere between 650 and 900 cycles.

In operation, this amount of rejection is reasonably adequate. (Selection of condensers and resistors of closer tolerance would probably have meant still better performance.) It is very striking to be able to throw the sideband selector switch, when listening in a crowded c.w. band, and hear an entirely different set of signals! An attachment of this sort effectively halves the bandwidth of the c.w. receiver, thereby removing half of the signals one would normally hear.[5] A remarkable feature is that this great increase in selectivity is obtained without resort to crystal filters or other highly-selective circuits which require great stability or careful tuning for proper operation.

Another remarkable feature is the fact that two audio outputs can be provided, so that two operators can listen simultaneously and without interference to the output of the same receiver —

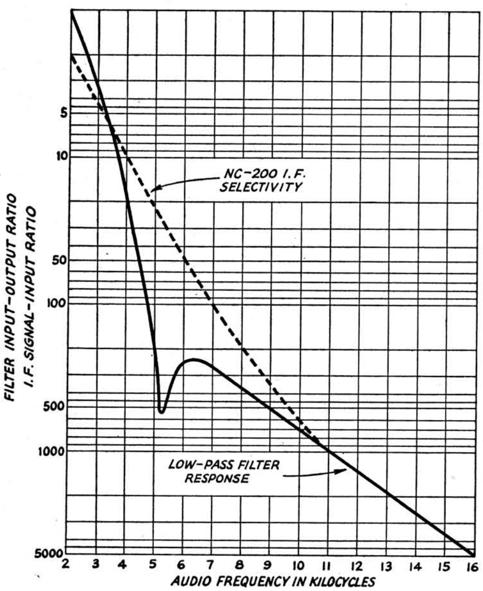
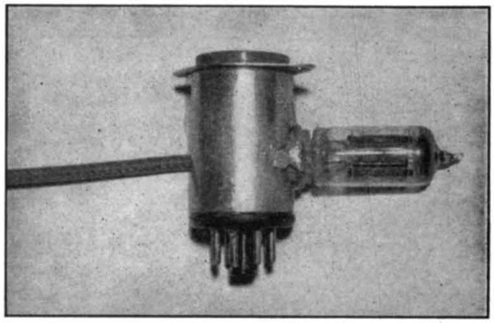


Fig. 7 — Response curve of the low-pass filter (solid curve). A typical receiver selectivity curve is shown for comparison (broken curve).

one hearing all signals lower than the beat oscillator, and the other all those higher. It is only necessary to add a second 6SL7 connected to the unused terminals of the 90-degree networks in Figs. 3 or 5. This ought to be an ideal arrangement for more-than-one-operator stations in DX or SS contests; each operator can listen for replies to CQs on his particular side of the transmitter frequency!

It must be remembered, when tuning in single-



Close-up of the plug-in adapter unit for connecting to the receiver.

sideband signals, that the selector switch must be thrown to the correct position. If it is on the position which rejects the sideband being transmitted, the station will be heard very poorly.

In certain types of s.s.s.c. transmitters, it is possible to select the sideband transmitted at will. When, at the receiving end of a circuit, the receiver is equipped with a sideband selector, it is possible to change frequency instantaneously from one sideband to the other merely by throwing a switch. Thus a QSY of one channel-width can be accomplished without any retuning. In ham work, this should be ideal for avoiding QRM.

[5] The authors refer here to a "straight" super — one without a crystal filter. — *Ed.*

Strays

Numerous BCLs in Kendallville, Ind., complained loudly about the radio ham who was making it impossible for them to hear any programs. They carried their demands that something be done to the local politicos. It was, too. Intensive investigation disclosed that the cause of all the listeners' woe was centered right in City Hall — not high-powered oratory, mind you, but a high-tension line carrying 2300 volts which was arcing over at intervals! — *Indianapolis Star, via W9RDW*

We're in, gang! The new *American College Dictionary* (Random House), distributed by the Book of the Month Club, gives listing to the expression "ham radio," defining it as slang for "an amateur; a radio ham." — *W1BT*

Nonmetallic permanent magnets, known as "Electrets," are now being made of plastics, usually by solidifying a molten wax in a strong d.c. electric field. — *Ohmite News*

"Amateurs modifying surplus gear and looking for a solvent for Glyptal will find a friendly ally in ethylhexanedoil, commonly sold as the insect repellent '612.' Twelve hours after the solution is applied, the Glyptal will brush off." — *C. F. MacLean*

Swell tip, Mac; we'll try it. But please tell us, OM: Do you think the stuff also might help in debugging that pestiferous 807 of ours?