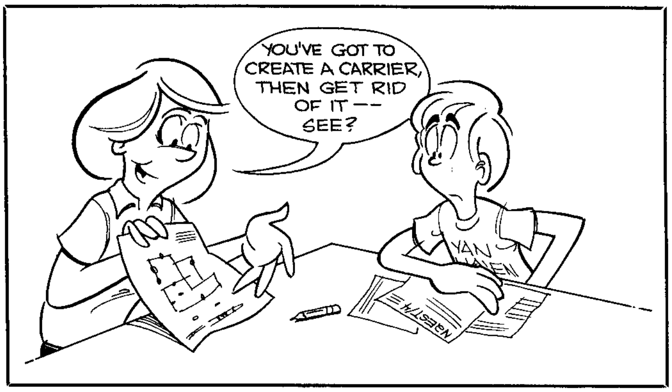
• *Beginner's Bench*

The Principles and Building of SSB Gear

This intermediate-level series is aimed at those who want to build a small SSB transmitter and learn how SSB equipment operates. A practical project will be described later in the series.



By Doug DeMaw, W1FB
ARRL Contributing Editor
P.O. Box 250, Luther, MI 49656

Would anyone *build* an SSB transmitter today? After all, doesn't everyone buy a commercial rig these days? These questions are worth asking ourselves if, indeed, we have no interest in what goes on within the cabinets of the store-bought transceivers most of us own. But, wouldn't it be fun to construct a low-power SSB transmitter for the experience and understanding it would provide? For some, the answer is yes. A secondary benefit is that you will be better equipped to pass the next higher license-grade test if you know what takes place in an SSB circuit. Beyond that, you will be able to do a better job of troubleshooting your commercial SSB ham gear if you know what the various circuits are supposed to do in the process of generating an SSB signal.

As we move along with this new series I will describe a QRP SSB transmitter for the 75-meter band. It will be easy to build and adjust. The total cost should be within most experimenters' budgets. But first, let's review the subject of SSB generation within the scope of modern filter-generator techniques.

Circuit Lineup

Rather than burden or confuse you with an elaborate SSB transmitter circuit, I'd like to illustrate the basic principles by using a block diagram that shows the bare essentials of an SSB generator. Please refer to Fig. 1 for this discussion.

If we start at the left of the diagram in Fig. 1, we see that the first stage or stages of an SSB transmitter are designed to amplify the energy from a microphone. This is necessary in order to provide ample speech power for the balanced modulator. The speech amplifier should be designed to pass only those voice frequencies needed for communications—typically 300 to 3000 Hz. Proper selection of resistor and capacitor values will shape the amplifier response for the specified passband. We must also ensure that there is no hum introduced in the speech-amplifier section. This means the dc operating voltage needs to be well filtered. Some form of RF suppression is desirable between the mic input jack and the speech amplifier. This will prevent distortion and howling from RF energy that could enter the input circuit of the speech amplifier through unwanted RF pickup on the microphone cable. These are subtle but important design steps. Later in this series, we will examine actual circuits for speech amplification, along with detailed circuit data for the other stages shown in Fig. 1.

Next comes the balanced modulator. This is perhaps the most important part of

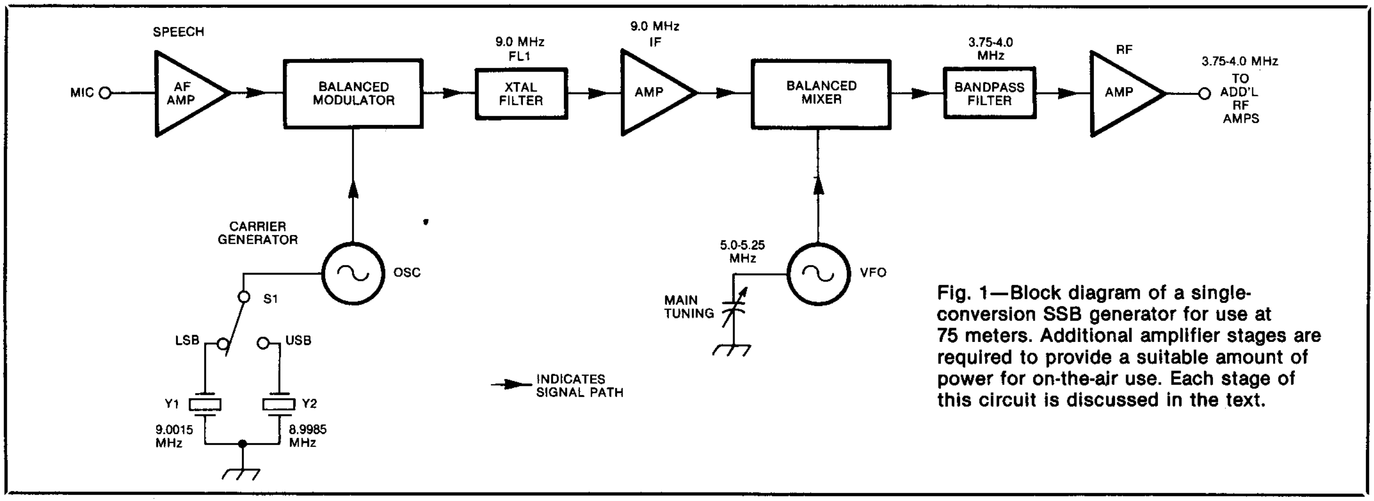


Fig. 1—Block diagram of a single-conversion SSB generator for use at 75 meters. Additional amplifier stages are required to provide a suitable amount of power for on-the-air use. Each stage of this circuit is discussed in the text.

the generator, other than the SSB filter (FL1). The balanced modulator combines the speech energy from the audio amplifier and the RF current from the carrier generator to provide modulated RF output at 9 MHz. It must also balance out (remove) the 9-MHz carrier. The output from the balanced modulator is double-sideband, suppressed-carrier energy at 9 MHz. Balanced modulators are similar to balanced mixers in the way they are constructed. There are many types of circuits for use in this part of an SSB generator; we may use individual transistors to form a balanced circuit, we may use ICs designed especially for this service, or we might choose a diode variety of balanced modulator. Some circuits are referred to as "singly balanced," while others are "doubly balanced." The doubly balanced modulators offer the greatest carrier suppression. Some simple illustrations of balanced modulators are given in Fig. 2.

Ideally, the unwanted carrier should be suppressed by at least 50 dB. If we were to allow the carrier to remain at the output of the balanced modulator, we would have a small AM transmitter (carrier and AM sidebands). Therefore, the greater the carrier reduction, the better the quality of the SSB signal. Poor carrier suppression can be observed by tuning off to the side of an SSB signal. It appears as a weak beat note.

Carrier Generator

We need to have a carrier generator in order to produce an SSB signal. The operating frequency of the carrier oscillator (Fig. 1) is chosen in accordance with the center frequency of the crystal lattice SSB filter (FL1). Two crystals (Y1 and Y2) are used to allow upper- or lower-sideband operation. The exact crystal frequencies used depend in part on the shape of the filter-response curve. The crystal frequencies must fall at points on the response curve that are approximately 20 dB below the peak response of the curve, as shown in Fig. 3. This procedure ensures the most realistic voice quality (natural sound) at the receive end of the SSB communications circuit. Wrong placement will lead to a high-pitched or low-pitched voice quality. Correct positioning of the carrier frequencies is important also for ensuring ample suppression of the unwanted sideband (reduction in level of the USB energy when working LSB, and vice versa).

If we want to use the SSB transmitter for CW operation, we must unbalance the balanced modulator. Generally, this is done by routing a dc voltage to a part of the balanced modulator, which, in turn, causes imbalance. This permits the carrier to ride through the circuitry that follows the balanced modulator and ultimately to the antenna. A drive or carrier-level control is often used to vary the degree of imbalance, and hence the level of the driving power to the RF amplifier stages after the mixer of Fig. 1. We will learn more about the mechanics of this feature later in the series.

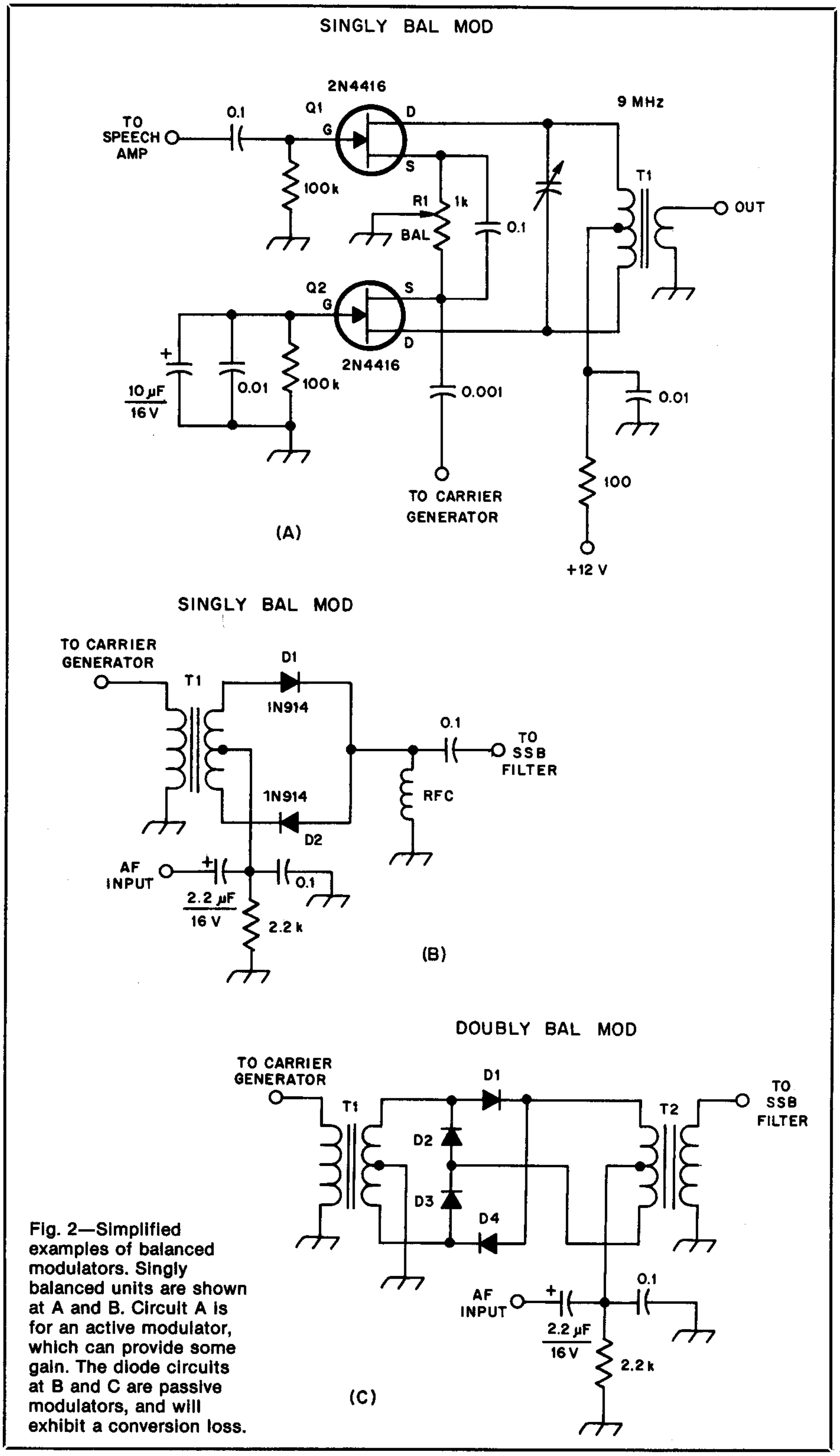


Fig. 2—Simplified examples of balanced modulators. Singly balanced units are shown at A and B. Circuit A is for an active modulator, which can provide some gain. The diode circuits at B and C are passive modulators, and will exhibit a conversion loss.

SSB Filter

Most SSB rigs today contain crystal filters, although mechanical filters remain available for intermediate frequencies up to 500 kHz. The most commonly available nonsurplus filter is designed for a center frequency of 9 MHz, and it is available by mail. Matching USB and LSB crystals are also available for the carrier generator.[1]

The function of the crystal filter is to

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[1] Notes appear on page 19.

suppress the unwanted sideband while passing the desired one. The greater the number of poles or crystal sections used in a filter (up to a practical limit), the steeper the filter side response (skirts) and the better the rejection of the unwanted sideband. Most SSB filters are listed as 4-pole or 8-pole types. Homemade lattice filters were commonplace when SSB first became popular, but we can now purchase a ready-made filter for less money than we would pay for new crystals that are etched for the exact frequencies required. Homemade ladder filters are practical and inexpensive if we build them with surplus crystals.[2]

Each crystal filter has a characteristic input and output impedance. We must be certain to provide a resistive termination of the proper value if we are to expect the specified performance of a given filter. Incorrect termination can vastly alter the response curve of a filter, and may lead to what is known as "ripple." This shows up as one or more dips in the flat part of the response curve (filter nose), and some of the unwanted dips in response can be several decibels in magnitude. Ideally, the nose of the filter-response curve is flat.

Post-Filter Amplifier

All filters (LC or crystal) cause some signal loss. This is called *insertion loss.* The amount of power loss varies with the design and brand of filter, but it is normally between 5 and 8 dB. Therefore, it is a good idea to recover that loss by adding an IF amplifier directly after the filter, as shown in Fig. 1. In fact, this stage can be arranged to provide a slight gain, say 15 dB. If we deduct the 8 dB of insertion loss from FL1, we still have a bonus 7 dB of gain for the 9-MHz SSB signal from FL1. It is not imperative that we make up the lost gain in this part of the circuit; it could be added after the balanced mixer. However, that would place an additional amplifier in the 3.75- to 4.0-MHz RF section, and having so many stages on the same frequency could encourage self-oscillation at 75 meters. We must be careful when using the post-filter 9-MHz amplifier. If we allow it to have too much gain, it can drive the balanced mixer too hard, and this will cause unwanted distortion products to be generated within the mixer. Mixer distortion would then be passed along at 75 meters and greatly amplified. The result would be a wide signal in the 75-meter band.

Balanced Mixer

Now comes the conversion section of our SSB generator. We must move (heterodyne) the 9-MHz SSB signal to the band of our choice. In this example, we are shifting from 9 MHz to 3.75-4.0 MHz. Our balanced mixer works just as it would in a receiver. That is, we inject the mixer with two frequencies (9 MHz and 5 MHz) to produce a sum or difference output frequency (9 − 5 = 4 MHz, or 9 + 5 = 14 MHz). If we are to generate 75-meter SSB energy, we must choose the difference frequency. We could build a 20-meter SSB transmitter by selecting the sum of the mixer frequencies. The RF amplifiers and filter (FL2) that follow the mixer would then have to be designed for 14-MHz operation. In fact, many early two-band homemade SSB transmitters were built for 75 and 20 meters in order to use this convenient frequency scheme. The use of upper sideband on 20 meters and lower sideband on 75 meters may be a result of this frequency arrangement (the sidebands become inverted when switching from the difference to the sum frequency).

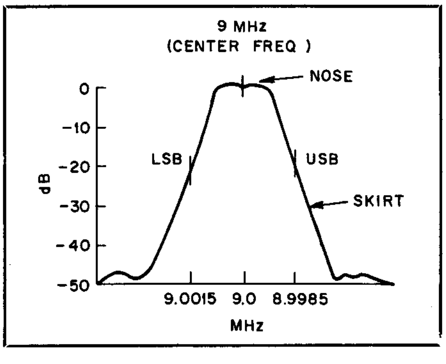

Fig. 3—A typical response curve for a crystal-lattice SSB filter. Note that the carrier-generator frequencies for USB and LSB are placed 20 dB down from peak response on the curve (see text).

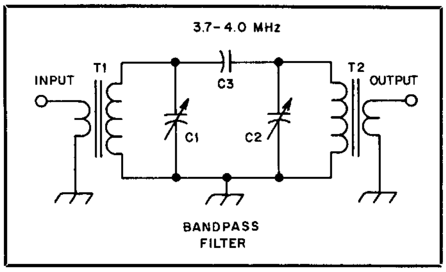

Fig. 4—Circuit example of a two-pole band-pass LC filter. The inductance values for T1 and T2, plus the capacitance used at C1 and C2, depend on the operating frequency and the general design of the filter. C3 is also a calculated value. Filters of this type are suitable at the output of a balanced mixer to minimize the passage of unwanted frequencies.

Mixers follow the same rule in SSB generators as they do for receiver design. This suggests that we should avoid single-ended mixers (a 40673 MOSFET, for example) and use singly or doubly balanced mixers. Once more, we can use bipolar transistors, FETS, ICs or diodes, just as is the case with the balanced modulator. In fact, the circuits of Fig. 2 can be adapted for use as balanced mixers by substituting the 9-MHz energy for the audio-frequency voltage specified.

The advantage of using balanced mixers is that cancellation of the 9- and 5-MHz energy is enhanced. A doubly balanced mixer will greatly suppress these two frequencies, whereas a singly balanced mixer will reduce only one of the unwanted frequencies. Our objective is to extract only 3.75-4.0 MHz energy from the mixer output.

It is advantageous to filter the mixer output with a band-pass LC filter (FL2 of Fig. 1). This further reduces the level of the 5- and 9-MHz components before the mixer output signal is fed to the 75-meter RF amplifier. A typical band-pass filter is shown in Fig. 4. It must have a broad enough response to pass the frequencies from 3.75 to 4 MHz without attenuation other than the usual insertion loss. The filter should attenuate all frequencies below 3.7 and above 4 MHz.

A reasonably pure signal should be available for the stages that follow the mixer. This will help to ensure that the various "straight-through" amplifiers do not act as mixers and cause spurious transmitter output frequencies. Getting rid of amplifier harmonics is a job by itself: We don't want to battle additional spurious frequencies along the way.

Installment Wrap-up

The discussion we have had this month relates primarily to the fundamental nature of an SSB generator. This treatment has been based on the single-conversion concept. Most commercial transmitters, receivers and transceivers use the double-conversion approach, which is more complex in terms of gain distribution and the reduction of spurious response. For the purpose of this series, we will stay with the single-conversion process. It will reduce the parts count and lessen our burden of providing a spectrally clean output from the transmitter.

The carrier generator of Fig. 1 and the VFO section in the same block diagram are not necessarily representative of a quality design. Normally, each stage would be followed by a buffer amplifier. This would isolate the oscillators from the circuits they connect to, thereby minimizing frequency changes caused by load variations. Single-stage oscillators are depicted for the purpose of simplicity.

We recognize that many of you are familiar with how an SSB transmitter functions. But we want to give newcomers a better understanding of this established mode of communications. The seasoned readers may want to stand by until we present the practical circuits that will be used in the workshop portion of this series.

Notes

[1] Spectrum International, Inc., P.O. Box 1084, Concord, MA 01742. Catalog available on request.

[2] W. Hayward, "A Unified Approach to the Design of Crystal Ladder Filters," *QST*, May 1982, p. 21.

hypotenuse to determine the admittance triangle: (Measure from the origin along the hypotenuse and mark the end point Y.) Conductance is then measured from point Y to the j axis, and susceptance from point Y to the R axis. Note the sign of B (distances above the R axis are negative; those below the R axis are positive), and convert G and B to R_p, X_p and C_p:

$$R_p = \frac{1}{G} \qquad \text{(Eq. 8)}$$

$$X_p = -\frac{1}{B} \qquad \text{(Eq. 9)}$$

$$C_p = \frac{1}{X_p(2)\ 3.14(f_o)} \qquad \text{(Eq. 10)}$$

where
f_o = operating frequency.

The equations yield:

$R_p = 2202.8\ \Omega$
$X_p = -6917.3\ \Omega$
$C_p = 4.604$ pF.

A Trigonometric Approach

Those having access to a calculator with trigonometric functions can apply equations to Y and θ:

$G = Y \cos(\theta) = 0.000454$ S
$B = Y \sin(\theta) = 0.000145$ S

The results are the same, but more accurate than those obtained through graphic analysis.

A Coordinate-Conversion Approach

A calculator that performs rectangular/polar coordinate conversions makes the solution almost trivial:

1) Enter X as the y coordinate (capacitive reactance is negative).
2) Enter R as the x coordinate.
3) Convert rectangular to polar coordinates.
4) Take the reciprocal of the polar magnitude.
5) Change the sign of the polar angle.
6) Convert polar to rectangular coordinates.
7) The x coordinate is now G, while the y coordinate is B: Use equations 8, 9 and 10 to obtain R and X.

The Memory Trick

The next time you need to perform a series-to-parallel or parallel-to-series network conversion, remember the relationships:

- Y and Z are reciprocals of each other
- The sign of θ is opposite for Z and Y diagrams

and the variables involved:

- An impedance diagram shows R, X, Z and θ
- An admittance diagram shows G, B, Y and θ

(continued from page 19)

maximum power output at a single frequency.

Each section of the circuit in Fig. 5 contains a decoupling network of resistors and capacitors in the +12-V line. A 10-ohm parasitic resistor is shown at the collector of Q1. Depending on the PC-board layout used, the resistor may or may not be necessary. Furthermore, a layout that encourages VHF oscillation may necessitate inclusion of a 10-ohm resistor at the collectors of Q2 and Q3. VHF or UHF self-oscillation can be detected with a scope, or you may observe it by listening to the 3.9-MHz signal: VHF oscillation usually shows up as a hiss or hash noise superimposed on the desired signal.

Terminals X and Y may be opened for use as a control line for push-to-talk operation. Generally, a small 12-V dc relay is triggered by the mic control switch, and the standby line (X and Y) is actuated by the relay contacts. A slip-on crown heat sink is recommended for Q3 to reduce the operating temperature during the SSB duty cycle.

Construction Notes

Parts kits and PC boards for this series are available.[1] If you prefer to make your own circuit board, be sure to keep all conductors as short and wide as possible. This will discourage the formation of unwanted VHF resonant elements. Double-sided PC board should be used for this module. The ground-plane side (component surface) will help to ensure stability; it should be grounded to the negative foil on the etched side of the board at several points.

A dab of Silastic® compound may be used to affix each toroid to the PC board. This will prevent the transformer leads from breaking because of vibration and similar stress.

In Summary

Upon completion of this and the previously described practical circuits for our SSB generator, it is only necessary to have a VFO to make this unit function as a low-power SSB transmitter. Do not put it on the air unless a harmonic filter is used between T4 of Fig. 5 and the antenna. However, it is okay to operate the system into a dummy load and monitor the output with your receiver.

Our next installment will address VFOs and some of their maladies. A practical VFO for this project will be included in the article.

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[1] A & A Engineering, 7970 Orchid Dr., Buena Park, CA 90620, tel. 714-521-4160.

Strays

BEGINNER'S BENCH PC-BOARD TEMPLATES AVAILABLE

☐ If you've been following "The Principles and Building of SSB Gear" series under the Beginner's Bench banner (the series debuted in September 1985), we have good news for you. PC-board templates and parts overlays are available from the ARRL for the material covered in the September and October issues. Other templates will be available as the series progresses.

The template package includes two PC-board patterns, two parts overlays and two schematic diagrams. You may order these templates from the Technical Department secretary. Please include $4 with your order. Request the October SSB Series Templates.

I would like to get in touch with...

☐ anyone with a service manual and schematic for a Teledialer automatic dialer, Model 32T-02, Part no. 201566-2, manufactured by American Telecommunications Corp. Sheldon Daitch, WA4MZZ, Box 8091, Greenville, NC 27835-8091.

☐ anyone with a manual for a Johnson Transceiver Tester. J. Sandberg, K6HE, 1138 E. Rustic Rd., Escondido, CA 92025.

Feedback

☐ The September Beginner's Bench article, "The Principles and Building of SSB Gear," contains a misstatement on page 19. The text—center column, 16th line from the bottom—reads: "(the sidebands become inverted when switching from the difference to the sum frequency)." As pointed out by Walt Schwarz, K3WNX, sideband inversions will never occur when sum frequencies of the mixer stage are selected, nor will they occur even when the difference frequencies are selected, unless the injection frequencies are *higher* than that of the SSB signal introduced to the mixer stage.

☐ In last month's It Seems to Us ... there are two typographical errors. The first sentence in the fourth paragraph should read " ... is of the opinion that most modern Amateur Radio facilities are safe ..." In the third to last sentence in paragraph three, the word "total" should be "tool."