The Principles and Building of SSB Gear

Part 3: This installment treats the SSB-generator mixer and subsequent low-level, class-A amplifier stages. Practical circuits for these portions of our sideband generator are included.

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

All parts of an SSB transmitter must be designed to minimize spurious responses and to enhance linear amplification at the transmitter output frequency. This is a matter of special concern in the design of the stages that follow the mixer in an SSB generator.

This month we'll examine the function of a mixer and learn methods for obtaining the best mixer performance at reasonable cost. We'll also consider low-power class-A RF amplifiers that can be used to increase the signal amplitude after the mixer stage. Next time, we'll focus on the VFO that serves as the main-tuning module for our little SSB transmitter. Later, we'll discuss a 10-W linear amplifier for the system we're building.

Transmitting Mixers

In effect, a transmitting mixer is no different from a mixer that is designed for receivers. Most mixers are intended for

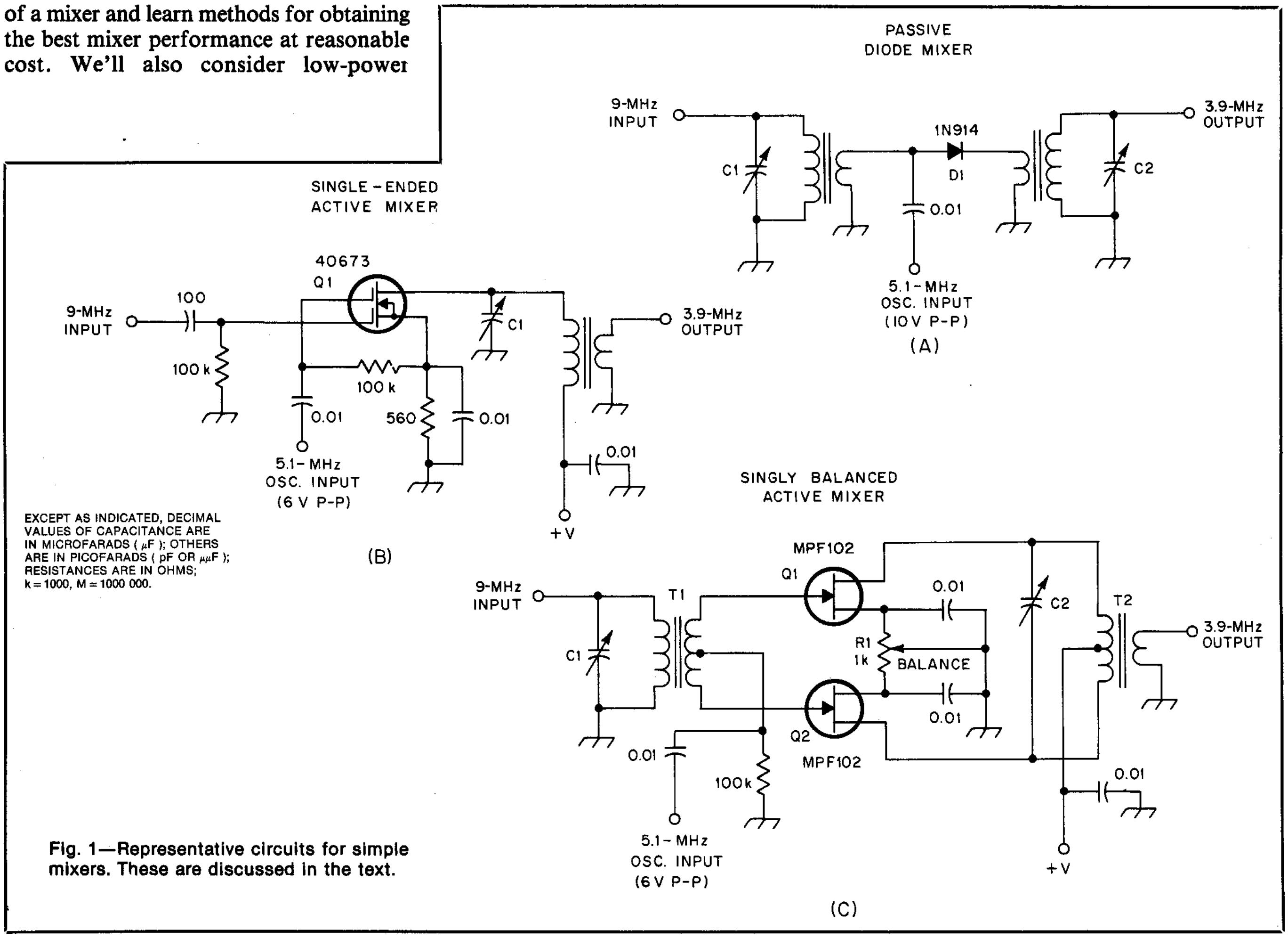

Fig. 1—Representative circuits for simple mixers. These are discussed in the text.

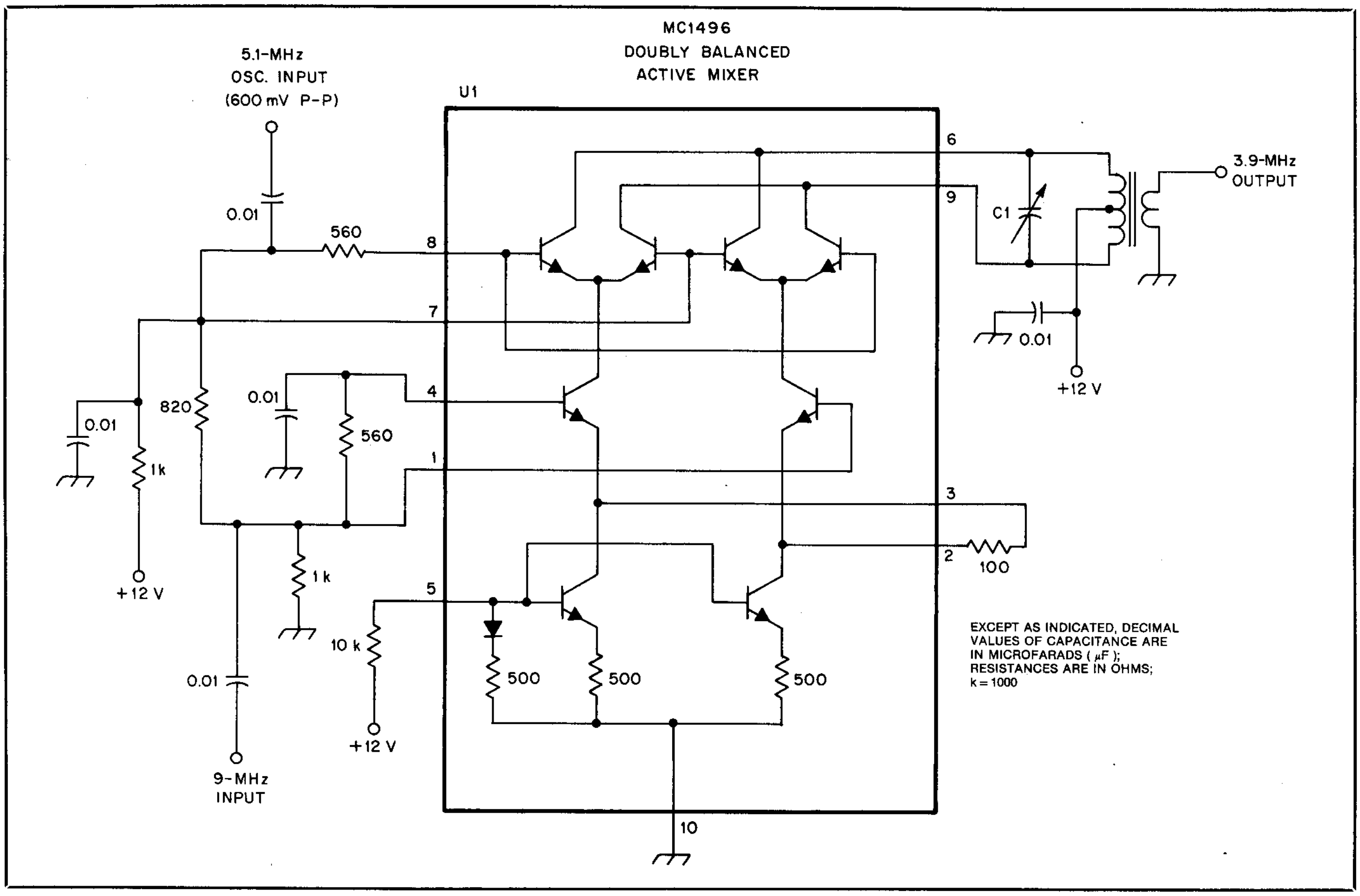

Fig. 2—Internal workings of an MC1496 doubly balanced-mixer chip. A pair of differential amplifiers are cross-connected to provide the doubly balanced format that aids in cancelling the two input frequencies. This leads to greater purity of the output (IF) signal.

low-power use (milliwatts of output power), but certain applications call for power mixers that produce watts of output energy. A disadvantage of power-class mixers is that spurious responses (sum-and-difference frequencies, plus the two input frequencies) are difficult to suppress because they are relatively powerful. A low-power mixer, on the other hand, may have the same percentage of spurious energy, as referenced to peak output power, but the succeeding RF-amplifier stages can provide the necessary filtering (selectivity) to greatly reduce the level of unwanted energy. Another advantage of low-power mixers is that the two input signals need not be high in amplitude to make the mixer function properly. This reduces the complexity of the VFO, or local-oscillator section, and minimizes the driving power needed at the remaining port of the mixer.

Examples of Mixers

Fig. 1 contains three circuits for simple mixers. Acceptable mixer-injection levels (5.1 MHz) are noted for each circuit. The most basic of mixers is seen at A of Fig. 1. D1 functions as a *passive* mixer because it requires no operating voltage. We may think of this mixer as being lossy: The 3.9-MHz output signal will be lower in power than the 9-MHz input signal. The single-diode mixer is not recommended for high-performance receivers or transmitters.

An *active* single-ended mixer is shown at B of Fig. 1. Circuits A and B do not cancel the 5.1- or 9-MHz input circuits. Therefore, we will find that energy appearing with the desired 3.9-MHz signal at the mixer output. This requires some filtering at the output of the mixer to ensure a relatively pure 3.9-MHz component for the succeeding RF or IF amplifiers. Circuit B, however, is quite popular with amateurs who build simple equipment. An operating voltage is required for the dual-gate MOSFET (Q1), and this mixer can provide 10 dB or greater gain.

Balanced mixers offer us greater rejection of the two input signals. This reduces the filtering requirements after the mixer. Fig. 1C shows a simple *singly balanced mixer* that uses two JFETs. Considerable cancellation of the 5.1-MHz energy takes place, but there is no appreciable rejection of the 9-MHz signal at the mixer output. The output tuned circuits of all three mixers provide some selectivity, and this aids in rejection of the two unwanted input signals. R1 of Fig. 1C is adjusted for minimum 5.1-MHz energy at the mixer output. It is used as a balance control. C1 and C2 are adjusted for peak output while observing the 3.9-MHz energy at the mixer output. It is essential that the exact electrical center of T1 and T2 (Fig. 1C) be used for the tap points if we are to ensure good balance. This is the reason many hams prefer to use trifilar-wound transformers at T1 and T2: Electrical symmetry is easier to achieve with trifilar transformers. The circuit layout in general, when working with balanced mixers, must also be symmetrical if we are to enhance the balanced condition.

ICs are available for mixer service, and they offer excellent performance in terms of low IMD (intermodulation distortion) and good balance. Fig. 2 illustrates the circuit for a *doubly balanced mixer*. A Motorola MC1496 mixer IC is the heart of this circuit. The internal workings are shown in order to reveal how the transistors are connected to provide the doubly balanced format. Owing to the superb electrical balance of the devices on an IC chip, there is no need for an external balancing control, such as that of Fig. 1C. A doubly balanced mixer cancels *both* of the input signals (9 and 5.1 MHz in this example), which leads to a cleaner mixer-output signal. This feature minimizes our need for elaborate filtering at the mixer output. The MC1496 mixer provides *conversion gain,* as do the active mixers of Fig. 1B and 1C. Numerous mixer ICs are available today,

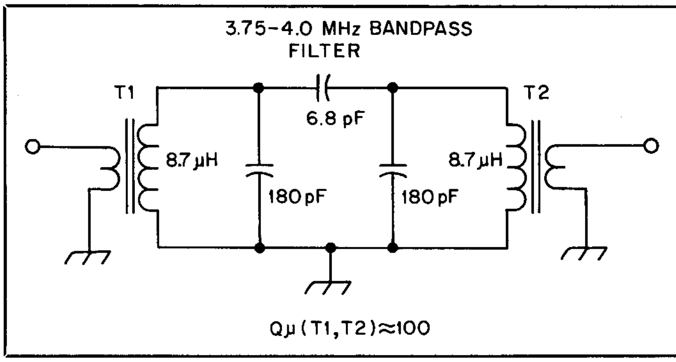

Fig. 3—Typical 5-element band-pass filter used to reduce undesired signals. Approximate values are given for operation from 3.75 to 4.0 MHz.

and the choice of brand and part number is arbitrary.

Post-Mixer Amplification

It is a matter of good design practice to "launder" the mixer-output signal before amplifying it. Generally, a simple band-pass filter will suffice for this duty. Filtering is especially important when the circuits of Fig. 1 are used. When working with receiver mixers, we can rely on the IF crystal filter to do this job. In transmitter circuits it is common practice to employ a filter of the type shown in Fig. 3. Data concerning these filters is given in *The ARRL Handbook*. The mixer filter should have ample bandwidth to cover the spread of the transmitter.

Post-mixer amplification is not casual if we are to preserve the linearity of the signal: Nonlinearity causes distortion. Therefore, we can't use a class-C amplifier for SSB work. Class-C amplifiers are suitable for FM work, however. Class-A or -AB amplifiers are required for SSB amplification. Vacuum-tube class-B amplifiers are also used for SSB circuits. Class-A operation is used for transistor amplifiers at low power levels. The trade-off between class C and class A or AB is *amplifier efficiency*. A 70- or 80-percent efficiency is common for class-C service, whereas 33- to 50-percent efficiency is the usual spread for class-A and -AB amplifiers. Hence if the dc input power to a given amplifier is 2 W, the RF output power will be in a range of 0.66 to 1 W in a typical case. The class of amplifier service is determined by the external bias applied to the active device in the amplifier circuit. A positive bias is used for solid-state amplifiers, as shown in Fig. 4.

Linear amplifiers must be free of self-oscillations. Such oscillations may occur at HF, VHF or UHF, and may even take place in the AF region. The cause of unwanted-signal generation of this type is related to poor layout and feedback from the amplifier output to the input section, or from feedback energy that migrates from other amplifier stages that operate on the same frequency as the unstable amplifier. Therefore, the voltage-supply bus should contain decoupling resistors and capacitors that isolate one stage from another. Short leads in the signal circuits are necessary. Also, the components of the amplifier input and output circuit need to be physically isolated from one another to minimize feedback.

Fig. 4 demonstrates the principles we are discussing in connection with amplifier-instability correction. For example, if VHF or UHF parasitic oscillations occur, we may insert R1 to damp the oscillations. Alternatively, we may add a 900-μ ferrite bead (Z1) near the base terminal of Q2. A bead can be used in place of R1 if we wish. Beads are preferred in circuits in which substantial current is flowing: The bead causes no voltage drop, whereas a resistor (R1) can lower the effective operating voltage of the amplifier. More than one bead (in series) may be necessary to suppress self-oscillation.

C1, C2, C3, C4, R2 and R3 form decoupling networks that prevent RF energy from following the +V line from one amplifier to the other. Without these RC networks the two stages might self-oscillate at or near the 3.9-MHz operating frequency. C4 serves as a bypass capacitor for low frequencies, including the audio region. In some designs, we may find a 1-kΩ resistor (or similar value) bridged across the primary winding of broadband transformer T2. The resistor will help to ensure stability, but it will dissipate some

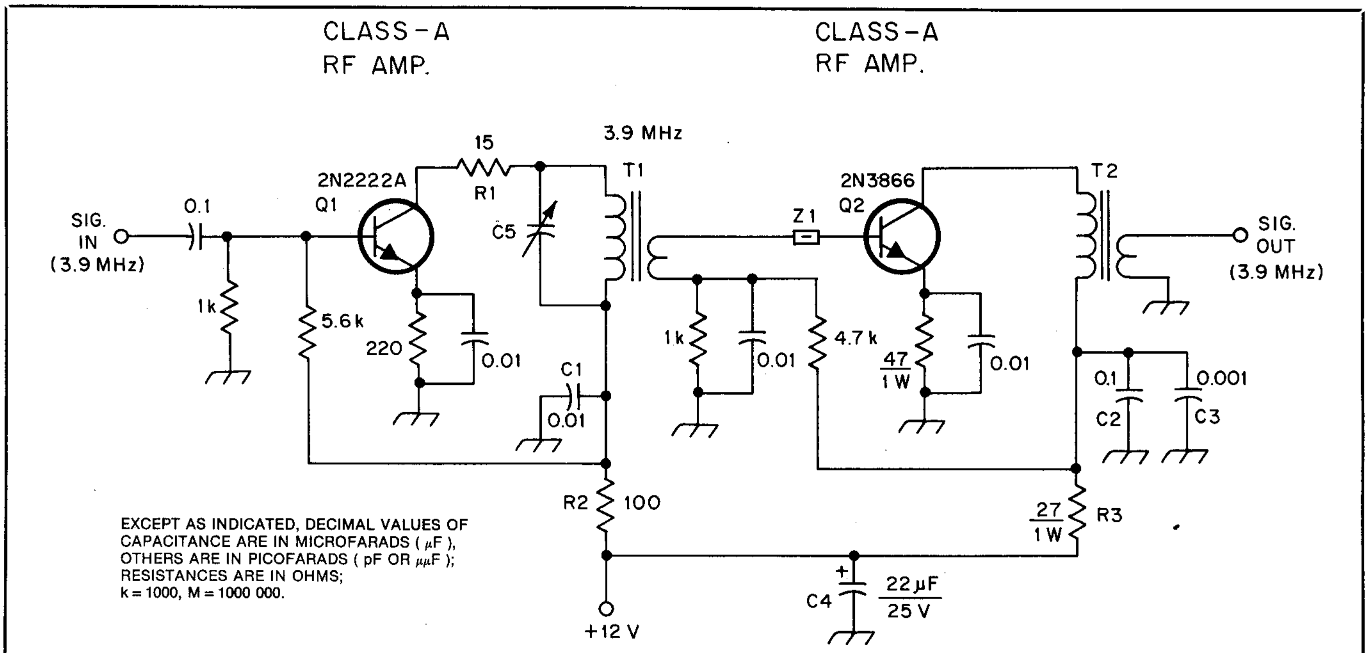

Fig. 4—Two-stage representative IF or RF amplifier for use after a transmitting mixer. See text for pertinent information about this linear-amplifier circuit.

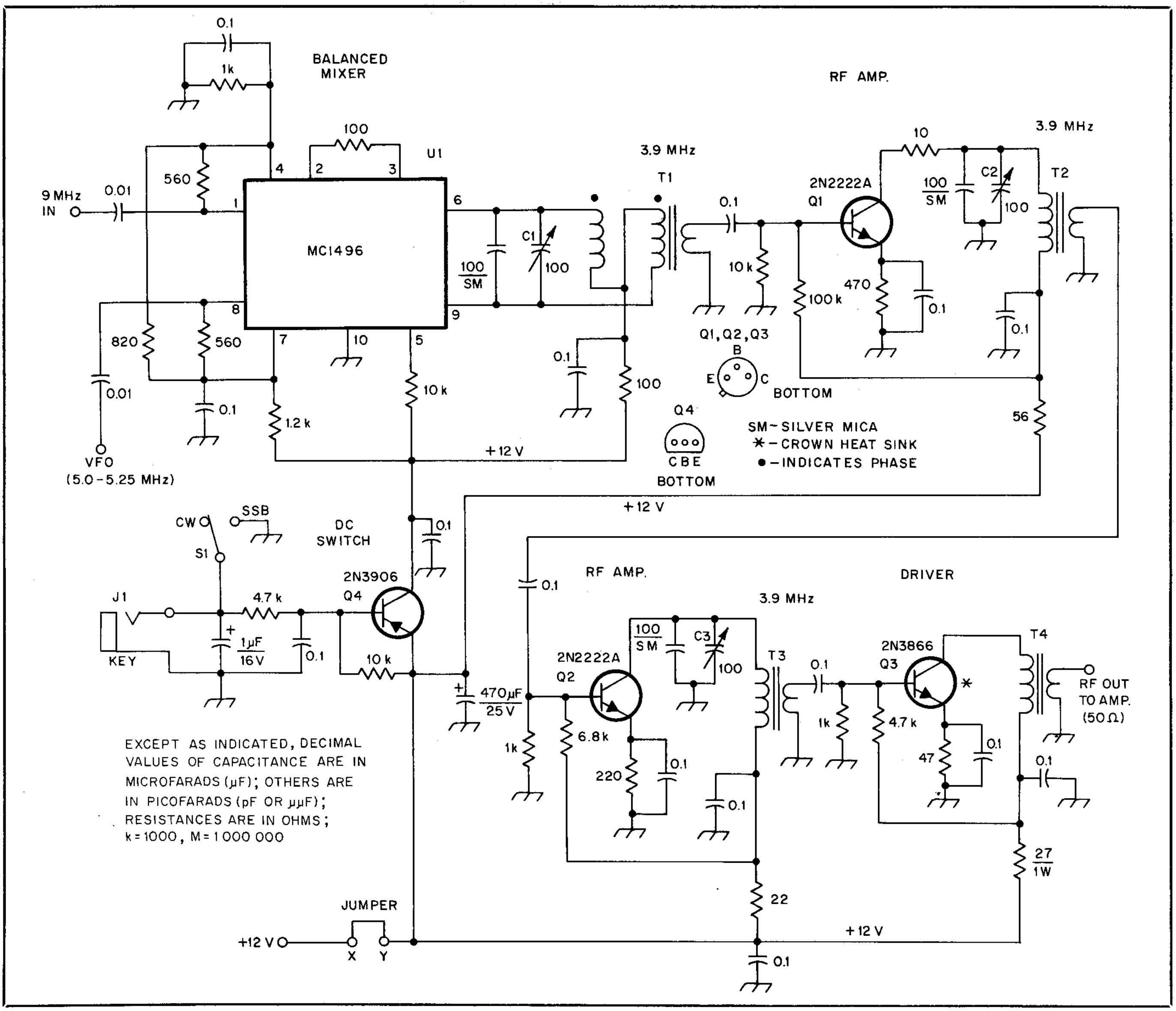

Fig. 5—Practical circuit for a mixer and three RF amplifiers. This circuit is designed for use with the practical circuits given earlier in the series. Fixed-value capacitors are disc ceramic unless otherwise indicated. Polarized capacitors are electrolytic or tantalum. Resistors are ¼- or ½-W carbon composition, except those with wattage notations.

C1, C2, C3—Miniature PC-mount trimmer, 100 pF max. capacitance.
J1—Key jack of builder's choice.
S1—SPDT toggle or slide switch.
T1—11-μH bifilar-wound primary. 13 turns of no. 26 enam. wire, 8 twists per inch (parallel wires) on an Amidon Assoc. FT-50-61 ferrite toroid (μ_i = 125). Secondary is 3 turns of no. 26 enam. wire over primary winding.
T2—11-μH primary, 13 turns of no. 26 enam. wire on FT-50-61 toroid. Secondary has 9 turns of no. 26 enam. wire.
T3—11-μH primary, 13 turns of no. 26 enam. wire on FT-50-61 toroid. Secondary has 4 turns of no. 26 enam. wire.
T4—15 turns of no. 26 enam. wire on an Amidon Assoc. FT-50-43 (950μ_i) ferrite toroid. Secondary has 7 turns of no. 26 enam. wire.

of the available RF power. Q1 and Q2 are biased for class-A operation.

Practical Mixer-Amplifier for 3.9 MHz

The circuit details for this month's module are provided in Fig. 5. U1, the doubly balanced IC mixer, follows the same circuit shown in Fig. 2. To simplify the diagram we have used the block form for the MC1496. A tuned transformer, T1, is used at the mixer output to provide an impedance transformation between U1 and Q1. It serves also as a selective element to help reduce spurious energy.

During CW operation, the mixer is keyed by means of a PNP dc switch, Q4. When S1 is set for the CW mode, the key or keyer shorts the base of Q4 to ground, which causes the transistor to conduct. This allows current to flow to U1. During SSB operation it is necessary to keep Q4 in a saturated state by closing S1.

Q1 operates as a class-A RF amplifier. Another tuned transformer, T2, provides impedance matching and additional selectivity. The next RF amplifier, Q2, operates linearly also, but draws more current than Q1. This yields sufficient power to drive Q3. T3 provides additional selectivity, which ensures Q3 is driven by a relatively clean signal.

Q3 also operates as a class-A linear amplifier, but the output contains a broadband transformer, T4. This adds to the stability of the overall amplifier section, and aids the bandwidth of the SSB generator. C1, C2 and C3 need to be stagger-tuned (peaked at the high, center and low frequencies of the operating range desired). This type of tuning reduces the maximum available output power, as opposed to peaking the three capacitors for

(continued on page 43)

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.

[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."