• *Beginner's Bench*

The Principles and Building of SSB Gear

Part 5: Man does not live by milliwatts alone! So let's learn how to increase our SSB exciter output power through linear amplification. Our project this month is a 10-W broadband amplifier.

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Faithful reproduction of the RF input signal, with minimum distortion, is the name of the game when using a linear amplifier. Of course, the amplifier must increase the signal power while preserving the waveform characteristic. If we are to ensure acceptable linear amplification, we must make certain that the low-power driving signal fed to the amplifier is relatively free of unwanted distortion products (and spurious responses that can originate in the SSB exciter unit). A clean driving signal should be available from the circuits described earlier in the series, so let's concentrate this month on the 10-W amplifier we will add to obtain a necessary boost in signal level.

RF Power Amplifiers in General

Whether we are considering vacuum-tube or solid-state power amplifiers, various linear and nonlinear operating classes are available to us. For example, we may use a class-C amplifier (nonlinear) to boost the power of an FM or CW signal without the need to worry about generating distortion products. Similarly, we may employ a class-C amplifier for AM power amplification, provided the modulation is applied to the last stage (class-C) of the transmitter. On the other hand, if we wish to amplify SSB signals, we must use a linear amplifier (class A, class AB or class B) to minimize unwanted distortion products developed within the amplifier. If we have a low-power AM transmitter and wish to increase the effective output power of the station, we need to use a linear amplifier after the transmitter stage to which modulation is being applied. The class of operation is controlled by the bias voltage we apply to the amplifier tubes or transistors. Linearity is dependent also upon the amount of driving power we supply to the amplifier input. Proper coupling to the load (antenna) is also important to linear operation, along with attention to impedance matching between the amplifier and the load.

The different classes of amplifier operation yield unlike percentages of *efficiency.* Class-C service is the most efficient (80%, approximately), and class-A operation provides roughly 33% efficiency. What is efficiency? It is the ratio of the RF power output to the dc power input to an amplifier, expressed as a percentage. For example, if an amplifier tube operated with a plate voltage of 500, and the plate current at resonance was 150 mA, the dc input power would be 75 W (0.150 A × 500 V = 75 W). Now, if the amplifier were operating efficiently in class-C, we would expect an RF-output power of 60 W (80% efficiency). If the same amplifier were changed to class-A operation (33% efficiency), the output power would drop to approximately 25 W.

The rules of efficiency apply rather well to vacuum-tube amplifiers; but solid state amplifiers, by and large, are designed for broadband rather than narrow-band service, and the efficiencies run pretty much the same for class AB or C service—50 to 60 percent, typically. This is caused in part by the need to include negative feedback (some of the output power is routed back to the input of the amplifier). The feedback voltage helps to ensure uniform power amplification across a wide range of frequencies, such as 3 to 30 MHz. Solid-state amplifiers, unlike their tube-type brothers, develop more gain as the operating frequency is lowered. A given transistor that is rated for 30 MHz may develop incredible gain at, say, 3.5 MHz, and this leads to destructive self-oscillation if careful design and feedback networks are not used. Self-oscillation occurs not only in the low-frequency or high-frequency spectrum, but it often takes place at audio frequencies! I have actually heard the transistors "screeching" when strong audio oscillations were taking place in a homemade transistor power amplifier. On one occasion I could see a bluish glow coming from within the transistors (visible through the ceramic heads of the devices) during a period of instability! Needless to say, the transistors self-destructed.

Class-AB and Class-C Circuit Comparison

A lengthy discussion would be necessary in order to define the various classes of amplifier operation. Biasing and the operating angles for AB and C types of amplifiers are subjects treated quite thoroughly in the ARRL *Handbook,* 1986 edition, pp 5-4 through 5-6. Also see p 3-17.

The mechanism of biasing is shown in schematic-diagram form in Fig 1. Theoretically, no collector current flows in Q1 (drawing A) when driving power is absent. No external bias is applied to the base of the class-C amplifier. If Q1 were a tube, a negative voltage would be required at the grid in order to cause plate-current cutoff for class-C service. But, the transistor of Fig 1A draws only leakage current (microamperes) when the base is returned to dc ground as shown. Collector current flows only when a driving signal is applied to the base. The efficiency can be increased somewhat by biasing the transistor to complete cutoff. The addition of a small-value resistor and bypass capacitor between the emitter and ground is the usual technique used for biasing a class-C transistor amplifier. Placing a resistance or negative bias between the base and ground is dangerous, because it applies a prohibitive potential between the transistor base and emitter, which will lead to internal destruction of the device during peaks in driving voltage.

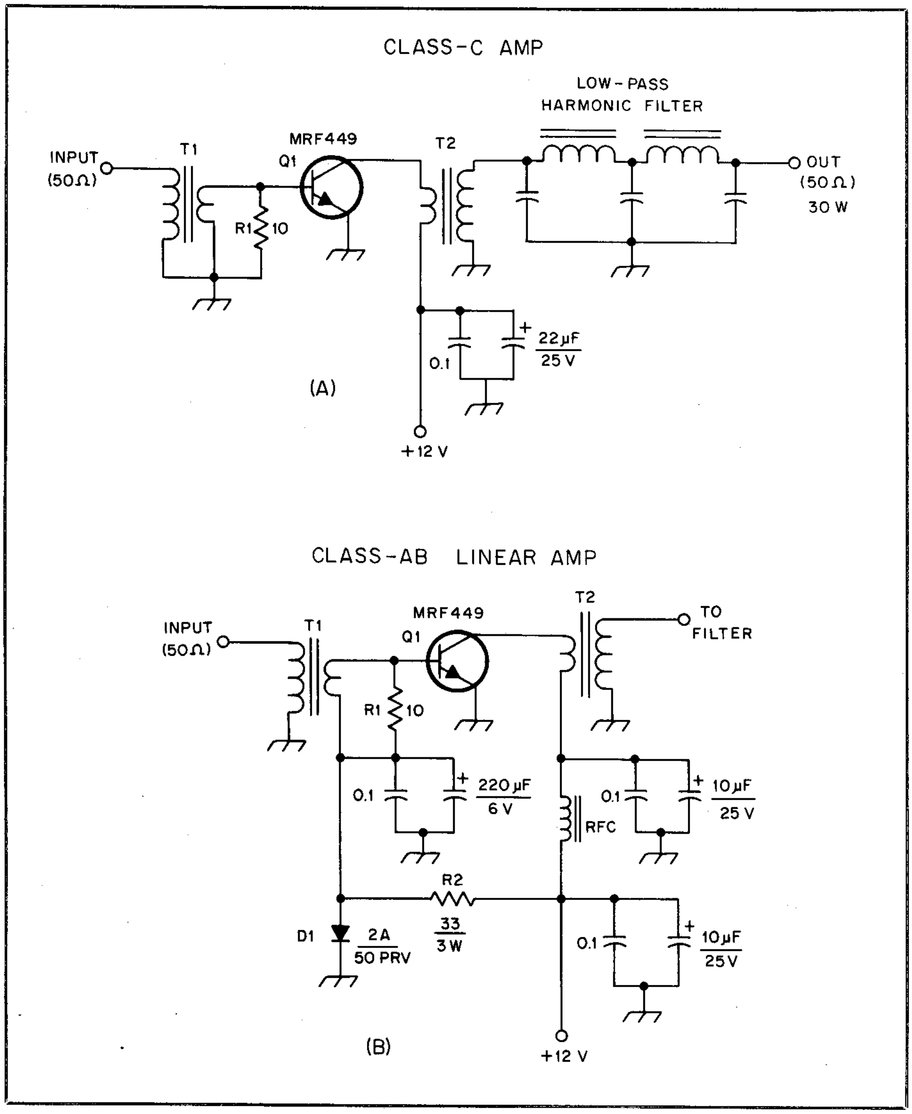

Fig 1—The circuit at A shows how a transistor RF amplifier is biased for class-C operation. T1 and T2 are broadband matching transformers. Circuit B demonstrates the linear-amplification concept. A positive bias voltage of approximately 0.7 is supplied to the base of Q1 to establish class-AB operation. D1 provides the required bias voltage (see text).

The 10-ohm resistor (R1) across the T1 secondary winding does not create a bias voltage when the stage is driven. The dc resistance of the transformer winding is a fraction of an ohm, which negates the effect of the resistor. R1 serves as a load resistor that lowers the Q of the T1 secondary winding. This helps prevent self-oscillation while creating a more constant load for the exciter that connects to T1.

A class-AB amplifier is shown in Fig 1B. The circuit is nearly identical to that of Fig 1A except for the addition of positive bias on the base of Q1. R1 is retained as a load resistor, but the bottom lead of the T1 secondary winding is lifted from ground to permit a positive voltage to reach the transistor base. This voltage causes a steady flow of standing or quiescent collector current when no excitation signal is present. The current increases when drive is applied.

D1 is a silicon diode. Therefore, the barrier voltage is roughly 0.7, which is the effective bias that is applied to Q1. The bias results from the voltage drop across the diode junction. R2 acts as a current-limiting resistor to protect the diode. An RF choke and two additional capacitors have been added to the collector circuit of Fig 1B. These serve as a decoupling network between the collector and base of Q1. This prevents RF output energy from flowing along the +12-V line to the base of Q1. Self-oscillation might result if this precaution were not taken.

Both amplifiers in Fig 1 are single-ended types. In practice, most solid-state RF power amplifiers are push-pull units. Push-pull operation offers the advantage of improved harmonic reduction (cancellation) at the even harmonics (2nd, 4th, and so on). This is particularly important when using solid-state amplifiers, which have substantially more harmonic currents present in the output than is normal for vacuum tubes. In a typical solid-state RF amplifier the 2nd and 3rd harmonics might be only 10 or 12 dB below the peak level of the desired signal power. Therefore, without proper harmonic filtering, a 100-W amplifier might produce 10-W harmonics that could be heard worldwide, depending on the antenna being used!

Pros and Cons of Tubes and Transistors

Tubes withstand output-load mismatches much better than transistors do in a severe case. When a high SWR exists between the transistor amplifier and the load, collector-to-emitter RF voltage can soar to prohibitive levels. This excessive peak voltage may exceed the safe ratings of the transistor, thereby causing immediate destruction of the device. Tubes are more tolerant of high peak voltages.

Heat is the enemy of tubes or transistors. We must be sure to provide ample heat sinking for our transistors. This is done by thermally coupling the transistor body to a large metal surface or heat sink. The heat sink absorbs much of the transistor heat and helps to keep the transistor junction temperature within safe boundaries. My rule of thumb for cooling transistors is to apply normal rated power for one minute, then turn off the amplifier and drive. If the heat sink is just warm to the touch, all is well. If holding my finger on the heat sink causes discomfort, I switch to a larger sink. This method has always worked for me, however unscientific it may be.

A notable advantage of a broadband transistor amplifier is that fixed-tuned filters and broadband matching transformers can be used in the output circuit. This eliminates the need to dip and load (tune) the output tank when changing operating bands or frequencies. Contesters, DXers and handicapped operators find this feature especially attractive.

Amplifier Distortion

Earlier, I referred to linear amplifier intermodulation distortion (IMD). This form of distortion takes place when an amplifier is fed more than one input frequency (tone). The tones combine to produce additional amplifier output signals that are not present at the input of the amplifier. These are unwanted signals. The human voice contains many varying-frequency bursts that can generate amplifier IMD products. They cannot be eliminated, but good design and proper operating procedures can limit the power of these responses. Fig 2 shows a spectral display of the output of a linear amplifier that is driven by a two-tone signal. The two high peaks at the center are the desired output responses. Left and right of these peaks we can see IMD-product responses (3rd-, 5th- and 7th-order IMD products). The first responses (3rd order) are over 30 dB below peak power, which is considered accept-

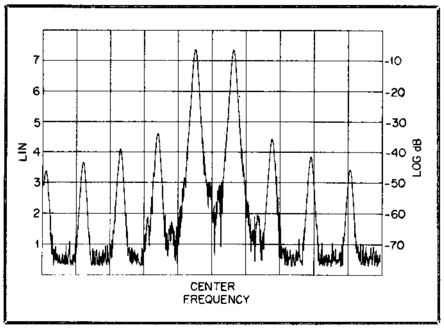

Fig 2—Spectrum-analyzer display of a two-tone SSB signal. It shows the IMD products caused by the two tones. Each horizontal division is equal to 1 kHz, and each vertical division represents 10 dB. See text for a discussion of the IMD phenomenon.

able. The 5th- and 7th-order products are somewhat lower in amplitude. If the IMD products are too great in magnitude, our signals will be excessively broad and will cause interference to others who share the amateur bands with us. The usual cause of excessive IMD in commercial amateur gear is the operator. That is, he or she may turn up the audio gain too high, shout into the mic, and grossly overdrive the linear amplifier.

A Practical Linear Amplifier

Fig 3 contains a schematic diagram of this month's workshop project. Circuit boards and parts kits for this amplifier are available from A & A Engineering.[1]

The circuit shows a pair of Motorola MRF475s in a push-pull arrangement. Broadband transformers (T1 and T2) provide a match to 50 ohms at each end of the amplifier. C1, across the primary of T1, tunes out unwanted reactance of the primary winding. This helps ensure a low SWR if the amplifier is used at frequencies in the 14- to 29-MHz range: This circuit is suitable for operation from 1.8 through 30 MHz when the appropriate filter is used at FL1. Suitable filter constants and parts values are available in the transmitting chapter of the ARRL *Handbook*.

C2, C3, R1 and R4 of Fig 3 are used as gain-leveling components. As the operating frequency is lowered, these components pass smaller amounts of the driving signal, thereby compensating for the increased transistor gain versus frequency mentioned earlier. Without this network we would have to reduce the driver output as the operating frequency was lowered. With the network in place, the exciter can operate at the same power-output level from 160 through 10 meters, should you choose to incorporate this circuit in an all-band rig.

Bias for class-AB service is developed by means of D1, as discussed with relation to Fig 1B. The efficiency of this amplifier is between 50 and 60 percent.

Negative feedback is provided by the inclusion of R6, Z1 and Z2. As the operating frequency is lowered, the feedback network allows more and more output energy to be fed back to the input circuit. This provides a gain-controlling action. R6 is located on the FL1 side of T2, and the hookup-wire leads from R6 are passed through the core of T2 (to the Q1, Q2 side of T2), where ferrite beads Z1 and Z2 are located. The wires continue along the PC board to the base pads for Q1 and Q2. The wires that pass through the T2 core pick up some of the output energy of the amplifier. Z1 and Z2 offer less and less resistance to the flow of RF current as the operating frequency is lowered. Therefore, we actually have two mechanisms for gain control versus fre-

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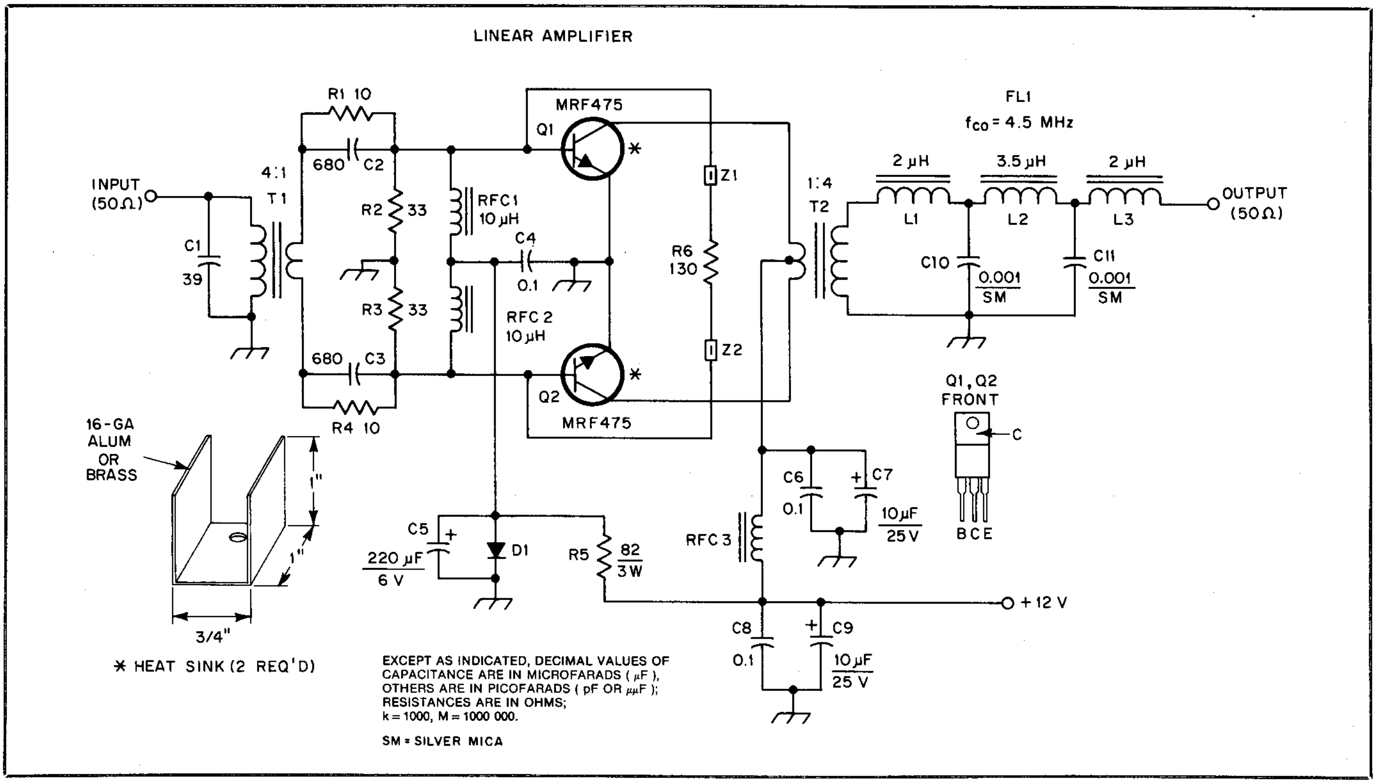
[1] Notes appear on page 32.



EXCEPT AS INDICATED, DECIMAL VALUES OF CAPACITANCE ARE IN MICROFARADS (µF), OTHERS ARE IN PICOFARADS (pF OR µµF); RESISTANCES ARE IN OHMS; k = 1000, M = 1000 000.

SM = SILVER MICA

Fig 3—Schematic diagram of a 10-W linear amplifier. Capacitors are disc ceramic unless otherwise noted. Polarized capacitors are electrolytic or tantalum. Resistors are ½-W carbon composition except for R5, which is a 3-W unit.

D1—2-A, 50-PIV silicon rectifier diode.

L1, L3—20 turns of no 22 enam wire on an Amidon T50-2 toroid core.

L2—26 turns of no 24 enam wire on an Amidon T50-2 toroid core.

Q1, Q2—Motorola power transistor. Avail. from MHz Electronics, 2111 W Camelback Rd, Phoenix, AZ 85015. Also see note 2 for imported equivalent.

RFC1, RFC2—Miniature 10-µH RF choke (Mouser Electronics or equiv).

RFC3—5 turns of no 22 enam wire on an Amidon FT50-43 toroid.

T1—Two rows of three each Amidon FT37-43 toroids. Glue toroids together to form two sleeves, then glue sleeves together side by side to form balun core. Epoxy cement recommended. Primary has 4 turns of no 24 enam wire. Secondary consists of 2 turns of small insulated hookup wire.

T2—Amidon large balun core, no 43 material (ferrite, 900 μ_i). Primary has one turn of no 22 hookup wire. Secondary has two turns of hookup wire. Feedback-loop hookup wire is passed through core (see text).

Z1, Z2—Jumbo Amidon ferrite bead, no 43 ferrite material (see text).

quency (feedback and input-leveling networks). This general scheme was borrowed from Motorola application notes.

T2 serves as a matching transformer to interface the 29-ohm collector-to-collector impedance to the 50-ohm harmonic filter. We may calculate the collector impedance of a single transistor by means of $Z = V_{ce}/2P_o$. Thus, if a transistor provided 5 watts of power output and the collector-to-emitter voltage was 12, the equation would become 144/10 = 14.4 ohms.

FL1 is a low-pass filter designed for a cutoff frequency slightly above the highest desired operating frequency (4.5 MHz in this case). Our filter ensures that all harmonic responses are at least 40 dB below peak desired output power. RFC3 and the related bypass capacitors act as a decoupling network for the +12 V supply line, as discussed earlier. C5 charges to help regulate the 0.7-V forward bias for Q1 and Q2. C7 and C9 function as bypass capacitors for VLF and audio frequencies. This minimizes the occasion for low-frequency self-oscillation. C6 and C8 act as bypass capacitors for the RF frequencies between 1.8 and 30 MHz. C4 serves in the same manner.

The driving power required to provide 10 W of amplifier output power is between 1 and 2 W. Less power would be needed if T1 did not have some losses, and if the RC leveling network were not present.

Construction Notes

When designing your own PC boards, be sure to keep the layout in a straight line to reduce unwanted coupling between the input and output parts of the circuit. Also, keep all PC-board foils large and direct. It is vital to minimize unwanted stray inductances in the low-impedance sections of the amplifier circuit. Wide, short foils reduce the inductance of the circuit-board elements.

The PC board used should be copper clad on both sides. The foil on the unused side of the board is included as a ground plane to help stability. It should be made common to the ground foils on the etched side of the board at several points. This can be done by passing short pieces of bus wire through the board, then soldering them in place on both sides of the PC board.

The metal tab of the MRF475 transistors is common to the collector. The homemade heat sinks are mounted on isolated PC pads to prevent short circuiting the +12-V line. The copper around the heat-sink mounting-screw holes (on the ground-plane side of the board) is etched away to prevent the screw heads from contacting the ground plane. Heat-sink compound (silicone grease) is used between the transistor bodies and the heat sinks. The Q1 and Q2 collector leads are snipped off, since the tabs serve as the circuit connection in this design.

You may substitute similar TO-220 transistors for the MRF475s. The devices specified were earmarked for CB use and carry specifications for 27 MHz. Any bipolar transistor with similar ratings should be suitable.[2] V_{ce} should be 24 V or greater, P_d at 10 W and the gain should be 10 to 13 dB at 30 MHz.

In Closing

Space was available here for the bare essentials of amplifier design and operation. I hope you will garner an up-to-date copy of the *ARRL Handbook* and dig deeper into the matter of linear amplifiers. Although the circuit in Fig 3 produces only 10 W of output power, you should be pleased with the contacts you will make on 75 meters—especially during the daylight hours when the band is not heavy with QRM.

Notes

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

[2] Two power transistors for $6, available from State Street Sales, PO Box 249, Luther, MI 49656.