A Legal-Limit Amplifier for 160 through 10 Meters

The amplifier described here is an update of the 1500-W output legal-limit amplifier described in the 1985 and 1986 *ARRL Handbooks*. It uses the EIMAC 8877 (3CX1500A7) high-mu triode in grounded-grid service. The 8877 will easily deliver 1500-W RF output with the drive levels afforded by most 100-W-class transceivers. Operating at 1500-W output, tube dissipation is well within the manufacturer's specification.

Shown in Figs. 58 through 68, this amplifier covers 160 through 10 meters, not including the WARC bands. Operation on the 24-MHz WARC band is possible with the band switch in the 28-MHz position, but the input SWR will be a little higher than on the other bands. Many of the components used were purchased at flea markets and from mail-order dealers. The names and addresses of the parts suppliers are detailed at the end of Chapter 35. Amplifier parts are expensive. The builder is encouraged to substitute components from surplus dealers or flea markets where possible if cost is a problem. Be sure, however, to use only components with adequate ratings. The dc and RF power levels found in this project are capable of destroying parts with insufficient ratings.

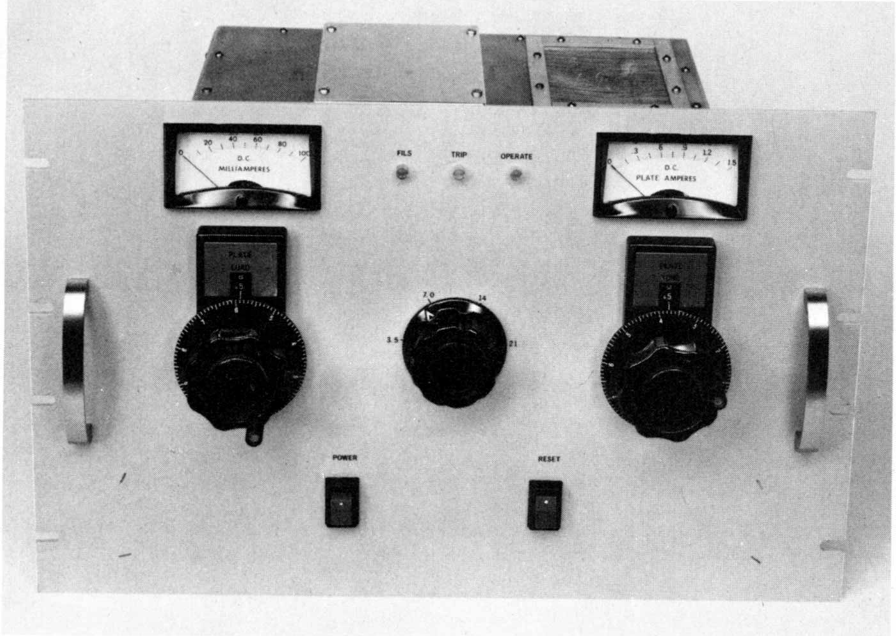


Fig. 58 — The 8877 HF amplifier uses a standard rack-type front panel. The tuning and loading capacitors are controlled by venier drives with turns counters. Once the settings for each band are determined, they can be recorded for quick band changes.

Dick Stevens, W1QWJ, designed and built this project. The power supply and RF deck are built on separate chassis because of the size and weight of the power supply. Standard 19-inch rack panels are used for the front panels, so both pieces may be rack mounted if desired.

Power Supply

The high-voltage power supply delivers 1 A continuously at user-selectable voltages of 2.5, 3 or 3.5 kV. During normal operation, only the 3-kV position is used, but a lower level is available for tuneup, and a higher level is available if line sag is a problem. Circuits are provided for protection, automatic start and PTT line control. Fig. 59 is the power-supply schematic diagram, and the unit is pictured in Figs. 60 and 61.

Circuit Details

The secondary side of the power supply is conventional. T1 is a Hipersil transformer with a 234-V primary and secondary taps at 1770, 2125 and 2475 V. S3 is a high-voltage switch with large contacts and ceramic insulation used to select among the taps. The 234-V primary and full-value secondary contribute to good voltage regulation. D2 through D5 are 14-kV, 1-A rectifiers connected in a full-wave bridge. C2 is a surplus 53-μF, 3.5-kV oil-filled capacitor. If the builder cannot locate one of these units, a suitable replacement should be at least 25 μF at a similar voltage rating. R4, the 200-kΩ bleeder resistor, is made up of eight 25-kΩ, 25-W units connected in series.

A high-voltage meter (M1) is included in the supply. The value of R_M, the multiplier resistor, will depend on the value of the basic meter movement. See Chapter 25 for information on meter multipliers and shunts. The B− lead floats above chassis ground. R3 is included to keep the B− near ground potential. The floating B− allows plate current to be metered in the negative lead for safety. C4 and C5 are bypass capacitors.

Power enters the supply from the 234-V line through a 20-A, 2-pole circuit breaker. DS1 will light when the circuit breaker is closed. With S1 in AUTOMATIC and S2 in START, a 24-V signal at J4 from the amplifier control circuitry will energize K1. K1A closes, energizing K2. DS2 lights. K2A and K2B apply reduced primary voltage to T1 through R2. After a second or so, C1 charges and energizes K3. K3A closes, shorting across R2, to apply full primary voltage to T1. This circuit protects D2-D5 from damage by effectively limiting inrush current through the rectifiers while C2 charges. R1 adjusts the charging time for C1. DS3 lights, signaling that the power supply is ready for service. An additional protective feature is that K1B is in the exciter PTT line to prevent keying the amplifier without high voltage present. Note that the supply can be activated manually (not by the amplifier control circuit) by placing S1 in the OFF position and using S2 to turn the supply on and off. PTT line protection is lost in the manual mode, however.

J1 is a grounded, polarized 117-V ac receptacle used to provide power to the RF deck. Correct 117-V ac wiring must be used here. The ground (green) wire is connected to the chassis ground. The neutral (white) wire is connected to the 234-V line neutral. The hot side (black) is connected to one side of the 234-V line. Likewise, standard wiring must be used in the RF deck.

J1 and J2 are Millen connectors rated at 7 kV. Test prod wire (5-kV insulation) is used for the B+ and B− runs to the RF deck. A braid ground strap bonds the power supply and RF deck chassis together for added protection.

Construction

The power supply is built behind a standard 12½-inch-high, 19-inch-wide rack panel. It is designed to fit inside a Bud Prestige series cabinet. T1 needs a good base to support the weight, so the bottom plate is made from a piece of ¼-inch-thick aluminum plate that is approximately 14 inches square. The size and shape of the power supply enclosure will depend on the actual components used. Be sure that it is sturdy, and allow sufficient room for air to circulate.

T1 and C2 are bolted to the bottom plate. The rectifiers, control relays and other parts mount on a shelf above C2. The eight 25-W resistors that make up the bleeder are mounted to two vertical strips of phenolic stock.

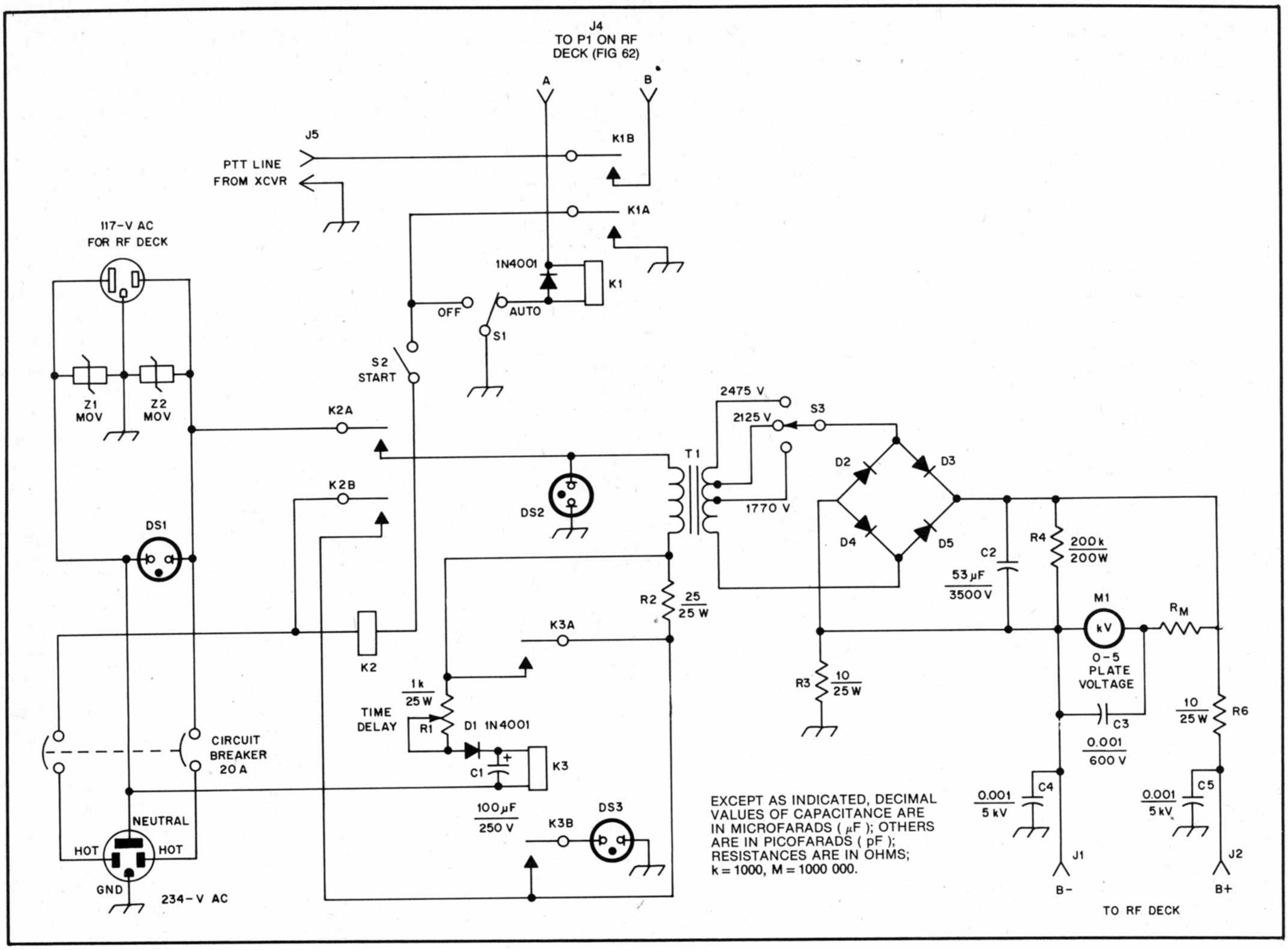


Fig. 59 — Schematic diagram of the high-voltage power supply. Capacitors are disc ceramic unless noted. Possible parts sources are listed in parentheses. See Chapter 35 for the addresses of the parts suppliers.

C2 — Oil-filled capacitor, 53 µF, 3.5 kV (Electronic Emporium cat. no. 4W308T or equiv.).
D2-D5 — Rectifier, 14 kV, 1 A (K2AW's Silicon Alley HV-14 or equiv.).
DS1-DS5 — Neon pilot lamp, 120 V, with built-in dropping resistor (Radio Shack).
J1, J2 — High-voltage connector (Millen 37001 or equiv.).
J3 — Chassis-mount three-wire 117-V ac socket.
J4 — Two-conductor Jones socket.
J5 — Chassis-mount phono jack.
K1 — 4PDT relay, 24-V dc coil, 2-A contacts. (Potter & Brumfield KH4703-1 or equiv.).
K2, K3 — DPST relay, 120-V ac coil, 20-A contacts. (Potter & Brumfield PRD7AYO or equiv.).
M1 — 0 to 50 µA meter with suitable multiplier resistor (R_M). See text.
R_M — Meter multiplier resistor. Exact value will depend on meter movement used. See text and Chapter 35 for information on meter multipliers.
R1 — Adjustable resistor, slider type, 1-kΩ, 25 W.
R4 — 200-kΩ, 200-W bleeder made from eight 25-kΩ, 25-W resistors in series (see text).
S1 — SPDT switch, 117-V, 3-A contacts.
S2 — SPST switch, 117-V, 3-A contacts.
S3 — High-voltage switch (see text).
T1 — Power transformer; 234-V primary, secondary taps at 1770, 2125 and 2575 V (Peter W. Dahl Co. no. PT-2475 or equiv.).
Z1, Z2 — 130-V metal-oxide varistor (Radio Shack).

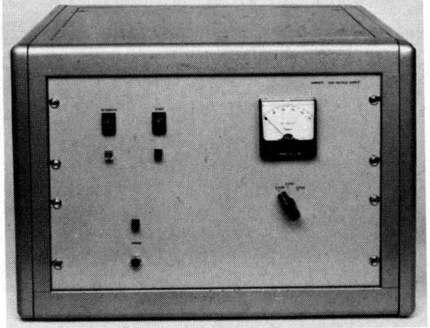


Fig. 60 — Front panel view of the 8877 amplifier high-voltage supply. It is built on a 12½-inch high rack panel and mounted in a Bud Prestige cabinet. Output voltages of 2.5, 3 and 3.5 kV are switch-selectable from the front panel.

RF Deck

The RF deck houses the 8877 and associated RF circuitry as well as the amplifier-control circuit board. This amplifier uses a tuned input circuit and a pi-L output circuit. The filament transformer (T1) and antenna relay (K6) are built in. Cooling is provided by blower B1. Fig. 62 is a schematic diagram of the control circuitry, and Fig. 63 shows the RF circuitry.

Control Circuits and Metering

The control circuits are somewhat involved and are designed to protect the expensive 8877 tube from excessive fila-

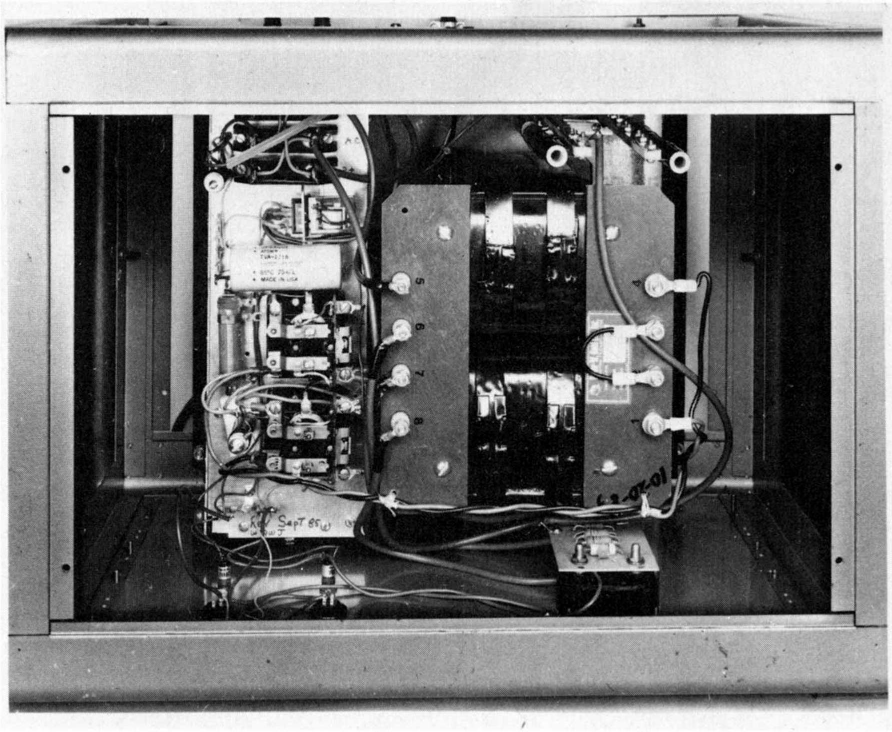


Fig. 61 — Interior of the high-voltage power supply cabinet.

ment inrush current, excessive grid current, and application of drive in the absence of plate voltage. A three-minute delay circuit prevents keying the amplifier until the tube gets up to operating temperature, and another time-delay circuit keeps the blower running for a short while after power is removed.

When S1 of Fig. 62 (POWER) is closed, several things happen. First, 117-V ac is applied through R2 to the primary of filament transformer T1. R2 limits inrush current and is in the line until C2 charges, energizing K2. K2A shorts across R2, applying full primary voltage to T1. K2B lights the FILS LED. Note that T1 has several primary taps to allow adjustment of the filament voltage (measured at the socket) to 5.0 V, ±0.25 V, as specified by the tube manufacturer. At the same time filament power is applied, blower B1 starts and time-delay relay K1 starts to heat. K1A does nothing at this time. When power is turned off, however, K1A will stay closed for several minutes to run the blower and cool the tube after filament voltage is removed. K1 does not control the blower directly, but rather does so through K8, a relay with contacts heavy enough to handle the current needed by the blower motor.

S1 also starts K3, a three-minute time-delay relay. When K3 energizes, the OPERATE LED lights. Finally, S1 applies primary voltage to T2 of the 24-V dc control-relay supply. When S2, RESET, is closed, 24 V is applied to various points in the control circuit. A 24-V signal is sent through relay contacts K4B and K3A to energize K1 in the high-voltage power supply. K3A also allows 24 V to reach K5, the PTT relay, so that the amplifier may be keyed from the PTT line. Note that since K3A is in the line to the HV-supply control relay and the PTT relay, the HV supply cannot be turned on and the PTT line cannot be keyed until after the three-minute warmup period.

The transceiver PTT control connects to the HV power supply, and K1B in the power supply activates K5 in the RF deck to prevent keying the amplifier in the absence of B+. K5A applies operating bias to the 8877, and K5B operates the antenna TR relays (K6, K7). K6 has a slight time delay, provided by C5. This feature assures that K7 will close before K6 to prevent hot switching.

Protection from excessive grid current is provided by Q1 and associated components. When the grid current exceeds a certain amount (set to approximately 70 mA by R5), Q1 fires and operates K4. K4C lights the TRIP LED. K4B opens, shutting off the HV supply and opening the PTT circuitry to protect the tube. To reset the amplifier, switch S2 off and then on again and everything will restart automatically. S2 can also be used to place the amplifier in standby if operation with the transceiver only is desired.

M1 and M2 of Fig. 63 monitor grid current and plate current. Plate current is monitored in the B− lead, rather than in the B+ lead, for safety. A pair of back-to-back diodes and 0.01-μF capacitors protect the meters from transients and RF voltages.

Input Circuitry

The RF input appears at J1 of Fig. 63. If the amplifier is turned off or bypassed by S2 of the control circuit, the input signal is routed directly to the output connector, J2. When the amplifier is in operation, the input signal goes to the tuned input circuitry and then to the 8877 cathode. Although the 8877 input impedance is close to 50 ohms and RF drive could be connected directly to the 8877 cathode, the tuned input is used for improved linearity and lower drive requirements.

There is a separate pi network (C1, L1, C2) for each band. S1 selects the appropriate network for the band in use. The input networks were designed with a Q of approximately 2 to be broadly resonant on each band. For clarity, only one pi network is shown in Fig. 63. Table 1 presents the complete input network data.

The coil (L1) for each band is wound on a 3/8-inch slug-tuned form. The slugs were purchased from a surplus dealer, but any 3/8-inch slug-tuned form with a red core should work. Table 1 gives both calculated capacitor values and the real-world values used in this amplifier.

Output Circuitry

B+ enters the RF deck through J3 and is routed through RFC2 and RFC3. The B+ line is bypassed by C8 and C9. C7 is a dc blocking capacitor that keeps dc voltages out of the tank circuit and off the feed

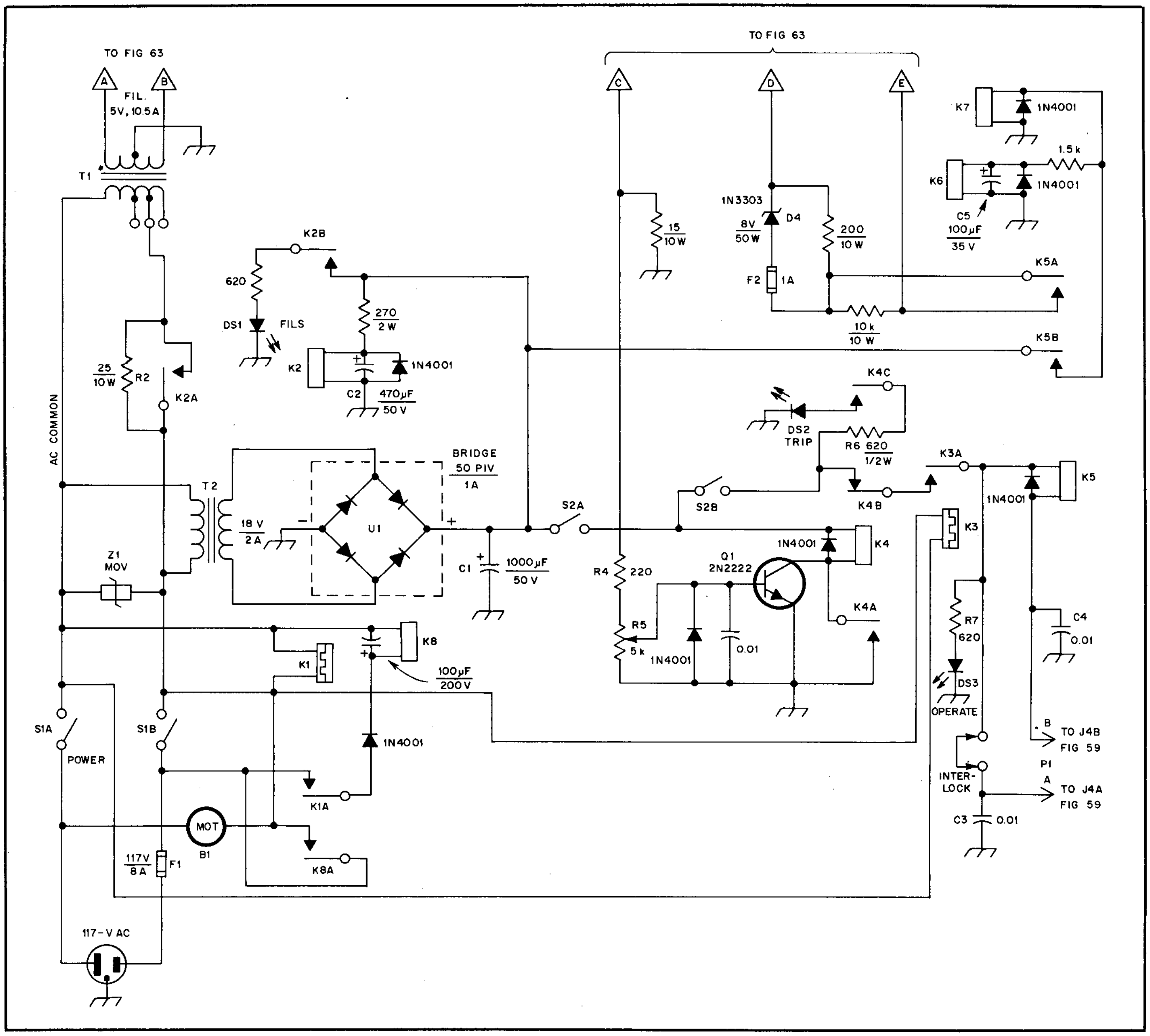


Fig. 62 — Schematic diagram of the 8877 amplifier control circuitry. Resistors are ¼-W types unless noted. Capacitors are disc-ceramic types unless noted. Capacitors marked with polarity are electrolytic. See Chapter 35 for the addresses of the parts suppliers.

B1—Blower, 54 CFM (Dayton 4C012A or equiv.).
DS1-DS3—LED.
D4—Stud-mount Zener diode, 8 V, 50 W (1N3303 or equiv.).
K1—Time-delay relay with a 2-3 minute delay on release, 115-V ac coil (Amperite 115NO69 or equiv.).
K2—DPDT relay, 12-V dc coil with 120-V, 10-A contacts (Radio Shack).
K3—Time-delay relay with a 3-minute delay on operate, 115-V ac coil (Amperite 115NO180 or equiv.).
K4, K5—4PDT relay, 24-V dc coil with 2-A contacts (Potter & Brumfield KH4703-1 or equiv.).
K6, K7—Dow Key Model 60 coaxial antenna relays with 24-V dc coils.
K8—DPDT relay, 120-V ac coil with 125-V ac, 10-A contacts (Radio Shack).
T1—Filament transformer. Primary: 120-V with taps for ±4% and ±8%; secondary: 5 V, 10.5 A (Avatar Magnetics AV-454 or equiv.).
P1—Two-conductor Jones plug to match J4 in the HV power supply (Fig. 59).
T2—Power transformer. Primary: 117-V; secondary: 18 V, 2 A.
U1—Bridge rectifier module, 50 PIV, 1 A (Radio Shack).
Z1—130-V metal-oxide varistor (Radio Shack).

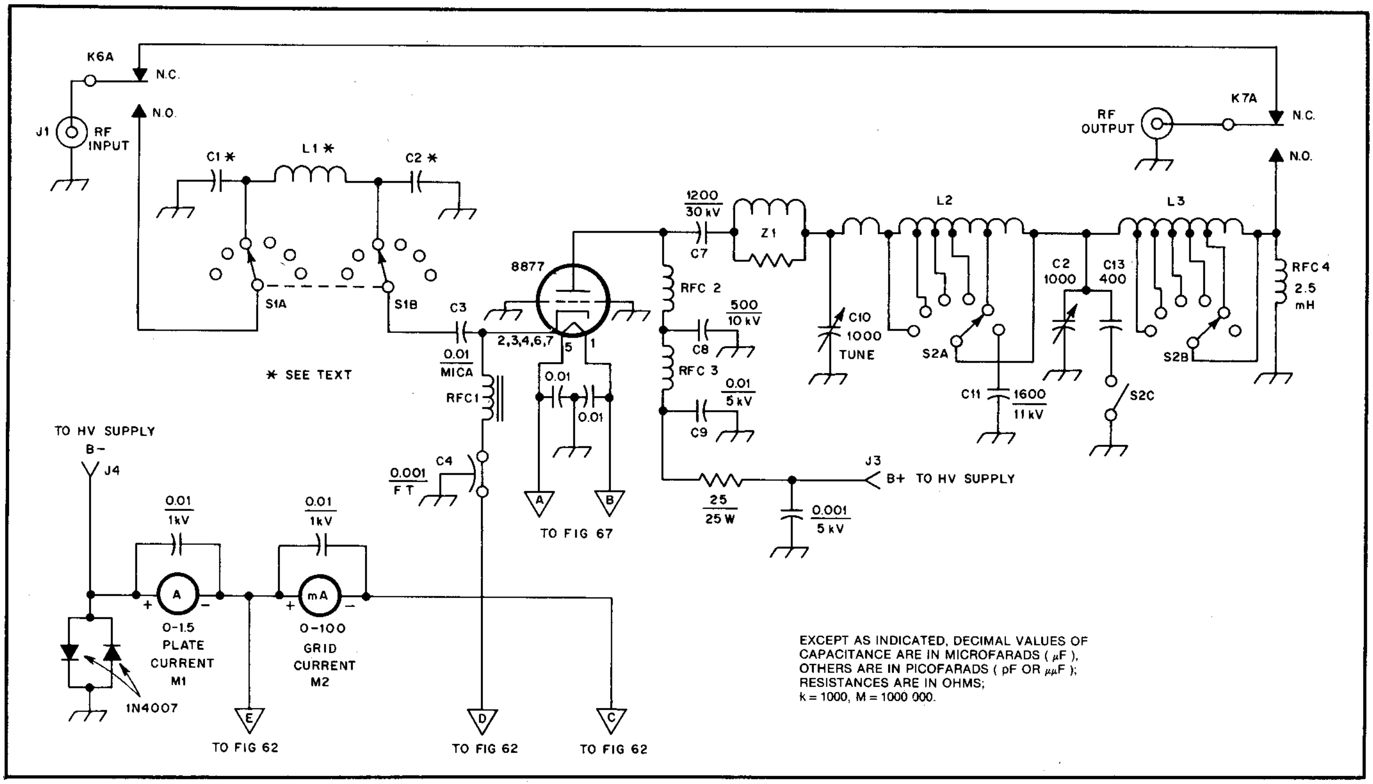


Fig. 63 — Schematic diagram of the 8877 amplifier RF deck. Resistors are ¼-W types unless noted. Capacitors are disc-ceramic types unless noted. Capacitors marked with polarity are electrolytic. See Chapter 35 for the addresses of the parts suppliers.

C1, C2—See Table 1.
C7—1200-pF, 30-kV RF-type doorknob capacitor (Electronic Emporium).
C10—1000-pF, 5-kV vacuum variable capacitor (Jennings UCSL 1000-5 or equiv.).
C11—Two 800-pF, 5-kV doorknob capacitors in parallel.
C12—1000-pF, 1.5-kV air variable (Cardwell 154-30 or equiv., avail. from RadioKit).
C13—400-pF, 5-kV doorknob capacitor.
J1, J2—Female UHF connector (in this case, part of K6 and K7).
J3, J4—High-voltage connector (Millen 37001 or equiv.).
K6, K7—See Fig. 62.
L1—See Table 1.
L2, L3—See Fig. 64.
RFC1—50 μH; 39T no. 24 enam. wire close wound on a ¼- inch powdered iron core.
RFC2—No. 24 enam. close wound on a 1-inch Teflon form. The form is 5 inches long; the winding is 4 inches long. Measured inductance is 195 μH.
RFC3—8.2 μH (Ohmite Z50 or equiv.).
RFC4—2.5 mH (Millen 4537 or equiv.).
S1—Single wafer, 2-pole, 6-position ceramic rotary switch with indexing to match S2.
S2—Six position, two section, high-power ceramic RF switch with non-shorting contacts and 60-degree indexing (Model 86, avail. from Radio Switch Corp., Rt. 79, Marlboro, NJ 07746). Section S2C is a homemade addition. See Fig. 68.
Z1—Parasitic suppressor. Made from 2T of ½-inch wide copper strap, ½-inch ID. Shunt the strap with two 100-Ω, 2-W carbon-composition resistors in parallel.

Table 1
Input Coil Data

Band	*L1 (μH) (Calculated)*	*L1 Winding Information*†	*C14, C15 (pF) (Calculated)*	*C14, C15 (pF) (Values Used)*
160	4.2	27T no. 24	1640	1120 + 560 = 1680
80	2.07	16T no. 22	820	820
40	1.18	9T no. 20	430	210 + 210 = 420
20	0.59	7T no. 20	220	210
15	0.39	5T no. 20	150	150
10	0.30	4T no. 20	100	100

†All coils wound on 3/8-in-diameter form; slug-tuned with red core. Available from Electronic Emporium, part number PLS5-B-2.

line and antenna. Should C22 short, placing dangerous voltage on the output connector, RFC4 will short the B+ line to ground and blow the power-supply circuit breaker.

This amplifier uses a pi-L tank circuit for better suppression of harmonic energy. To get a better Q and improved efficiency on 10 and 160 meters, a 1000-pF vacuum-variable capacitor was chosen for C10 (TUNE). C12 (LOAD), a 1000-pF air variable, does not have enough capacitance for operation on 160 and 80 meters. A spare contact on S2A switches C11 into the circuit for 160-meter operation, while S2C switches C13 into the circuit for 80-meter operation.

L2 is made from a section of ¼-inch copper tubing for 10 meters and a section of B&W Pi Dux stock for the other bands. The L coil, L3, is also made from a small section of Pi Dux stock. S2 switches the taps for use on the various bands. Fig. 64 is a detailed diagram of the tank coil connections.

Construction

The completed RF deck is shown in Figs. 65 and 66. The main support for the components is a standard 4- × 17- × 10-inch (HWD) chassis (Bud AC-427). Like the power supply, the chassis is mounted

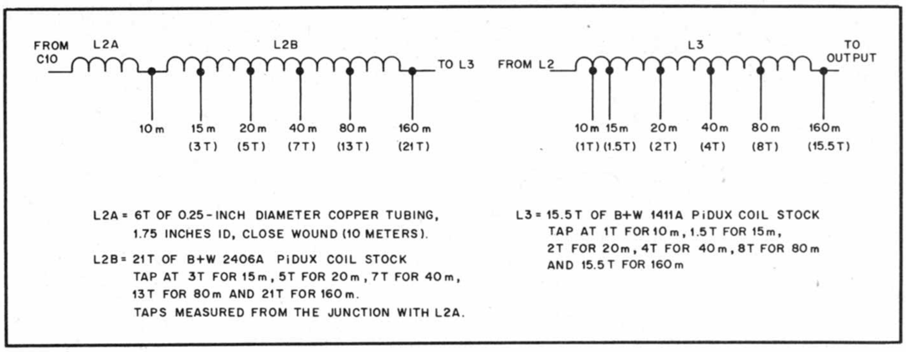


Fig. 64 — Details of the pi-L coils, L2 and L3 of Fig. 63.

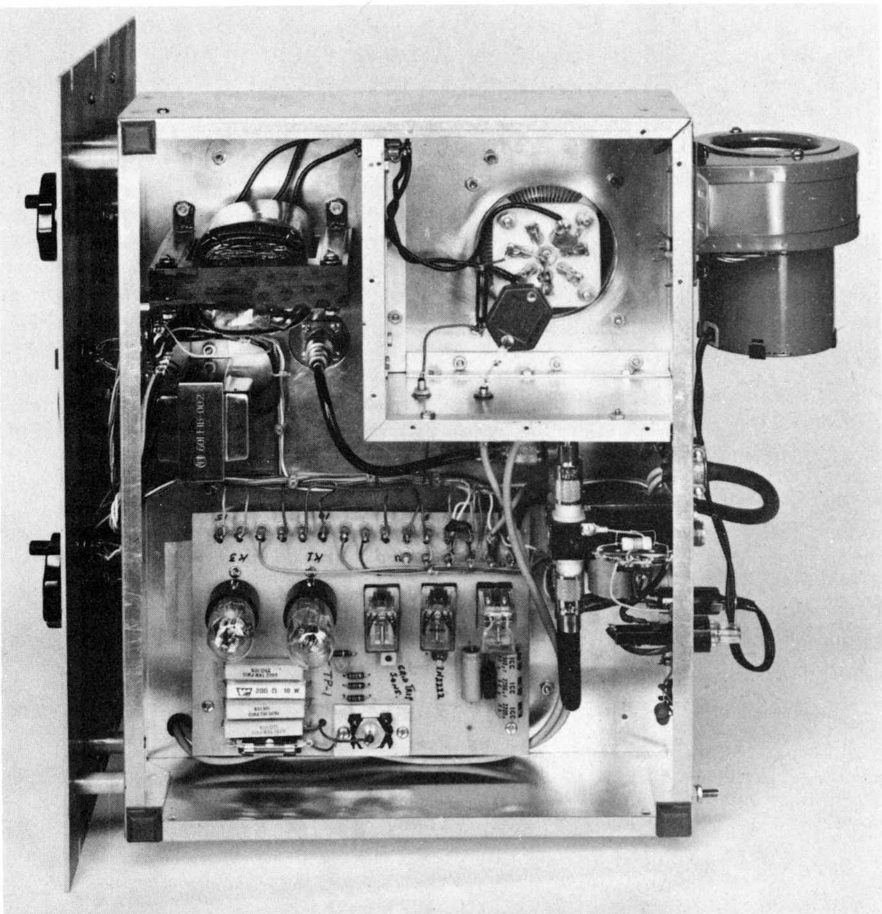


Fig. 65 — Underside of the 8877 amplifier chassis.

to a 19-inch-wide, 12½-inch-high rack panel. For RF shielding, sidewalls 4¾ inches high are mounted to the chassis with aluminum angle stock. A top cover bolts to aluminum angle stock that is connected to the sidewalls. Similar aluminum-sheet-and-angle-stock construction is used to enclose the tube socket underneath the chassis.

A separate enclosure that is bolted to the amplifier top cover houses the input circuitry. This enclosure is positioned so that its band switch is directly above the main band switch in the output network. A simple chain drive from the main band switch makes both input and output switches turn in unison from a single front-panel control. The sprockets (part no. RCS-12) and chain (RCX-25) are available from Small Parts, Inc. See the parts suppliers list in Chapter 35. Align the chain drive with both switches in the 10-meter position. Leave some slack in the chain to allow the detents in both switches to function effectively.

The underside of the chassis is shown in Fig. 65. A single circuit board in the lower half of the photo contains the bias and control circuitry. The antenna relays are mounted to the rear chassis wall, to the right of the control circuitry. The filament and control circuit transformers are mounted at the top left of the photo, near the front panel, and the tube socket is to the right of the transformers. A Dayton blower pressurizes the enclosed cathode compartment, and air exits through the tube anode cooler. A Teflon chimney directs the exhaust air.

The tube socket is homemade from a Johnson 247 ceramic socket and miscellaneous hardware. Complete details for fabrication of this socket are shown earlier in this chapter, associated with a 160-meter 8877 amplifier. The recommended EIMAC socket is part number SK-2200.

The relative positions of the output-network components is shown in Fig. 66. The tuning capacitor is mounted close to the tube, and the loading capacitor is on the other side of the chassis. Both of these capacitors use Groth turns-counter dials with vernier drives for smooth tuning. These drives were purchased from Robert H. Bauman Sales, P.O. Box 122, Itasca, IL 60143.

The band switch is in the center of the chassis. S2C, to switch in additional loading capacitance for 80 meters, is a homemade addition to the band switch. It consists of two Barker and Williamson high-power switch contacts (available from B&W or RadioKit — see Chapter 35) and a wafer made from a piece of double-sided PC-board material. See Fig. 68. S2C is attached to the main band switch shaft.

The pi coil, L2, may be seen to the left of the 8877. The two coil pieces are supported by a rectangular piece of glass-epoxy circuit board material with all copper removed. The coil assembly is mounted above the chassis with ceramic standoffs. The L coil is mounted with a similar arrangement to the left of the band switch and perpendicular to the pi coil. The two coils must be mounted at right angles to prevent undesired coupling. All plate circuit connections are made with copper straps.

In this amplifier, it was necessary to provide a ½-inch wide ground strap between the tuning and loading capacitors to prevent ground-loop currents. Connect the frame of the loading capacitor to the leadscrew mechanism of the vacuum variable. Do not ground this strap to the chassis.

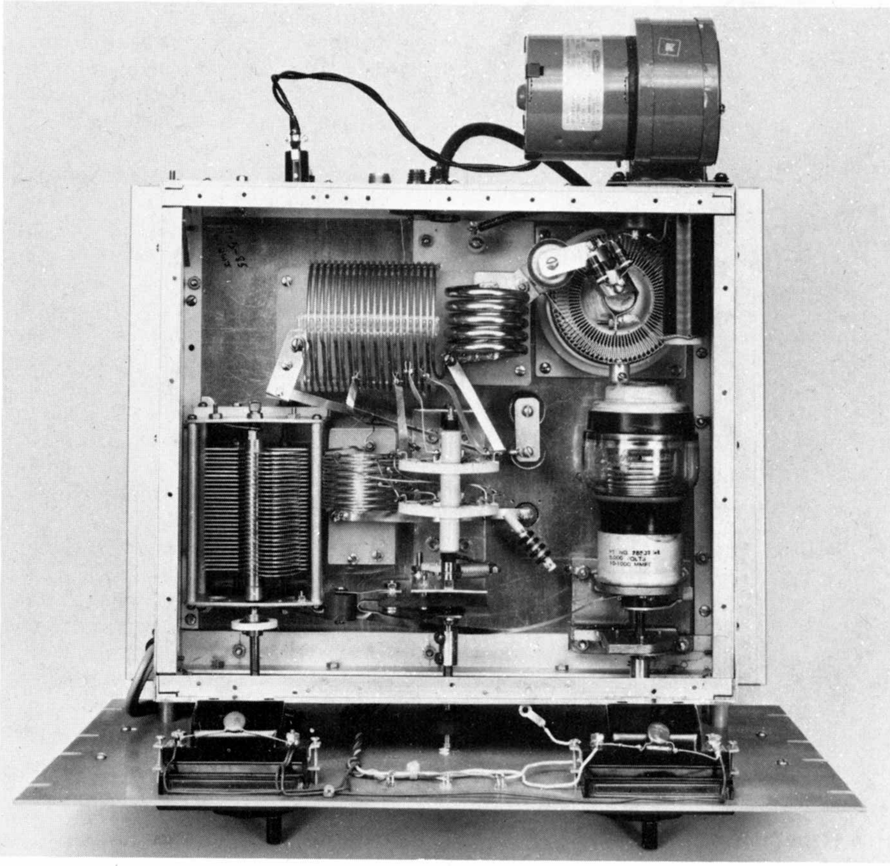


Fig. 66 — Interior of the 8877 amplifier RF deck. The input compartment, which was attached to the top cover, has been removed. The chain-drive sprocket on the main band-switch shaft is visible between the chassis and the front panel.

Tuneup and Operation

Check the high-voltage power supply for proper operation before connecting it to the RF deck. Check all circuit paths in the B+ supply and RF deck for possible short circuits. Verify the operation of all control circuitry with the high-voltage off and with the tube removed from the socket. If everything works, apply power to the filament transformer, blower and control circuitry, and measure the filament voltage at the tube socket. If all is well, remove power from the RF deck and install the covers. Connect the high-voltage supply. Connect an exciter capable of delivering about 100 W to the input through a wattmeter and connect the amplifier output to a suitable dummy load through a second wattmeter.

Place the power-supply switches in AUTOMATIC and START. Close the RESET switch on the RF deck and turn the POWER switch on. The blower will start and filament power will be applied. The FILS lamp will light. After three minutes, K3 will close and the high-voltage supply will turn on. Press the transceiver PTT switch. M2 should indicate about 150 mA resting plate current.

Apply about 10 to 20 W of drive and adjust the TUNE and LOAD controls until the grid-current meter reads about 70 mA. Adjust R5 until the grid-trip circuit functions. Reset the circuit and verify that the grid-trip circuit functions at about 70 to 80 mA.

Apply about 10-W drive and adjust the slugs of the coils in the input pi networks for lowest SWR at the center of each band. Adjust the TUNE and LOAD controls for maximum output. Tuning of a pi-L circuit is similar to that for a conventional pi circuit, except that the setting of the LOAD capacitor is much more critical. Gradually increase drive until the power output reaches 1500 W. Recheck the input SWR on each band with the amplifier running at full output.

Table 2 shows the operating parameters for this amplifier as measured in the ARRL lab. Fig. 67 shows the exceptionally clean spectral output from the pi-L network.

Table 2

8877 Amplifier Operating Characteristics

Band	*Power Output (W)*	*Plate Voltage (V)*	*Plate Current (mA)*	*Grid Current (mA)*	*Drive Power (W)*	*Input SWR*
160	1500	2700	1000	30	65	1.1:1
80	1500	2800	900	35	65	1.2:1
40	1500	2800	900	40	65	1.1:1
20	1500	2800	1000	40	65	1.2:1
15	1500	2800	1000	45	65	1.2:1
12	1500	2800	1000	50	65	1.5:1
10	1500	2800	980	50	65	1.4:1

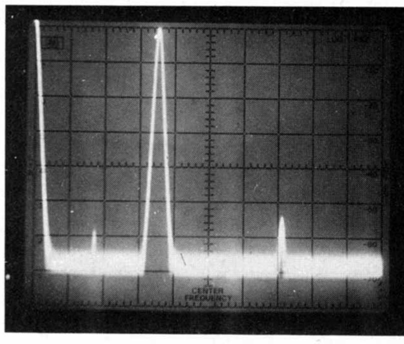
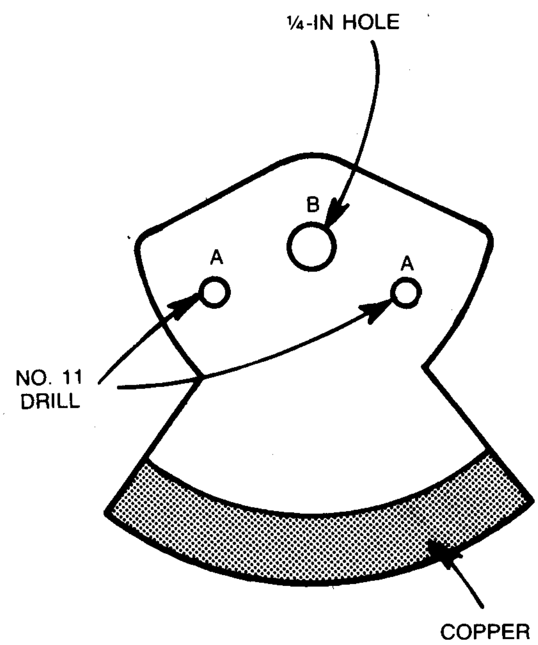
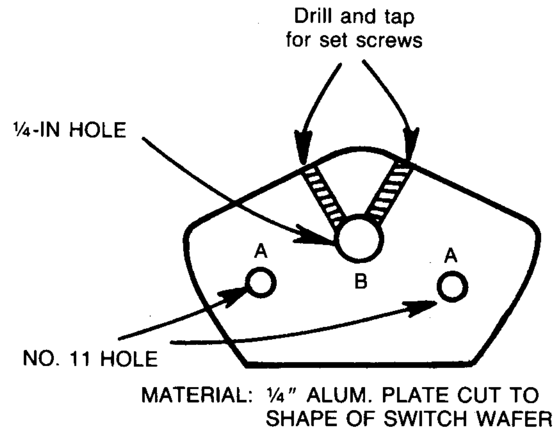


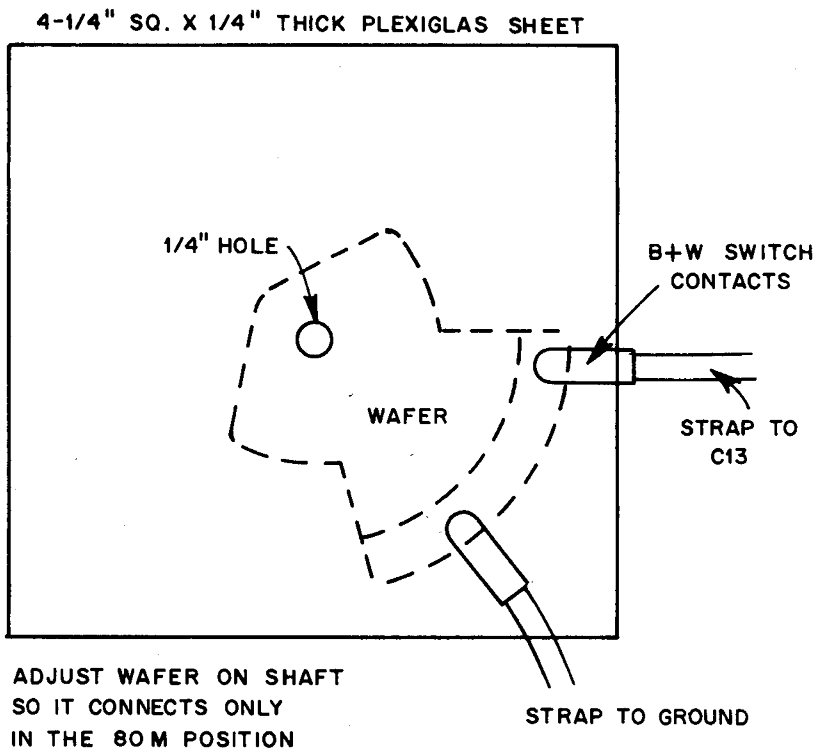
Fig. 67 — Worst-case spectral photograph of the 8877 amplifier. Power output is 1500 W on 3.5 MHz. Each vertical division is 10 dB, and each horizontal division is 1 MHz. All harmonics and spurious emissions are at least 54 dB down. This amplifier complies with current FCC spectral-purity requirements.



(A)



(B)



(C)

Fig. 68 — Details of the homemade switch used for S2C. At A is a full-size template of the wafer. Material is double-sided circuit board. Remove all copper but that indicated by the shaded area; the pattern should be the same on each side of the board. The aluminum piece that mates the switch wafer to the band-switch shaft is shown at B. At C, the entire switch is assembled on a Plexiglas sheet.