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A 144-MHz Amplifier Using the 8874

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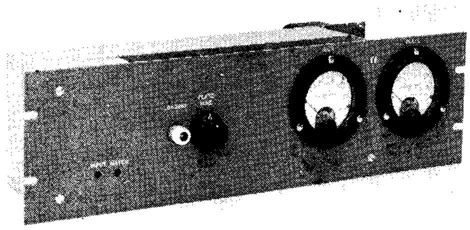

Fig. 1 – Front view of the 144-MHz amplifier. The grid-current meter is on the left and plate meter on the right. Plate-circuit loading is increased by pushing in on the coax connector. Input circuit tuning is done with an insulated screwdriver through the two holes at the left side of the panel labeled INPUT and MATCH.

THIS 144-MHz amplifier is an inverted ultra-audion, grounded-grid, or a cathode-driven amplifier, depending upon what point in electronics history you choose to speak from. The first description has now been dropped and is probably recognized only by the real old timers, or students of radio history.[1] The second, grounded grid, is still widely used but somehow fails to describe how an amplifier works; it also implies no grid bias, but bias is often used. The third, by its words, cathode driven, tells you how the amplifier operates, without being unduly restrictive as to operating voltages.

The Cathode-Driven Amplifier and Tube

The cathode-driven amplifier has become very popular with amateurs using the high-frequency bands. This popularity has developed primarily in the past fifteen years. One of the principal reasons is the availability of single-sideband exciters with a PEP output of one hundred or more watts. With exciters of that power capability, the natural step in increasing power level is to go to an amplifier which will absorb all, or almost all, of the exciter power – the cathode-driven amplifier. Also in the past few years, new modern-design tubes have been introduced which were developed for this service, having a very high mutual conductance and operating with very little or no grid bias. The best of these tubes operate satisfactorily at the lower vhf range, but are difficult to handle in the upper part of that range.

Now a new family of tubes has been developed which performs very well at hf, vhf, and well into the ultra-high-frequency range. These tubes are the 8873, 8874, and 8875. The tubes differ from each other only in the anode cooler construction. The 8873 is intended for heat-sink cooling, the 8874 for forced-air cooling, and the 8875 for cooling by large volume but very low-pressure air, such as is supplied by a fan. The 8874 is used in the amplifier which is to be described.

The requirements for a good cathode-driven tube will be briefly reviewed.

1) In order to have acceptable gain, the tube should have high mutual conductance.

2) The tube should have low grid interception of electrons. All other things being equal, the tube having the lowest grid interception is the easiest to drive.

3) The tube should have the least possible inductance between the grid in the tube and the external grid connection. Inductance in the grid lead causes degeneration which, in turn, means that more drive power has to be supplied to drive the tube to a particular plate current.

Incidentally, the long wire grid lead in the old glass high-mu triodes is the main reason for lack of vhf capability of those tubes. It is of interest to note that while the cathode-driven tubes require low grid-lead inductance, the grid-driven tube requires low cathode-lead inductance; lack of attention to this detail results in a tube which is hard to drive, and, for the same reason in both cases, degeneration.

The 4X150A/4CX250B tetrode tubes are still considered very good performers in the vhf range. However, the 8873 triode family, in cathode-driven service, gives power gains which approach that of the older tetrode types in a grid-driven arrangement and does that without the necessity for a screen supply or neutralization; and at the lower

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1 It is interesting to note that a cathode-driven amplifier was described in *QST* almost forty years ago. See *QST* for September, 1933, "The Inverted Ultraudion Amplifier," by Hugo Romander, W2NB (now W6CH).

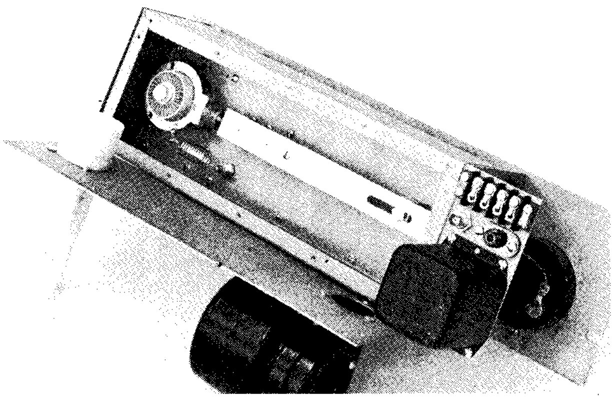

Fig. 2 – Looking into the box containing the plate-circuit strip line. The slot in the plate line is for a rough adjustment of frequency. Once set properly, all of the 2-meter band can be covered using only the front-panel controls. The Teflon chimney and wave-guide-beyond-cutoff vent pipe are attached to the box cover.

plate voltages the tube can be operated at zero bias. If fixed bias is needed, it can be obtained from a comparatively inexpensive Zener diode.

The 2-meter amplifier to be described uses one 8874 in a cathode-driven circuit and with a strip-line plate circuit. It is capable of 1100-watts PEP input for ssb suppressed carrier and 550 watts for cw. As an a-m linear amplifier it will run at 500-watts input.

Construction

The amplifier is built so as to fit behind a standard 5 1/4 x 19-in. panel as shown in Fig. 1. The plate circuit enclosure is 13 x 5 x 3 in. and made of aluminum (see Fig. 2). This one happens to be of the hand-made variety, but a standard chassis of this size could have been used and would have saved some time. The cathode input circuit is in a 5 x 3 3/8 x 1-in. aluminum box. A standard 4 1/2 x 3 1/2 x 1-in. chassis would have served as well, as the box is not crowded. Two end brackets space the rf unit 1 3/4 in. behind the panel to allow room for the meters.

The tube socket is centered between the two sides of the plate-circuit enclosure and is 1 1/2 in. from one end. The grid is connected directly to the chassis by a grid collet. The grid collet was made by soldering a grid contact ring, Eimac part No. 882931, to a 1/16-in.-thick brass ring. The brass ring has three No. 6-32 stud bolts attached which match the location of the three mounting holes of the Johnson 124-311-100 socket. There are other ways to make a good grid collet, and ingenuity of the individual builder can assert itself. Certainly the multiple contacts that finger stock gives is the type of thing needed. Never depend on the control-grid socket connections (pins 4, 7, and 11) to be good enough for vhf or uhf service.

Contact to the anode of the tube is made by a plate collet. The collet was made by sandwiching an Eimac plate contact ring, part No. 008294, between two 1/16-in.-thick brass pieces. The upper piece is circular with a 1-in.-wide tab on one side, the tab having a 3/8-in. lip bent at 90 degrees for the plate blocking-capacitor mounting. The lower brass piece is also circular, but without the tab. The plate collet is shown in Fig. 3.

The plate line is made of copper, 1/8-in. thick and 1-in. wide. A 3/8-in. lip is bent at the tube end of the line for connecting to the plate blocking capacitor. The far end of the line stops about 1/4-in. short of the enclosure wall. The plate line is supported near the far end by a 1 x 1 x 1/2-in. block of copper, and by a 1-in.-high ceramic insulator 5 1/4-in. from the tube center. A 1/4-in. bolt passes through the plate-line slot, the support block and a slot in the enclosure wall. The exact location of the ceramic insulator is not critical, except that it must not interfere with the location of the plate tuning and coupling capacitors which are between it and the tube! Both copper and soft aluminum have been used for the plate line and the 1 x 1 x 1/2-in. support block. Very careful power measurements showed no difference in performance, whichever material was used. Brass might be satisfactory, if it is silver plated. For those willing to experiment, 1/16-in.-thick material might be used instead of 1/8-in., as in this amplifier. The line would then have to be slightly shorter to tune to resonance.

Rf power is taken out of the amplifier by capacitance coupling to the plate line. A 1-in.-dia disk is positioned near the tube end of the line and coupling is varied by a sliding arrangement. Details of this coupling device are shown by Fig. 6.

Plate tuning is done with a 1-in.-dia disk on a 1/4-in. threaded shaft which positions the disk relative to the plate line. The shaft turns in a threaded bearing mounted on the enclosure wall. When the plate-line support block is properly set, it is possible to tune the amplifier from 144 to 148 MHz without changing the position of the block. The plate tuning capacitor is spring loaded to prevent a variable ground-return path, sometimes encountered in this kind of device. The spring loader is made by soldering a threaded nut of the correct size to a piece of thin metal; brass or steel will do. This is then threaded on the turning shaft until it rests on two pillars mounted on the outside enclosure wall. Just enough compression to prevent play in the tuning shaft gives the best results. This device can be seen just to the right of the output coaxial connector in Fig. 4.

The tube anode is cooled by a blower mounted on the plate-circuit enclosure cover. The only escape for the air is through the tube anode cooler, the chimney, and then the vent pipe. The chimney used in this amplifier was made from sheet Teflon approximately .050-in. thick, formed into a cylinder and then taped to keep that shape. Since this material is not readily available, a suitable arrangement can be worked out using the standard ceramic chimney for the 4X150 or 4CX250, such as the Eimac SK-606. The idea is to prevent the air from going directly to the vent pipe without going through the tube anode.

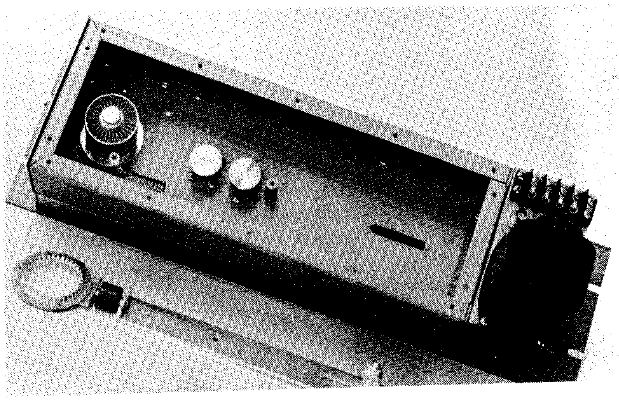

Fig. 3 – Plate-line box with the strip line removed. The output coupling capacitor is the disk nearer the tube. The other disk is the plate-tuning capacitor. A one-inch-high ceramic pillar supports the plate line and is located next to the tuning capacitor.

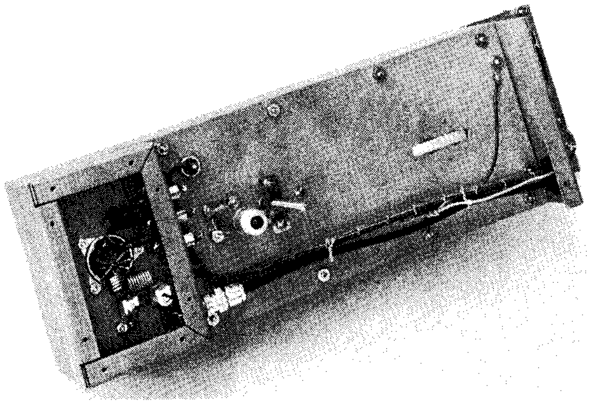

Fig. 4 — The front of the amplifier with the panel removed. The input-circuit enclosure which is to the left is normally covered with a piece of perforated aluminum. The spring-compression device which prevents erratic tuning of the plate-circuit resonating capacitor is shown just to the right of the type N output coax connector.

Circuitry

In cathode-driven service the average input impedance of the 8874 is approximately 95 ohms. An input circuit, therefore, is needed for two reasons: (1) the input to the amplifier should look like 50 ohms to accommodate the transmission lines and the driver output impedance; this calls for an impedance transformer; and (2) the 95-ohm average input impedance varies tremendously during the rf cycle. For example, if the tube is operated Class B, the plate current is zero during half the rf cycle and the impedance is very high, but during the part of the cycle that the tube peak currents occur, the impedance is lower than 95 ohms. Since drivers don't like to have the load impedance varying wildly, a storage reservoir should be provided. A tuned circuit with some Q serves this function and also transforms the impedance.

The cathode input circuit is an L-pi network using lumped constants. It was designed to have a loaded Q of 3. Knobs were not provided for adjusting the input circuit because of its broadband nature. Instead, screwdriver slots in the capacitor shafts permit adjustment of the capacitors from outside the box. The "screwdriver" should be nonmetallic. A short 1/4-in.-dia Bakelite shaft filed in the shape of a screwdriver on one end and with a knob on the other end works very well. If the input circuit is matched at 146 MHz, changing frequency to either 144 or 148 MHz without touching the input adjustments will give an SWR of less than 1.7 to 1. At either 145 or 147 MHz the SWR is less than 1.35 to 1. Of course the input can be matched at any frequency within the band, if desired.

Fig. 5 shows tha layout of parts in the input-circuit compartment. All of the six cathode terminals of the socket are connected together. The bifilar heater choke is wound on a small length of insulating rod and was made bifilar for the convenience of using only one form instead of two. Sharp-eyed readers who like to count turns will note that the outside layer of this coil has one less turn than the one on the inside. Again, it was a matter of convenience, not a requirement.

Although the pi-L or L-pi and T networks have been around a long time, the T network has not been used much. The T is useful where low-impedance transformations are necessary. The solid-state designers have this sort of problem in their work and have developed tables of solutions for a wide variety of impedance transformations.[4] A copy of these tables is very useful, indeed.

All of the power leads into the rf compartments enter via feedthrough bypass capacitors. They help keep the rf where it belongs. Three are low-voltage types, which feed the cathode and filament circuits. The fourth is a high-voltage unit for the plate voltage supplied to the tube.

Cooling the Tube

The cooling of the tube is done somewhat differently than is usually the case. The tube data sheet, for 400-watts plate dissipation, specifies a minimum air flow of 8.6 ft^3/min for 50 degrees C at sea level (you can use a little less if the air is cooler than 50 degrees C). The pressure required to move that quantity of air through the tube cooler is 0.37 inches of water, assuming no back pressure on the discharge side of the anode. This cooling air is provided by a Dayton model 2C782 blower.[5] The blower forces air into the box containing the tube plate circuit. A Teflon chimney connects the top of the tube anode to the vent pipe fastened on the box cover. All other holes in the plate-circuit box are sealed, so that the air blown into the box

4 *Matching Network Designs with Computer Solutions*, Application Note AN-267, Motorola, Box 20912, Phoenix, AZ 85036.

5 Available from W. W. Grainger, Inc., 2750 W. Fulton St., Chicago, IL 60612.

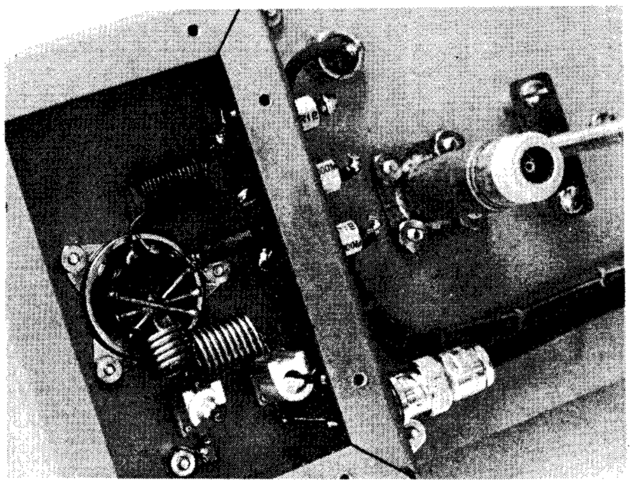

Fig. 5 — Close-up view of the input-circuit box. The bifilar-wound filament choke is above. The cathode choke is to the right and the input T-network coils and capacitors are below the tube socket. The slide mounting of the type N output coupling capacitor is shown to the right of the input-circuit enclosure.

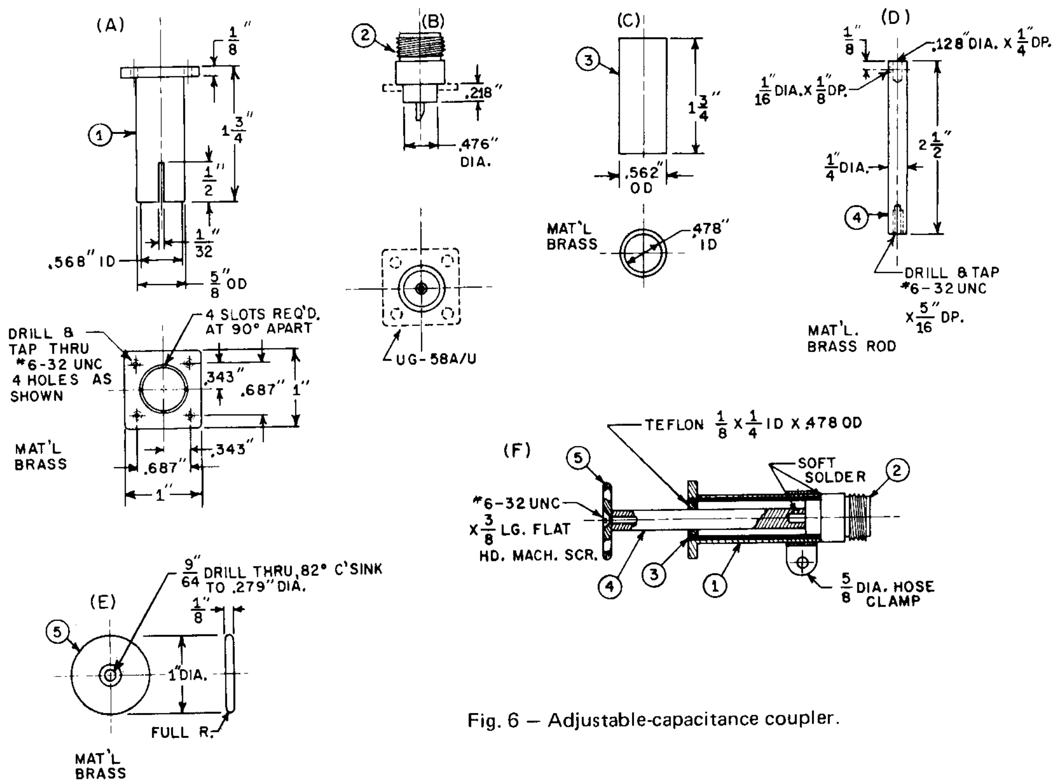

Fig. 6 — Adjustable-capacitance coupler.

can only escape by going through the tube anode cooling fins and then to the outside world. The vent pipe has practically no air restriction, yet acts as a very effective choke at these radio frequencies.

Equipment built for amateur service has not often taken advantage of the particular principle of microwave radio by which the vent pipe works – electronically, that is. In this case it is used for what it will *not* do, rather than for what it *will* do; that is, it will not transmit a radio signal of any frequency below about 4600 MHz. The pipe has a diameter of 1 1/2 in. For frequencies above 4600 MHz this would be an excellent transmission line. However, for frequencies much below 4600 MHz, the cutoff frequency, it becomes a choke. Its effectiveness as a choke depends upon how long it is. The usual description of this phenomenon is "wave guide beyond cutoff"; in this case "beyond" means below! The attenuation of this device is given by the formula:[6]

$$\text{Aa} = \text{Aperture attenuation (dB)} = 32\frac{D}{d}$$

D = length of pipe

d = inside diameter of pipe

The vent pipe used in this amplifier is 4 1/2-in. long and 1 1/2-in. ID. When these figures are put into the formula, this gives an attenuation of 96 dB! This attenuation is for frequencies well below the cutoff frequency, not for those close by. However, the 144-MHz output of the amplifier and its harmonics up to about the 20th can be considered well below cutoff.

6 *Electrical Design News,* October, 1963.

Tune-up Procedure

Tuning a cathode-driven amplifier is not much different than tuning one which is grid driven. There is one precaution that must be observed, though. Never run drive power into a cathode-driven amplifier unless the plate voltage is on. Running normal drive power with no plate voltage produces high grid dissipation and will quickly destroy the tube.

The 8874 has an indirectly heated cathode. Always allow at least 90 seconds for the heater to warm up before the tube is required to draw plate current.

When tuning a new amplifier for the first time, it is very helpful to start with reduced plate voltage. If the final operating conditions with this amplifier are to be 2000 V at 500 mA, then apply 1000 V to the plate and only enough drive to be able to tune the plate circuit to resonance. Then increase drive and adjust plate loading and tuning to maximize power output, while watching the grid meter to make sure that the current is not excessive, indicating high grid dissipation. When the drive, plate loading and tuning are optimized for maximum power output at 1000 V and 250-mA plate current, then the loading adjustments will be very nearly correct for the 2000-V 500-mA condition. Before going to the higher plate voltage, the cathode input circuit can be adjusted for a low input SWR. Do not waste time matching the input circuit exactly, as the input match will change somewhat at the higher power level.

Scan by Dan

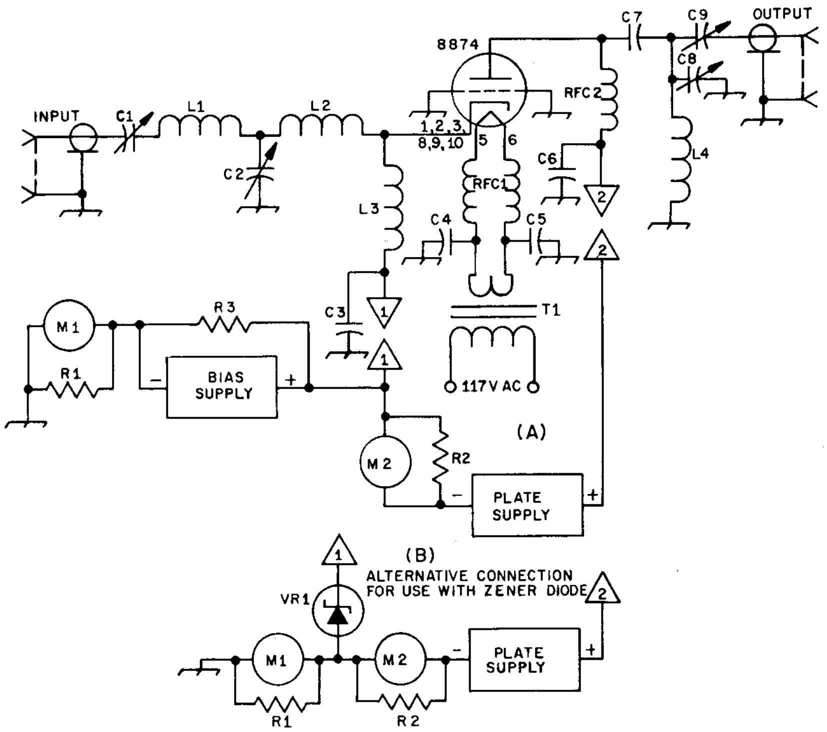

Fig. 7 — 144- to 148-MHz 8874 amplifier.

C1 — 2.4 to 24.5 pF air variable (E. F. Johnson 189-509-4).
C2 — 1.7 to 14.1 pF air variable (E. F. Johnson 189-505-4).
C3, C4, C5 — 1000-pF feedthrough (Erie 327-005-X5UO-102M or equiv.).
C6 — 1000-pF feedthrough, 2.5 kV (Erie 1270-10 or equiv.).
C7 — 100 pF, 5 kV (Centralab 8505-100N or equiv.).
C8, C9 — See text.
L1 — 9 turns No. 16 wire, 3/8-in. dia, 5/8-in. long.
L2 — 5 turns No. 16 wire, 3/8-in. dia, 3/8-in. long.
L3 — 0.47-μH choke, 300 mA (Miller 4588 or equiv.).
L4 — Plate line; 1 X 1/8-in. copper or soft aluminum, 8 1/2-in. long.
M1 — 50-mA dc meter.
M2 — 500-mA dc meter.
R1, R2 — 50 ohms, 10 W.
R3 — Bias-supply bleeder; select for approx. 100 mA current and appropriate wattage.
RFC1 — Bifilar wound, each winding 15 turns on 3/8-in.-dia form. See text and photos.
RFC2 — 10 turns No. 16 wire, 1/2-in. dia, 1 1/8-in. long.
T1 — Filament trans., 6.3-V 4-A secondary (Triad F-43X or equiv.).
VR1 — See text.

Now the plate voltage can be raised to 2000 V and drive power increased to give about 500-mA plate current. Again, plate loading and tuning and drive power are adjusted for maximum power output at the desired power level. And of course the grid-current meter is watched to avoid excessive grid dissipation. When the plate-circuit adjustments have been completed, then the input circuit can be adjusted for minimum SWR. If the drive power is free of harmonics or other spurious signals, an SWR of better than 1.1 to 1 is easily obtained on the drive line.

Of course it is not necessary to tune up for the first time with reduced plate voltage. However, if you start off at 2000 volts, then a great deal more care must be used. Unwanted or unexpected effects happen a lot faster and with more violence at 2000 volts than at 1000!

The preceding tune-up procedure applies to either cw or ssb linear operation. For a-m, the method would be the same provided that loading is adjusted for the most output at the crest of the modulation cycle when the drive signal is being 100-percent modulated. A peak-voltage-responding indicator is needed on the output of the amplifier to do that. An rf vacuum-tube voltmeter is one of the instruments that can be used.

A second method that can be used is to adjust the amplifier loading and tuning for minimum distortion when the drive signal is being 100-percent modulated. Still another method that will produce the correct loading adjustment is to simulate the conditions that exist at the crest of the modulation cycle, but by using a cw signal only. For example, if a driver with a 5-watt carrier is to be used, it will have a peak output of 20 watts

Table I

Typical Performance

Plate Voltage	*No-Signal Plate Current*	*Grid Bias*	*Plate Current*	*Grid Current*	*Drive Power*	*Power Output*	*Efficy.*	*Gain*
1000	10 mA	−4.6V	250 mA	24 mA	7.2W	146W	58%	13.1 dB
1500	10	−7	250	25	8.4	238	63	14.5
2000	10	−9.8	250	22	9.4	320	64	15.3
1000	92	0	300	26	7.0	171	57	13.9
1500	140	0	400	27	11.4	362	60	15
2000	150	−1.7	500	29	18.3	636	64	15.4

at the crest of the modulation cycle. Therefore a cw signal of 20 watts can be used as a driver temporarily while the linear amplifier is being adjusted for maximum power output, just as it is for cw or ssb operation. After the adjustments are completed the 5-watt driver can replace the 20-watt unit, and the amplifier is ready to go.

The important point to remember about an a-m linear amplifier is that the amplifier must be adjusted to accommodate the peak power conditions. One of the most difficult facts to accept is that amplifier settings which give the best and most readable signal are not the same as those which give the strongest carrier. After the amplifier has been correctly tuned, one is always tempted to touch up the tuning to get more carrier output. When the temptation is great, reread the paragraphs on a-m linear-amplifier adjustment!

You should now have amplifier performance which is very nearly like that shown in Table I. Because of variations from tube to tube, the grid current at a particular operating level may vary considerably from that shown in the table, possibly as much as 2 to 1. Drive power requirements may also vary, but to a smaller degree. This may be lesser or greater by 10 or 20 percent.

Performance

The amplifier can be used for cw or as a linear amplifier for either ssb or a-m work. The mode of operation will determine the maximum input power that can be used. Table I shows the measured performance of the amplifier with different plate voltages and idling plate currents.

Table II

Type 8874 Tube Data	
Heater Voltage	6.3 V
Heater Current	3.2 A
Maximum Plate Voltage	2200 V
Maximum dc Plate Current (key down)	250 mA
Maximum dc Plate Current (modulation crest)	500 mA
Maximum Plate Dissipation	400 W
Maximum Grid Dissipation	5 W

Some conclusions can be reached from the data shown in Table I. The table shows that higher efficiencies and gain are possible with higher plate voltage and, of course, higher power output. Also, the lower the idling plate current, the lower the gain, but efficiency goes up.

For linear-amplifier service, good results can be obtained if the tube bias is set for an idling plate current of 25 to 50 mA. A Zener diode in the cathode return is probably the simplest way to get the needed bias. However, a variable low-voltage supply can be used and has the advantage of flexibility if much experimenting is to be done. A suitable circuit for such a supply is shown in the 1971 ARRL *Handbook.*

Other construction techniques such as coaxial resonant cavities can be used to build a good amplifier. What has been described is a fairly simple, easy-to-build unit. The 8873 family of tubes will do a good job at vhf and uhf in a well-designed amplifier. QST

The Simulmonitor

(Continued from page 23)

A commercial transistorized amplifier suitable for Z1 is available at very nominal cost. It has a diode and filter capacitor, for rectification and filtering, so it is necessary to power the unit with only the 6.3 volts ac from the filament supply. This amplifier provides the local audio, and drives a local speaker for monitoring purposes during maintenance. Amplifier Z2 is similar. It provides the needed line level from the tone oscillator and the microphone.

A jumper shown as a broken line between Terminals 5 and 9 of K2 determines whether a tone burst is received only when the primary receiver is operative, or when either primary or secondary receiver is operative. This is the first step toward a future control system.

This, then, is the Simulmonitor, as conceived and utilized by CFAR. As channel occupancy increases and more satellite receiving setups come into the system, the approach becomes more sophisticated, and the Simulmonitor may change almost beyond recognition. In other areas the technique is used under other names and with other features, but the basic concept will most likely remain, and provide many benefits. The net result will be further advancement in the story of amateur radio repeaters. The story is just now starting to be told. QST