Cathode Modulation

By FRANK C. JONES,* W6AJF

Some amateurs are grid-modulation addicts; others prefer plate modulation. But it appears we have been passing up a good bet by not using a combination of both. The many advantages of cathode modulation make it safe to predict great popularity for this system.

An excellent system of modulation has long been overlooked by radio amateurs. The purpose of this article is to bring the system into the limelight and to attempt an easily understandable explanation of cathode modulation.

The audio power required for full modulation with cathode modulation is a great deal less than that required for plate modulation. The average value of audio power for 100% modulation is 10% of the value of d.c. input to the plate circuit of a cathode modulated class C amplifier. Plate modulation with pure tone input requires an audio power of 50% of the class C amplifier input for full modulation. For example, a plate modulated 200 watt transmitter requires an audio modulating power of 100 watts, while the same 200 watt set requires only about 20 watts for cathode modulation. In addition, the cathode modulated amplifier does not require as much grid excitation.

The 200 watt plate modulated set will supply a carrier output of from 130 to 150 watts. A 200-watt cathode modulated set will supply a carrier of from 100 to 120 watts. For further comparison, a 200-watt grid modulated set will supply a carrier of from 35 to 90 watts, depending upon the system of grid modulation. It can be seen that cathode modulation approaches plate modulation in efficiency and will supply roughly two times as much output as can be obtained from a correctly operated grid modulated transmitter.

Cathode modulation is a combination of grid modulation and plate modulation, and is exceedingly simple to adjust for proper operation. The audio power is inserted into the cathode or center-tap lead of the class C amplifier, which is common to both grid and plate circuits. A typical circuit is shown in figure 1, in which the filament or cathode is by-passed *for r.f. only* with a total capacity of not over .005μfd. The modulation transformer works into an average load of about 500 ohms but this value is not critical. Values of load of 200 to 1000 ohms have been tested and found satisfactory in a number of different class C amplifiers. The actual cathode impedance seems to be proportional to $\frac{1}{G_m}$ where G_m is the operating transconductance of the tube.

As far as audio load values are concerned, push-pull or parallel class C tubes are similar to a single tube but with twice as high a value of transconductance or half as great a cathode impedance. An impedance mismatch of 4 to 1 or even 6 to 1 in practice has practically no

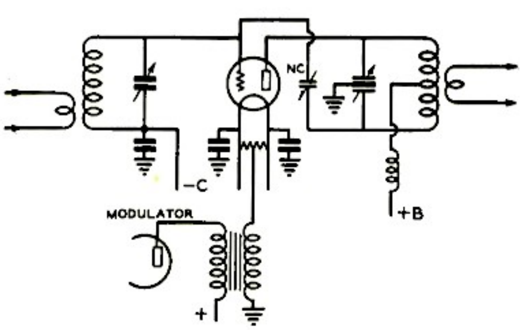
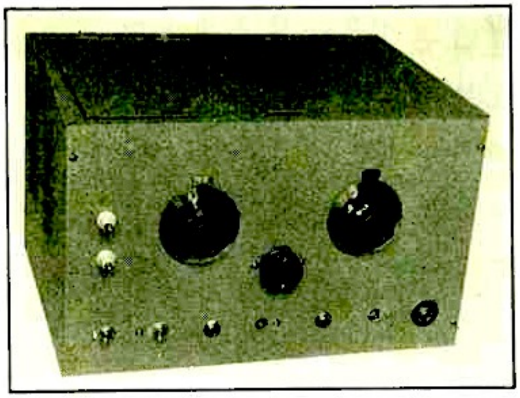


Figure 1. Simplified schematic of a cathode modulated triode r.f. amplifier

* 2037 Durant Ave., Berkeley, Calif.



Front view of the 6L6G cathode modulated phone.

effect on the quality of modulation; however, some audio power is wasted and a larger modulator stage is required. A value of 500 ohms seems to be optimum for nearly any type of class C amplifier of high or low power. Several manufacturers produce public address or class B output transformers having a secondary designed to work into a 500-ohm load, and most of these have sufficiently heavy wire on the 500-ohm winding to handle considerable d.c.

The audio modulating power is applied to both grid and plate circuits of the r.f. amplifier in figure 1. If 10 watts of sine-wave audio power is applied across a 500-ohm load resistance, the r.m.s. voltage would be 71 volts or the peak value of 100 volts. This value of 100 volts would be applied to the grid bias voltage and also to the d.c. plate voltage. The a.f. variation in d.c. plate voltage of 100 volts produces plate modulation of relatively low percentage at normal values of plate voltage supply. A similar variation of a.c. cathode current aids in the plate modulation function. The same a.c. voltage applied in series with the d.c. grid bias produces grid modulation of from 50% to 80%, depending upon the effective grid impedance and whether an external resistance is connected in the a.f. grid circuit to limit the degree of grid modulation. The ideal arrangement is to balance the grid and plate modulation values to obtain perfectly linear modulation up to 100%. Fortunately this is automatically obtained without an external resistance in nearly all types of tubes used in class C amplifiers.

An r.f. linear amplifier or a grid modulated amplifier of conventional type usually operates at about 30% efficiency with no modulation. If the degree of modulation is limited to 60% or 70%, the resting efficiency can be greatly increased and about twice as much carrier power can be obtained. In cathode modulation this effect is used to obtain resting or idle efficiencies of from 50% to 60%. This permits grid modulation up to 70% or even 80%; the remainder is obtained by plate modulation in the cathode circuit.

If the d.c. plate input is 100 watts, an audio power of only 3⅛ watts will permit plate modulation of 25% if the plate impedance is matched. In this example, with 10 watts of a.f. power in the cathode circuit, about 1 watt is needed for the grid circuit modulation and about nine watts is available for plate modulation.

A positive peak of a.f. voltage in the cathode circuit between the tube filament (or cathode) and ground acts as an additional negative grid bias peak which tends to reduce the peak r.f. output from the amplifier. At the same time a positive peak on the cathode reduces the d.c. plate voltage and so further reduces the r.f. output. In a similar manner a negative a.f. peak adds to the d.c. plate voltage and subtracts from the negative d.c. grid bias to increase the r.f. output. From this it can be seen that the grid and plate modulation are in phase, or additive, and the system is capable of reaching 100% modulation easily.

The d.c. grid bias should preferably be obtained from a C bias supply or C battery; however, grid-leak bias can be made to operate satisfactorily. The *grid leak must be by-passed for audio frequencies.* This sometimes causes a little blocking action if the d.c. grid current is not high enough. This effect may be noticed if the crystal oscillator is detuned or quits oscillating, in which case a "singing" action may be set up in the modulated amplifier. No difficulty is present when the set is operating normally.

The d.c. grid current is set at some intermediate value between that for grid modulation and that required for plate modulation. The d.c. grid bias should be several times cut-off value, and if grid leak bias is used exclusively, the grid leak value will be from *4 to 8 times as high as that used for c.w. or plate modulation.* The r.f. driver should be nearly as large as that required to drive the final amplifier as a c.w. transmitter, or roughly half as large as for a plate modulated amplifier of the same power.

Cathode modulation has several advantages over grid or plate modulation. It is not at all critical in adjustment as regards audio quality. If too much r.f. drive is present, the audio quality does not suffer appreciably, but the modulation capability drops. Similarly, insuf-

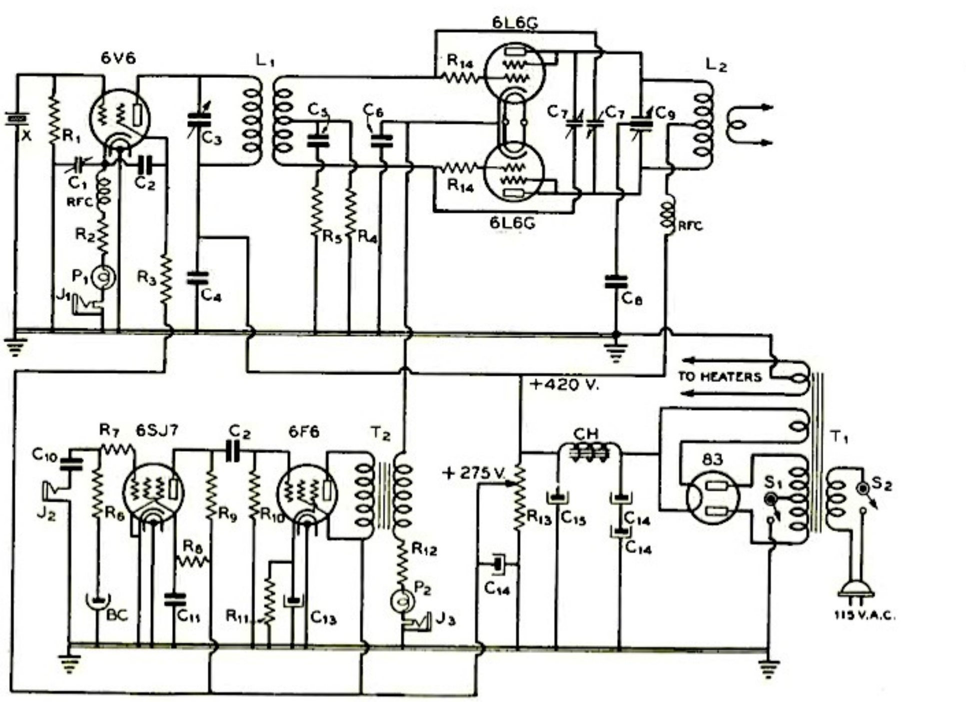


Figure 2. Schematic of the cathode modulated 6L6G phone.

C_1—170-600 μμfd. mica trimmer condenser.
C_2—.01-μfd. 600-volt tubular
C_3—100-μμfd. midget variable.
C_4—.01-μfd. 600-volt tubular
C_5—0.5-μfd. 200-volt paper
C_6—.005-μfd. 600-volt mica
C_7—Homemade neut. condenser, 1" by 2" parallel plates
C_8—.002-μfd. 600-volt mica
C_9—100-μμfd. per section split stator
C_{10}—.01-μfd. 600-volt paper
C_{11}—.05-μfd. 600-volt tubular
C_{12}—.005-μfd. 600-volt mica
C_{13}—10-μfd. 25-volt elect.
C_{14}—8-μfd. 450-volt elect.
C_{15}—16-μfd. 450-volt elect.
R_1—100,000 ohms, 1 watt
R_2—300 ohms, 10 watts
R_3—10,000 ohms, 1 watt
R_4—10,000 ohms, 10 watts
R_5—3000 ohms, 1 watt
R_6—1 megohm, ½ watt
R_7—25,000 ohms, ½ watt
R_8—2 megohms, ½ watt
R_9—500,000 ohms, ½ watt
R_{10}—1 megohm, ½ watt
R_{11}—400 ohms, 2 watts
R_{12}—200 ohms, 10 watts
R_{13}—25,000 ohms, 50 watts
R_{14}—50 ohms, 1 watt
T_1—800 v. c.t., 175 ma.; 6.3 v., 5 a.; 5 v., 3 a.
T_2—2500 ohms to 500 ohms, 10-watt rating
CH—15-hy., 200-ma. choke
BC—Bias cell
Coils—See coil table
S_1—Plate on-off switch
S_2—A.c. on-off switch
P_1—150-ma. 6-volt lamp
P_2—250-ma. 6-volt lamp
J_1—Crystal plate current jack
J_2—6L6G cathode current jack
RFC—2.5mh., 125-ma. choke

ficient antenna coupling reduces the potential linear modulation. (Too little antenna load will produce "downward" modulation of antenna current.) Cathode modulation is more efficient than any of the popular forms of grid modulation, and is not as critical to adjust.

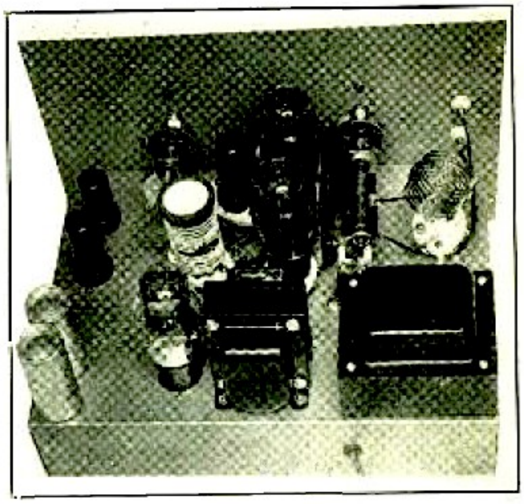
Cathode modulation is more economical than either grid or plate modulation for a given power output. The modulator and its power supply are only ¼ to 1/5 as large as for a plate modulated rig with the same carrier output. The class C tube or tubes should be a little larger unless their dissipation rating is high in proportion to plate current and plate voltage maximum ratings. The plate dissipation of a plate modulated set increases with modulation. It decreases somewhat with grid modulation, and usually decreases very slightly with cathode modulation. Therefore, by operating the tubes at a little greater plate dissipation under resting conditions, no larger tubes are required.

The peak plate current is less with cathode modulation, which should result in greater tube life. The plate tuning condenser in a cathode modulated amplifier is smaller physically because only 60% to 70% as much plate spacing is required.

Transmitter Example

The small transmitter illustrated in the photographs and diagrammed in figure 2 has cathode modulation applied to a pair of 6L6G tubes. A carrier output of about 25 watts is obtained with slightly over 40 watts input. Better modulation linearity was obtained with the 6L6G tubes connected as low μ triodes rather than as tetrodes. This amplifier is modulated by a 6F6 tube which has an audio output of about 4 watts. The modulation transformer has a 500-ohm secondary and the 6F6 tube was connected across the 2500-ohm primary. A 6SJ7 high gain pentode drives the 6F6 from an ordinary high level crystal microphone for close talking purposes.

The crystal oscillator is inductively coupled to the 6L6G triode push-pull stage in order to conserve space. The crystal oscillator is an improved form of harmonic oscillator in which 160-, 80- or 40-meter crystals can be used on their fundamental or second harmonics. 10- and 20-meter crystals should be used "straight through," that is, with the 6V6 plate circuit tuned to 10 and 20 meters respectively. The screen grid of the 6V6 is by-passed to the cathode rather than to ground as this gives a circuit in which the adjustable cathode condenser can be set at one value for all bands. The 10,000-ohm 1½-watt resistor in series with the 6V6 screen acts as an r.f. choke to prevent an r.f. short circuit across the cathode circuit. A combination of cathode and grid leak bias in the 6V6 provides for fundamental efficient doubler action and low crystal current for fundamental or second harmonic operation.



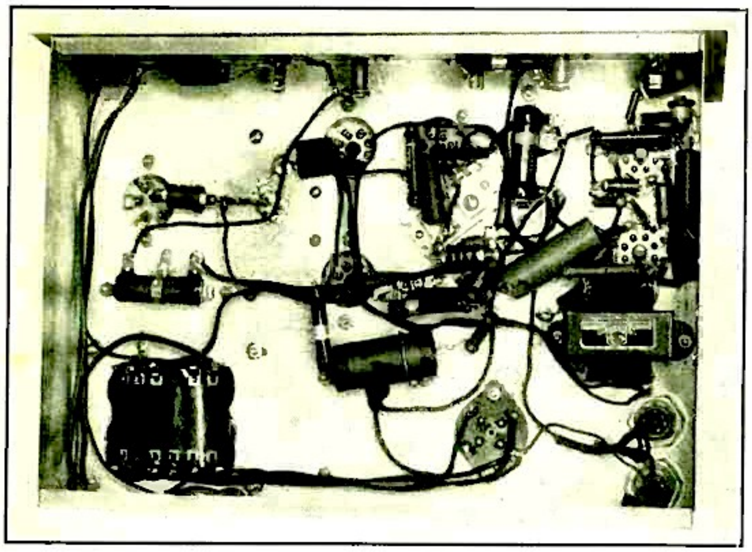
Top view of the chassis of the 6L6G cathode modulated transmitter

The 6L6G amplifier has a ½-μfd. 400-volt condenser connected across the grid leak to pass the audio frequencies. Better linearity was obtained with a 3000-ohm resistor connected in series with the condenser in order to reduce the actual a.f. voltage applied to the grid circuit. Too much grid modulation in comparison to plate modulation in this particular tube

COIL DATA
CATHODE MODULATED 6L6G TRANSMITTER

BAND	OSCILLATOR (1½" dia. forms) — Plate	OSCILLATOR (1½" dia. forms) — Grid	FINAL PLATE
10	3½ turns no. 20 d.c.c. 1" long. ⅛" separation btwn plate and grid coils	5 turns no. 20 d.c.c. ½" long, c.t.	6 turns no. 14 E. 1¼" long. 1¼" dia., c.t.
20	7 turns no. 20 d.c.c. 1" long. ⅛" separation btwn plate and grid coils	12 turns no. 20 d.c.c. ½" long, c.t.	8 turns no. 14 E. 1" long, 1¾" dia., c.t.
40	14 turns no. 20 d.c.c. 1" long. ⅛" separation btwn plate and grid coils	32 turns no. 24 d.c.c. 1" long, c.t.	18 turns no. 16 E. 1¾" long, 1⅝" dia., c.t.
80	24 turns no. 24 d.c.c. close-wound. ⅜" separation btwn plate and grid coils	56 turns no. 26 E. close-wound, c.t.	32 turns no. 18 E. 1½" long, 1⅝" dia., c.t.
160	44 turns no. 26 E. close-wound. ⅜" separation btwn plate and grid coils	80 turns no. 28 E. close-wound, c.t. Shunted with 3-30 μμfd. trimmer	56 turns no. 22 d.c.c. 2" long, 2¼" dia., c.t.

Amp. "grid" windings semi-resonant. Space for best operation before cementing turns on form.



Bottom view of the chassis of the 6L6G cathode modulated phone transmitter.

• • •

arrangement produced a slight curvature on the sides of the triangle or trapezoid as viewed on an oscilloscope. The 6L6G tubes connected as shown have a μ of about 6 and are more easily grid modulated than are medium or fairly high μ tubes. No grid a.f. resistor is needed in transmitters having tubes with a μ of from 25 to 30.

The final amplifier has a combination of cathode and grid leak bias, the former to protect the tubes in case of oscillator detuning or failure of excitation. In the particular layout used, a u.h.f. parasitic oscillation took place in the neutralizing circuit until it was damped out by the use of a couple of 50-ohm 1-watt resistors in the 6L6G grid leads. The neutralizing condensers were each made of two plates 1" x 2" separated about 1/10 of an inch. Neutralization was accomplished by removing the 250-ma. 6-volt lamp from its socket in series with the 6L6G cathodes—then bending the neutralizing condenser plates while checking the plate circuit with a 2-volt 60-ma. lamp and turn of wire coupled to the plate coil. Pilot lamps in series with the tube cathodes act as tuning indicators when no d.c. milliammeter is available.

The set was built on a 10" x 14" x 3" chassis and fits into a 11" x 15" x 9" cabinet. It has a single power supply built in and requires no expensive parts. Operation in any band from 160 to 10 meters is possible with proper crystals and coils. If the set is operated straight through on the crystal frequency, the 6V6 cathode condenser can be left at about full capacity. However, less crystal reaction takes place when doubling in the 6V6 plate circuit, in which case the cathode condenser should be set at a lower value. Too low a value will cause uncontrolled 6V6 oscillation and r.f. output at other than that of the crystal harmonics. Good active crystals are needed for harmonic operation.

The 6L6G grid coil turns and location on the coil form were chosen to result in about 10 to 15 ma. of cathode current (grid current mainly) when no plate voltage is applied to this stage. Too much grid current or too much r.f. grid drive will not allow 100% modulation to be obtained. Too little grid drive means low carrier output.

The antenna coupling should be fairly heavy so the cathode current is from 125 to 150 ma. The antenna coupling should be great enough to reduce the amplifier efficiency to a point where "upward" modulation of antenna current takes place. A small lamp and turn of wire loosely coupled to the final amplifier coil will serve as an indicator for this test.

A larger cathode modulated transmitter with a pair of T40's is tentatively scheduled for the next issue of RADIO, together with data on cathode modulation of larger tubes of several varieties.

•

Correction

We forgot to let you know the wire sizes for the coils of the Conklin-Reubhausen Converter unit, published in the July issue. All coils should be wound with no. 14 except the antenna coil, which should be wound with no. 22.