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NEW SUPER HAS STABILITY AND SENSITIVITY PLUS

Uses Frequency Stabilizer and Voltage Regulator

"The AR-77 puts an end to dial twiddling when you give the other fellow the 'GA' to comeback." So enthuses Mr. Ed. Braddock, Manager of RCA Amateur Equipment Sales.

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Other features of the AR-77 include the use of a voltage regulator for the plate supply of the h-f oscillator and first detector, a sure-fire noise limiter, and a carrier-level meter. Negative feedback is employed in the a-f output circuit for improved fidelity.

The AR-77 uses one single-ended RCA-6SK7 in the tuned r-f stage, two 6SK7's in each of the two i-f's, a 6K8 first detector and oscillator, a 6H6 second detector and noise limiter, one 6SQ7 a.v.c. and a-f amplifier, one 6F6 a-f power amplifier, one 6SJ7 as b.f.o., one 5Z4 rectifier, and one VR-150/30 voltage regulator. Amateur net price of the AR-77 is $139.50; net price of the 8-inch dynamic speaker in matched cabinet, $8.00. Give this receiver a whirl at your nearest RCA distributor.

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The new, big RCA Receiving Tube Manual, the RC-14, is just off the press. This book now contains 224 pages brimful of tube theory, application, circuits, and charts—and above all, it includes up-to-the-minute information on a total of 237 different receiving tube types.

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STEADY AS A ROCK

Frequency-drift compensation and tremendous usable gain makes the new AR-77 one of the most brilliant communication receivers ever hooked to an antenna. The AR-77 uses 10 tubes (5 high-gain single-ended types) and has a frequency range that extends all the way from 540 to 31,000 kc. It employs band-switching in 6 ranges with individual coils and uses a crystal filter with a 6-stage selectivity control that provides band widths from 6 kc to 80 cycles!

CATHODE MODULATION

The Whys and Wherefores

By E. E. Spitzer, A. G. Nekut, and L. C. Waller

Research and Engineering Dept., RCA Manufacturing Company, Inc., Harrison, N. J.

The subject of cathode modulation has recently received the spot light of amateur attention. The features of this modulation system have been described in a number of writings, notably those by Mr. Frank C. Jones. In this article, we shall discuss several aspects of cathode modulation from the viewpoint of the transmitting-tube engineer. It will be shown that, for a typical cathode-modulated stage, the modulating power required is approximately equal to 20 per cent of the d-c plate input to the modulated r-f amplifier. Furthermore, it will be shown that the cathode impedance of a typical single-tube r-f amplifier is about 6000 ohms; that of a typical push-pull stage about 3000 ohms.

> ## COMING !
>
> **Featured in the next issue is a constructional story on an 811 class B modulator. Data will include curves for a-f power output, harmonic distortion, and frequency response, as well as circuits for a complete speech amplifier and class AB_1 driver. A constructional article on a 1250/1500 volt, 500-ma. power supply will also be included. This husky supply is designed to operate both the 811 modulator and the p-p 812 r-f stage (described in November Ham Tips).**
>
> **Be sure to contact your RCA Transmitting Tube Distributor for the next issue of Ham Tips!**

An elementary circuit for cathode modulation is shown in Fig. 1. If some a-f modulating voltage, e_m, is introduced in the cathode or filament-return circuit of an r-f amplifier, this a-f voltage will modulate both the plate voltage and the grid voltage of the stage. Let us assume that on the

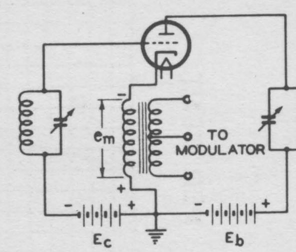

Figure 1

first half-cycle of the modulating voltage, the polarity of e_m is as indicated in Fig. 1. In the series circuit between the cathode and the plate, voltage e_m will *add* to the plate-supply voltage, E_b, because their polarities are correct for addition. The resulting increase in plate voltage will cause the plate current and amplifier power output to increase. In the grid circuit, however, e_m acts so as to oppose the grid-bias voltage, E_c. The resulting *decrease* in negative grid voltage will also cause the plate current and amplifier power output to *increase*. Thus, the effects of e_m on both the grid circuit and the plate circuit are *in phase*, because both effects tend to increase the amplifier power output. On the next half-cycle of modulating voltage the polarity of e_m is reversed, resulting

*See Reading List

(*Continued on page 3, column 1*)

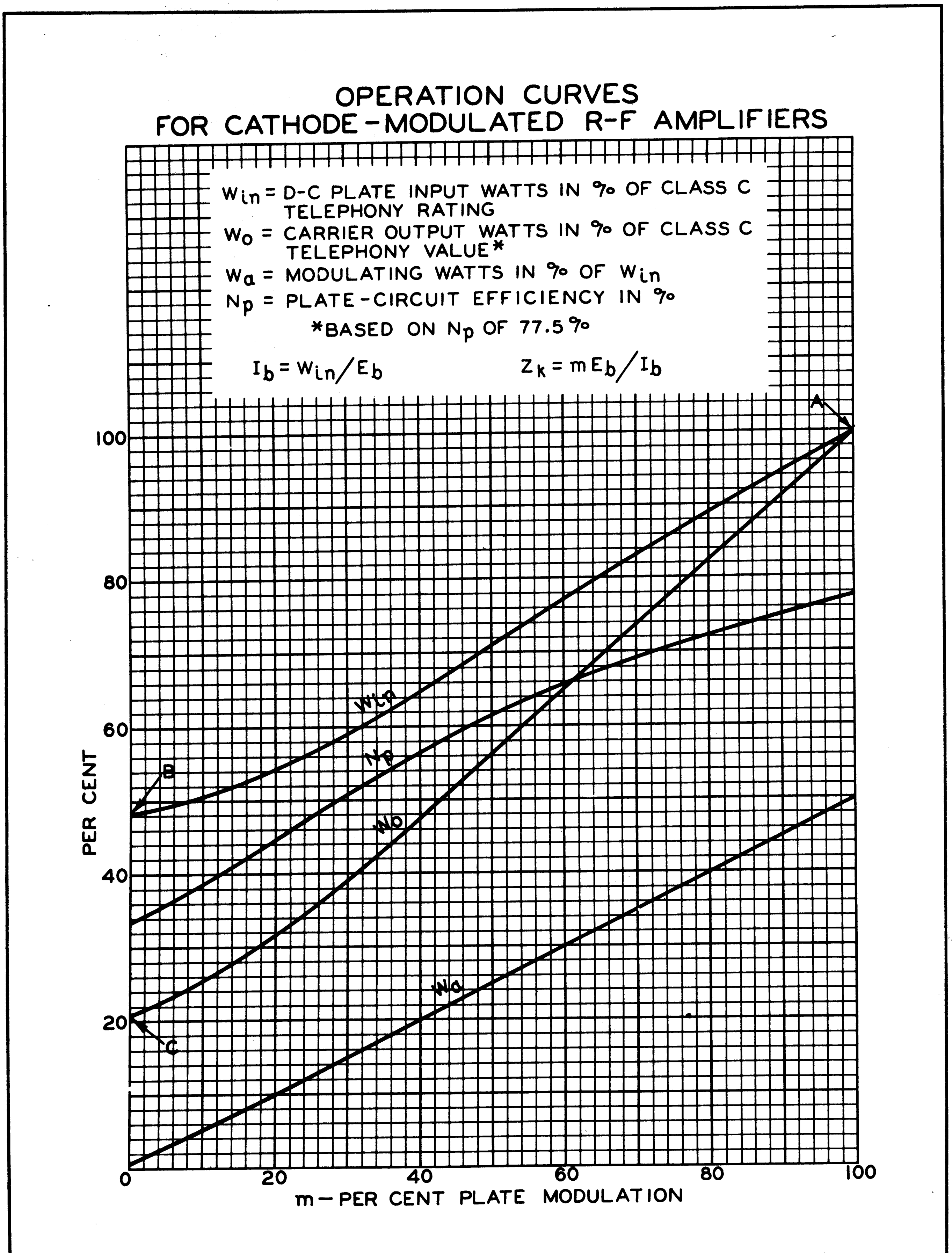
OPERATION CURVES
FOR CATHODE-MODULATED R-F AMPLIFIERS
Win = D-C PLATE INPUT WATTS IN % OF CLASS C TELEPHONY RATING
Wo = CARRIER OUTPUT WATTS IN % OF CLASS C TELEPHONY VALUE*
Wa = MODULATING WATTS IN % OF Win
Np = PLATE-CIRCUIT EFFICIENCY IN %
*BASED ON Np OF 77.5%
Ib = Win/Eb
Zk = mEb/Ib
A
B
C
Win
Np
Wo
Wa
PER CENT
0
20
40
60
80
100
m—PER CENT PLATE MODULATION

Figure 2

Cathode Modulation

(*Continued from page 1, column 4*)

in less plate voltage, a larger negative grid bias, and a *decrease* in amplifier output. In other words, the effect of modulating voltage e_m, acting in the cathode circuit, is to produce simultaneous, in-phase, grid-and-plate modulation. Thus, 100 per cent modulation of the carrier can be accomplished by a combination of, say, 40 per cent plate modulation with 60 per cent effective grid modulation. For this reason—and for other reasons which will become apparent as we go along—we can think of the cathode system of modulation as "grid-and-plate" modulation.

Comparison of Modulating Systems

It is necessary at this point in our discussion to consider both grid modulation and plate modulation for a moment. The salient characteristics of these systems of modulation are well known.

Grid modulation results in
- (1) Low power output
- (2) Low plate-circuit efficiency
- (3) Low audio power requirements

Plate modulation results in
- (1) High power output
- (2) High plate-circuit efficiency
- (3) High audio power requirements

For example, a grid-modulated RCA-812 has a carrier output of 25 watts at a plate-circuit efficiency of about 33 per cent. The a-f power required for 100 per cent carrier modulation may be only 1 watt or so. The same tube, plate modulated, has a carrier output of 120 watts at a plate-circuit efficiency of about 77 per cent, but the modulating power required for 100 per cent carrier modulation is nearly 78 watts. A cathode-modulated amplifier may be adjusted to operate at any suitable point between these two extremes.

Determination of C-M Operating Conditions

The question immediately arises as to how to determine the proper operating conditions for a cathode-modulated stage. To simplify the problems involved, the four curves of Fig. 2 have been prepared. These curves are useful because they show what happens to the d-c plate input (W_{in}), the carrier output (W_o), the modulating power (W_a), and the plate circuit efficiency (N_p), as the percentage of plate modulation ($_m$) is varied from zero to 100 per cent.

The data for the curves of Fig. 2 were obtained for an RCA-812, but have been plotted on a percentage basis so as to be applicable to any tube or tubes for which the class C telephony ratings are known. That is, point "A" on the W_{in} curve represents the *rated class C plate-modulated telephony power input*, or 155 watts for the 812. All other values along the W_{in} curve can be determined as the indicated percentage of the value at point "A". Similarly, point "A" on the W_o curve represents the class C telephony carrier output (based on a plate-circuit efficiency of 77.5%), or 120 watts for the 812. Other values on the W_o curve are found by taking the indicated percentages of the value at point "A".

Point "B" on the W_{in} curve and point "C" on the W_o curve represent the values for "pure" grid modulation (where "m" is zero %). For the example of the 812, W_{in} at point "B" is 75 watts, or about 48% of 155 watts;

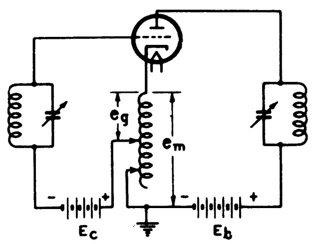

Figure 3

W_o at point "C" is 25 watts, or about 21% of 120 watts.

It is apparent that points "A", "B", and "C" are readily obtainable from the published values given in the tube bulletin. Intermediate points on the W_{in} and W_o curves were obtained as follows: In a test stage, a peak a-f voltage equal to ⅓ of the d-c plate voltage was applied to the plate circuit; this held "m" at 33⅓%. An in-phase grid-modulating voltage was then applied to the grid circuit so that an oscillograph pattern of the carrier showed 100% carrier modulation. This procedure was repeated for various values of grid bias, grid excitation, and plate loading until operating conditions were found which gave maximum power output without exceeding the tube's plate dissipation or producing objectionable distortion at 100% carrier modulation. The entire procedure was then repeated with "m" at 66%, or with 66% plate modulation. Thus, curves W_{in} and W_o provide data for the design of a cathode-modulated amplifier, expressed in terms of the class C plate-modulated telephony input and output.

Values for the plate-circuit efficiency curve (N_p) are easily obtained from the relation $N_p = (W_o/W_{in})(100)$, in per cent, where values of W_o and W_{in} correspond to various values of "m".

Data for the W_a (modulating power) curve are calculated from the relation

$$W_a = \frac{m}{2} W_{in} \text{ (approx.)}$$

where "m" is the percentage of plate modulation employed and W_{in} is the d-c plate input. This relationship is derived as follows (see Figs. 3 and 4): The a-f power, W_a, is equal to the product of the RMS a-f modulating voltage and the RMS a-f component of the plate current—that is, $W_a = (E_{ac})(I_{ac})$. If e_m is the peak a-f modulating voltage, $E_{ac} = e_m/\sqrt{2}$. Because the carrier is 100% modulated, the d-c plate current I_b is also modulated 100% (see Fig. 4). Therefore, the peak value of the a-f component of current is equal to I_b, and the RMS value is $I_{ac} = I_b/\sqrt{2}$. Thus,

$$W_a = \left(\frac{e_m}{\sqrt{2}}\right)\left(\frac{I_b}{\sqrt{2}}\right) = \frac{e_m I_b}{2}$$

Because $e_m = mE_b$, by definition of the plate modulation factor "m", we find that

$$W_a = \frac{m}{2} E_b I_b, \text{ or, } \frac{m}{2} W_{in} \text{ (approx.)}$$

This derivation neglects the fact that the cathode current flowing through the modulation transformer secondary is not I_b, but I_b plus the d-c grid current (I_c) of the r-f amplifier. However, since I_c is quite small compared to the d-c plate current, and since the grid current flows through only a small portion of the secondary winding (the part marked "e_g" in Fig. 3), it is permissible to neglect the effect of grid current in calculating W_a.

The equation for W_a is very interesting because it states that the modulating power required is m/2 times the d-c plate input to the cathode-modulated amplifier. The audio power required, therefore, varies with "m" and is not a fixed percentage of the d-c plate input. The commonly accepted "rule of thumb" for calculating the audio power states that W_a equals 10% of the d-c power input. This 10% rule is correct for the case where "m" is 20%, or where 20% plate modulation is employed. Reference to the curves of Fig. 2 shows that where "m" is 20%, the plate-circuit efficiency (N_p) is about 44%. This is somewhat lower than the commonly accepted figure of 50 to 60% for the efficiency of a cathode-modulated stage. Undoubtedly, N_p can be made as high as 50 to 60%, even when "m" is only 20%, provided the carrier is modulated slightly less than 100% and/or increased distortion is permissible.

Plate-Circuit Efficiency About 55%

The question is sure to arise as to just what constitutes a properly designed cathode-modulated r-f amplifier. It can be answered simply if we make the logical assumption that a typical cathode-modulated stage is one in which *the plate-circuit efficiency* (N_p) *is just half way between the 33% (approx.) of pure grid modulation and the 77% (approx.) of pure plate modulation—that is, 55%*. In order to have N_p equal 55%, we find from Fig. 2 that "m" *must be almost 40%*. The a-f modulating power, W_a, is then *20% of the d-c power input.*

Another circuit value which is of primary importance in the design of a cathode-modulated stage is Z_k, the *cathode impedance* of the r-f amplifier. Z_k, in ohms, is approximately equal to the peak modulating voltage divided by the peak a-f component of plate current in amperes. Thus,

$$Z_k = \frac{e_m}{I_b} \text{ or, } m\frac{E_b}{I_b}$$

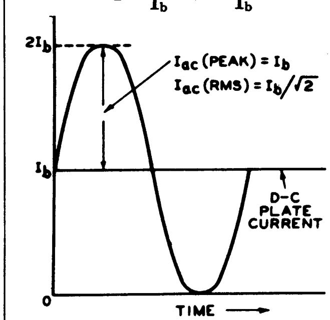

Figure 4

For a typical cathode-modulated r-f amplifier triode such as the RCA-812, operating at 1250 volts and 81 ma., Z_k turns out to be (0.4)(1250)/0.081, or 6180 ohms. Two 812's in push-pull or in parallel have one-half this cathode impedance, or 3090 ohms. If "m" is chosen as 20%, the values of Z_k become 3700 ohms and 1850 ohms, for the single 812 and the two 812's, respectively. To take an extreme case, a single RCA-852 operating at 2000 volts and 100 ma. has a cathode impedance of 8000 ohms (when "m" is 40%).

C. W. to 'Phone

Perhaps a practical way to design a cathode-modulated rig, especially where an existing cw transmitter is to be changed over to 'phone, is to begin with the largest modulator which we desire to use. Suppose this is to be push-pull 6L6's in class AB_2, delivering 55 watts of audio power. We then find, from the relation $W_{in} = \frac{2W_a}{m}$, that $W_{in} = \frac{(2)\cdot(55)}{0.4} = 275$ watts. This

(*Continued on page 4, column 1*)

Fig. 5—Comparative Performance of 2 RCA-812's, Push-pull

Plate Modulation Percentage (m)	20	40	100	
D-c plate voltage (E_b)	1250	1250	1250	volts
D-c plate current (I_b)	0.135	0.162	0.248	ampere
D-c plate input (W_{in})	169	202	310	watts
R-f carrier power output (W_o)	75	114	240	watts
Total max. plate dissipation required (W_p)	94	88	105	watts
A-f modulating power (W_a)	16.9	40.4	155	watts
W_a as a percentage of W_{in}	10	20	50	%
Plate-circuit efficiency (N_p)	44.5	56.5	77.5	%
Cathode impedance (Z_k)	1850	3090	5000	ohms
A-f power to *plate modulate* an equivalent carrier 100% (W_e)	48.5	73.5	155	watts
Ratio, W_a/W_e x 100	35	55	100	%
Total max. plate dissipation required to give equivalent carrier (W_o) in a plate-modulated stage (W_t)	33	49.5	105	watts
Plate-dissipation ratio (W_p/W_t) for equivalent carrier (F)	2.85	1.78	1	

Cathode Modulation

(*Continued from page 3, column 4*)

power is the maximum r-f amplifier input we can use with our 55-watt modulator, assuming "m" to be 40%. Let us assume, however, that Fig. 2 shows our r-f tubes to be capable of handling only 200 watts input. We must now resort to the relation

$$m = \frac{2W_a}{W_{in}}, \text{ or } m = \frac{(2)\,(55)}{200} = 0.55.$$

Thus, we can use 55% plate modulation and get a value of 64% for the plate-circuit efficiency (N_p). This means 128 watts of carrier output and 73 watts of plate dissipation—just about right *if* our push-pull final amplifier tubes are rated at 35 or 40 watts plate dissipation each. In other words, we can juggle the value of "m" up and down the scale until W_a is suitable for W_{in}, and until W_{in} is compatible with N_p *and* the rated plate dissipation of our r-f tubes.

Cathode-Modulated 812's

The curves of Fig. 2 will be found very useful in the design of any cathode-modulated triode r-f amplifier. As a specific example, suppose we are required to design a push-pull 812 rig so as to obtain an intermediate plate-circuit efficiency of about 56%, along with 100% carrier modulation and low distortion. Referring to the 812 tube bulletin, we find that the maximum ICAS values for plate-modulated class C telephony service are as follows (2 tubes):

D-c plate voltage (E_b)	1250 volts
D-c plate input (W_{in})	310 watts
R-f power output (W_o)	240 watts†

We already know that "m" is approximately 40%, or 0.4, for our typical cathode-modulated stage. Applying this value of "m" to the W_{in} curve of Fig. 2, we find that W_{in} is 65% of 310, or (0.65) (310) = 202 watts. Similarly, W_o is found to be 47.5% of 240, or (0.475) (240) = 114 watts.

The d-c plate current I_b is equal to W_{in} divided by E_b; hence, $I_b = 202/1250 = 0.162$ ampere. The audio modulating power equals $\frac{m}{2} W_{in}$, or $\frac{(0.4)\,(202)}{2} = 40.4$ watts. The cathode impedance into which our modulator must work is $Z_k = m\, E_b/I_b$, or (0.4) (1250)/0.162 = 3090 ohms. The same calculations have been made for the push-pull 812's using a value of 20% for "m", and all results tabulated in Fig. 5, for quick comparison with the 100% plate-modulation conditions listed in the fourth column of Fig. 5. The data in this table bring out several interesting facts. The ratio W_a/W_o is 55% when "m" is 40%. That is, the a-f modulating power required for such a cathode-modulated stage is only 55% as large as for a plate-modulated stage delivering the *same carrier output*. Only 35% as much a-f power is required for cathode modulation when "m" is reduced to 20%. In the latter case, however, the plate-circuit efficiency is reduced to 44.5%, because the tube operating conditions approach more closely those of pure grid modulation.

†Based on a plate-circuit efficiency of 77.5%.

Plate-Dissipation Comparisons

The factor "F" in Fig. 5 indicates the relative size (in terms of plate dissipation) of the tubes required for cathode modulation as compared to the size of tubes for a plate-modulated stage of the same carrier output. Where "m" is 20%, a cathode-modulated tube must have a maximum plate dissipation 2.85 times as large as the maximum plate dissipation of a plate-modulated tube. For example, a pair of plate-modulated 812's with an input of 310 watts will deliver a 240-watt carrier and must be capable of handling, at 100% modulation, a total plate dissipation of 105 watts. A pair of cathode-modulated 810's with an input of 450 watts will also deliver a 240-watt carrier, but they must be capable of handling (at zero modulation) a total plate dissipation of 300 watts. These figures check the value of "F" previously mentioned—that is, 300/105 = 2.85. When "m" is 40%, "F" is 1.78, the reduced value being due to the higher value of plate-circuit efficiency.

The tabulated data in Fig. 6 give a still better comparison of cathode modulation and plate modulation. It so happens that push-pull 809's, plate modulated, provide the same carrier output as push-pull 812's, cathode modulated. This table shows that the cathode-modulated stage requires 1.37 times as much d-c plate input and 1.78 times as much plate-dissipation, but only 0.55 times as much a-f power.

The d-c plate voltage employed for a cathode-modulated r-f amplifier can be the same as the maximum rated voltage for plate-modulated telephony service. The maximum rated plate voltage for class C telegraphy can be used if desired, provided $E_t + m\, E_t$ is not greater than $2\, E_p$, where E_t and E_p are the maximum rated voltages for telegraphy and telephony, respectively.

The maximum d-c plate current (I_b) for any cathode-modulated tube should never exceed the maximum rated current value for plate-modulated telephony. For example, 125 ma. is the maximum rating for a single RCA-812, cathode modulated. In most cases, of course, E_b is chosen first, W_{in} is determined from Fig. 2, and I_b is automatically fixed by the relation, $I_b = W_{in}/E_b$.

In order to obtain the desired percentage of plate modulation (m) in a cathode-modulated stage, it is necessary not only to have sufficient modulating power available, but also to adjust carefully the grid-return tap on the transformer secondary. The a-f grid voltage can be varied, as shown in Fig. 3, by means of a number of low-impedance taps on the cathode end of the transformer secondary. This winding should also include suitable taps to provide the desired value of cathode impedance.

The higher the "mu" or amplification factor of the r-f amplifier tube, the smaller the a-f grid voltage (e_g) required to produce a given percentage of effective grid modulation. The proper adjustment of a cathode-modulated stage, designed for any given value of "m", will occur when the value of e_g is the *minimum* necessary to produce 100% carrier modulation without unreasonable distortion. Careful adjustment of d-c grid bias, r-f grid excitation, and output loading are required in order to obtain correct operation. A cathode-ray oscillograph will be found of great assistance in making these circuit adjustments.

Conclusion

In our discussion so far we have been primarily interested in the mechanics of cathode modulation as regards what it is, how it is applied, and how it affects tube operating conditions. Of perhaps more importance in the final analysis, is the answer to the question, "Of what value is it?" Because the answer to this question depends on many external factors, we shall proceed on the basis of comparing cathode modulation (C.M.) to the system now in general use, i.e., plate modulation (P.M.).

It should clearly be understood that the following statements apply to modulated r-f amplifier stages having *equivalent carrier outputs*, as distinguished from a given type of tube modulated by one method or the other. C.M. requires larger r-f amplifier tubes having more plate dissipation capability, but uses considerably less audio-modulating power and a smaller, less expensive a-f transformer. C.M. requires a larger d-c plate input and a larger power supply for the r-f amplifier, but permits the use of a smaller, lower-voltage power supply for the modulator. A C-M stage is not quite as easy to adjust for optimum operation, but this is not a serious objection, especially where an oscillograph is available for test purposes. C.M. is much better suited for changing over a high-power cw transmitter to 'phone operation, where medium efficiency and power output are permissible, where low audio power is desired, and where the number and cost of circuit changes must be held to a minimum.

In the design of an entirely new 'phone transmitter, the choice between C.M. and P.M. for a given carrier output must necessarily depend on a *precise cost analysis* of each type of transmitter, complete in every important detail. The increased size of r-f tubes and their power supply for C.M. must be balanced against the reduced size of the modulator and its auxiliary equipment. One possibly important advantage of a C-M transmitter depends on the amount of cw operation contemplated. For example, referring to Fig. 6, let us assume that the *total net cost* of the plate-modulated 809 rig turns out to be *no more* than that of the cathode-modulated 812 transmitter. The 812 rig operated in class C telegraph service *will probably deliver an output of 230 watts*, whereas about 115 watts is all that could be obtained from the 809's, assuming that the plate voltage is not changed in either case. The plate current of the 812 stage would be pushed up to about 250 ma. This would not overload either the tubes or the power supply because in telegraph service the load is of an intermittent nature and the plate-circuit efficiency can be made quite high. The 812's would require somewhat more grid excitation, of course, but some surplus is usually available from the buffer stage.

Unquestionably, cathode modulation deserves far more attention than it has so far received, not only for use in amateur transmitters, but also in certain other specialized services. Mr. Frank C. Jones deserves much credit for the work he has done in focusing attention on this system of modulation.

Fig. 6—Plate-Modulated 809's Versus Cathode-Modulated 812's For Equivalent Carrier Output

Tube Type—2 in push-pull	809's	812's
R-f carrier output, watts	114	114
Type of modulation	Plate	Cathode
Carrier modulation, per cent	100	100
Percentage of plate modulation (m)	100	40
Percentage of effective grid modulation	0	60
D-c plate voltage, volts	750	1250
D-c plate current, milliamperes	196	162
D-c plate input, watts	147	202
A-f modulating power, watts	73.5	40.4
Plate-circuit efficiency, per cent	77.5	56.5
Plate dissipation at zero modulation, watts	33	88
Plate dissipation at 100% carrier mod., watts	49.5*	71.4**
D-c plate input ratio, C.M. to P.M.#	....	1.37
A-f power ratio, C.M. to P.M.#	....	0.55
Plate-dissipation ratio, C.M. to P.M.#	....	1.78

* At 100% carrier modulation, both the plate power input and the carrier output increase 50%. Thus, plate dissipation also increases 50%, since the efficiency is practically constant.

** At 100% carrier modulation, the plate power input increases only m/2%, or 20% where "m" is 40%. The carrier output, however, increases 50% as before. Thus, plate dissipation *decreases* about 19%. It is interesting to note that when $m = N_p$, the plate dissipation is *constant* at both zero modulation and 100% carrier modulation. When "m" is 68.5%, N_p is also about 68.5%. Under these conditions, the plate will operate at an *even temperature*, either with or without modulation.

\# This factor applies to any C-M stage where "m" is 0.4, or 40%.

READING LIST

(1) CATHODE MODULATION (a manual) by *F. C. Jones*, Pacific Radio Publishing Co., Inc., San Francisco, California.

(2) CATHODE MODULATION by *F. C. Jones*, RADIO, October, 1939.

(3) CATHODE MODULATION by *F. C. Jones* and *F. W. Edmonds*, QST, November, 1939.

(4) MORE ON CATHODE MODULATION by *F. W. Edmonds*, QST, December, 1939.