University of Arkansas
Bulletin

Vol. 23 MAY, 1930 No. 21

A PLATE MODULATION TRANSFORMER FOR BROADCASTING STATIONS

By LOY E. BARTON

Associate Professor of Electrical Engineering

1871

BULLETIN NO. 8
ENGINEERING EXPERIMENT STATION
FAYETTEVILLE, ARKANSAS

Published by the University of Arkansas. Issued bi-weekly. Entered at the Post Office at Fayetteville, Arkansas, as second-class matter under Act of Congress, July 16, 1894.

TABLE OF CONTENTS

CURVES

A Plate Modulation Transformer for Broadcasting Stations

INTRODUCTION

The problem of heterodyne interference of broadcasting stations assigned to the same frequency channel is probably the most difficult problem the stations have to confront. Because of the limitation of power output to reduce heterodyne interference the signal range for the average existing station can be increased considerably by increasing its modulation to a peak of 100 per cent and yet cause no more interference than now exists. Many of the newer stations are equipped to modulate their carrier to 100 per cent and a general use of high modulation should improve the heterodyne interference problem materially.

The Engineering Experiment Station at the University of Arkansas has developed a system with which 100 per cent modulation may be obtained, and believes it is the most economical system for high modulation.

The system permits the modulators to be driven as class "B" amplifiers and are coupled to the plate circuit of the radio frequency output stage by means of a special transformer.

EFFECT OF HIGH MODULATION

The loudspeaker signal strength from a broadcasting station with a given power output is essentially proportional to the variation of the antenna current or the percentage to which the antenna current is modulated. The requirements for the above condition are that the radio frequency carrier voltage applied to the detector is constant, that the input-output characteristic of the detector is essentially linear, and that the detector does not overload.

The high voltage detectors now commonly used meet the above requirements to a fair degree so that present radio receiving sets should receive broadcasting stations using high modulation with no more distortion than usually exists if the station uses low modulation.

The following example of a 1,000-watt broadcasting station will make clear what is meant by percentage modulation and the current and power conditions for various percentages modulation. If it is assumed that the antenna resistance of the above station is 10 ohms the antenna current may be found as follows:

$$I^2 = \frac{P}{R}$$

$I = 10$ amperes
where P = Power in the antenna (watts)
and R = Resistance of antenna in ohms.

With no variation of the above antenna current the received loudspeaker signal is zero and the percentage modulation is zero. If the peak variation of the antenna current above and below the 10 amperes is one ampere the modulation is 10 per cent and the loudspeaker signal may be taken as unity. If the peak variation in antenna current is 2 amperes the modulation is 20 per cent and the loudspeaker signal is double the signal at 10 per cent modulation. Such is the increase in loudspeaker signal from the above station until the peak variation of antenna current becomes 10 amperes or 100 per cent modulation and a loudspeaker signal 10 times the signal at 10 per cent modulation.

When the antenna current is caused to fluctuate according to a wave of any shape the average antenna current may remain the same, but the effective value of the current increases, therefore, increasing the average power input to the antenna. This increase in antenna power must be supplied by the modulators or the equivalent increase in power may be obtained by an increase in plate current to the power amplifier tubes or by an increase in average efficiency of the power amplifier tubes.

The following is a method of determining the increase in antenna power due to modulation when the modulating source is a sinusoidal audio wave of voltage. Referring to Fig. 1, the current I_1 is the effective value of the antenna current without modulation. The current I_2 is the maximum variation of the antenna current due to modulation from its normal value.

The effective current to the antenna is equal to the root mean square of the instantaneous currents.

Therefore $I = \sqrt{I_1^2 + \frac{1}{2}I_2^2}$ (1)*

$P_1 = I_1^2 R$ (2)

$P_2 = (I_1^2 + \frac{1}{2}I_2^2)R$ (3)

In which P_1 = Antenna power without modulation
and P_2 = Antenna power with modulation
then $P_2 - P_1$ = Power increase due to modulation.

---

*Derivation of this formula may be found in many of the radio text books.

In the above example of a 1,000-watt station a modulation of 10 per cent will cause a peak variation of 1 ampere in the antenna current and from formulas (2) and (3) the increased power due to modulation is 5 watts as shown below:

$$P_2 - P_1 = \tfrac{1}{2} I_2^2 R \qquad (4)$$

$$\therefore \quad P_2 - P_1 = 5 \text{ watts}$$

If plate modulation is used, the 5-watt increase in antenna power must be transferred thru the output radio frequency tubes whose plate to antenna efficiency is usually considered as 50 per cent. Therefore, the output required of the modulators in the above case is 10 watts audio power transferred to the plate circuit of the radio frequency output tubes.

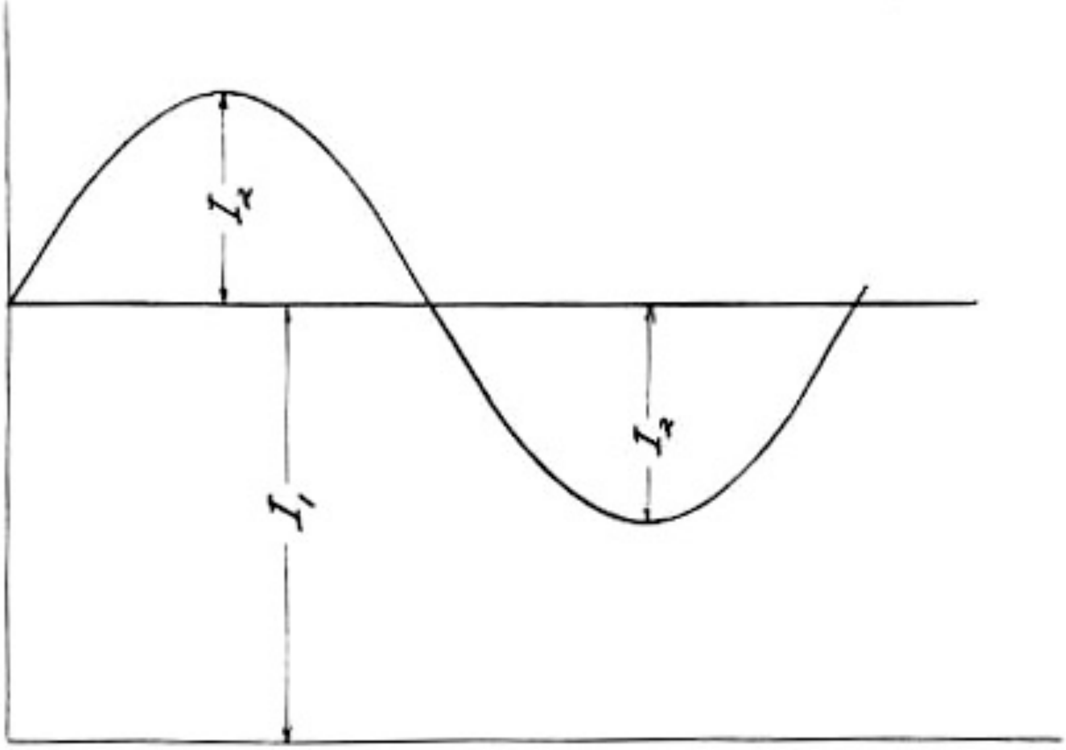

Figure 1.

The following table gives the necessary modulator power output to modulate the above 1000-watt station from zero to 100 per cent modulation if in the rating of the station a plate circuit to antenna efficiency is assumed as 50 per cent.

Per cent modulation	Modulator output required in watts
0	0
10	10
20	40
30	90
40	160
50	250
60	360
70	490
80	640
90	810
100	1,000

From the above table and formula (4) the audio power required of the modulator tubes is proportional to the square of the modulation factor. The modulator output increases so rapidly for an increase in percentage modulation, that it seems that there should be an economical limit for the percentage modulation. The following, however, indicates that 100 per cent modulation is the most economical degree of modulation. In the above assumed 1,000-watt station, a 100 per cent modulation produced a variation in antenna current of 10 amperes and the loudspeaker signal is proportional to this antenna current variation. In this case 1,000 watts modulator output power is required.

If a 10,000-watt station were connected to the above 10 ohm antenna, the antenna current would be:

$$I_1 = \sqrt{\frac{P_1}{R}} = 31.6 \text{ amperes.}$$

If 1,000 watts modulator power were used in the 10,000-watt station to modulate the plate circuit of the output tubes, the antenna power increase would be 500 watts and the antenna current variation is found by using formula (4).

$$\tfrac{1}{2} I_2^2 R = 500$$

$$I_2 = 10 \text{ amperes}$$

$$\text{Modulation} = 31.6 \text{ per cent.}$$

Therefore, the peak antenna current variation of a plate-modulated station is dependent only upon the power available from the modulator tubes provided I_2 of Fig. 1 does not exceed I_1.

The loudspeaker signal from the above antenna at a given point and distance from the antenna for the two power conditions will be the same provided that the receiver has the same sensitivity, that the detector does not overload, and that the detector characteristic is essentially linear. The detector may overload in the case of the higher power because the average radio frequency applied to the grid is 3.16 times that of the 1,000-watt station and the peak variation of applied voltage is the same in the two cases.

Although the loudspeaker signal in the above instances is the same, interference when receiving the higher power output with lower modulation will be approximately 3.16 times the amplitude of interference experienced in receiving the lower-powered station with high modulation. The higher antenna power will also cause heterodyne interference over a radius probably three times that of the lower-powered station, although the actual useful range of the two power conditions are essentially the same.

From the above discussion it seems evident that the most economical station design is an output power that can be modulated to a peak of 100 per cent. Such design is not only the most economical design for a given signal range, but the design tends to reduce interference at the receiver from other stations or static sources. The design also reduces the interference range of the station to a minimum.

TRANSFORMER METHOD OF PLATE MODULATION

The above discussion of the antenna power increase because of modulation indicates the necessity of obtaining the necessary audio power to permit high modulation of plate-modulated stations or the power increase may be effected by operating the radio frequency output tubes as class "B" amplifiers. The grid of the class "B" amplifier is driven by a modulated radio frequency signal from a lower power stage than the output stage. This type of amplifier limits the unmodulated output of a tube to about 25 per cent of its rating as an ordinary radio frequency power or class "C" amplifier and requires at least tubes equivalent to about 35 to 50 per cent of the size and number of tubes used in the output stage to properly control the grids of the output tubes. If the output tubes are used as class "B" amplifiers, a 1,000-watt station would require the equivalent of at least six 1,000-watt tubes. The above method of obtaining high percentage modulation is quite commonly and successfully used in many of the recent up-to-date broadcasting stations.

The transformer method of modulation as discussed in this bulletin permits the use of the modulators as class "B" audio or aperiodic amplifiers, the power output of which is about 5 to 10 times the audio power output of the tubes if used as an ordinary modulator or class "A" amplifier. If the radio frequency output tube is operated as a class "C" amplifier and the modulators are operated as class "B" audio amplifiers, a 1,000-watt station requires the equivalent of 3 to 4 1,000-watt tubes to deliver 1,000 watts to the antenna with a modulation of 100 per cent.

It is well at this point to define briefly the three types of amplifiers that are referred to above and that will be referred to frequently in the discussion to follow. The class "A" amplifier is the type used most in receiving sets and usual audio or radio amplifiers in which the average value of plate current does not vary appreciably when a signal is impressed on the grid and the grid is usually not driven positive. The output a.c. voltage bears a linear relation to the input a.c. voltage.

The class "B" amplifier is biased to essentially plate current cutoff and the average value of direct current varies with the input a.c. voltage. Plate current only flows during the positive swing of the input voltage. The grid may be driven positive until the output voltage begins to deviate from a linear relation with the input voltage. Since plate current only flows during one-half of the cycle, the plate circuit must be tuned to preserve the input wave form or if an audio or aperiodic amplifier is desired, two tubes must be used in a typical push-pull arrangement in order that plate current to one or the other of the tubes is flowing at all times.

The class "C" amplifier is biased to about double the value for plate current cut-off and the grid is driven to a degree that small changes in input voltage does not appreciably change the output voltage. This type of amplifier is the most efficient type, but the plate circuit must be tuned if sinusoidal voltage output is desired. For constant input voltage, the output voltage or antenna current is proportional to the plate voltage. Therefore, this type of amplifier is well adapted to plate modulation. If enough energy is taken from the output of a class "C" amplifier to drive its grid, the amplifier becomes the usual radio frequency oscillator.

CIRCUIT FOR PLATE-MODULATION TRANSFOFRMER

The general circuit used in coupling the modulators to the plate circuit of the radio frequency output stage is shown in Fig. 2. The plate-modulation transformer under discussion is represented by T and the primary is connected to the modulators in a typical push-pull manner. The secondary is connected in series with the d.c. plate supply for the radio frequency power amplifiers which may be separately excited at the desired radio frequency. The inductance L_1 is a radio frequency choke coil and C_1 is a by-pass condenser for radio frequency currents to ground. The circuit C_2L_2 is tuned to the desired frequency and power may be drawn from this circuit to excite an antenna. It is obvious that a suitable audio amplifier with a push-pull input transformer is necessary to drive the grids of the modulators. A turn ratio of transformer T may be selected to permit the optimum loading of the modulator tubes and if sufficient power is obtained from the modulators, a peak voltage in the secondary circuit may be made to equal the d.c. supply voltage to the radio frequency output tubes. This value of a.c. voltage in the plate circuit of the radio frequency output tubes is a condition for 100 per cent modulation. This condition means that the plate voltage to the output tubes will be zero for its minimum value and double the supply voltage for its maximum value. If the output tubes function properly the current in the antenna has a linear relation with plate voltage to the tubes.

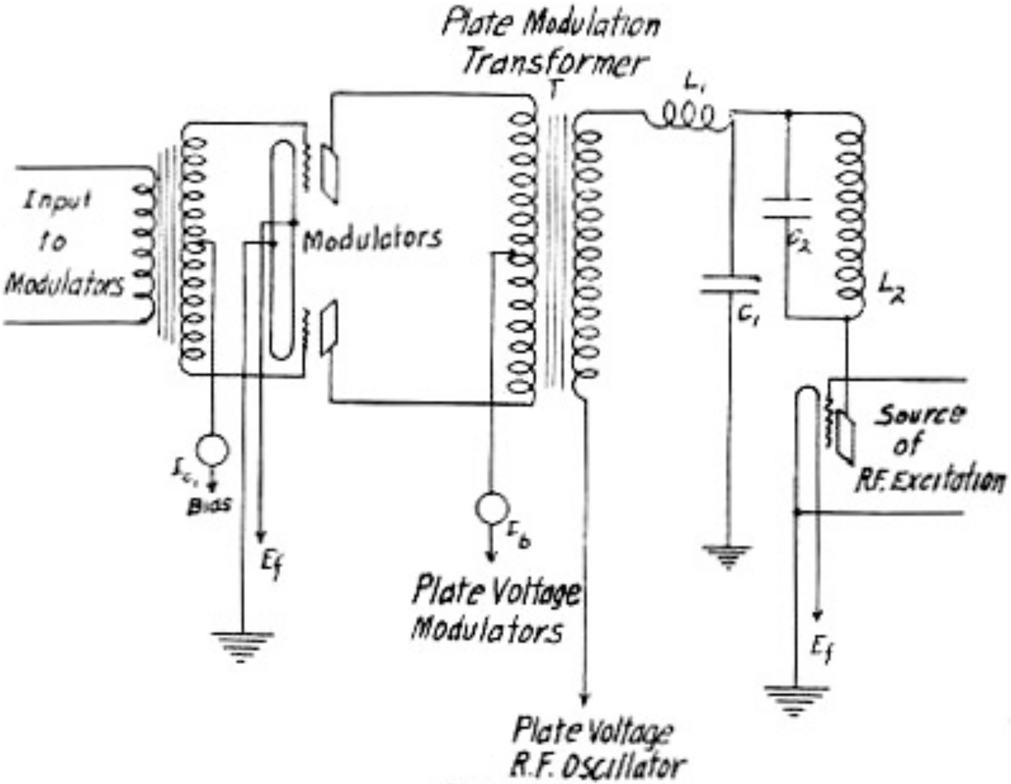

Figure 2.

In the preceding discussion on modulator power required for 100 per cent modulation of the plate circuit of a 1,000-watt station, it was found that 1,000-watt audio power was required. If the above transformer were used to couple class "A" amplifiers to the radio frequency system about eight to ten 1,000-watt tubes would be required to deliver the power. If, however, the modulators are driven as class "B" amplifiers, 1,000 watts modulator power may be obtained from two 1,000-watt tubes or even smaller tubes. The actual power output of two 1,000-watt tubes will be given and discussed later.

THE TRANSFORMER DESIGN

The design of the transformer is more or less a compromise between several factors controlling the design. Some of the more important items to be considered are discussed as separate items.

1. *Frequency characteristic:*—Good low-frequency response requires that ample number of turns be used for the primary in order that the reactance at low frequencies may be somewhat larger than the plate resistance of the modulators. However, at high frequencies, the reactance requirements may be met with fewer turns which will also reduce capacity effects of the winding. The requirements for low frequencies must be met and a type of winding must be used that reduces capacity between sections of the winds to a minimum.

2. *Flux density:*—The iron with which the transformer core is made, may saturate because of the direct current in the secondary and because of high a.c. flux densities. Low a.c. flux densities may be obtained by using many turns, but at the expense of high-flux densities due to the direct current in the secondary. It is necessary to resort to an air gap in the transformer core to reach a compromise for the number of turns to be used in the primary.

3. *Flux leakage:*—The flux leakage between primary and secondary may be high because only one-half of the primary functions at a time. Therefore, it is desirable to have the coils occupy a space as small and as near the core as possible.

4. *Insulation:*—The insulation is difficult to determine because of the above requirements of compactness and because of surges and radio frequency voltages that may reach the transformer.

The initial step in the design of the transformer is to determine the probable load resistance the tubes should work into. Without going into detail concerning the characteristics of a tube as a class "B" audio amplifier it may be assumed that the proper load resistance should be near the optimum load resistance of the tube as a class "C" amplifier. The approximate load resistance of the 1,000-watt modulator tubes the transformer was designed to work with, was about 1,500 to 2,000 ohms as a class "C" amplifier. Since the tube as a class "C" amplifier functions only a part of a half cycle for each cycle, the load resistance for the tube during the half cycle it functions is about 750 to 1,000 ohms. The class "C" amplifier is inherently more efficient than a class "B" amplifier so that a load of 1,000 to 1,200 ohms may be used as the load resistance for each modulator during the half cycle it functions.

If the transformer is expected to function to 30 cycles without a drop of more than about 30 per cent in frequency characteristic, the open circuit impedance should be at least 1,500 ohms at 30 cycles.

$$L = \frac{1{,}500}{2\pi f}$$

$$L = 8 \text{ henries.}$$

In order that a relatively few turns be used and that the a.c. flux density be kept low, a core of large cross-section is necessary. The following fundamental formula may be used to determine the inductance of a coil in which the coupling between turns is 100 per cent.

$$L = \frac{1.26 N^2 \mu A \times 10^{-8}}{l} \text{ henries} \tag{5}$$

In which

L = Inductance in henries

N = Number of turns

μ = Permeability of the core (effective a.c.)

A = Area of cross-section of core in sq. cm.

l = Length of magnetic path in cm.

After several preliminary estimates and calculations, the cross-sectional area of the core was made 4 inches by 7 inches or a net of about 140 sq. cm. of iron allowing for varnish on the laminations. The total length of the magnetic path was also chosen as approximately 140 cm.

A formula which gives the maximum flux density for a given number of turns, area of cross-section, voltage, and frequency is given as follows:

$$B_{m_{a.c.}} = \frac{10^8 E}{4.44 A f N} \text{ Lines per sq. cm.} \tag{6}$$

E = Effective voltage across N turns

f = Frequency.

Since $B_{m_{a.c.}}$ is inversely proportional to frequency, the lowest frequency that is expected to be reproduced should be used in the calculations. A frequency of 30 cycles was considered as low as need be reproduced.

The flux density due to the direct current in the secondary of the transformer is found by the formula

$$B_{m_{d.c.}} = \frac{1.26 \times N I \mu}{l} \tag{7}$$

In which

I = Average d.c. amperes through secondary.

The flux density given by formulas (6) and (7) will oppose each other at times and will add during the next half cycle, therefore, the sum of $B_{m_{a.c.}}$ and $B_{m_{d.c.}}$ should not reach the saturation point of the iron used for the transformer core. The peak permissible flux density of the iron used in the transformer was 10,000 lines per sq. cm. It is more convenient to consider the secondary first, because it carries the direct current of one ampere for the 1,000-watt station and a peak a. c. voltage of 2,000 or an effective voltage of 1,414 volts will be induced on the winding for 100 per cent modulation if the plate supply is 2,000 volts. Assuming that the flux densities due to a.c. and due to d.c. are equal and have a value of 5,000 lines per sq. cm. each, the approximate number of turns, N, found from formula (6) is 1,500.

From formula (7) using the above value for N

$$\frac{\mu}{l} = 2.65$$

Substituting the above value of $\frac{\mu}{l}$ in formula (5) with other calculated and assumed values,

$$L = 10.5 \text{ henries approximately}$$

and $$\mu = 370.$$

The a.c. permeability of the iron used at 30 cycles was about 2,000 so that an air gap was necessary to reduce the permeability to about 370.

The load on the secondary of 1,500 turns is 2,000 ohms for a plate current of one ampere at 2,000 volts and if each modulator is to have a load of 1,200 ohms the turns on each side of the transformer primary are

$$\sqrt{\frac{1{,}200}{2{,}000}} \times 1{,}500 = 1{,}115 \text{ turns}$$

and $$\frac{1{,}200}{2{,}000} \times 10.5 = 6.3 \text{ henries primary inductance.}$$

The above primary inductance for each side of the primary is below the limit of 8 henries set above. Because of the type of winding chosen, it was convenient and desirable to use 1,680 turns on the secondary and 1,220 turns on each side for the primary. The above winding on each side of the primary, according to formula (5), has an inductance of about 7 henries, which is somewhat lower than the initial calculations of what the inductance should be. However, it should be kept in mind that a slight change in air gap will change the inductance as will other variable factors.

The above calculations are given to indicate the method by which the transformer windings were determined. It is somewhat diffiffcult to approximate very closely the effective a.c. permeability used in formula (5) and it is also difficult to determine an accurate leakage factor.

TRANSFORMER CONSTRUCTION

A sketch of the transformer as built is shown in Fig. 3. A form was made of flat bakelite ¼ inch thick with four sections

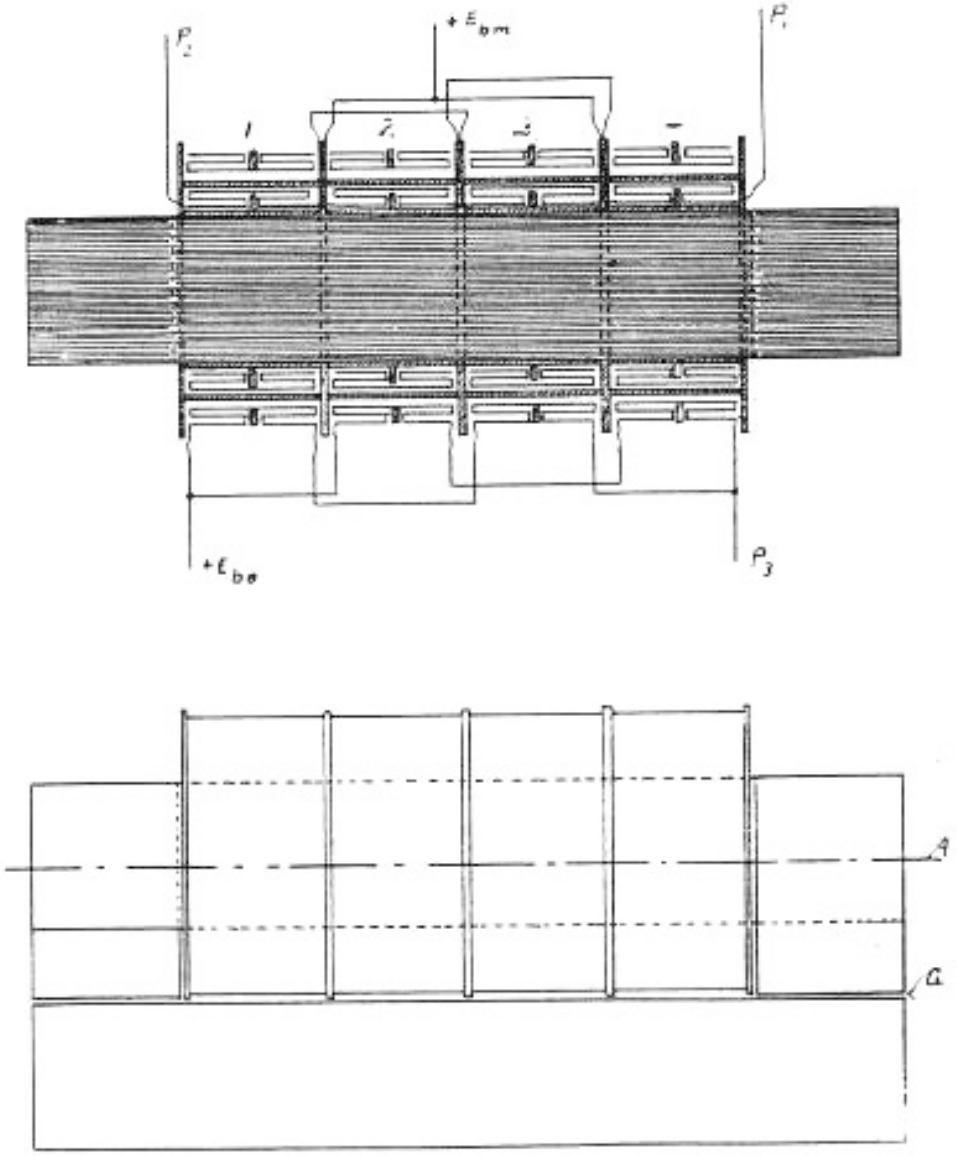

Figure 3.

on which to place the winding and with an opening thru the center 4 by 7 inches for the core. Each section contained a certain portion of primary and secondary winding. The winding next to the core represents the primary and the outer winding represents the secondary with insulation between the windings. As stated above, high voltages between turns is not desirable because of capacity effects and also insulation requirements. It is also necessary to obtain close coupling of the windings. The method of winding is explained below and apparently meets the above requirements satisfactorily.

Beginning the primary at the left in Fig. 3, the lead P_2 was taken through the bakelite end and a layer of wire was wound extending to the insulated spacer in the center of section 1. From this point a layer was wound back over the first with paper insulation between and so on until five layers were wound. The beginning of the other half section was brought in thru the bakelite spacer between sections 1 and 2 and a layer started at the spacer toward the insulated spacer at the center of the section. Another layer was wound back over the first until five layers were wound. The second half of the section was wound in the proper direction so that the finish of the two windings could be connected and make the winding continuous from left to right. The primary of the other three sections was wound as above and in a direction so that the winding would be continuous from left to right, but with the leads for each section brought out.

Since only half of the primary functioned at a time, the leakage was reduced by connecting sections 1 and 3 in series for one modulator. and sections 2 and 4 in series for the other modulator tube. Then P_2 would connect to the plate of one modulator tube, P_1 to the plate of the other modulator tube, and E_{bm} to the plate-supply generator.

The secondary winding was wound in sections similar to the method used in winding the primary, except that the terminals of each section were taken from the outside layers as indicated in the sketch. Seven layers were wound for each section of the secondary and leads brought out for each section as indicated. Sufficient turns were placed in each section of the secondary to permit a series-parallel connection of sections for the proper secondary impedance. The method of connecting the secondary sections permitted a much closer coupling of primary and secondary than would have been possible if the secondary had been one continuous winding. One end of the secondary, E_{bo}, connects to the plate-supply generator and the other end of the secondary, P_3, connects to the radio frequency output tubes.

The primary was wound with No. 22 B. & S., D.C.C. copper wire and consisted of 620 turns per section or 1,240 turns per each side of center or plate supply point. The secondary was wound with No. 22 B. & S., D.C.C. copper wire and consisted of 840 turns per section or 1,680 turns as secondary, but with another 1,680-turn group in parallel with the first.

The core consisted of rectangular stampings of high silicon transformer steel 4 by 24 inches to place inside the winding. The winding form was 20 inches long so that alternate laminations extended 4 inches beyond the form. The end laminations consisted of alternate rectangular pieces 4 by 6 inches and 4 by 2 inches, and were fitted into the ends of the core in such a way that the built-up core was essentially a solid inverted U. The magnetic path was completed by rectangular laminations 4 by 28 inches with a air gap at both ends indicated by *G*. All the laminations were .014 inches thick.

The assembled transformer is shown in the photograph, Fig. 4, in which the general method of assembly and clamping may be seen. The transformer weighed approximately 500 pounds, which probably can be reduced considerably if designed for commercial application. The temperature rise of the transformer after three or four hours normal operation in a 1,000-watt station, was not over 10 degrees centigrade indicating that the design was quite liberal. Although the transformer core was clamped tightly, the audible sound emitted from the transformer was so loud that it had to be removed from the trans-

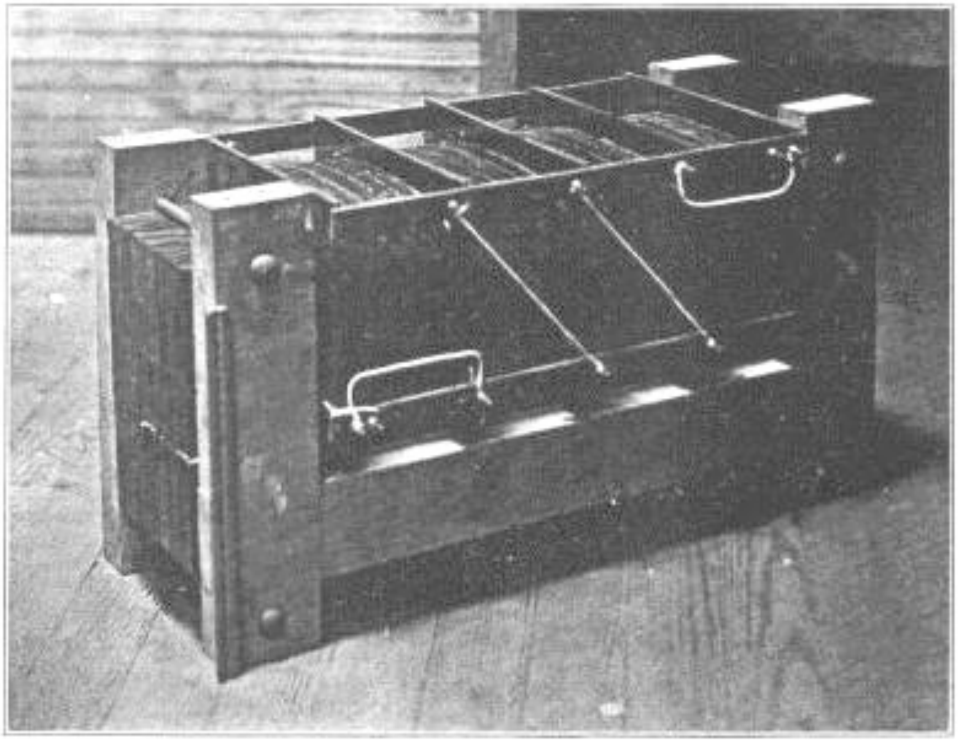

Figure 4.

mitting room in order that it would not cause interference with sound from the monitoring loudspeaker.

TESTS

The results obtained by coupling the modulator tubes as class "B" amplifiers to the plate circuit of the radio frequency tubes by means of the above transformer have been quite satisfactory from the listeners' viewpoint. The above results were based upon reports of regular listeners and upon listeners from practically every state in the United States who happened to tune in on many of the early morning test programs. The listeners were unanimous in reporting that the signal was unusually loud for a 1,000-watt station and that the signal was clear.

The nature of the reports by the listeners indicated that the high modulation was effective in covering distances, but in order to know definitely the power capabilities of the modulators, the frequency characteristic, and the actual percentage modulation several measurements were made on the station and modulators.

It is well at this point to give a brief description of the audio system used in making the measurements. The signal source consisted of a beat frequency audio oscillator which supplied a signal to the studio end of the line leading to the input of the audio amplifier in the transmitting room. The transmitting room amplifier consisted of a volume control, line-to-tube transformer, one UX210 stage of audio amplification driving two UX210 tubes in push-pull which in turn drove two UV211 tubes in push-pull. The output of the UV211 tubes was fed thru a 3 to 1 step-down transformer, the secondary of which was connected to the grids of the modulators in a push-pull arrangement. The low impedance output from the tubes used to drive the modulators was necessary because at high outputs the grids of the modulators drew about 140 milliamperes. The grid current had to be supplied without an appreciable drop in signal voltage delivered by the UV211 stage; otherwise, serious distortion would have resulted. Another important factor was to keep the resistance of the bias voltage source for the modulators as low as possible so that when grid current flowed the bias on the tubes did not change appreciably.

The output power measurements of the modulators driven as described above and with a resistance load on the secondary of the transformer are given in Fig. 5. The power output was calculated from the measurement of current thru the load resistor of known value. The modulator tubes were biased to a plate current of about 20 milliamperes for each tube. The bias required on one tube was about 80 volts while the bias required on the other tube was about 94 volts. It is obvious that the tube with the lower bias would start taking grid current first, but no apparent difficulty was experienced because of the difference in bias required by the two modulator tubes.

Two load resistances were used for the curves in Fig. 5 that indicate the power output levels at which distortion becomes serious. In order that no appreciable distortion occurs from the signal generator to the output of the transformer the curve of output current against input volts should be essentially straight. It is probable that no appreciable distortion would occur until about .85 amperes output was reached or a peak-power output

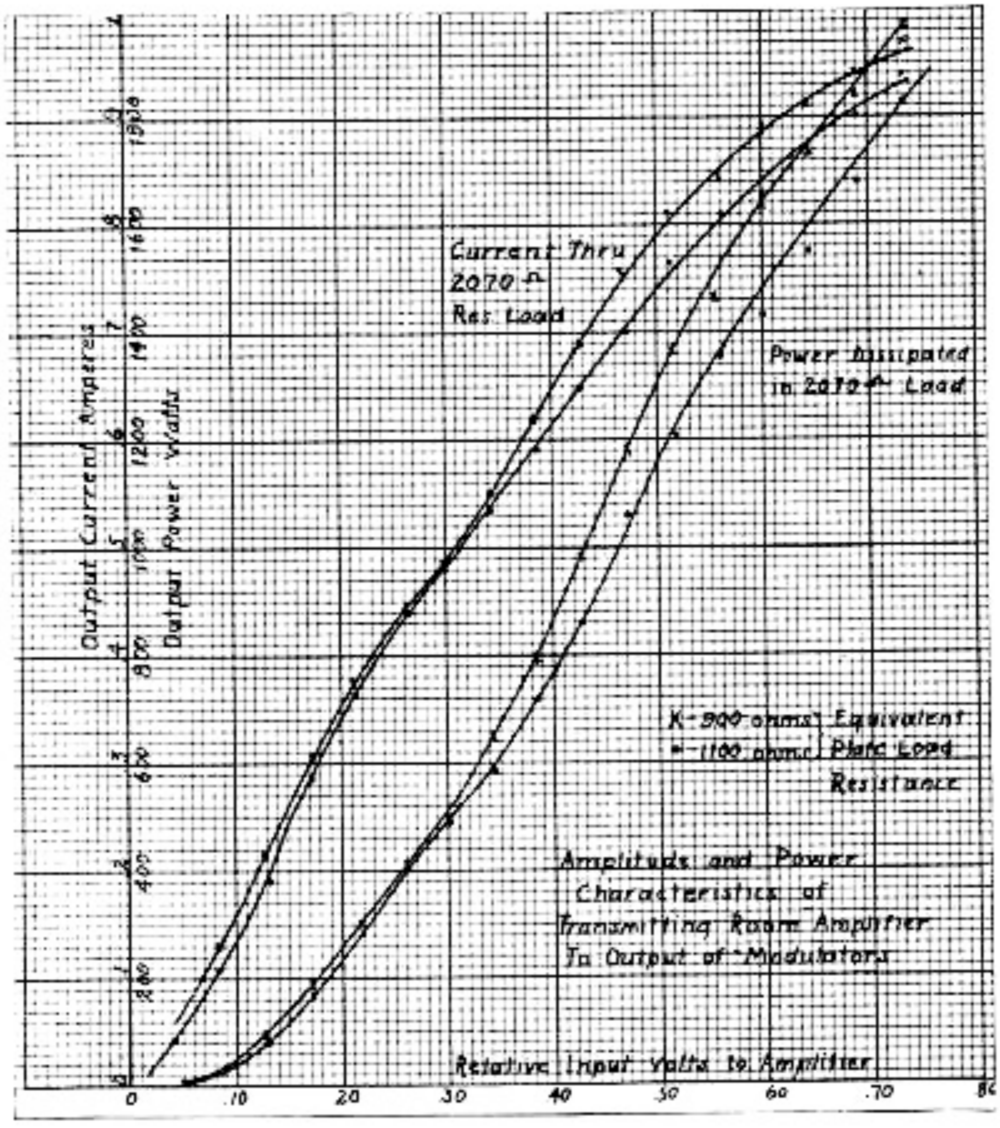

Figure 5.

of approximately 1,500 watts from the two tubes. There also seems to be little choice between the two load resistances. It should be noted that 1,000 watts output of the modulators is all that is required to modulate a 1,000-watt station to 100 per cent modulation or an output current of about .7 amperes in Fig. 5.

Fig. 6 indicates the variation of plate and grid currents for the curves of Fig. 5 with the load resistance of 900 ohms per tube. It is interesting to note that the grid current in Fig. 6 starts at about .175 volts input to the amplifier and that the corresponding power output in Fig. 5 is about 200 watts. This power is the maximum output rating of the tubes when used as class "A" amplifiers with no grid current to the tubes. There-

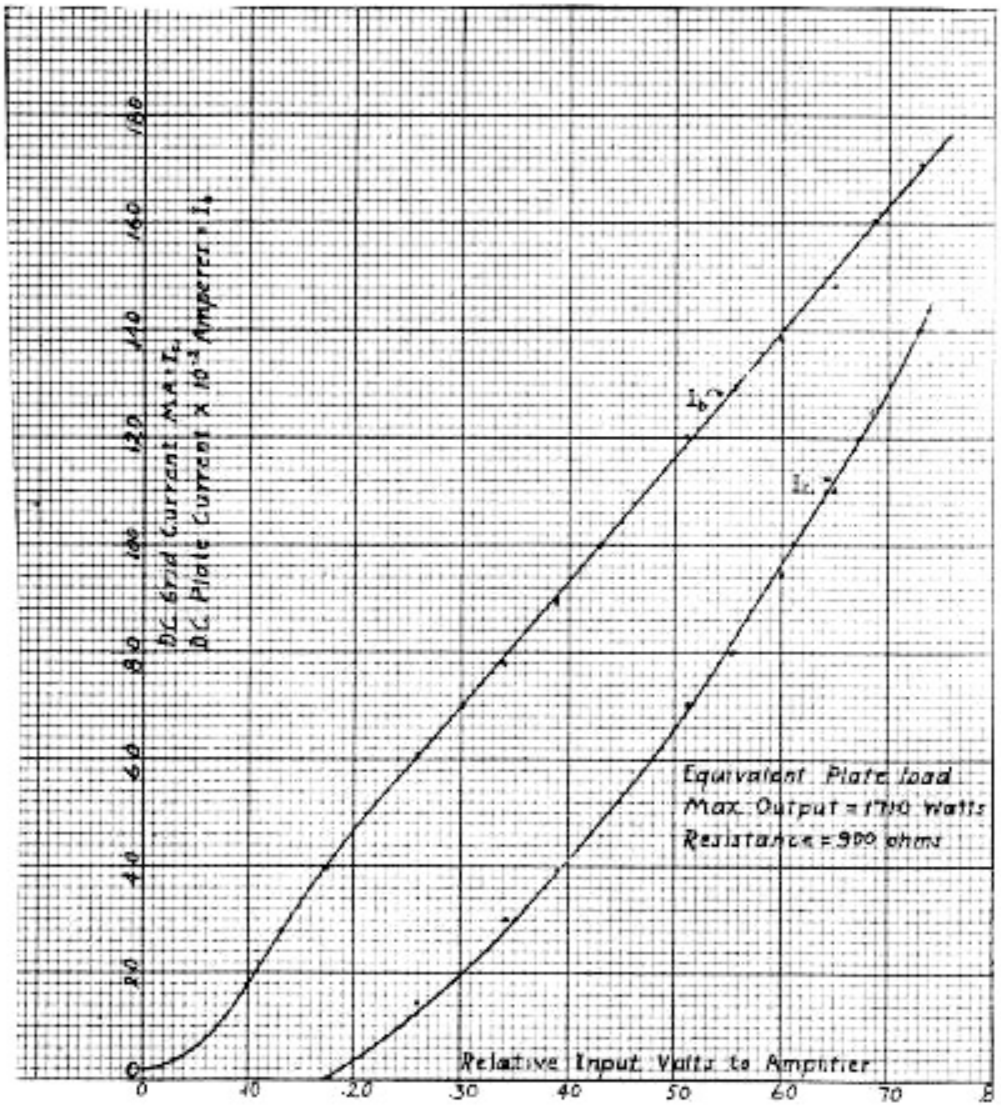

Figure 6.

fore, the greater output from the tubes driven as above is readily appreciated.

The frequency characteristic of the system including the amplifier and transformer as above and at a 428-watt output level at 1,000 cycles is given in Fig. 7. The curve is the frequency characteristic of the entire transmitting room audio amplifier as described above and is flat enough for all practical purposes.

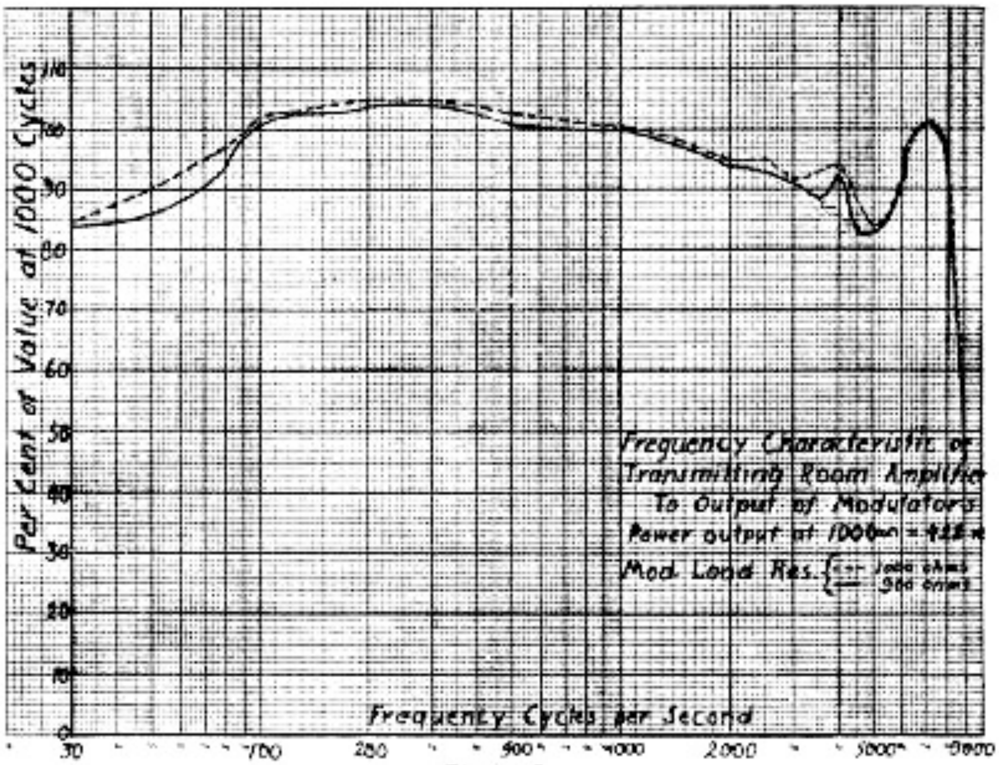

Figure 7.

The above measurements indicate the power capability of the modulators with the special transformer and can easily vary the plate supply voltage to the radio frequency power amplifier from zero to 4,000 volts when the supply is 2,000 volts. It is expected that such a variation will result in a corresponding variation in antenna current, but the plate current requirement of the radio frequency tubes was rather severe at peak plate voltage double that of the normal voltage. The peak plate current, however, required of the tube was reduced 50 to 70 per cent by the use of a special filter as reported in a bulletin* published recently.

A simple antenna and rectifier system in connection with a standard General Electric Company oscillograph was used to

---

*University of Arkansas Engineering Experiment Station Bulletin No. 7.

take oscillograms of the modulated carrier as transmitted from the University of Arkansas broadcasting station, in which the transformer has been used since February, 1928. The rectified radio frequency current was about 40 milliamperes with no modulation.

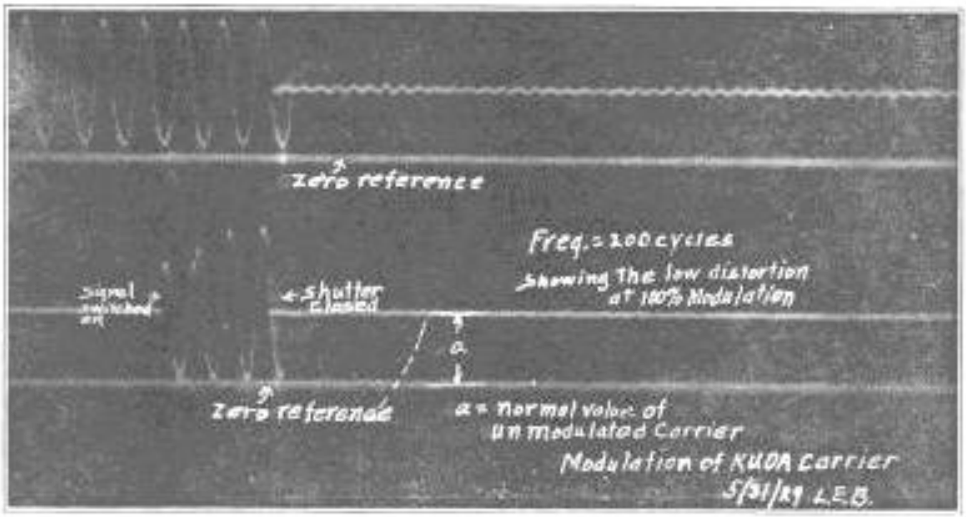

Figure 8.

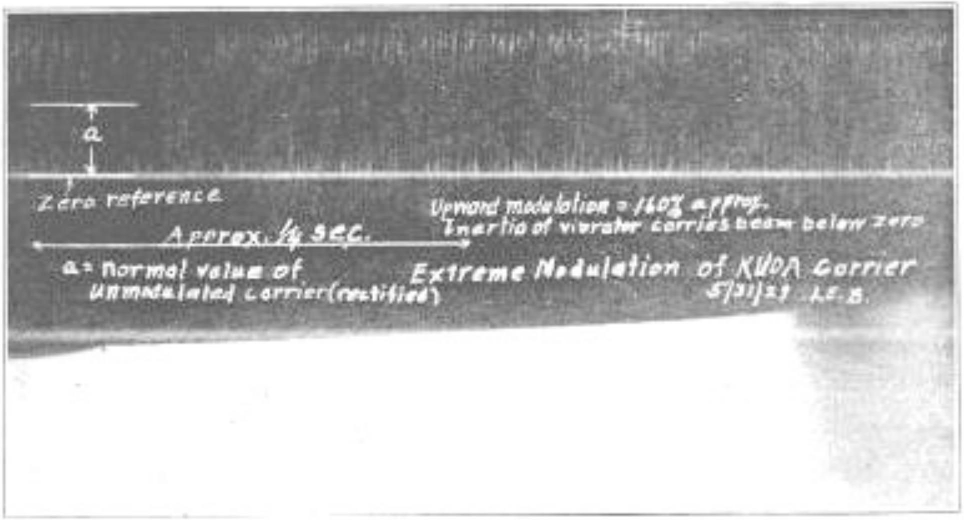

Figure 9.

Fig. 8 is an oscillogram of the carrier modulated to essentially 100 per cent at 200 cycles. It can be readily seen that the distortion of the wave is not serious at such amplitudes and that most receivers would not reproduce the wave with a fidelity as good. Fig. 9 is an oscillogram with an extreme modulation of the carrier with orchestra music. Although the quality was hardly passable, the test did indicate that if the modulators do

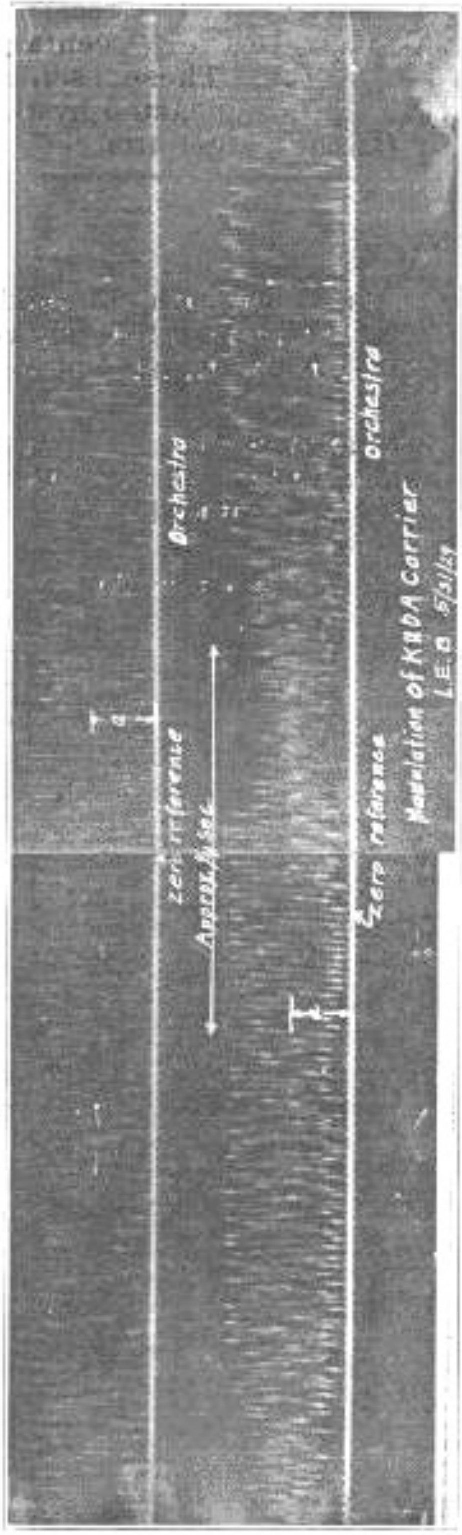

Figure 10.

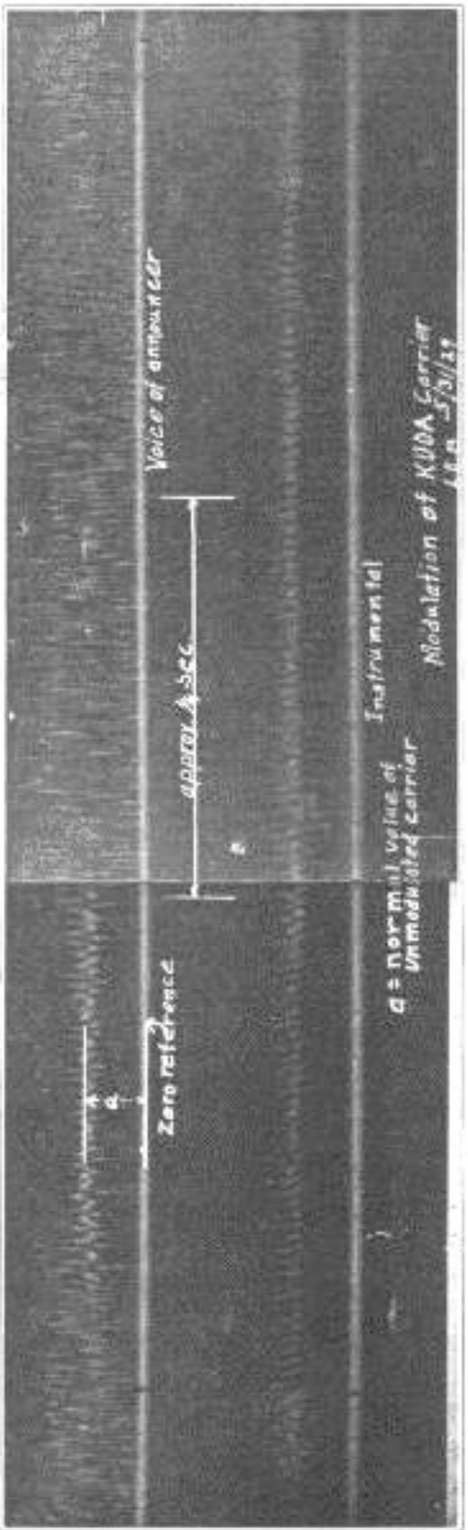

Figure 11.

not over load, the upward modulation may be fully 100 per cent or more on peak signals without serious effects on the received signal. Figures 10 and 11 are given to indicate the percentage modulation the station attempted to maintain. These oscillograms were taken during a regular program broadcasted by the University station, but an attempt was made to get the record during periods of loud signals.

CONCLUSIONS

The use of the plate modulation transformer with the modulator tubes operating as class "B" amplifiers as described above seems to be the most economical means of obtaining 100 per cent modulation with good fidelity.

The plate supply must be well regulated so that the plate voltage will remain constant to the modulators as well as to the radio frequency out-put tubes at times of peak modulator plate currents or peak signals.

The plate dissipation of the modulator tubes varied with the amplitude of the signal and did not exceed the rated plate dissipation on peak signals. At sustained peak signals the normal plate dissipation was reached and the plates attained a normal operating color. However, since sustained peak signals were not usually obtained, the plates of the tubes only showed varying degrees of slight color. Therefore, the life of a tube should be prolonged considerably by using the tube as a class "B" modulator.

After using the above system of modulation for the past two years no inherent difficulty with the system has been experienced and high modulation is very desirable because of the increased signal range and a lower static interference for a given loudspeaker signal.

The general use by the broadcasting stations of the above system of modulation or any other system which permits high modulation should result in a minimum of heterodyne interference. In other words, if the existing broadcasting stations were required to reduce their power to a point at which its modulator system would permit 100 per cent modulation of the carrier, the signal range of the stations would not be decreased, but the interference range of the average station should decrease 50 per cent or more.