Design and construction of an experimental radio transmitter for Montana State College
by Robert Bertrand Edwards

A THESIS Submitted to the Graduate Committee in partial fulfillment of the requirements for the Degree of Master of Science in Electrical Engineering
Montana State University

Abstract:
The problem set in this thesis is the design and construction of a radio transmitter for Montana State College. The transmitter complies with the Federal Radio Commission's regulations, and is suitable for general experimental use.

Through this instrument the writer was enabled to experimentally attack the problem of negative regeneration and carrier control.

No given design is copied in the construction of this transmitter.

The circuits and arrangement of equipment are governed by the material available, the appropriations allowed, and the plans for carrier control and negative regeneration.

The design follows only the fundamentals of circuit theory and design practice and involves some original ideas on carrier control.

Part II of the thesis gives a brief description of the transmitter.

The description covers the general characteristics and the special features involved in the operation of the instrument.

Part III gives a discussion of carrier control and negative regeneration and explains the theory and assumptions that governed the. experimental work.

Part IV takes up a discussion of the experimental work and gives the results of the tests that were made on the carrier control and negative regeneration equipment.

DESIGN AND CONSTRUCTION OF AN EXPERIMENTAL RADIO TRANSMITTER FOR MONTANA STATE COLLEGE

by

ROBERT B. EDWARDS

A THESIS

Submitted to the Graduate Committee in
partial fulfillment of the requirements
for the Degree of Master of Science
in Electrical Engineering at
Montana State College

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PART I

INTRODUCTION

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PART II.

DESCRIPTION OF TRANSMITTER

The transmitter here described, operates under the call letters W7XB and was redesigned and rebuilt primarily for telephone communication. It can be used as a telegraph transmitter, however, if it is desirable. The transmitter is a crystal controlled, 100% modulated, short wave machine and is made to operate from a 110 volt, 60 cycle, single phase, A. C. power supply.

The transmitter was designed principally to operate on 8,655 and 17,310 kilocycles frequency, but can be operated at any of the assigned frequencies if a suitable antenna, crystal, and coils are substituted for the ones now in use.

The normal power output as a telephone transmitter is from 20 to 25 watts at 8,655 kilocycles frequency and from 15 to 20 watts at 17,310 kilocycles frequency. At 100% modulation the instantaneous peak power is four times the above given values. These values are for unmodulated carrier power.

The carrier control, power output of the transmitter is about one fourth of the normal power output.

A complete schematic wiring diagram of the transmitter is shown in Figure 1. A description of the various parts, shown in Figure 1, is given in the appendix. A simplified, schematic, wiring diagram of the carrier control and negative, regeneration circuits is shown in Figure 3. The notation on parts is the same in both Figure 1 and Figure 3.

When the switch, S_1, (Figure 1 or 3) is thrown to the ground position, the carrier wave of the transmitter is "off the air", except when the transmitter is modulated. This provision allows the transmitter to be used as an i. c. w. telegraph transmitter and also serves as a means of carrying on a two way, break in, telephone conversation. When S_1 is thrown to the resistance position, the transmitter emits a continuous carrier, the same as any normal telephone transmitter.

The transformer, TR_2, and the resistance, R_{21}, (Figure 1 or 3) serve as distortion correction devices. When carrier control is used, their use is very necessary, if satisfactory telephone communication is desired. Their use is beneficial in normal telephone modulation, but is not necessary in telegraph communication.

If the primary winding of TR_2 is disconnected, R_{21} can be used for noise suppression and secondary, emission correction. These uses of R_{21} are only necessary when a faulty filter is used in the power supply or a defective tube is used in the power amplifier stage. A more complete discussion of carrier suppression, negative regeneration, noise suppression, and secondary emission correction is taken up in Part III and Part IV.

A study of the modulated amplifier diagram of Figure 3 will disclose that simultaneous screen and plate modulation is used. This method of modulating a screen-grid tube, is the only one that gives good quality at 100% modulation. The writer assisted Mr. R. J. Kircher at the Bell Telephone Laboratories in some experimental work on modulation of screen-grid tubes. The use of the screen-grid potentiometer gave the most satisfactory results.

H. A. Robinson (4) obtained good results using a series screen-grid resistance. The potentiometer method is incorporated in the transmitter, being described, as it is believed to be the superior method.

The use of a screen-grid tube is not necessary in carrier control modulation, but was used in this transmitter because the materials available, and the associated equipment, made its use desirable. This method of modulating a screen-grid tube is not well known, but it is believed that the method will become more popular in the future.

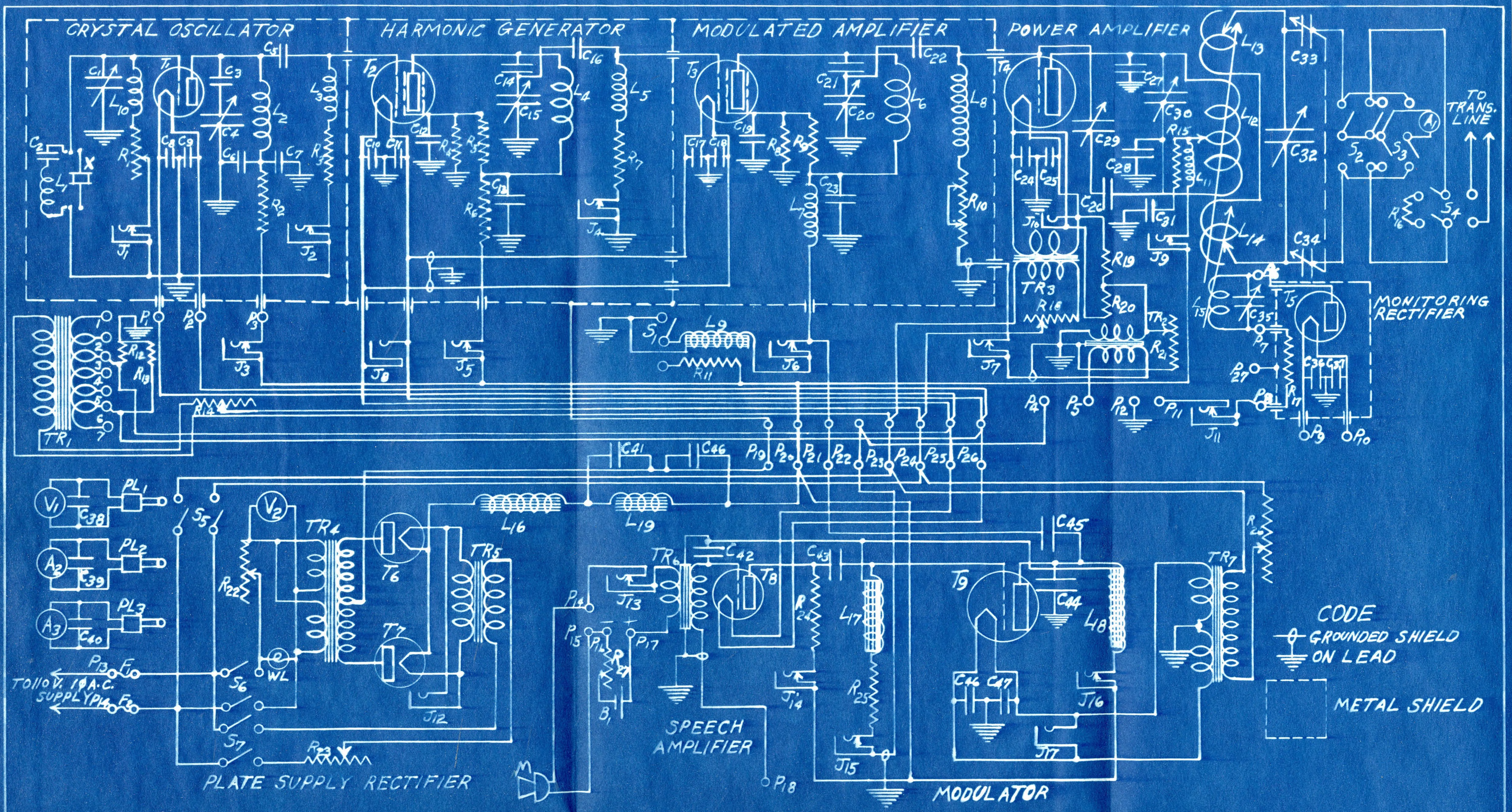

FIGURE 1

SCHEMATIC WIRING DIAGRAM OF RADIO STATION W7XB
MONTANA STATE COLLEGE
BOZEMAN MONTANA

PART III

CARRIER CONTROL AND NEGATIVE REGENERATION

In some forms of radio telephone communication, it is desirable to have the carrier wave of the transmitter shut off when the transmitter is not being modulated. This is especially true in cases where the receiver is located close to the transmitter and has to receive a signal whose frequency is close to that of the transmitter. Carrier control also has certain other advantages such as a reduction in the requirements for noise suppression in the transmitted carrier and a saving in power costs of operating a high powered transmitter. In the case of carrier noise due to poorly filtered power supplies, it is apparent that the noise will not be noticeable if the carrier should be shut off when no modulation is taking place. A saving in power can be realized with a transmitter using low level modulation if the radio frequency current is suppressed in one of the amplifier stages ahead of the large power amplifiers. This is due to the fact that the power amplifiers are operated in such a manner as to cause the plate current to decrease considerably when the radio-frequency drive is removed from the grids.

Carrier control is desirable in trans-oceanic, ship to shore, amateur and aeronautical radio telephone communication and has been accomplished by means of voice or hand operated relays. These relays change grid bias on amplifier tubes or on thyrotron rectifier tubes, which in turn, shut off the plate current to the amplifier tubes.

The present methods are satisfactory in operation, but are complicated, expensive, and easy to get out of adjustment. A method has been considered, whereby, the modulator tube supplies all of the plate current for the modulated, radio-frequency, amplifier. The principle of using an A. C. voltage on the plate of a radio-frequency amplifier or oscillator has been in use for some time in telegraph transmitters.

E. B. Ferrell (8) supplied the plates of an oscillator with a single 1000 cycle tone from modulator tubes and keyed the tone input to the modulator for the purpose of sending pulses out from the transmitter in some Kennelly-Heaviside layer measurements during the solar eclipse of August 31, 1932. This method of keying gave results that were quite satisfactory. When, only, A. C. is supplied to the plates of a radio-frequency amplifier or oscillator, the plate current only flows during the positive half of the cycle of the applied voltage. This gives a carrier envelope similar to the current wave of an unfiltered half wave rectifier. If this A. C., supplied to the plate of a radio-frequency amplifier, is speech-frequency from a modulator tube, so much distortion takes place, that the speech is not very intelligible when picked up by a receiver, unless some means of improving the quality is employed at the transmitter. The use of negative regeneration for the improvement of quality, was considered and was decided upon as the most practical method of solving this problem.

The use of negative regeneration, for reducing distortion, was devised by J. C. Schelleng (8) and has been put to several practical uses by E. B. Ferrell. The only publication where negative regeneration is discussed, as far as the writer knows, is that of H. Nyquist (3). This article considers both positive and negative regeneration from the standpoint of stability and not from the standpoint of quality.

ANALYSIS OF CARRIER ENVELOPE

In our mathematical analysis, we will first assume that the plate current of the modulated amplifier varies linearly with the applied plate voltage and then we will assume that it varies as the square of the plate voltage. This analysis is not rigorous, but it will give an approximation to actual conditions that should be close enough for most practical purposes. The first wave form assumed, is similar to that shown in Fugure 2A. This wave form results from a single sinusoidal frequency being applied to the plate. For convenience, we will consider E cos X as the applied voltage. Referring to Figure 2A, it will be observed that $f\ (X) = \frac{E}{R} \cos X$ when $-\frac{\pi}{2} < X < +\frac{\pi}{2}$, and $f\ (X) = 0$ when $+\frac{\pi}{2} < X < +\frac{3}{2}\pi$. Any mathematical treatise discussing Fourier's series, will show that a function can be represented by a series of sines and cosines as long as any discontinuities that occur, are finite. (6) The wave will be assumed to be of the form $f\ (x) = A_1 \sin X + A_2 \sin 2X + A_3 \sin 3X + \text{--------} A_n \sin nX + \frac{bo}{2} + b_1 \cos X + b_2 \cos 2X + b_3 \cos 3X + \text{-----} b_n \cos nX$. The "A" coefficients can be evaluated by multiplying both sides of the equation by $\sin nX dX$ and integrating between the limits of $-\pi$ and $+\pi$. The "b" coefficients can be evaluated by multiplying both sides of the equation by $\cos nX dX$ and integrating between $-\pi$ and $+\pi$. All terms go to zero in the above process except the following:

$$f\ (X) \sin nX\ dX = \int_{-\pi}^{+\pi} A_n \sin^2 nX\ dX = A_n \pi,$$

$$f\ (X) \cos nX\ dX = \int_{-\pi}^{+\pi} b_n \cos^2 nX\ dX = b_n \pi.$$

Solving for the coefficients:

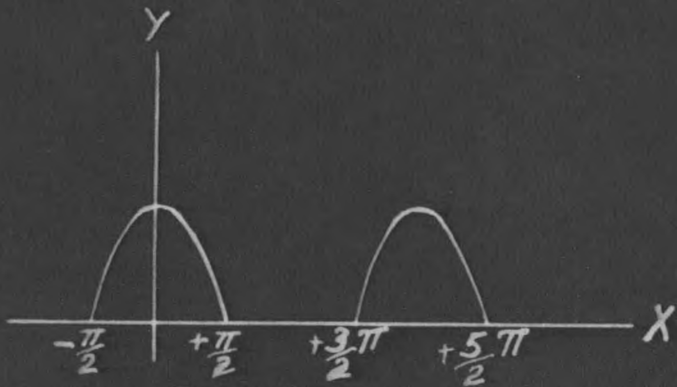

FIGURE 2A

$Y = \frac{E}{R} \cos X, \; -\frac{\pi}{2} < X < +\frac{\pi}{2}. \; Y = 0, \; +\frac{\pi}{2} < X < +\frac{3}{2}\pi.$

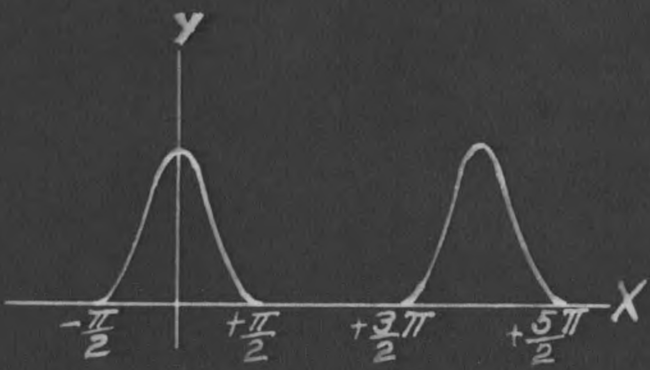

FIGURE 2B

$Y = KE^2 \cos^2 X, \; -\frac{\pi}{2} < X < \frac{\pi}{2}. \; Y = 0, \; +\frac{\pi}{2} < X < +\frac{3}{2}\pi$

FIGURE 2
ASSUMED WAVE FORMS

$$A_n = \frac{1}{\pi}\int_{-\pi}^{+\pi} f\,(X)\ \sin n X\ dX \text{ - - - - - - } 1.$$

$$b_n = \frac{1}{\pi}\int_{-\pi}^{+\pi} f\,(X)\ \cos n X\ dX \text{ - - - - - - } 2.$$

b_n is obtained either by multiplying both sides of the original equation by dX and integrating between $-\pi$ and $+\pi$, or by letting n equal zero in equation 2. If f (X) is an odd function, the "b" coefficients disappear and if f (x) is an even function the "A" coefficients disappear. f (X) is an odd function if f (-X) = -f (X) and an even function if f (-X) = f (X). The intefval under discussion does not have to be from $-\pi$ to $+\pi$. It can be between 0 and 2π or any values of X as long as the interval is 2π in value. The series is based on the assumption that the function repeats itself every interval. It is known however, that the coefficients can also be evaluated when f (X) is more than one function during the interval. That is, f (X) can be one function for the first part of the interval and another function for the rest of the interval. The interval may be broken up into convenient parts as long as f (X) does not become infinite in any of the parts being considered.

In the case of the radio-frequency amplifier, the plate current, i, will be the f (X). The tube resistance, R, is assumed to be a constant in the first part of the interval and to be infinite in the second part of the interval. Since cos X is an even function the "A" coefficients will vanish. The "b" coefficients will be given by $b_n = \frac{E}{\pi R}\int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} \cos X \cos n X\ dX$. Since f (X) is symmetrical about the y axis and the cosine product can be expanded;

$$b_n = \frac{E}{\pi R}\int_0^{\frac{\pi}{2}}\left[\cos (n+1) X + \cos (n-1) X\right] dX.$$

$$b_n = \frac{E}{\pi R}\left[\frac{\sin (n+1)\frac{\pi}{2}}{(n+1)} + \frac{\sin (n-1)\frac{\pi}{2}}{(n-1)}\right].$$

If n is now allowed to take on values from 0 to ∞ we get

$$i = \frac{E}{R}\left[\frac{1}{\pi} + \frac{1}{2}\cos X + \frac{2}{3\pi}\cos 2X - \frac{2}{15\pi}\cos 4X - - - \frac{2}{(n^2-1)\pi}\cos\frac{\pi n}{2}\cos nX - - 3.\right.$$

The above series and the one to follow are of course based on the assumption that plate current flows as soon as the plate voltage becomes positive. This would be true in the case of any amplifier tube that would be drawing grid current while being modulated.

If we assume that the plate current varies as the square of the applied plate voltage, we will get a carrier envelope similar to the one shown in Figure 2b. This is of the form, $i = kE^2 \cos^2 X$ (k is a proportionality constant) for one half the cycle and $i = 0$ for the rest of the cycle. The "A" coefficients will vanish here also, as $\cos^2 X$ is an even function. The "b" coefficients will be given by

$$b_n = \frac{2kE^2}{\pi}\int_0^{\frac{\pi}{2}}\cos^2 X \cos n X \, dX$$

$$b_n = \frac{kE^2}{\pi}\int_0^{\frac{\pi}{2}}(1 + \cos 2X)\cos_n X \, dX$$

$$b_n = \frac{kE^2}{\pi}\int_0^{\frac{\pi}{2}}\left[\cos_n X + \tfrac{1}{2}\cos (n+2) X + \tfrac{1}{2}\cos (n-2) X\right] dX.$$

$$b_n = \frac{kE^2}{\pi}\left[\frac{\sin_n\frac{\pi}{2}}{n} + \frac{\sin (n+2)\frac{\pi}{2}}{2(n+2)} + \frac{\sin (n-2)\frac{\pi}{2}}{2(n-2)}\right].$$

If n takes on values from 0 to ∞ we get

$$i = kE^2 \left[\frac{1}{4} + \frac{4}{3\pi} \cos X + \frac{1}{4} \cos 2X + \frac{4}{15\pi} \cos 3X - \frac{4}{105\pi} \cos 5X - - - \right.$$

$$- \frac{4}{\pi n(n^2-4)} \sin \frac{n\pi}{2} \cos nX - - - - - - - - - - - 4.$$

It is observed that all odd harmonics are missing from equation 3 and all even harmonics, higher than the second, are missing from equation 4.

The indeterminate forms that occurred in evaluating the coefficients in equations 3 and 4 were

$$\frac{\sin (1-1)\frac{\pi}{2}}{(1-1)}, \frac{\sin 0\frac{\pi}{2}}{0} \text{ and } \frac{\sin (2-2)\frac{\pi}{2}}{2\,(2-2)}.$$

It is known (7) that some indeterminate forms can be evaluated by differentiating the numerator and denominator separately and then allowing the variable to approach the desired value.

$$\lim_{(n\to 1)} \frac{\sin (n-1)\frac{\pi}{2}}{(n-1)} = \lim_{(n\to 1)} \frac{\frac{d\left[\sin (n-1)\frac{\pi}{2}\right]}{dn}}{\frac{d\,(n-1)}{dn}} =$$

$$\lim_{(n\to 1)} \frac{\frac{\pi}{2} \cos (n-1)\frac{\pi}{2}}{1} = \frac{\pi}{2}.$$

$$\lim_{n\to 0} \frac{\sin n\frac{\pi}{2}}{n} = \lim_{n\to 0} \frac{\frac{\pi}{2} \cos n\frac{\pi}{2}}{1} = \frac{\pi}{2}.$$

$$\lim_{n\to 2} \frac{\sin (n-2)\frac{\pi}{2}}{2\,(n-2)} = \lim_{n\to 2} \frac{\frac{\pi}{2} \cos (n-2)\frac{\pi}{2}}{2} = \frac{\pi}{4}.$$

In modulation studies it is usually desirable to express the values of the harmonics in terms of decibels, below the fundamental. In equation 3, the second harmonic is 20 $\log_{10} \frac{1/2}{2/3\pi}$ = 7.54 d. b. below the fundamental and in equation 4, the second harmonic is 4.5 d. b. below the fundamental. All harmonics of higher order than the second are small enough to be neglected in both equations. All harmonics more than 30 d. b. down from fundamental are too small to have any noticeable effect. Since a total harmonic level, 26 d. b. below fundamental is desirable, it can readily be seen that a relatively large reduction in distortion will have to be made before the emitted signal can have desirable quality.

In the linear case, which is represented by equation 3, the d. c. component is $1/\pi$, compared to the fundamental of 1/2. In the square law case, (equation 4) the d. c. component is 1/4, compared to the fundamental of $4/3\pi$. This means that we will have more than 100% modulation in both cases. The carrier is assumed to be proportional to the d. c. component. Assuming a maximum amplitude of 1, in both cases, we have, according to the I. R. E. definition for per cent modulation (1); $\frac{1/2}{1/\pi}$ X 100 = 157% modulation in the linear case, (Equation 3) and $\frac{\frac{1}{2}}{\frac{1}{4}}$ x 100 = 200% modulation in the square law case (Equation 4). With this method of carrier control, the modulator will have to have a peak power capacity of four times that required in regular modulation, if the same peak, modulated, carrier amplitude is to be obtained. The above statement is made because of the assumption that the radio-frequency amplifier has the maximum, allowable, peak plate voltage applied to it in both types of modulation. For normal, 100% modulation, the peak audio-frequency is equal to the d. c. plate voltage. If the d. c. voltage is removed, the modulator will have to develop twice the peak audio-frequency voltage to produce the same peak plate voltage as that produced in normal modulation. This, of course, would require four times the peak power capacity on the part of the modulator. If we use the square law case and assume the same peak, plate voltage is developed, the carrier peak will only be half of that of normal modulation. In the linear case the carrier peak will be about 64% of that of normal modulation. The fundamental will be the same in the linear case and 85% of normal in the square law case.

It is apparent that we must reduce the second harmonic to a small percentage of the fundamental and also reduce the fundamental to the same amplitude as the carrier if we want good quality from the transmitter.

NEGATIVE REGENERATION

There are several methods of obtaining negative regeneration. Some of them are as follows: 1, Feed part of the carrier envelope from a linear rectifier back to the input of the speech amplifier, and shift the phase by means of some phase shifting circuit. 2, Feed part of the carrier envelope from the plate circuit of a radio frequency amplifier back to the grid of the modulator, by means of a transformer. 3, Insert an impedance between the filament and ground of a radio-frequency amplifier, which offers impedance to audio frequency only. 4, Feed part of the carrier envelope from the plate circuit of a radio-frequency amplifier back to the grid circuit of the same amplifier by means of a transformer. Systems 2, 3, and 4 were tried on station W7XB and a combination of 3 and 4 gave the best results. This is the system shown in the power amplifier in Figures 1 and 3.

Morecroft (2) shows that a modulated wave has the form, $(E_0 + E_1 \cos m) \times \cos X$. $m = w_1 t$ and represents the audio-frequency, $X = w_2 t$ and represents

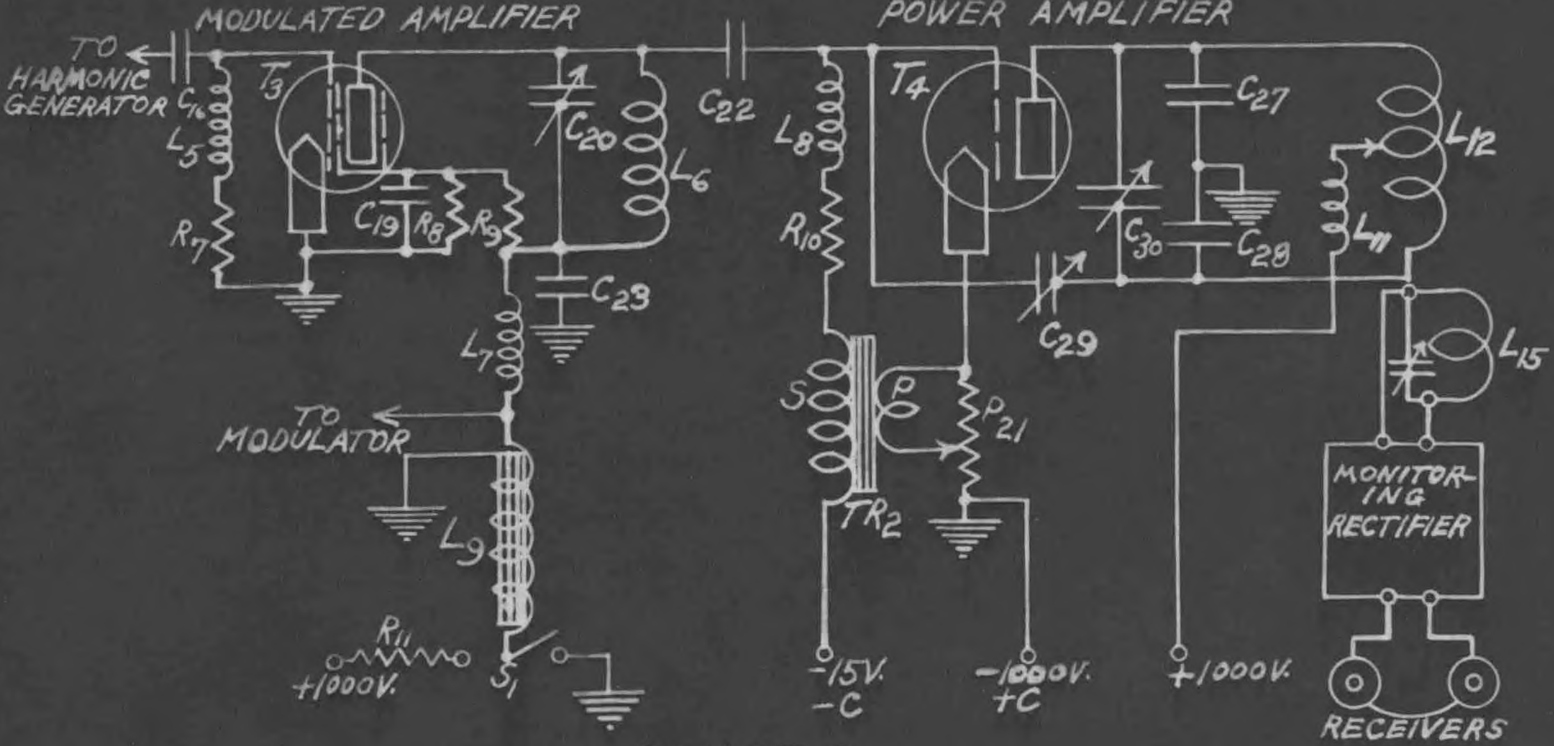

FIGURE 3
SIMPLIFIED SCHEMATIC WIRING DIAGRAM OF CARRIER CONTROL AND NEGATIVE REGENERATION EQUIPMENT IN STATION W7XB

the carrier frequency. We will assume that the modulated amplifier supplies a complex wave of the form, $(E_o + E_1 \cos m + E_2 \cos 2m + E_3 \cos 3m + \cdots)\cos X$ to the grid of the power amplifier shown in Figures 1 and 3. The plate current of the power amplifier will have a complex wave of the form, $\frac{E_p}{R_d} + \frac{U}{R_a} \times (E_1 \cos m + E_2 \cos 2m + E_3 \cos 3m + \cdots)$. E_p = the d. c. plate voltage. U = amplification constant of the tube. R_d = d. c. plate resistance of the tube. R_a = a. c. plate resistance of the tube. Since the primary winding of the negative regeneration transformer, TR_2, is in the plate circuit of the power amplifier tube and the secondary winding is in the grid circuit of this tube, we will have grid bias modulation and it will be out of phase with the original modulation components, from the modulated amplifier, by some phase angle, ϕ. We will in turn, of course, feed these last mentioned components back, also, and they will show up in the plate circuit of the power amplifier. Our actual wave form that is fed to the antenna will be of the form,

$$\left[E'_o + C\left\{E_1' \cos(m+\phi) + E_2' \cos 2(m+\phi) + E_3' \cos 3(m+\phi) + \cdots\right\} + E_1' \cos m + E_2' \cos 2m + E_3' \cos 3m + \cdots\right]\cos X. \text{ ------------- } 5.$$

C = some constant less than one, and depends on the effectiveness of the negative, regeneration feed back. The feeding back is of course an endless process and unless ϕ is of the proper value the power amplifier will sing at audio-frequency. The assumption that the power amplifier is linear is of course necessary in order that the reasoning just given be somewhere near accurate. The principle of negative regeneration still holds however, even if the power amplifier is not linear. If the power amplifier should introduce distortion, this distortion would also be fed back out of phase. Inspection of equation 5 indicates that the greatest cancellation of second harmonic will occur when ϕ is 90°.

However, it is also observed that the fundamental, third, fourth, fifth and seventh harmonics would be reenforced, and the sixth cancelled. We noticed in equations 3 and 4 that the second harmonic was the only one that had an appreciable amplitude.

It will be observed in Figure 3 that the negative regeneration transformer, TR_2, has practically no load on the secondary winding. The grid impedance of the tube, T_4, is very high, even when some positive grid current is flowing. This seems to indicate that the voltage fed back to the grids would be somewhere near 90° out of phase with the plate current, if R_{21} should be of a much higher resistance value than the inductive reactance value of the primary winding of TR_2. It is also apparent that audio-frequency singing might take place. Equation 5 also indicates that the distortion correction will be proportional to the constant C, which is determined by the winding ratio of TR_2, the inductive reactance of the primary winding of TR_2, and the resistance of R_{21}. If ϕ, of equation 5, is 90°, the fundamental will be actually reenforced instead of reduced. This will have a tendency to increase the percentage modulation and to cause the side band amplitude to be greater than the carrier amplitude and thus produce a certain amount of distortion. A phase shift of 120° would neither reenforce nor cancel the fundamental or the second harmonic and no gain or loss would be experienced. Equations 3 and 4 indicate that the fundamental is likely to be greater than the carrier even before entering the grid circuit of the power amplifier. It seems that a 180° phase shift would be desirable in the modulated radio-frequency stage and a 90° phase shift would be desirable in the power amplifier stage. The fundamental would then be reduced in the modulated amplifier and the second harmonic would be reduced in the power amplifier.

It appears that a phase shift of 180° would also be desirable for noise suppression, as a suppression of the fundamental would also suppress the noise. This method of noise suppression would be very satisfactory, if inserted in the radio-frequency stage ahead of the modulated stage. No reduction in audio-frequency would then take place. A 180° phase shift would take place if TR_2 of Figure 3 should be removed and R_{21} left in place.

If the out of phase components of equation 5 are combined we get an equation of the form,

$$E_o' \cos X + \frac{k_1E_1'}{2} \cos (X + m + \theta_1) + \frac{k_1E_1'}{2} \cos (X - m - \theta_1) + \frac{k_2E_2'}{2} \cos \left[X + 2 (m + \theta_2)\right] + \frac{k_2E_2'}{2} \cos \left[X - 2 (m + \theta_2)\right] + --- + \quad ---- \quad 6.$$

The factors, k_1, k_2, k_3 etc. and the phase angles, θ_1, θ_2, θ_3 etc. are results of vector addition of the components of equation 5. Equation 6 indicates that we have what Roder describes as false phase modulation. Roder (5) shows however, that if the phases of the upper and lower sidebands are shifted by an equal amount and in opposite directions and the sidebands are of the same amplitude, no distortion or phase modulation takes place. Equation 6 fulfills the above condition, so the effect is harmless.

PART V

EXPERIMENTAL WORK

All experimental work was done by listening tests on the monitoring rectifier and on a receiver located about $1\frac{1}{2}$ miles from the transmitter. While it is true that the human ear is not a very good judge in distinquishing small changes in volume and distortion, it is evident that if the ear detects a decided change, the improvement or deterioration must be an appreciable amount.

In the experimental work, the greatest distortion correction was obtained when R_{21} was opened completely. The power amplifier would sing when the right reversal was used on the secondary or primary leads of TR_2. The adjustment of R_{21} did not have any appreciable effect on the signal output of the transmitter, although a slight increase in both noise and signal was noticed when R_{21} was changed from the shorted position to the open position. To test the phase shift conclusion, the primary winding of TR_2 was disconnected and R_{21} was left to carry the plate current. The grid bias was reduced to compensate for the bias introduced by R_{21}. This set up should make ϕ of equation 5 equal to 180°. A reduction in signal output was obtained, along with a reduction in noise. No improvement in quality was noticed. When TR_2 was connected again and R_{21} opened, an appreciable improvement was found when TR_2 was connected as a 40 to 1 ratio transformer instead of being connected as a 20 to 1 ratio transformer. Equation 5 shows that the greatest improvement should be obtained when the winding ratio of the transformer is infinite. C would approach one as the ratio approached infinity. As would be expected, the tuning, the neutralization, the grid drive and the grid bias voltage materially affected the results obtained. When the above mentioned adjustments were made for the best results in normal modulation, the best results were then obtained with controlled carrier modulation.

The listening tests indicated that the quality was good enough for intelligible voice communication but not satisfactory for good reproduction of music or singing. A small amount of carrier could be picked up on the receiver when no modulation was taking place. This was probably due to some carrier leakage that resulted from imperfect shielding in the modulated amplifier and harmonic generator.

Normal modulation gave slightly better quality on speech and a greatly superior quality on music, when compared to carrier control modulation.

While negative regeneration tests were being conducted, the filament emission of the power amplifier tube was impaired and there was a strong tendency for secondary emission to take place from the grid of this tube. The secondary emission caused negative grid current, which in return, caused a reduction in grid bias, because of the voltage drop across the grid resistor, R_{10}, shown in Figure 1. As the grid bias decreased, the plate current increased and in turn increased the secondary emission. The temporary trouble was remedied by disconnecting the primary winding of TR_2 and allowing R_{21} to carry the plate current of the power amplifier tube. The voltage built up across the resistance, R_{21}, increased the potential difference between the grid and filament, thus having the same effect as increasing the negative grid bias. As soon as secondary emission started from the grid, the plate current increased and increased the negative grid bias. The resistance R_{21} had a stabilizing effect and allowed satisfactory operation. In many high powered transmitters, a situation exists that is similar to this. It is necessary to have resistance in the grid circuit for the purpose of controlling grid bias. The resistance is in the form of a potentiometer across a grid bias, power supply. The power supply has to have a relatively large power delivering capacity, because the grid bias, potentiometer resistance must be low to prevent the reduction of grid bias that results from secondary emission from the grids of the power tubes. It is believed that the grid bias potentiometer resistance could be increased and the power delivery requirements of the grid bias supply reduced by inserting a resistance between the filament center tap of the filament power supply and ground. If the effect of negative regeneration should be undesirable, the resistance could be shunted by fixed condensers of a voltage rating high enough to stand the voltage built up across the resistance. This would not be over 200 volts in most cases, and condensers of this voltage rating are not expensive. The saving in cost, due to the decrease in size of the grid bias supply source, should be sufficient to cause this method to be given some consideration.

In the case of this particular transmitter, the secondary emission trouble was finally taken care of by rejuvenating the tube. The trouble, however, gave rise to an idea that could be used in high power transmitters where grid, secondary emission takes place in a normal, fully active tube.

CONCLUSION

The tests that were conducted on the carrier control and negative regeneration equipment were not as thorough as the writer would desire. They did, however, verify the assumptions trat were made in the mathematical analysis. It would be highly desirable to take oscillograms of the carrier envelope, but the available equipment is not suited to such purposes. It is hoped that arrangements can be made to make oscillographic studies on the carrier envelope in the near future and thus obtain more exacting evidence of the assumed effects.

The tests gave evidence that was favorable for this method of carrier control. This system would probably be satisfactory in both large and small transmitters, providing the demands on quality of reproduction were not too great. The cost of constructing a transmitter, for using this type of carrier control, would probably be as great as the construction cost of a transmitter using relays. It is believed, however, that the method discussed in this paper would have an advantage because of its greater simplicity and because electrical circuits do not get out of order as easily as do mechanical, moving parts.

It is believed that further experimental work would yield improvements in the methods given in this paper.

The tests that were conducted gave every indication that W7XB would be quite satisfactory for two-way communication, with the circuit and equipment now in use.

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APPENDIX

Crystal Oscillator Parts

C_1--.00005 ufd., midget, grid circuit, tuning condenser.

C_2--.001 ufd., stopping condensers.

C_3--.001 ufd., stopping condenser; 5000 volts, d.c. rating.

C_4--.0003 ufd., plate circuit, tuning condenser.

C_5--.0001 ufd., coupling condenser; 5000 volts, d.c. rating.

C_6--.002 ufd., tank circuit, by-pass condenser, 5000 volts, d.c. rating.

C_7--2 ufd., filter condenser; 500 volts, d.c. rating.

C_8--C_9 -- .002 ufd., filament, by-pass condensers.

L_1--Grid circuit inductance.

L_2--13 turn, plate inductance; wound on $2\frac{1}{2}$ inch form with no. 20 d.c.c. copper wire.

L_3, L_{10}--50 turn, duolaterally wound, radio-frequency, choke coils; wound on $\frac{1}{2}$ inch form with no. 26 d.c.c. copper wire.

R_1--20,000 ohm, grid leak, variable resistance; 50 watts, rating.

R_2--35,000 ohm, plate resistance; 50 watts rating.

R_3--100,000 ohm, grid leak; 50 watts, rating.

J_1--Crystal oscillator, grid current jack.

J_2--Harmonic generator, grid current jack.

J_3--Crystal oscillator, plate current jack.

X--4,327.5 k. c., X-cut crystal.

P_1, P_2--Crystal oscillator, filament terminals.

P_3--Crystal oscillator, plate supply terminal.

T_1--Radiotron UX-210, $7\frac{1}{2}$ watt tube.

Harmonic Generator Parts

C_{10}, C_{11}--.002 ufd., filament, by-pass condensers.

C_{12}--.01 ufd., screen-grid, by-pass condenser; 2500 volts, d.c. rating.

C_{13}--.002 ufd., tank circuit, by-pass condenser; 5000 volts, d.c. rating.

C_{14}--.001 ufd., stopping condenser; 5000 volts, d.c. rating.

C_{15}--.00032 ufd., plate circuit, tuning condenser.

C_{16}--.0001 ufd., coupling condenser; 5000 volts, d.c. rating.

L_4--10 turn, plate circuit inductance; 2 inches in diameter, 4 inches long, No. 12 bare copper wire, no form.

L_5--50 turn, duolaterally wound, radio-frequency choke coil; wound on $\frac{1}{2}$ inch form, No. 22 d.c.c. copper wire.

R_4--10,000 ohm, screen-grid, potentiometer resistance; 10 watts, rating.

R_5--30,000 ohm, screen-grid, potentiometer resistance; 25 watts, rating.

R_6--20,000 ohm, plate resistance; 50 watts, rating.

R_7--100,000 ohm, grid leak; 50 watts, rating.

J_4--Modulated amplifier, grid current jack.

J_5--Harmonic generator, plate current jack.

T_2--DeForest 565, $7\frac{1}{2}$ watt, screen grid tube.

Modulated Amplifier Parts

C_{17}, C_{18}--.002 ufd., filament, by-pass condensers.

C_{19}--.01 ufd., screen-grid, by-pass condenser; 2,500 volts, d.c. rating.

C_{20}--.00028 ufd., plate circuit, tuning condenser.

C_{21}--.001 ufd., stopping condenser; 5000 volts, d.c. rating.

C_{22}--.0001 ufd., coupling condenser; 5000 volts, d.c. rating.

C_{23}--.002 ufd., tank circuit, by-pass condenser; 5000 volts, d.c. rating.

L_6--10 turn, plate circuit inductance; 2 inches diameter, 4 inches long, No. 12

bare copper wire, no form.

L_7, L_8--50 turn, duolaterally wound, radio-frequency, choke coils; wound on ½ inch form, No. 22 d.c.c. copper wire.

L_9--Secondary winding of 2000/100 volt, voltage transformer; winding has a d.c. resistance of 400 ohms, a saturated core inductance of about 30 henrys.

R_8--10,000 ohm, screen-grid, potentiometer resistance; 10 watts, rating.

R_9--30,000 ohm, screen-grid grid, potentiometer resistance; 25 watts, rating.

R_{10}--10,000 ohm, variable, grid leak; 50 watts, rating.

R_{11}--20,000 ohm, plate resistance; 50 watts, rating.

J_6--Modulated amplifier, plate current jack.

S_1--Carrier control, change over switch.

T_3--DeForest 565, 7½ watt, screen grid tube.

Power Amplifier.

C_{24}, C_{25}--.002 ufd., filament, by-pass condensers.

C_{26}--.01 ufd., neutralization, stopping condenser; 2,500 volts, d.c. rating.

C_{27}, C_{28}--.0001 ufd., tank circuit, capacity, center tapping condensers; 5000 volts, d.c. rating.

C_{29}--.00005 ufd., neutralizing condenser.

C_{30}--.0005 ufd., plate circuit, tuning condenser.

C_{31}--.002 ufd., tank circuit, stabilizing condenser; 3000 volts, r.f. rating.

L_{11}-70 turn, radio-frequency, choke coil; No. 24 d.c.c. copper wire wound on 1¼ inch form.

L_{12}--3 turn, plate circuit coil; 4 inches diameter, 5½ inches long, ½ inch copper tubing, no form.

R_{15}--5000 ohm, tank circuit, stabilizing resistance; 10 watts, rating.

R_{19}, R_{20}--200 watt, 125 volt, tungsten filament, light globes; filament center tap resistors; cold d.c. resistance, approximately 10 ohms.

R_{21}--190 ohm, negative regeneration, control resistance.

TR_2--2000/50/50 volt, voltage transformer; used as a negative regeneration transformer; 65 watts, rating.

J_7--Power amplifier, grid current jack.

J_8--Power amplifier, plate current jack.

P_5--Power amplifier, negative, grid bias terminal.

T_4--Radiotron UV-203-A, 50 watt tube.

Antenna Tuning System.

C_{32}--.00036 ufd., parallel, tuning condenser.

C_{33}, C_{34}--.00024 ufd., series, tuning condensers; both mounted on the same shaft.

L_{13}, L_{14}--5 turn, antenna coils; 3 inches in diameter, 3 inches in length, No. 4 bare copper wire, no form.

S_2, S_3--Antenna current, ammeter, change over switches.

S_3--Load transfer switch.

R_{16}--25 watt light bulb; used as dummy antenna.

Monitoring Rectifier Parts.

C_{35}--.00029 ufd., pick up, tuning condenser.

C_{36}, C_{37}--.002 ufd., filament, by-pass condensers.

L_{15}--10 turn, pick up coil; $2\frac{1}{2}$ inch form, wound with No. 20 d.c.c. copper wire.

R_{17}--100,000 ohm, resistance; 5 watts, rating.

J_{11}--Monitoring rectifier, current jack.

T_5--Radiotron UX-281, rectifier tube.

P_6, P_7--Pick up, coil terminals.

P_8--Output terminal.

P_9, P_{10}--Indicator terminals.

P_{27}--Ground terminal.

Speech Amplifier Parts

C_{42}--.001 ufd., radio-frequency, by-pass condenser.

C_{43}--2 ufd., audio-frequency coupling condenser; 1200 volts, d.c. rating.

L_{17}--17 henry, modulator, grid choke; 500 ohms resistance.

R_{24}--10,000 ohm, speech amplifier, plate resistance; 50 watts rating.

R_{25}--5000 ohm, modulator, grid resistance; 25 watts, rating.

R_{27}--200 ohm, microphone, battery resistance.

TR_6--40 to 1 ratio, microphone transformer.

J_{13}--Microphone, current jack.

J_{14}--Speech amplifier, plate current jack.

J_{15}--Modulator, grid current jack.

P_{14}, P_{15}--Microphone terminals.

P_{16}, P_{17}--Microphone, battery terminals.

P_{18}--Speech amplifier, grid bias terminal.

T_8--Radiotron UX-250, 5 watt tube.

B_1--Microphone battery; one standard, dry cell.

M--Telephone, transmitter microphone.

Modulator Parts

C_{44}--.002 ufd., radio-frequency by-pass condenser; 3000 volts, r.f. rating.

C_{45}--2 ufd., audio-frequency, coupling condenser; 1200 volts, d.c. rating.

C_{46}, C_{47}--.002 ufd., radio-frequency, by-pass condensers.

L_{18}--Plate, choke coil; secondary winding of 2000/100 volt, voltage transformer, 65 watts , rating, 30 henrys, saturated, core inductance; 400 ohms, d.c. resistance.

J_{16}--Modulator, plate current jack.

P_4--Modulator, grid bias terminal.

T_9--Radiotron, UV-203-A, 50 watt tube.

Power Supply Parts

C_{41}--1200 volt, 5 k.v.a., oil filled condenser; 9.5 ufd., capacity.

C_{46}--3 ufd., condenser bank; consists of 4, 3 ufd., 500 volt (d.c. rating) condensers in series parallel.

L_{16}--Secondary winding of 2000/100 volt, voltage transformer; 65 watts, rating, saturated core inductance value, 35 henrys, d.c. resistance of winding, 245 ohms.

L_{19}--17 henry choke with air gap in core; d.c. resistance of winding, 60 ohms.

R_{12}, R_{13}--Filament, center tap resisters for 7½ volt filament supply; 115 volt, 150 watt, light globes, resistance, about 17 ohms.

R_{14}--63 ohm, 250 volt, 1.8 - 1.2 amp., transformer rheostat for 7½ volt, filament supply.

R_{18}--26 ohm, 125 volt, 5 amp.,trans~~ƒ~~former rheostat for power amplifier, filament supply.

R_{22}--25 ohm, 10-5 amp., 125 volt, rectifier, plate transformer rheostat.

R_{23}--50 ohm, 5 amp., 125 volt, rectifier filament transformer rheostat.

R_{26}--200 ohm, 250 volt, 1.5-.75 amp., transformer rheostat for modulator, filament supply.

J_8--7½ volt, filament jack.

J_{10}--Power amplifier, filament, voltage jack.

J_{12}--Rectifier filament, filament, voltage jack.

J_{17}--Modulator filament, voltgge jack.

P_{13}, P_{14}--110 volt, a.c., power supply terminals.

P_{19}--Transmitter ground, negative 1000 volt, and positive grid bias, battery connector terminals.

P_{20}--Positive, 1000 volt, connector terminals.

P_{21}--Modulator, connector terminals.

P_{22}--Modulator, grid bias, connector terminals.

P_{23}, P_{24}--110 volt, filament, power supply terminals.

P_{25}, P_{26}--$7\frac{1}{2}$ volt, filament supply terminals.

TR_1--110/8/10/11 volt, filament transformer for $7\frac{1}{2}$ volt tubes.

TR_3--110/11 volt, filament transformer, for power amplifier filament.

TR_4--1150/1150/115/115 volt, house lighting transformer for 1100 volt, plate supply; 1 k.v.a. rating.

TR_5--6600 volt, 100/5 ampere, current transformer for rectifier, filament supply.

TR_7--110/$5\frac{1}{2}$/$5\frac{1}{2}$ volt, filament transformer for modulator, filament supply.

F_1, F_2--110 volt, 6 ampere, power supply fuses.

S_5--D. P. S. T., 110 volt, filament supply switch, for radio tube, filament transformers.

S_6--D. P. S. T., 110 volt, plate supply switch for plate supply transformer.

S_7--D. P. S. T., 110 volt, rectifier tube, filament, transformer switch.

T_6, T_7--Radiotron UX-866, half wave, mercury vapor, rectifier tubes; 7500 volts inverse peak voltage, 600 milliamperes peak current, rating.

V_1--0 to 15 volt, a.c. voltmeter.

V_2--0 to 2300 volt, a.c. voltmeter.

A_2--0 to 10 milliampere, d.c. milliammeter.

A_3--0 to 250 milliampere, d.c. milliammeter.

C_{38}, C_{39}, C_{40}--.01ufd., radio frequency, by-pass condensers.

PL_1--0 to 15 volt, a.c., voltmeter plug.

PL_2--0 to 10 milliampere, d.c., milliammeter plug.

PL_3--0 to 250 milliampere, d.c., milliammeter plug.

WL--110 volt, red, warning light.

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