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AN AUTOMATIC SPECTRAL-SENSITIVITY CURVE TRACER

T. B. PERKINS*

Abstract of paper delivered at the meeting of the Radio Club, April 13, 1939

To avoid the slowness and laboriousness of the point-by-point method of determining the spectral response of any great number of photo-sensitive surfaces, there has been built an automatic device capable of tracing on a cathode-ray tube the spectral-sensitivity characteristic of any photo-sensitive surface in approximately 30 seconds with an accuracy within 10% over the entire curve.

The basis of the design of the automatic curve tracer to be described is quite simple. All that is required is that in the cathode ray tube on which the trace of the spectral sensitivity characteristic is to appear the horizontal deflection be made linear with respect to the wave length of the light exciting the photo-sensitive surface while the vertical deflection be made proportional to the sensitivity of the photo-surface.

To provide these relations a source of monochromatic light—comprising a tungsten filament lamp, 4,000 to 12,000 angstroms, divided by means of a mono-chromator—was used to excite the photo-sensitive surface. The monochromator wave length indicating drum is so rotated that its rotation is proportional to the dispersion of the instrument and, at the same time the associated cathode ray horizontal sweep voltage is caused to vary linearly with respect to time. This provides the first of the required relations.

The second is realized by providing in the amplifier system which is interplaced between the photo-sensitive surface and the cathode ray tube, an attenuator so proportioned and so operated that the gain of the amplifier is maintained inversely proportional to the radiant energy falling upon the photo-sensitive surface.

The practical realization of these relations in a workable instrument is, however, far less simple.

The amplifier is capable of amplifying the minute current from the photo-sensitive device when excited by the small incident energy received from the blue end of the spectrum to a suitable level for the deflection of the cathode ray tube. To avoid the need for d.c. amplification modulation is used.

Thus, by means of a balanced modulator operated with a low frequency carrier (420 cycles for convenience) and a high-Q tuned amplifier (see Fig. 1) using relatively low tube voltages and having high gain per stage, a high signal-to-noise ratio is obtained. The signal output is rectified by a voltage-doubler circuit, which also allows the midpoint of the vertical deflection plate resistance to be grounded. Thoro shielding and filtering, are of course, necessary to prevent oscillations and eliminate pick-up.

The modulator circuit is an adaptation and improvement of the bridge circuit originally proposed by Wynn-Williams.[1] The modulator tubes should be as nearly identical in characteristics as possible, but the commoner variations in tube

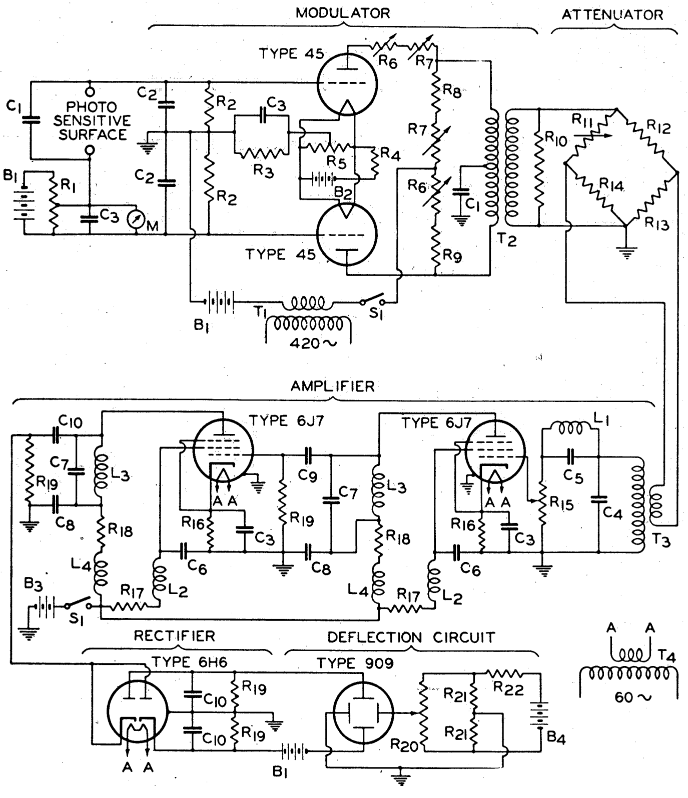

Fig. 1.—Automatic spectral-sensitivity curve tracer circuit.

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[1] C. E. Wynn-Williams, "A Valve Amplifier for Ionization Currents," Proc. Camb. Phil. Soc. 23, 810, 1927: "The Application of a Valve Amplifier to the Measurement of X-Ray and Photoelectric Effects," Phil. Mag. 6,324, 1228.

characteristics as well as circuit variation and other variable factors can be taken care of with the proper circuit compensations.

The problem of providing suitable attenuator is not an easy one. It is difficult to obtain the rapid change in attenuation required at the low-wavelength end of the spectrum with any simple arrangement of potentiometers. It was found, however, that what is, in effect, a wide range of tapering could be obtained by using a linearly variable resistor such as R_{11} in one arm of a bridge. Then, by using a bridge ratio giving approximately the desired attentuation, it was possible to make a controlling cam compensate for the difference.

The work of making linear the dispersion-rotation curve of the monochromator to provide a suitable wavelength scale for the horizontal deflection of the cathode-ray is relatively simple. This merely requires that the rise of the operating cam per wavelength interval be proportional to the rotation of the wavelength drum per wavelength interval, while the horizontal sweep potentiometer R_{20}, is varied linearly.

The complete curve tracer is shown in Figure 2. The modulator, attenuator, and amplifier shield boxes are open to show the arrangement of the parts. The modulator unit, including the photo tube under test, is shown at the extreme left of the picture, attached to the monochromator.

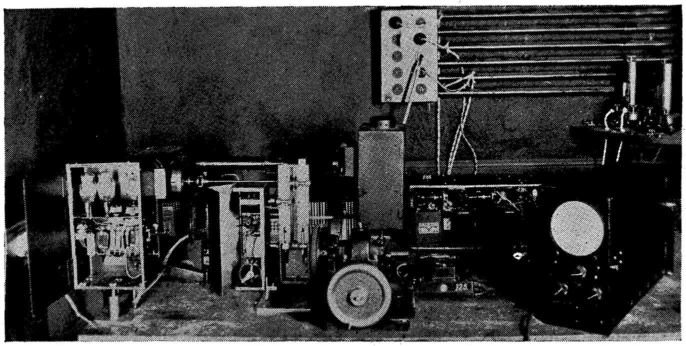

Fig. 2.—Automatic spectral-sensitivity curve tracer apparatus.

Once the equipment is in operation the tracing of the desired characteristics accomplished by the operation of the control wheel located at the lower center, which is connected to the unified control unit through a 20-to-1 reduction gear box and by means of pullies and belts. The unified control unit comprises the cams which control the rotation of the attenuator rheostat, R_{11}, and the wave length drum. The cams as well as the sweep potentiometer (R_{20}) are driven by a common shaft.

To the right of the lamp housing, is shown the three shielded sections housing the two amplifier stages and the rectifier. The meter directly in front of the amplifier is used to maintain the correct color-temperature of the tungsten lamp. The galvanometers visible in the upper right-hand corner are those used in the old point-by-point method.

Figure 3 is a photograph of the flourescent trace on the screen of the cathode ray tube when a typical phototube was being measured. Since the cathode ray tube here used has a phosphor of the long-persistence type, the full spectral-sensitivity curve can be seen for several minutes after the beam has completed the trace.

The speed with which spectral characteristics can be taken with this equipment is such as to make readily available information on the effects of various surfaces and sensitization processes in phototubes as would have been economically impractical of determination by the point-by-point method. Transmission or absorption properties of filters and the like can be satisfactorily determined while transitory changes which could not be detected by older methods can be readily noted with this equipment.

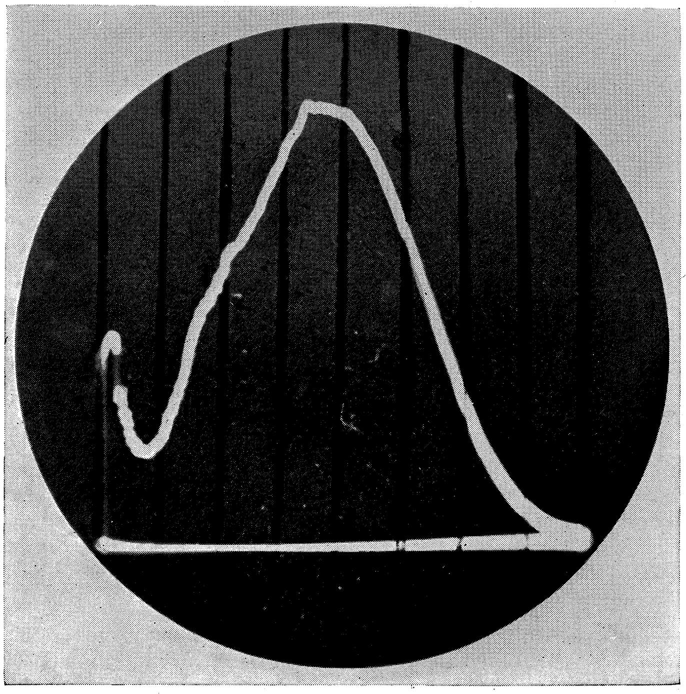

Fig. 3—Photograph of spectral-sensitivity curve on RCA-918 phototube taken directly from RCA-909 cathode-ray tube.

TRANSMITTER CIRCUIT DESIGN FOR FREQUENCIES ABOVE 100 MEGACYCLES

O. E. DOW*

Delivered at the Meeting of the Radio Club, February 9, 1939

The power commonly required from ultra-high-frequency transmitters ranges from less than a watt for the portable transmitter for broadcast pickup to several kilowatts for the television broadcast transmitter. Intermediate is the experimenter's transmitter where as much power as can be obtained from not too elaborate a tube complement is made to serve for many useful purposes.

It is the purpose of this paper to discuss the design of one such transmitter as this. A power of 50 watts was found feasible and the design carried through on this basis. The completed transmitter is shown in Fig. 2 while the important circuit elements and arrangements are shown diagramatically and otherwise in other figures. The push-pull arrangement of the amplifier of Fig. 1 is chosen to simplify neutralizing and to eliminate r-f chokes or reduce voltage across them.

The two wire transmission line of this figure is the ideal circuit element to use for plate and grid circuits. If the conductors are made large enough for mechanical rigidity, the electrical losses will be low. The spacing of the conductors is made approximately 4 times their diameter, although this is not critical and may be adjusted to suit mechanical designs. Supporting insulators should be kept out of the r-f fields where possible. A construction which has been used is to place the supporting insulator at the low voltage end of the circuit and make the conductors and shorting bridge so rigid that but one support is required.

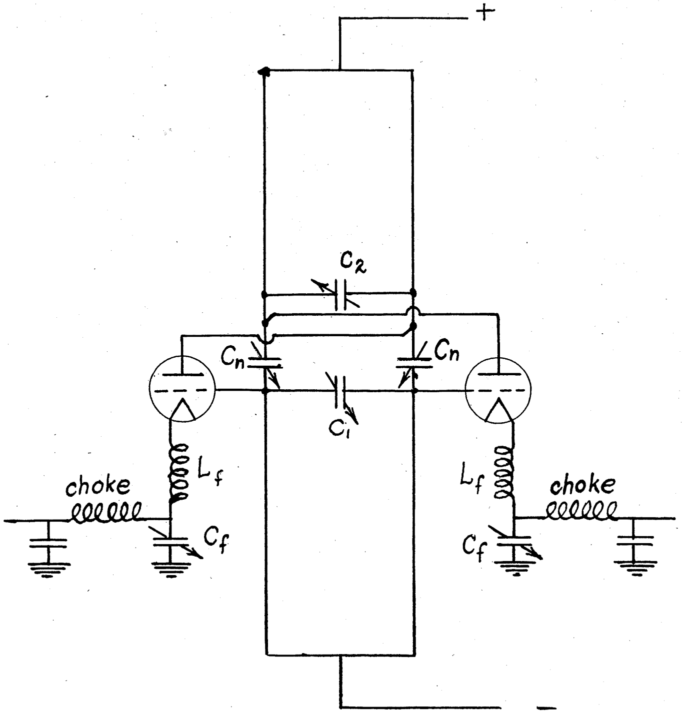

Fig. 1—Schematic Diagram of a Cross Neutralized Amplifier.

The reactance X of the short circuited transmission line is given by:

$$X = +jZ_0 \tan \frac{2\pi l}{\lambda} \text{ ohms} \qquad (1)$$

where Z_0 is the characteristic impedance of the line, λ the operating wave length in centimeters, and l the length of the line in centimeters. The value of Z_0 as determined by transmission line equations will be higher than the actual characteristic impedance due to the presence of shields and the length l will be smaller than the actual electrical length because of end effect and the length of the shorting bridge; generally the impedance determined by the above equation will be close enough. For tuning purposes a small two plate condenser is mounted at the tube end of the line. For large adjustments in tuning the shorting bridge is made to slide along the line. However, it is important that this bridge makes good contact with the line when in operation as it is located at a current maximum point. The variable condenser will be used for only micrometer adjustments in tuning. The reasonable average value for this condenser in the output circuit is the plate to grid capacitance plus the plate to filament capacitance, while for the input circuit its value may be about equal to the grid to plate plus the grid to filament capacitance. A study of Fig. 1 will show that the total capacitance from plate to plate is twice the sum of the plate to grid and plate to filament capacitance. The reactance of the line circuit is made equal to the reactance of this capacitance at the operating frequency. This establishes the length l of the tank or output circuit. In a similar way the length of the grid circuit is determined.

An important consideration in designing the power amplifier is the arrangement of the two tubes for an absolute minimum of lead length from tube electrodes to neutralizing condensers. This means that the lead which is a common conductor of current to neutralizing condenser and current to output circuit should be as short as circuit arrangement will permit. Care must be taken to keep capactive and inductive coupling between input and output circuits low. Fig. 2 shows a tube arrangement which meets these requirements. The power amplifier is located in the left hand compartment. The plate leads of the tubes are at the left and the grid leads at the right, and both are in the neutral plane of the two conductor output circuit located at the extreme left. By this arrangement the leads are all short and of equal length. The neutralizing condensers are the concentric cylinder type. The horizontal cylinders at the center of the tube compartment are the outside electrodes of the neutralizing condensers and are connected to the plates. The outside electrode consists of two telescoping tubes for adjusting the neutralizing capacitance. The inside cylinders are connected to the grids.

It will be noticed that the output circuit of this amplifier consists of two two-wire lines in parallel. This arrangement permits the output circuit to be supported at two points which are at voltage nodes. If desired it could be supported with by-

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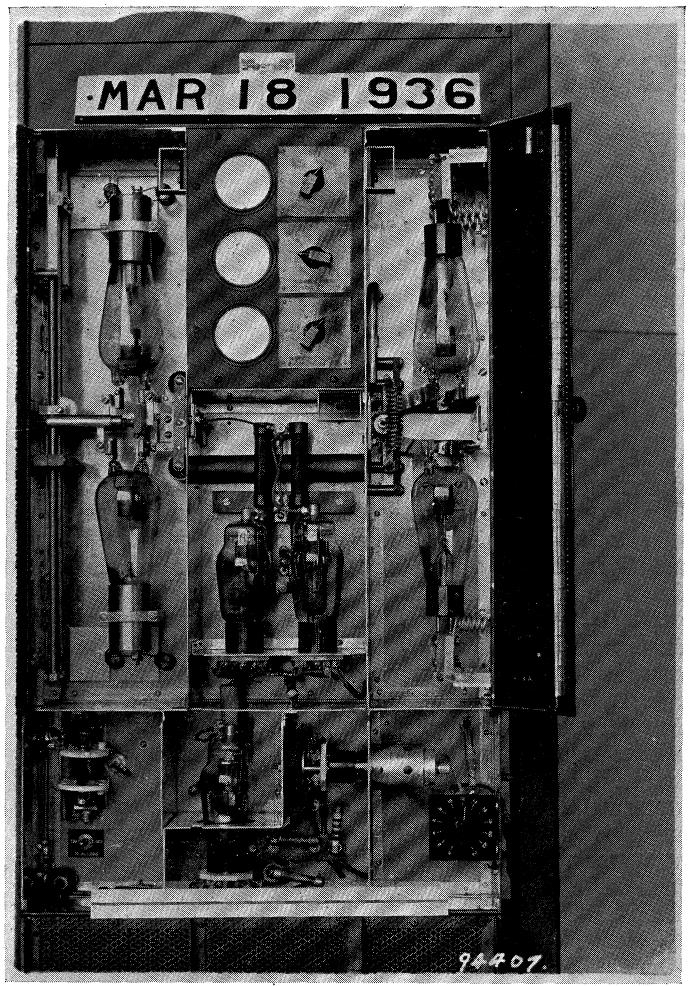

Fig. 2—A UHF Transmitter Illustrating Tube Placement for Minimum Length Leads.

pass condensers at these two points. This arrangement also makes the output circuit symmetrical to the two tubes. The outer electrodes of the neutralizing condensers are supported from the conductors of the output circuit.

In Fig. 1 the inductance L_f is the filament lead inductance, most of which is inside the tube envelope. If the reactance of this inductance at the operating frequency is troublesome it will be necessary to series tune it as indicated by condenser C_f. The necessary low frequency path to ground is furnished by the choke. Only one lead is shown. The additional lead or leads may be parallel circuits, or the better way is to make the conductor comprising the choke of tubing and run the additional leads inside the tubing. All the leads should be connected together with by-pass condensers at the high side of the series tuning condenser.

An estimate of the filament inductive reactance can be made by considering the filament leads as the inner conductor of a short concentric conductor line. The diameter of the outer conductor is taken as the average of the dimensions of the cross section of the tube compartment. The diameter of the inner conductor is taken as the average spacing of the filament leads. The length of the inner conductor is the distance in centimeters from the active part of the filament to its terminals or to the high potential electrode of the series condenser C_f. The characteristic impedance Z_o of this line is $Z_o = 138 \log_{10} (d_1/d_2)$ where d_1 and d_2 are the diameters of the outer and inner conductors as given above. From equation (2) the reactance of L_f can be approximated and the necessary value of C_f determined. Ample variation in C_f should be provided due to the many approximations made.

The filaments may also be made to operate at ground potential by connecting the filament terminals to a section of transmission line grounded at the far end and of such length that it is one-half wave from ground to the active part of the filament. Circuits for doing this have been described in QST by Ross Hull.(1)

At this point it may be in order to describe an operating procedure which is somewhat different than normally practiced. While neutralizing, the potential of the active part of the filament at the operating frequency must be reduced to zero by the series capacitance Cf. To accomplish this adjustment by itself is difficult because of the inaccessibility of the filament to measuring instruments. A study of the effect of the filament reactance on the energy fed back from plate to grid will show a way of accomplishing this adjustment. Refer to Fig. 1. Let L_f be series tuned by C_f, thereby placing the filament at ground potential. From an external source excite the output circuit. By means of a suitable lamp or meter in the grid circuit, tune input and output circuits and adjust the neutralizing condensers for zero energy in the grid circuit. Thus both the grid and filament are at ground potential. This is verified by no current in the grid d-c meter. If the filament circuit is now made inductive by a misadjustment of C_f, the filament will build up to a potential determined by the plate voltage, plate to filament capacitance and the filament inductance. Energy will now be fed into the grid circuit by way of the filament to grid capacity. The grid may be restored to ground potential by a readjustment of the neutralizing capacitance. Under this condition there is no potential from grid to grid, but there is a potential from grid to filament which will be indicated by the rectified grid current. Thus neutralizing is accomplished by feeding energy into the plate circuit and adjusting the neutralizing condensers and filament series condensers until zero voltage is obtained from grid to grid and from grid to filament.

Inductive coupling between stages and to the output is believed to be the most satisfactory. One method which has proved successful is to locate the primary and secondary circuits on opposite sides of a metal partition. The partition has an opening near the current loop part of the two circuits. This opening is made larger than necessary to obtain the required coupling and is reduced by adjustable shields until the desired coupling is obtained. To insure balance in the push-pull output the mid-point must be securely tied to ground.

The power required to drive the output stage is computed from the output tube's operating parameters.(3) From an operating standpoint the number of types of tubes used should be kept as low as performance will permit. It is generally practical and reasonable to use the same type of tube in the power amplifier drive stage as in the power amplifier. For ordinary requirements the output stage may be driven by the master oscillator if the power amplifier is carefully neutralized and shielded to prevent reaction on the oscillator. Under more severe requirements a buffer amplifier may be used. The construction of a buffer amplifier will follow along lines described for the power amplier.

For ultra high frequencies and particularly for frequencies above 100 Mc the low-loss line controlled oscillator is an excellent driver for the output stage. The number of stages required is reduced and the reliability increased. The degree to which the line can be made the predominating factor in determining the frequency of an oscillator is proportional to

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(1) Working At One Meter And Below, Ross A. Hull, QST, Vol. 20, No. 9, September 1936.

the Q of the line. For fixed diameters of inner and outer conductors of concentric conductor lines the Q is proportional to the square root of frequency used. Fig. 3 gives the theoretical Q's of concentric conductor copper lines of various diameters at various frequencies for the optimum ratio of conductor diameters. At a frequency of 150 megacycles and an inside diameter of the outer conductor of ten inches the Q is 13,000. Hansell and Carter (2), have described the characteristics of lines and their application as frequency controlling devices. Good workmanship in constructing the lines and the oscillator circuits is a requirement for good frequency stability. All parts must be rigid and all contacts good. Fig. 4 shows the construction of a line with an invar rod to minimize the temperature coefficient of the copper conductors.

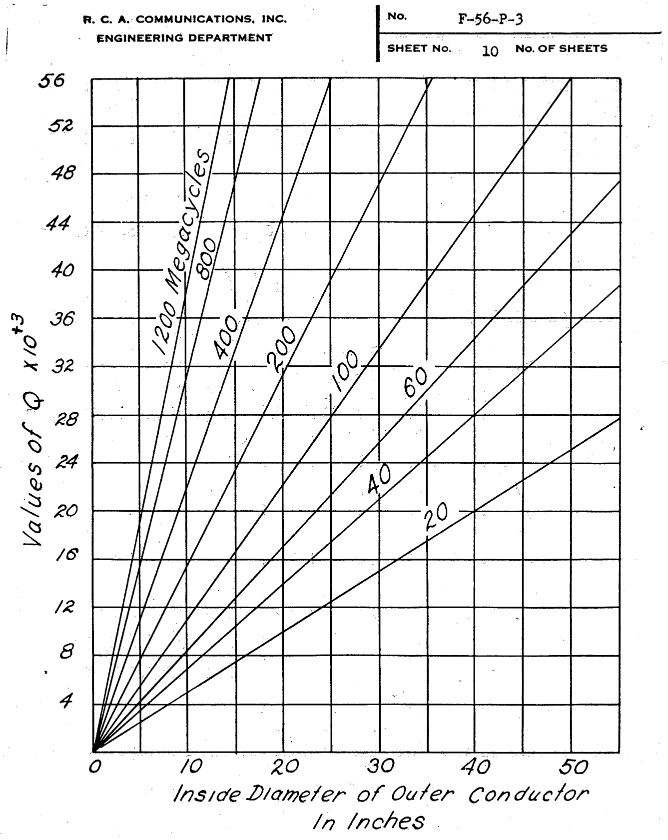

Fig. 3—Theoretical Q's of Concentric Conductor Copper Lines.

Fig. 5 is the schematic diagram of a push-pull oscillator controlled by a single quarter-wave line. Neutralizing condensers are used to regulate the amount of regeneration. The resonant frequency of the grid circuit without the line should be as high as is consistent with the coupling loop area necessary for proper coupling to the line. Although lumped inductance is shown for the plate circuit a section of transmission line is recommended to supply the required inductance.

The circuit shown in the schematic diagram of Fig. 6 is stable, i.e., it is very difficult, if not impossible, to make it oscillate off the line frequency through misadjustment. The arrangement permits a short grid connection to the line. At all frequencies different from the line frequency the grid reactance to ground is capacitive, a condition unfavorable for oscillation since the feedback reactance is also capacitive. Coupling of the grid to the line is regulated by the condenser C which completes the tuning of the line. The insulating supports of this condenser should be designed to reduce its temperature coefficient. The electrical length of the line is one-half wave. The distance from the tapping point of the grid leak resistor to the open end of the line is slightly less than one-quarter wave due to the end effect capacitance. The input impedance Z_1 to the line, when the ratio of conductor diameters is 3.6 and the reactance, X_{c1}, of the line condenser is less than 30 ohms is:

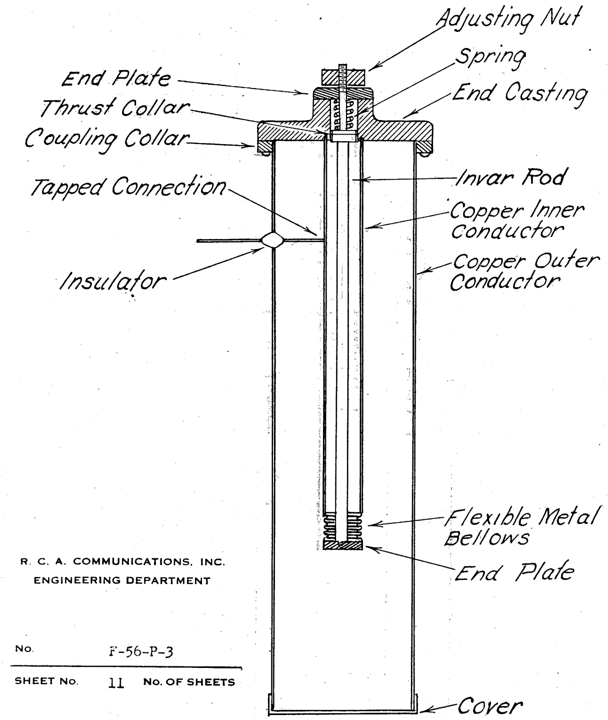

Fig. 4—Invar Rod Equipped Line.

$$Z_1 = \frac{X^2_c Q}{120} \text{ ohms} \qquad (2)$$

Experience has shown that with a tube similar in construction and dimensions to the 834 filament tuning is not required in the oscillator for frequencies up to about 160 megacycles. A trough-line(5) or a concentric conductor line is suitable for the filament circuit when a single tube is used, while for the push-pull arrangement the balanced open line is simpler to construct. The conductors are made of tubing to permit the heater leads to be run inside. The center tap of the filament or the cathode is connected directly to the tubing and the heater leads by-passed to its high potential end.

The shielding of the units of the transmitter requires good workmanship. No shielding at all is better than shielding poorly constructed. Faulty contacts between parts will result in amplitude and frequency modulated noise, or if the compartment happens to have an unfavorable dimension the efficiency of the stage may be seriously reduced. The shelves, sides, and doors of a compartment must be well bonded together. This is particularly true of shielding adjacent to circuit elements carrying radio frequency current.

To illustrate the procedure of designing an ultra high frequency transmitter let it be assumed as suggested at the beginning of this paper that the power is to be 50 watts. Two 834's will easily supply this power at a frequency of 150 megacycles and a plate voltage of 600 volts. Tube performance calculations have been illustrated by Wagener(3) and will not be gone into here. From the peak value of the fundamental

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(2) Frequency Control By Low Power Factor Line Circuits by Clarence W. Hansell and Philip S. Carter, Proc. I.R.E., Vol. 24, No. 4, April 1936.

(3) Simplified Methods for computing Performance of Transmitting Tubes, W. G. Wagener Proc. I.R.E., Vo. 25, No. 1, Part I, January 1937.

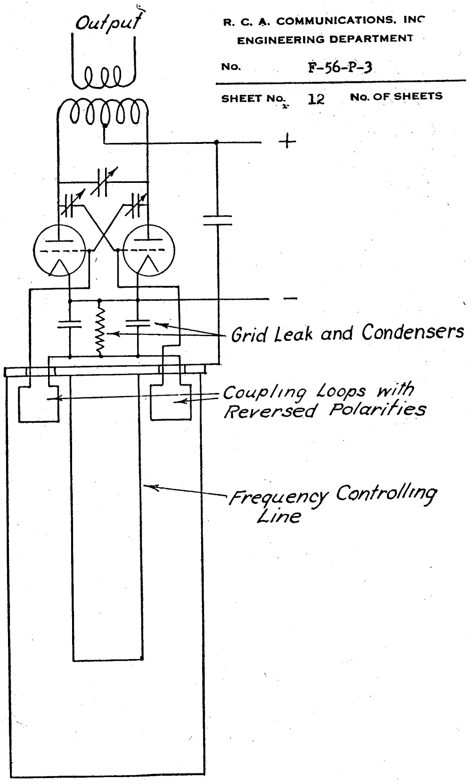

Fig. 5—Push-Pull Oscillator Controlled by a Single Quarter Wave Line.

component of plate current and plate voltage the load impedance for each tube is 4300 ohms, or the plate to plate load is 8600 ohms.

The plate to grid plus the plate to filament capacitance is 3.2 mmf. This value is doubled because of the tuning capacitance and the resulting capacity reactance is 165 ohms. If the plate lecher-wire circuit is made of one-quarter inch conductors spaced one inch the characteristic impedance is 250 ohms.(4) The tangent of the electrical length of the plate circuit must be 165/250 or .65. The electrical length is 33 degrees and the physical length is $33/360\lambda$ or 18.3 centimeters. Although it is not correct to consider the lecher wire as a lumped inductance, since it is but a fraction of a quarter-wave long it will be so considered to check on the approximate Q of the tank circuit. The plate to plate r.m.s. voltage was found to be 650 volts, the volt-amperes in the condensers will be $\frac{650^2}{165} = 2560$, and approximate $Q = \frac{2560}{50}$ or 50. This value is rather high and indicates that the tuning condenser could be reduced if desired.

The grid to filament plus the grid to plate capacitance is 4.8 mmf. Doubling this value as before the capacity reactance used to determine the grid circuit length is 110 ohms. For uniformity the conductor diameters and spacing will be made the same as for the plate circuit. The grid circuit length will be 13.2 centimeters. The grid driving power required is 6 watts, and the r.m.s. volts from grid to grid is 380 volts. The volt-amperes in the grid circuit is approximately 1300. Actual operation will reveal whether this circuit must have additional loading for stability. A single 834 will easily furnish the additional power this requires.

The small driving power required for the power amplifier indicates a single tube in the master oscillator. The circuit of Fig. 6 is suitable for use with a single tube. The plate circuit is made push-pull by making the balancing condenser equal to the plate to ground capacitance. The length of the plate circuit is determined by using half this capacity reactance.

The proper coupling of the grid to the line is best determined from adjustment after the circuit is built. To obtain the approximate value for the line condenser C the power into the line is made equal to the power taken from the plate circuit. The total power supplied by the oscillator will be approximately 15 watts. The r.m.s. voltage of the grid will be about 200 volts. The power into the line is 6 watts and the input impedance is $\frac{200^2}{6}$ or 6600 ohms. An inside diameter of 10 inches for the outer conductor will make the line Q equal 13,000. This means the volt-amperes in the line is 78,000. From equation (2) the size of the line condenser can be determined and is found to have a reactance of 7.8 ohms. The optimum ratio 3.6 of conductor diameters will be used and the characteristic impedance will be 77 ohms. The length of the inner conductor from the voltage nodal point to the condenser plate can be found from equation (1) where l is the required length and X the reactance of the line condenser. The tangent of the electrical length is 7.8/77 or 0.1. The electrical length is 5.7 and the physical length is 3.2 centimeters. In the same way the length of the inner conductor from the voltage nodal point to the open end can be found. The capacity reactance now used is that due to the end effect. A close approximation of this capacitance in mmf is .7 the radius of the inner conductor in centimeters. The spacing between the ends of the inner and outer conductors should be at least as large as the diameter of the outer conductor. The radius of the inner conductor is 3.5 centimeters, thus the end effect capacitance is taken as 3.5 mmf and its reactance is 300 ohms. The length of the inner conductor from the voltage nodal point to the open end is 41.6 centimeters.

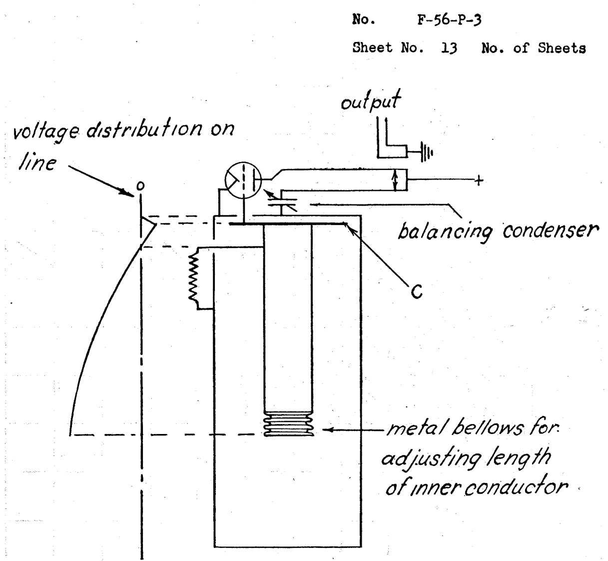

Fig. 6—Single Ended Oscillator Controlled by a Single Quarter Wave Line.

The above results will give circuit constants such that the correct values may be reached with but moderate adjusting ranges.

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(4) Transmission Lines for Short-Wave Radio Systems, E. J. Sterba and C. B. Feldman, Proc. I.R.E., Vol. 20, No. 7, July 1932.