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UNICONTROL RADIO RECEIVER FOR ULTRA HIGH FREQUENCIES USING CONCENTRIC LINES AS INTERSTAGE COUPLERS

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ABSTRACT

A new type of radio receiver for frequencies between 100 and 300 megacycles per second (Mc/s) is described. This receiver differs from previous designs in that it utilizes quarter-wave concentric transmission lines as coupling impedances between amplifier stages. A method of using a single line per stage and means for varying the effective line length for unicontrol tuning are shown. The deviation of the line length from the actual full-quarter wave length over the frequency range of the receiver is given. Measurements showed an amplification of the order of 2 per stage at 300 Mc/s, 6 per stage at 200 Mc/s, and 9 per stage at 175 Mc/s. With four stages of radio-frequency amplification and a detector, an effective over-all amplification of the order of 100,000 may be expected at 200 Mc/s.

The paper gives the circuit arrangement for a receiver consisting of four stages of radio-frequency amplification and a detector. This receiver uses four concentric lines with ganged tuning plungers for varying the effective line lengths in unison. The lines are arranged with their major axes about a common center.

CONTENTS

I. INTRODUCTION

The ultra high radio frequencies (above 30 Mc/s) are daily finding new applications. There is therefore increasing need for receivers designed to function at these frequencies. This paper describes the development of a radio receiver for these frequencies which differs from previous designs in that it utilizes quarter-wave concentric transmission lines grounded at one end as coupling impedances between amplifier stages. The theory and possibilities of concentric lines for such purposes were treated in an article in The Electrical Engineer by F. E. Terman.[1] This paper will therefore deal only with the special features and operating characteristics of this receiver.

[1] *Resonant lines in radio circuits*, Elec. Eng. **53**, no. 7, 1046–1053 (July 1934).

II. PRINCIPLE OF OPERATION

The use of quarter-wave lines as interstage coupling impedances is shown in figure 1 (a). A is a quarter-wave concentric line made up of an outer tubing B and an inner tubing C. B is grounded. C is connected to the plate of the electron tube G and is insulated from ground for direct current, but its lower end is grounded for radio frequency by means of plunger P, which is in metallic contact with C and capacitively connected to B. When the transmission line A is adjusted by moving plunger P to be some length less than a quarter of the wave length of the voltage impressed on the grid of tube G (the length is always shorter than $\lambda/4$ because of the capacitance of the plate in tube G, connecting leads, and circuit elements), a maximum voltage is built up in the plate circuit of tube G and

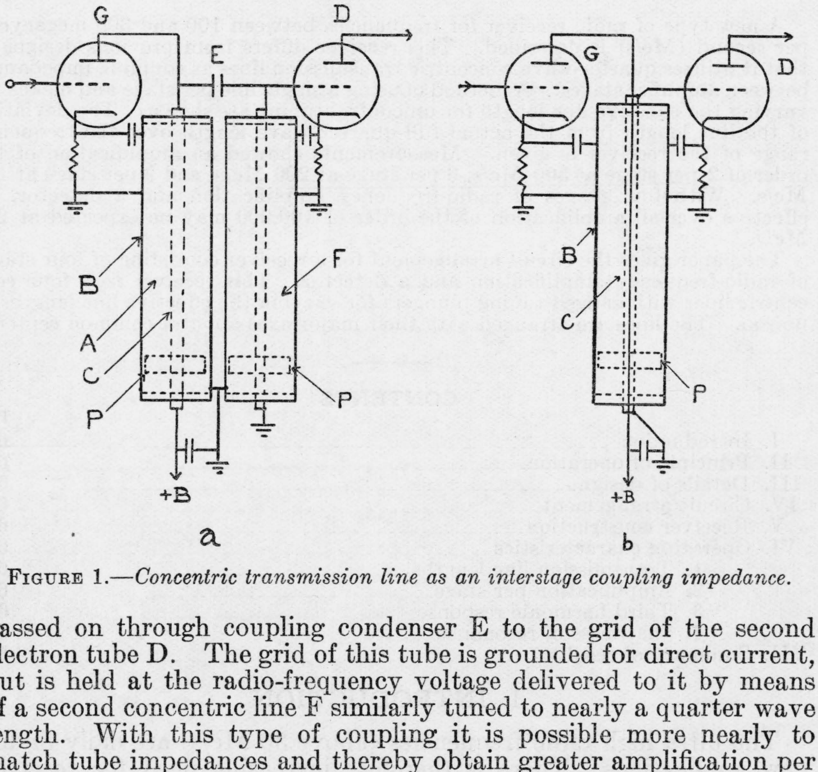

FIGURE 1.—*Concentric transmission line as an interstage coupling impedance.*

passed on through coupling condenser E to the grid of the second electron tube D. The grid of this tube is grounded for direct current, but is held at the radio-frequency voltage delivered to it by means of a second concentric line F similarly tuned to nearly a quarter wave length. With this type of coupling it is possible more nearly to match tube impedances and thereby obtain greater amplification per stage at ultra high radio frequencies than by other means.

Instead of a transmission line both in the output and in the input of each electron tube as shown in figure 1 (a), it is possible to reduce the number of lines by one-half by using a single line for both output and input circuits. This is made possible as shown in figure 1 (b) by running the insulated direct-current plate supply lead down through the center of the inner concentric line. In this way the plate of electron tube G is supplied with its proper direct current voltage without grounding it with respect to the radio frequency. The capacitance of this plate lead to the central concentric line C, takes the place of condenser E (fig. 1 (a)) and provides unity coupling at the ultra high radio frequencies used, so that the radio-frequency voltage in the plate circuit of tube G is readily transferred to the central concentric line and thence to the control grid of tube D. The grid of electron tube D is grounded as before for direct current but held at the radio-frequency voltage delivered to it from electron tube G due to the high impedance built up when the line is tuned with plunger P.

III. DETAILS OF DESIGN

In order to obtain maximum efficiency, between frequencies of 100 and 300 Mc/s, from an amplifier using concentric lines as interstage coupling impedances, the concentric lines should be arranged so that all high-frequency connecting leads are as short as possible and arranged to have a minimum of capacitance to ground. This arrangement of lines should also be such as to facilitate their ganging for unicontrol operation. Each line should terminate in a separate shielding compartment. A convenient method of varying the effective line length is essential. This should be accomplished without introducing noise due to variable contacts or undue resistance in the line. The concentric lines should be made of copper or copper plated. The concentric line on the input should be provided with means for a proper impedance match to the antenna and associated transmission line. The receiver should of course be designed so that all wiring and parts are accessible and easily replaced.

IV. CIRCUIT ARRANGEMENT

The circuit arrangement of a receiver designed with the above facts in mind and incorporating a number of new features is shown in figure 2.

This receiver consists of four stages of radio-frequency amplification and a detector. A single concentric line per stage is used with the direct-current plate supply lead running down through the center line. The electrical length of each line is varied by means of a metallic plunger P, in contact with the central line but capacitively connected to the outer line in order to avoid noise due to variations in a friction contact. The plungers for a number of stages may all be controlled by insulated rods extending through the rear of the line and suitably ganged to give unicontrol tuning.

The transmission line tuning the grid of the input electron tube has a sliding contact A on the central line which connects to one side of the transmission line C coming from the antenna. In this way a better input impedance match may be realized.

The grid of each electron tube is grounded for direct current by connecting its low radio-frequency voltage end to ground. Grid bias is obtained with the usual cathode resistor properly bypassed.

The high-voltage end of each transmission line terminates in a separate shielding compartment containing a type 954 electron tube with associated wiring.

The detector circuit in this receiver was designed for detection at modulation frequencies in the broadcast radio-frequency band. The output terminal is therefore connected to the antenna terminal of a broadcast receiver and the resulting added amplification realized.

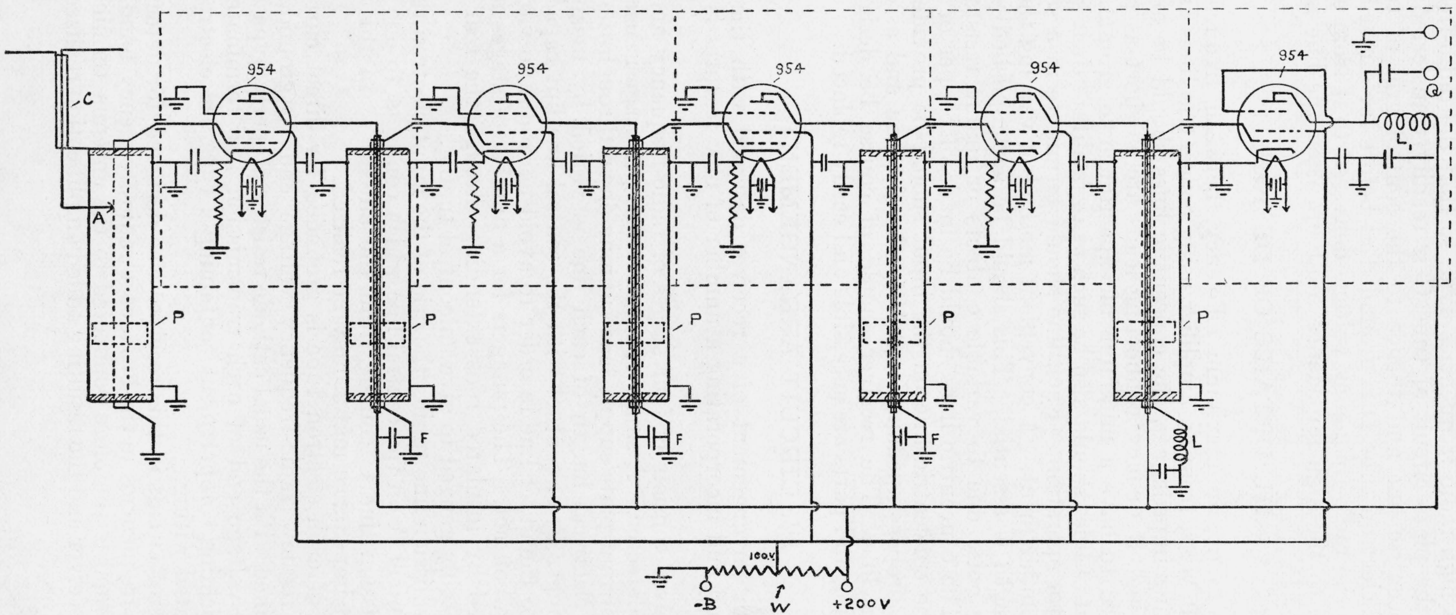

FIGURE 2.—*Circuit arrangement for a multistage ultra high radio-frequency amplifier using concentric line tuning.*

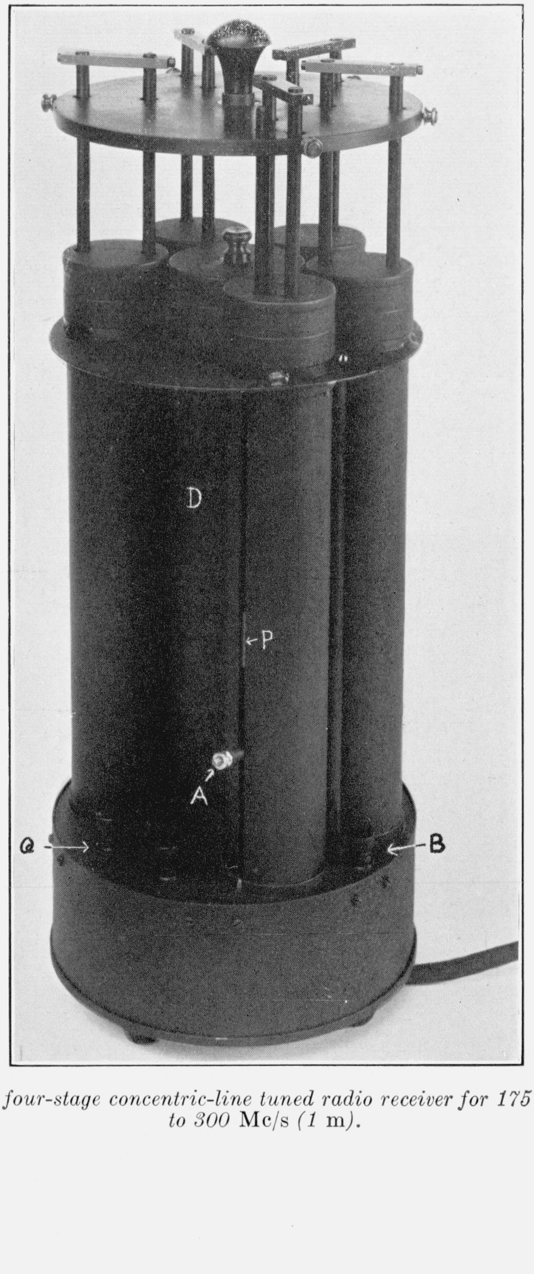

FIGURE 3.—*A four-stage concentric-line tuned radio receiver for 175* Mc/s *(1.71* m*) to 300* Mc/s *(1* m*).*

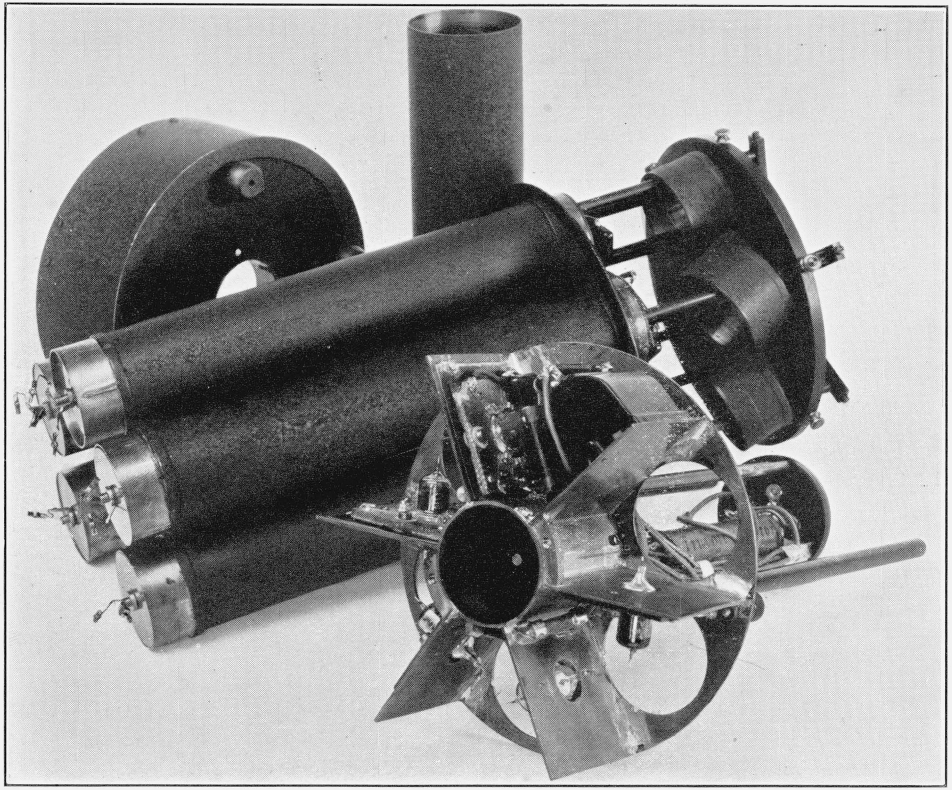

FIGURE 4.—*The concentric-line receiver showing method of assembly.*

The grid of the detector tube is held at the voltage of the modulated signal impressed on it by means of choke L in the low-voltage end of the transmission line. A similar choke L_1 in the plate circuit serves to deliver the modulation frequency to the output terminal. These chokes may be replaced by inductors tuned to the modulation frequency if desired, in which case the capacitance of the central line and plunger P to ground serve as part of the tuning capacitance for inductor L.

If the ultra high radio-frequency carrier has several radio-frequency modulations impressed upon it, these may all be obtained at terminal Q and received simultaneously on separate broadcast receivers connected to this terminal; or with a properly designed detector circuit and concentric lines designed to pass a band width of 2,000 kc/s, terminal Q may deliver a television signal if such a signal has been impressed on the ultra high radio frequency carrier.

V. RECEIVER CONSTRUCTION

Figures 3 and 4 show a receiver using the circuit arrangement shown in figure 2 and constructed in accordance with the design details mentioned in a previous paragraph. This receiver covers a useful frequency range of from 170 to 300 Mc/s (1.76 to 1.0 meters). The lower frequency limit is restricted only by the length of the transmission lines used. With but slight modifications longer lines may be inserted and the lower frequency limit thereby extended.

Figure 3 shows the receiver completely assembled. The five transmission lines are shown terminating at their lower ends in the circular shielding housing containing the separate shielded compartments for each line termination. The radio-frequency input terminals are shown at A and B. A makes contact through a slider operating on the central line of the input concentric line. (This is shown in detail in fig. 5.) Q is the output terminal which with its neighboring ground terminal is connected to the input of a standard broadcast receiver. The central cylinder D is merely a shield covering the voltage divider W (fig. 2) and associated wiring; it could also inclose a power pack if desired.

Each line contains a tuning plunger P attached to two bakelite rods extending through the upper ends of the lines. These rods are all attached to a common tuning control handle through a disk by means of set screws. By loosening the set screw on a given control rod that line may be tuned independently when desired. A suitable frequency scale (not shown) is attached to the disk. The third rod in the input transmission line is for operating the sliding contact attached to terminal A. The cap covering the upper end of cylinder D contains a terminal block where the B supply voltage is supplied to the upper end of each transmission line. The shielding cover on the top end of each transmission line covers the bypass condenser F shown in figure 2, and in the case of the last transmission line it contains the radio-frequency choke L in the detector grid to ground circuit.

Figure 4 shows the receiver in a knockdown condition. This photograph shows how, with this type of assembly, the grid and plate leads to the electron tubes may be kept very short. These leads with tube clips attached may be seen on the left end of the transmission lines. One lead is fastened to an insulated wire running down through the hole in the central line (the plate lead) and the other (the grid lead) is attached to the central line.

The insulating disks holding the central line in position at the high-voltage end should have as little insulating material in them as possible, and this should be of high grade.

By loosening a few screws and taking the grid and plate clips from the electron tubes the receiver may be easily taken apart as shown.

In figure 5 is shown the type of transmission line used in the receiver. The one shown in this figure is used in the input circuit. It differs from the other four lines only in that it contains the sliding contact carrying the binding post A (see fig. 3 at A), and in that it does not contain the plate lead through the center line. The white pieces of paper held in slots in the tuning plunger are for insulating it from the outer line so as to prevent a direct metallic contact with resulting friction and noise. They are about 0.008 inch (0.02 cm) thick. This capacitance contact, so to speak, has an approximate capacity of 156 $\mu\mu$f and an impedance of 10 ohms at 100 Mc/s and 3.3 ohms at 300 Mc/s.

The outer conductor of each transmission line has an inside diameter of 4.6 cm and the inner conductor has an outside diameter of 0.49 cm. This ratio of 9.2 is the correct one according to Terman[2] to give maximum impedance.

Both inner and outer lines and plungers are of brass, copper plated.

VI. OPERATING CHARACTERISTICS

1. TRANSMISSION LINE LENGTHS

In figure 6 at A is shown the length of a quarter-wave line at different frequencies without external capacitance shunting the free end of the line.

When used as an interstage coupling impedance, however, each line has shunting it the capacitance of the plate of one type 954 electron tube and the grid of the following tube with associated leads. The total capacitance due to the electron tube elements is 6 $\mu\mu$f. The leads probably introduce an additional 3 $\mu\mu$f. The line length at resonance is therefore reduced accordingly, the line behaving as an inductance of such value as to form a parallel resonant circuit with the total shunting capacitance.

Curve B shows the calculated line lengths for different frequencies assuming the above shunting capacitance and a line surge impedance of 120 ohms.

Curve C shows the lengths as determined experimentally by tuning the receiver to each of the frequencies.

It will be seen from these curves that the electron tube and lead capacitance on the end of the transmission line have a marked effect in reducing the line length from a full quarter wave. In fact this reduction is some 73% at 300 Mc/s and 50% at 171.5 Mc/s, this percentage becoming progressively less as the frequency is lowered.

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[2] F. E. Terman, *Resonant lines in radio circuits*, Elec. Eng. 53, no. 7, 1046–1053 (July 1934).

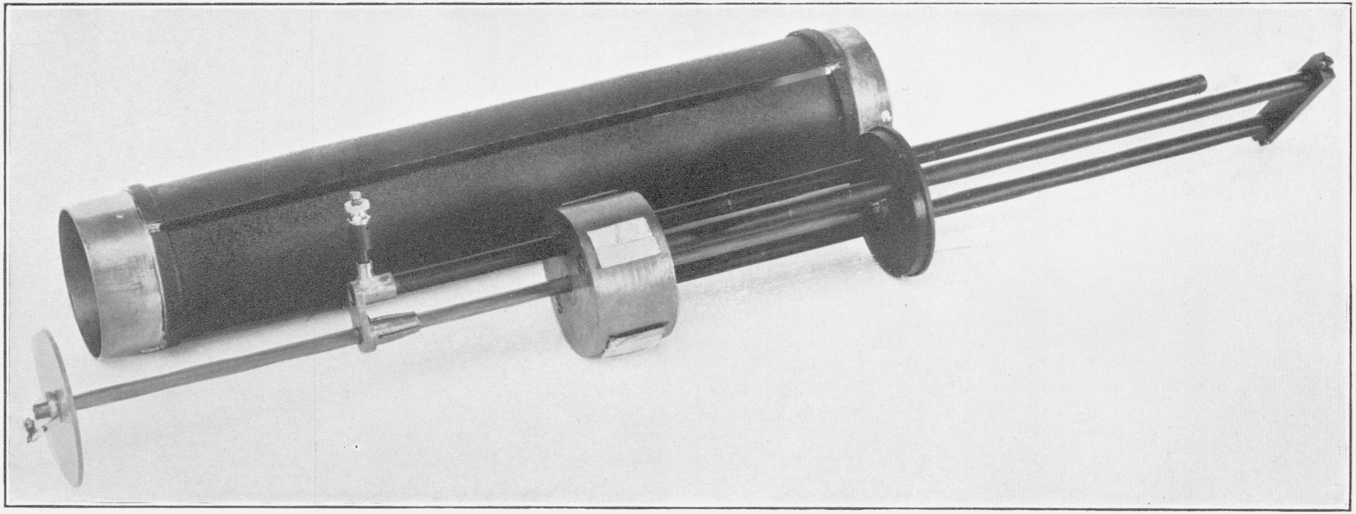

Figure 5.—*One of the concentric lines showing tuning plunger and sliding antenna input terminal.*

The 100- and 140-megacycle points were obtained experimentally for curve C by temporarily replacing the line in the detector input circuit with one 50 cm long.

All concentric lines, except the input (which has only a grid element on its end), were found to be about the same length when the receiver was tuned to a given frequency. Variations in tube and lead capacitances made differences in length not over 1.0 cm. The input line is

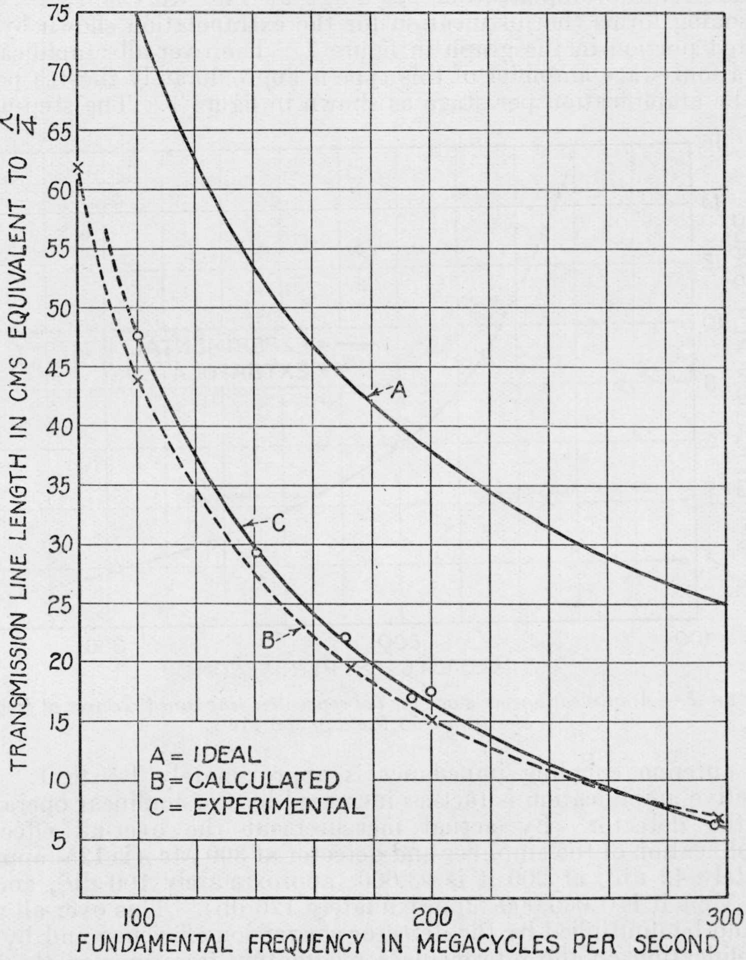

FIGURE 6.—*Transmission line length with and without capacitance of electron tubes and associated leads.*

some 2 to 4 cm longer than the others depending upon the position of contact A (fig. 2).

2. AMPLIFICATION PER STAGE

The amplification per stage as measured at different frequencies is shown in figure 7. From this graph and from the lengths of the concentric lines required for tuning to the different frequencies, the equivalent series resistance of the parallel resonant circuit formed by the shunting capacitances and the concentric line used as an inductance may be computed. Assuming a tube amplification factor of 1,500 and a plate resistance of 1.5 megohms, the series resistance is 1.5 ohms at 300 Mc/s, 0.9 at 200 Mc/s, and 0.85 ohm at 171 Mc/s. From these values it may be assumed that the equivalent series resistance at 150 Mc/s is, say, 0.8 ohm. Computing backwards, on the basis of the same assumptions of amplification factor and plate-resistance, the amplification per stage at 150 Mc/s is 13.2. This reasoning forms the justification for the extrapolation shown by the dotted portion in the graph in figure 7. The over-all amplification for a four-stage amplifier of this type is approximately the 4th power of the amplification per stage as shown in figure 7. The step-up in

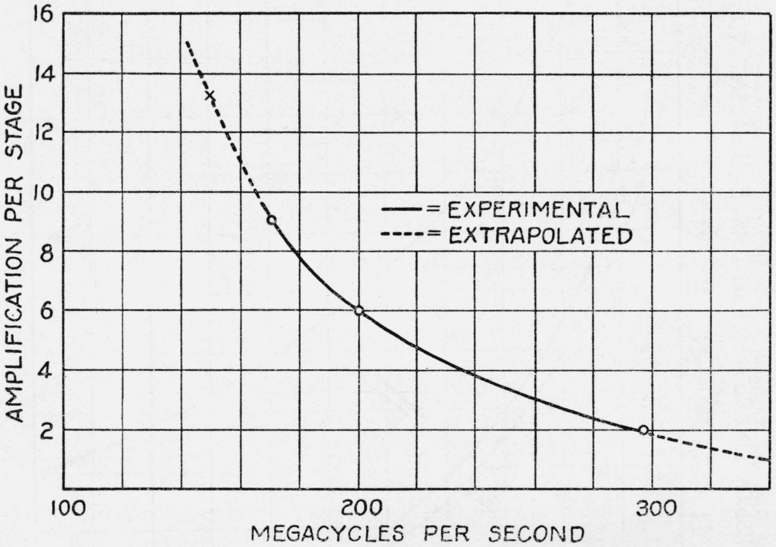

FIGURE 7.—*Amplification per stage for the concentric line tuned receiver at frequencies from 150* Mc/s *to 300* Mc/s.

the antenna coupling impedance is approximately 1.5 to 1. The effective amplification is further increased by the nonlinear operation of the detector. By actual measurement the over-all effective amplification of the amplifier and detector at 300 Mc/s is 125 (approximately 42 db), at 200 it is 93,000 (approximately 100 db), and at 170 Mc/s it is 1,060,000 (approximately 120 db). This over-all gain should be multiplied by the detector conversion efficiency and by the amplification on the intermediate modulating frequency in the first detector and in the broadcast receiver in order to determine the over-all amplification of the complete receiving set-up.

Measurements were made on a line with a ratio of inner and outer line diameters of 3.60 instead of 9.20. While this ratio should have given more gain due to a greater Q, measurements did not show this effect at 300 Mc/s. This was probably due to the predominance of lead and electron-tube resistance over the concentric line equivalent series resistance. The smaller ratio of diameters tuned to resonance with the line 3.5 cm longer than for the 9.2 ratio line. This was to be expected according to theory.

3. THIRD HARMONIC RESPONSE

A transmission line tuned to a certain fundamental frequency will also respond to a frequency near the third harmonic of this fundamental, as well as to other odd harmonics. This is due to the fact that the half-wave length section of a three-quarter-wave length line remains fixed at its full half-wave value, the variations due to the shunting capacitance occurring in the initial quarter-wave section. Thus for example the length of line for tuning to 300 Mc/s, as actually obtained by measurement, is 6.5 cm as shown by curve B, fig. 6. A half-wave length line for 300 Mc/s is 50 cm, therefore the length of line tuned to some fundamental frequency for which 300 Mc/s is an interfering third harmonic frequency is 50+6.5 or 56.5 cm. From

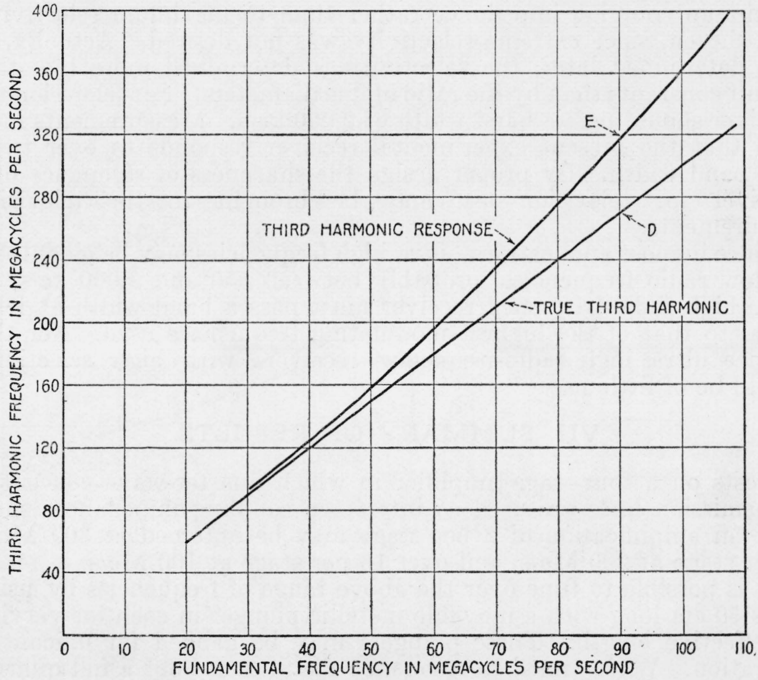

FIGURE 8.—*Deviation between the third harmonic response frequencies and the true third harmonic frequencies.*

graph B (fig. 6) the fundamental frequency to which the line (56.5 cm long) is tuned, is 86 Mc/s. In other words, when tuned to a fundamental of 86 Mc/s, a frequency of 300 Mc/s would be received (if present) and not 258 Mc/s, the actual third harmonic frequency.

In figure 8, curve E shows how this third harmonic response frequency differs from the true third harmonic for various fundamental frequencies. The question of interference which may be caused by this third harmonic response effect when using transmission lines as interstage coupling impedances is not as serious as one might expect due to the rapid decrease in amplification per stage at the higher (third harmonic) frequencies.

Thus, for example, from figure 7 the amplification per stage at 100 Mc/s is probably well over 16. From curve E, figure 8, the third harmonic response frequency for this fundamental is 360 kc/s. The amplification per stage at this frequency as shown from figure 7 is probably less than 1, a considerable difference when the over-all gain is considered. For fundamental frequencies higher than 100 Mc/s the receiver becomes even less responsive to the third harmonics. A receiver of this type for use above 100 Mc/s should require a very strong third harmonic interfering signal as compared to the fundamental before any interference would be noted. Furthermore the gain for a three-quarter wave length line would be considerably less than for a $\lambda/4$ wave line due to increased attenuation along the longer line.

4. SHARPNESS OF RESONANCE

In the design of this receiver, a ratio of diameters corresponding to maximum coupling impedance rather than to maximum selectivity, was chosen, since extreme selectivity was not desired. Actually, as was determined later, the selectivity is determined more by other circuit constants than by the ratio of line diameters. For television the receiver should pass a band width of 2,000 kc/s. Measurements indicate that the present experimental receiver responds to over twice this band width. By proper design the sharpness of resonance of a receiver for television use may be brought to the television requirements.

Since in most applications, ultra high frequencies may be modulated by low radio frequencies, probably between 550 and 3,000 kc/s, an ultra high radio-frequency receiver must pass a band width at least equal to that of the highest modulating frequencies used. For this service ultra high radio-frequency receivers with high selectivity would be of little use.

VII. SUMMARY OF RESULTS

Tests on a four-stage amplifier in which quarter-wave concentric transmission lines are used as interstage coupling impedances show that an amplification of 2 per stage may be obtained at 300 Mc/s, 6 per stage at 200 Mc/s, and over 16 per stage at 100 Mc/s.

It is possible to tune over the above range of frequencies by using lines 50 cm long with a movable metallic plunger in each for varying its effective length. These plungers may be ganged for unicontrol operation. When tuned to resonance the lines are not a full quarter wave long but 27% of this amount at 300 Mc/s, 50% at 171 Mc/s, and 58.7% at 100 Mc/s. By running the direct current plate supply lead down through the center of the inner concentric line it is possible to use one in place of two concentric lines between each stage and the next.

The possibility of interference in this receiver due to third harmonic response is probably negligible as the receiver is insensitive above 360 Mc/s.

I am indebted to H. Diamond for advice during the progress of this work and for the theoretical analysis of many of the data obtained.

Acknowledgment is also due L. L. Hughes for the construction of the receiver and for valuable suggestions on the mechanical design.

WASHINGTON, October 14, 1935.