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MISCELLANEOUS APPLICATIONS OF VACUUM TUBES

BY

F. H. SHEPARD, JR.*

Delivered before the Radio Club of America
May 9, 1935

Introduction

It is generally accepted that a great number of seemingly impossible functions can be performed by the use of vacuum tubes. If enough tubes are used and complicated enough circuits are devised, almost anything can be done.

The object of this paper is to show a few of the numerous applications where ordinary vacuum tubes can be used in comparatively simple circuits to accomplish things that have heretofore required special tubes, expensive apparatus and comparatively complicated circuits. It is also the object of this paper to show that circuits can be devised in which variations of supply voltages and of tube characteristics will have little or no effect on the operation of the circuits.

1. A NEW LIGHT-RATIO INDICATOR CIRCUIT

In a great number of conventional phototube bridge circuits, it is possible to balance out the effects of light-source variations at one particular balance point. To the best of the Author's knowledge, there are no available circuits that can be used to indicate directly a ratio of the intensities of two light sources. A device which does this, is useful for making comparisons of the light transmitted or reflected by different specimens. For instance, in color matching the unknown samples can be set up so as to transmit or reflect light directly or indirectly to each phototube. A color filter is then placed between the light source and the samples. If a variation in the ratio is indicated by the device, it is obvious that one sample transmits or reflects more of the color in question. In this way, by putting various color filters in front of the light source we can match the samples in any desired light bands.

Because this method indicates changes in the ratio of light, we can use it successfully to compare the color of extremely small objects with a larger standard sample by mounting the small specimen against a black background.

Figure #1 Shows a circuit that will give a definite output versus light-ratio curve regardless of the actual intensities of the lights in question provided, of course, the intensities are greater than a certain threshold value. This value is determined primarily by the leak-

LIGHT-RATIO INDICATOR CIRCUIT

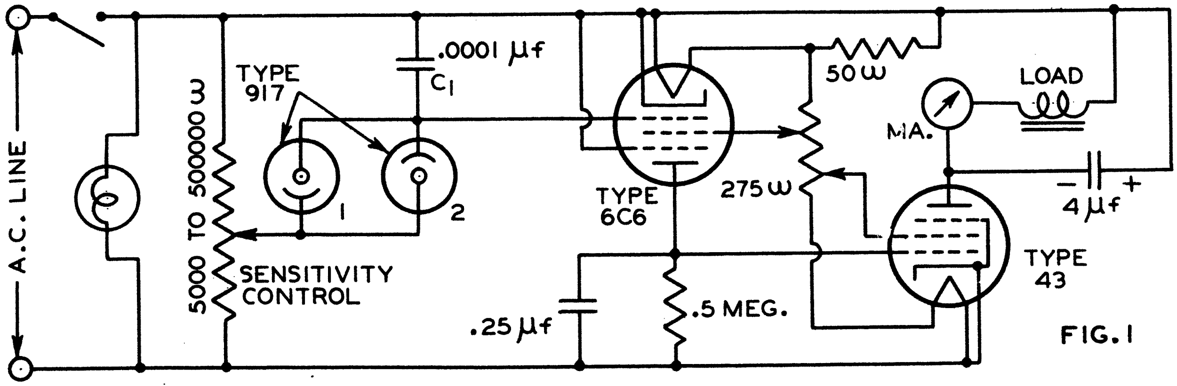

FIG. 1

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*Research & Development Laboratory
Radiotron Division
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age currents of the phototubes as affected by dirt and moisture, of the amplifier tube, as well as the leakage current of C_1 and the grid current of the first amplifier tube.

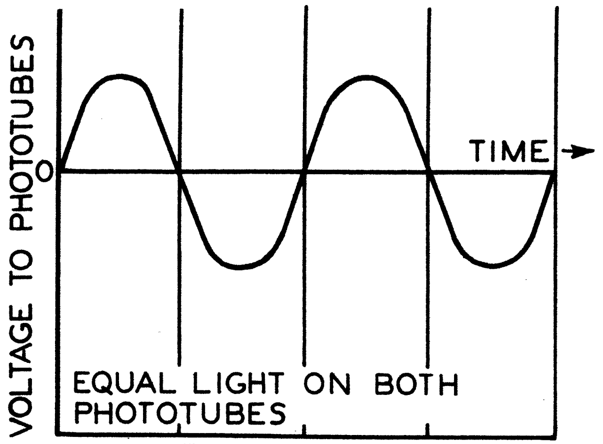


FIG.2A

Figure 2_a shows the a-c voltage which is applied across the phototubes when the voltage across C_1, in figure #1 is zero. The anode voltage on each photocell is positive for one-half the cycle and for an equal amount of time. Figure #2_b shows the currents drawn by the phototubes. The distance of the curve above the axis indicates the current drawn by photocell #1; the distance of the curve below the axis indicates the current drawn by photocell #2; the area under the curves above the axis is a function of current multiplied by time and is a measure of the charge fed into the condenser C_1 by photocell #1. Likewise the area under the curve below the axis is a measure of the charge fed into C_1 by photocell #2. The average current going into or out of C_1 over a period of time must be zero. The areas included by the curve above or below the axis, therefore, should be equal. Now, suppose we double the light on photocell #1; this will cause the distance of the curve above the axis to be doubled, the distance of the curve below the axis remains unchanged. See Figure #2_c. Momentarily, the area under the curve above the axis is increased and condenser C_1 charges, See Fig. #2_d; this in turn causes the time that the anode voltage on photocell #2 is positive to be increased. Condenser C_1 thus charges until the areas above and below the curves are again equal. See Figure #2_e. This takes place, when the a-c supply voltage to the phototubes is fixed, with a definite voltage across C_1 for every light ratio between the two photocells. The voltage across C_1 for any given light ratio will be directly proportional to the a-c voltage supplied to the phototubes. Thus the d-c voltage change across C_1, when the a-c supply voltage to the phototube is known, can be taken as a measure of the light ratio. This d-c voltage is indicated by the d-c amplifier shown, see Figure #1.

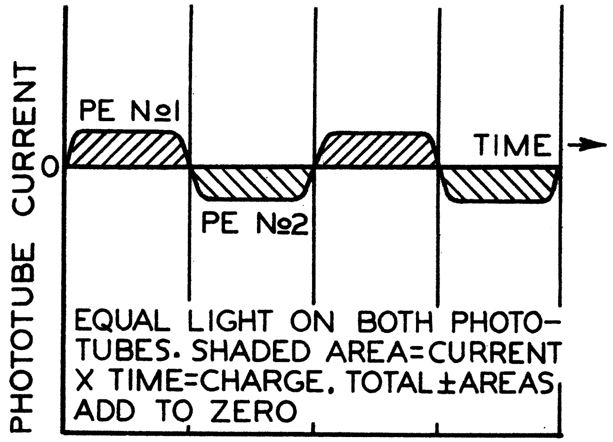


FIG.2B

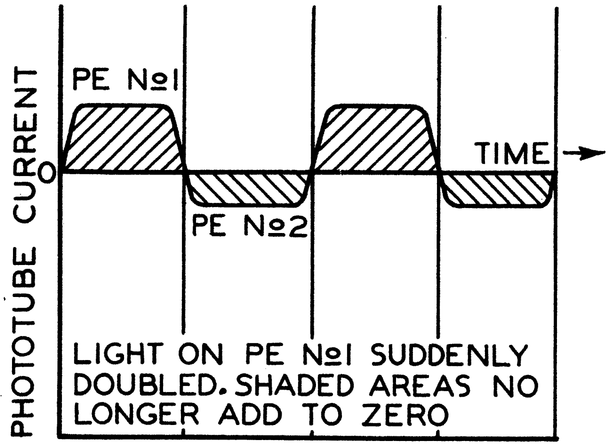


FIG. 2C

2. AN A-C OPERATED D-C AMPLIFIER

The use of an a-c supply voltage for the plates of a d-c amplifier has a definite advantage over conventional d-c amplifier circuits in that it eliminates the necessity of cascading "B" supply voltages or of using bucking or batteries between stages.

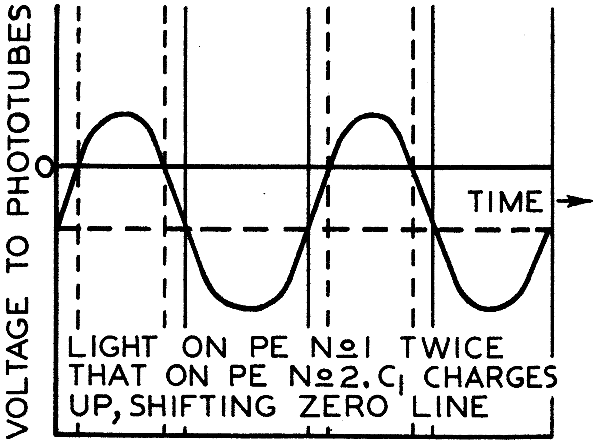


FIG.2D

Referring to the d-c amplifier used in figure #1 to indicate the d-c potential accumulated across C_1 by the phototubes as explained above, we can see that the plate supply is the a-c line. In considering the operation of this circuit, it is well to remember that the d-c potential between the two sides of the a-c line is zero. The tubes in this circuit can conduct only during the part of the a-c cycle that their own anodes are positive with respect to their own cathodes. Because of the direction of current flow thru the tubes, the drops in the load resistors are such that the plates of the tubes assume potentials negative with respect to the plate supply. Now, since the d-c value of the supply voltage is zero, the plates of the tubes in these circuits assume average potentials that are actually negative with respect to their own cathodes. The tube currents, and hence the drop across the plate load, is controlled as in conventional circuits by the grid bias. Because of this, the plate of the first amplifier stage, shown in figure #1, can be connected directly to the grid of the second stage to supply d-c. bias and signal to the output stage. The output will be a rectified pulsating d-c current which is smoothed out by the indicated electrolytic condenser and passed thru the output load.

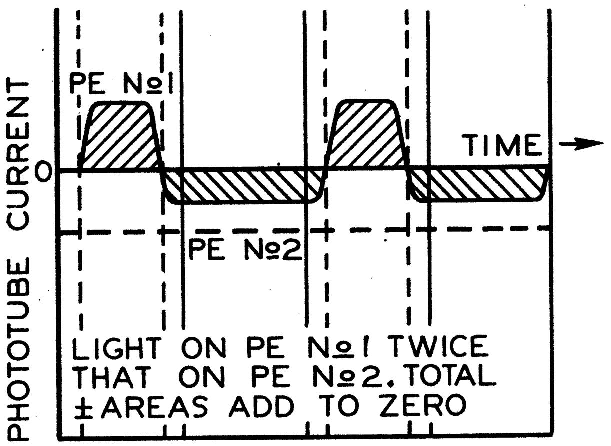


FIG. 2E

3. A SENSITIVE RELAXATION-TYPE CURRENT AMPLIFIER

Figure #3 shows what the author believes to be a new type of current-amplifier circuit. This circuit can be used to amplify the extremely small currents of a phototube which is receiving very small amounts of light. The circuit consists primarily of a phototube, a relaxation oscillator the frequency of relaxation of which is controlled by the light or current thru the phototube, a diode rectifier connected to the relaxation oscillator in such a way that the voltage it develops indicates the frequency of relaxation, and a power output tube controlled by the diode output voltage. The operation of the circuit is as follows:- The oscillator circuit oscillates violently, builds up a negative charge on its grid and suddenly blocks or stops oscillating. The oscillator will not again start oscillating until the charge on C_1 (see figure #3) has leaked off thru the phototube to such an extent that the oscillator will again conduct. Thus the time between the bursts of the oscillations of this oscillator are directly controlled by the rate at which C_1 is discharged thru the phototube.

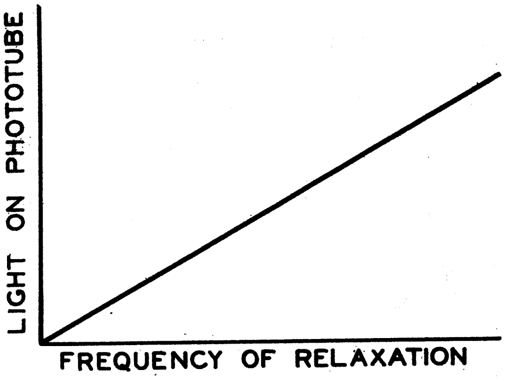


FIG. 4A

Figure #4_a shows the linear relation between the frequency of relaxation and the light on the phototube. Figure #4_b shows how the voltage developed by the above mentioned diode and fed as grid voltage to the power tube varies with the frequency of relaxation. When the frequency of relaxation is very low, the pulses of rectified current fed to the grid of the power tube are not numerous enough to cause any appreciably voltage drop across the power-tube grid resistor. As the frequency of these bursts of oscillation increases, more and more rectified current will be fed thru the power-tube resistor; this results in an increasing bias to the grid of the power tube. This bias starts out increasing directly with the frequency of relaxation and then it approaches the peak of the a-c voltage of the oscillator.

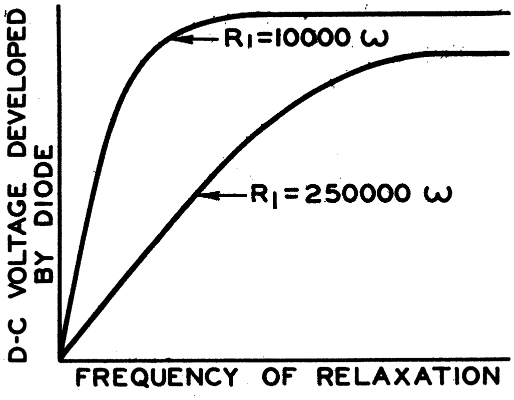
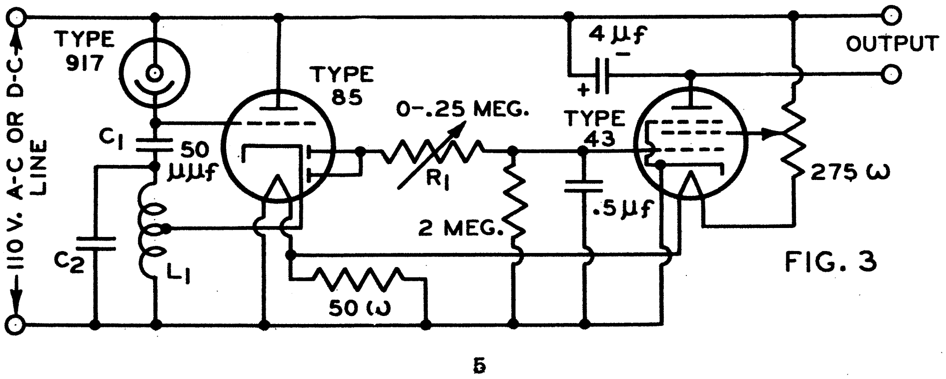


FIG. 4B



RELAXATION-TYPE PHOTO-AMPLIFIER CIRCUIT
FOR MEASUREMENTS OF SLOW LIGHT VARIATIONS

FIG. 3

See figure #4_b. As R_1 is increased the current or charge fed to the grid of the power tube per individual burst of oscillation will be reduced. The upper curve in figure #4_b is shown for a low value of R_1 while the lower curve is shown for a higher value of R_1. As the voltages on the grid of the power tube varies the power tube current also varies; thus, the output of the amplifier is a function of the power tube grid voltage which in turn is a function of the frequency of relaxation of the oscillator, which in turn is a function of the phototube current, which is in turn a function of the light on the phototube. Thus we can see that the output of this power tube is a function of the light on the phototube.

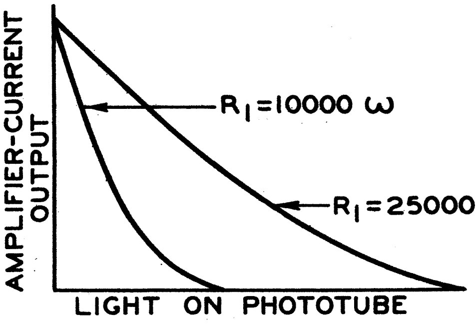


FIG. 4C

This is illustrated by figure #4_c which shows two curves for two values of R_1. Theoretically, it is possible to reduce R_1 to a sufficiently low value to get full swing of the output for a definite percentage variation of a very small amount of light. The advantage of this circuit lies in the fact that the oscillator is completely inactive, that is, its plate current is completely cut off during the part of the cycle that the phototube is discharging condenser C_1. Because of this, any gas which may be in the tube can not be bombarded or ionized by electrons in the tube and hence cannot contribute any gas current to influence the accuracy of this device. In conventional circuits, gas current is one of the greatest limitations in making small current measurements. Using a demonstration model of this circuit in air, currents as low as one-thousandth of a microampere will operate a 20 milliampere relay. If the apparatus is placed in a dessicator much lower currents can be measured.

4. A CAPACITY-OPERATED RELAY

Another interesting vacuum-tube application is illustrated by the capacity operated relay circuit shown in Figure #5_a. The sensitive part of this circuit consists of an oscillator, the feed-back, and hence the intensity of oscillation, of which is controlled by the antenna capacity to ground. The feed-back of this oscillator is a function of the difference in the ratio between the two parts of the oscillator coil and the ratio between C_1 and C_3. As C_1 or C_3 is varied, the feed-back is varied smoothly from a negative value thru zero to some maximum positive value. As this takes place, the intensity of oscillation varies smoothly from zero to some maximum value. In the circuit illustrated, a diode-triode combination type of tube is used as the oscillator. The diode is grounded for the oscillator frequency thru the 0.1 ufd condenser shown. Thus, the diode will develop a negative d-c voltage equal to the peak oscillator voltage present between the cathode of the oscillator and ground. This negative d-c voltage is fed to the grid of a power-output tube which can be used to operate a milliammeter or a relay. Figure #5_b shows how the output current varies with the antenna-to-ground capacity (C_1) for various values of C_3. This circuit finds its usefulness in operating or initiating an advertising display at the approach of a customer, a burglar alarm, a door opener, etc. In a demonstration model of this circuit, the antenna-to-ground capacity is about 50 uuf. A person holding his hand about five feet away from the antenna will cause a two or three-milliampere output variation by wiggling his forefinger.

5. A ROADSIDE PHOTOELECTRIC TRAFFIC-SPEED INDICATOR

A simple roadside photoelectric speed indicator is shown in Figure #6. This circuit contains all of the necessary parts to indicate the speed of passing vehicles. A relay operates to indicate when a passing vehicle exceeds a predetermined speed, and the meter swings to indicate the speed of each passing vehicle. Briefly, the operation of the circuit is as follows: A car first interrupts the light to the upper photocell causing the grid of the first section of the tube type 19 to be made negative by the photoelectric current of the lower cell. This negative grid potential causes the plate current of the first section of the 19 to be cut off, the IR drop in the plate load resistor to decrease, and the plate potential to increase. The grid of the second

A CAPACITY - OPERATED RELAY

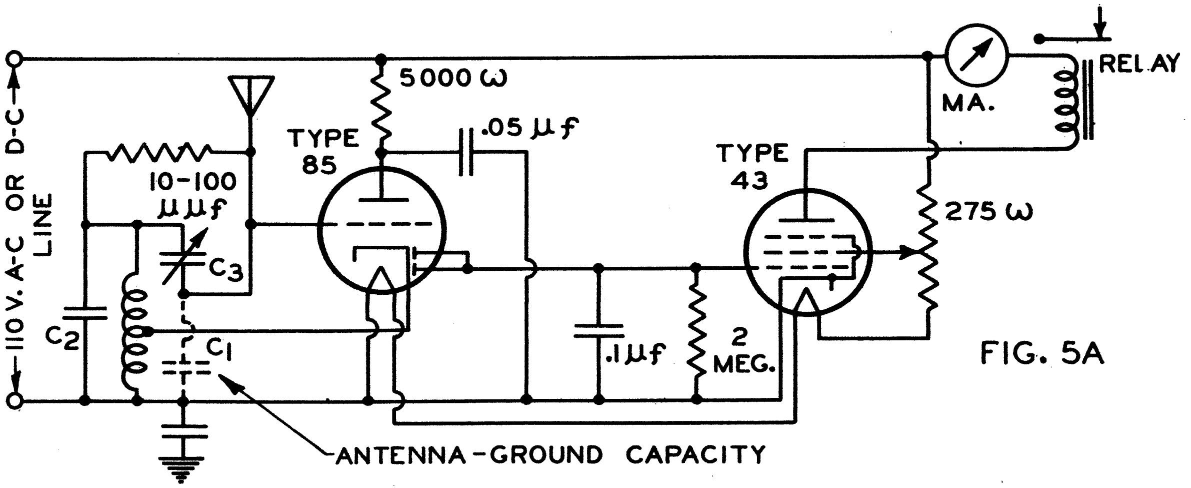


FIG. 5A

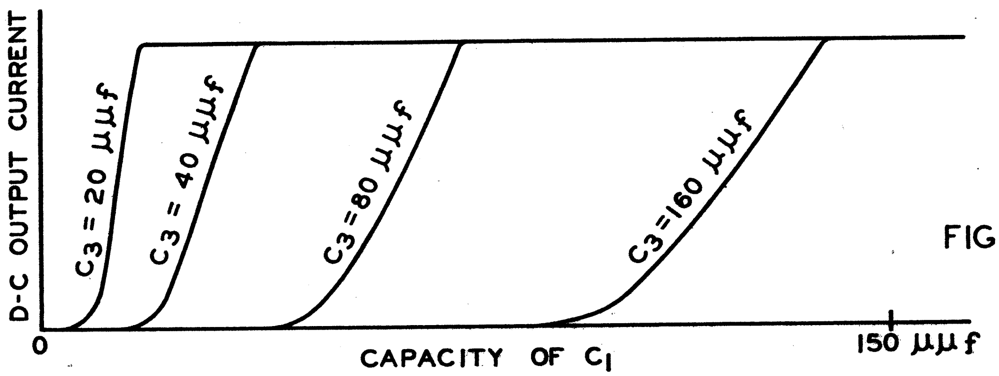


FIG. 5B

triode unit is pulled slightly positive by the increased positive voltage of the plate of the first tube section acting thru the condenser C_1 and register R_1. During this interval, condenser C_1 is being charged thru the plate-load resistor of the first triode unit, resistor R_1, and the electron current to the grid of the second triode unit. During this same interval because of the positive voltage on the grid of the second triode unit, its plate current rises and causes the relay to pull over. After an interval of time, the length of which depends on the speed of the passing vehicle, the light to the lower photocell will be interrupted. Thus, the light on both photocells is interrupted and the grid of the first triode unit is pulled slightly positive or to zero bias by the current thru the 10 megohm resistor. The positive or zero biased grid will cause the plate current of the first triode unit to rise, and its potential to drop to its former normal zero-bias value. Thru the coupling action of condenser C_1 and resistor R_1, the grid of the second triode unit will be driven negative below its normal bias by an amount proportional to the charge accumulated by C_1 during the interval between the interruptions of the lights to the two photocells. Since this negative voltage is proportional to the elapsed time between interruptions of light to the phototubes, it is, therefore, an inverse function of the speed of the passing vehicle. Thus, the reading of the output meter in the plate circuit of the second triode unit can be calibrated directly in miles per hour. If the elapsed time is long enough, that is, if the speed of the passing vehicle is slow enough, the charge accumulated will be sufficiently great to cause the grid of the second triode unit to be driven sufficiently negative to reduce its plate current below the point that will cause the relay to be released thus indicating the passage of a slow moving vehicle. If the passing vehicle had exceeded a certain speed, the relay would not have released. The relay used is of the usual magnetic type having considerable back-lash between its pull-over and release values. Because of this, the relay will stay either open or closed on the normal output current of the second triode unit.

A SIMPLE ROADSIDE PHOTOELECTRIC SPEED INDICATOR

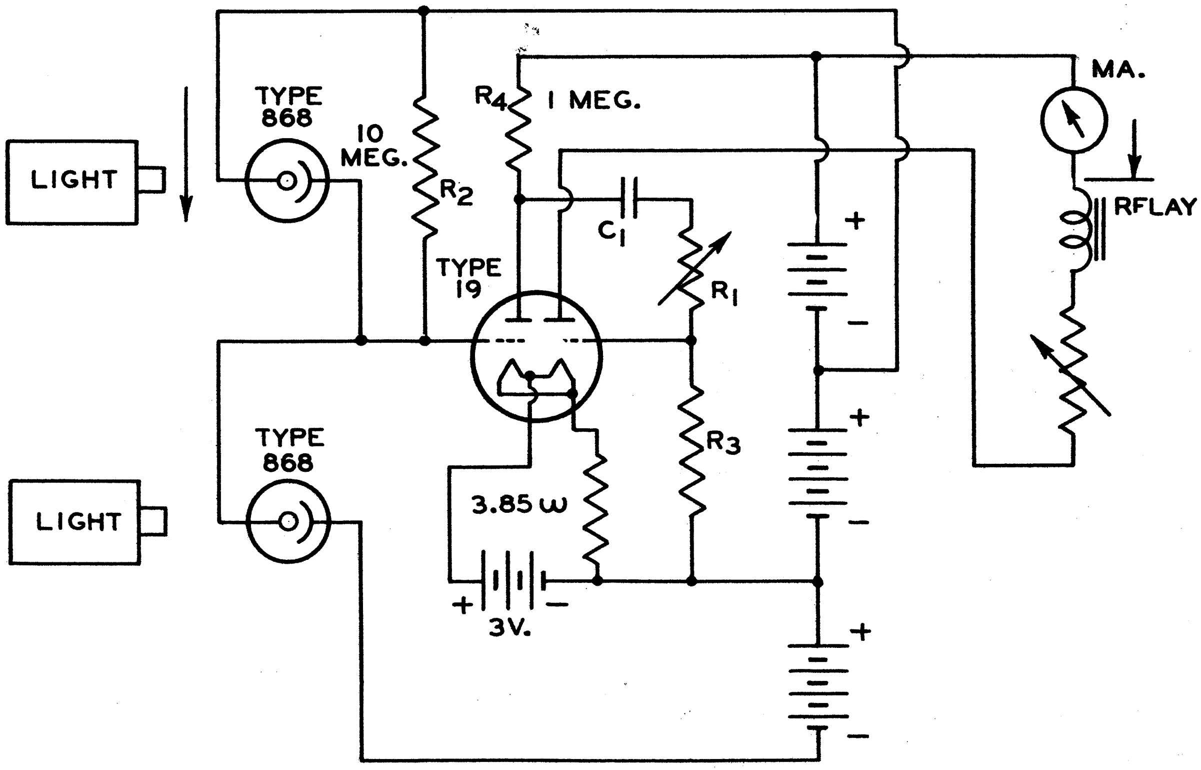


FIG.6

A PRACTICAL ROADSIDE PHOTOELECTRIC SPEED INDICATOR

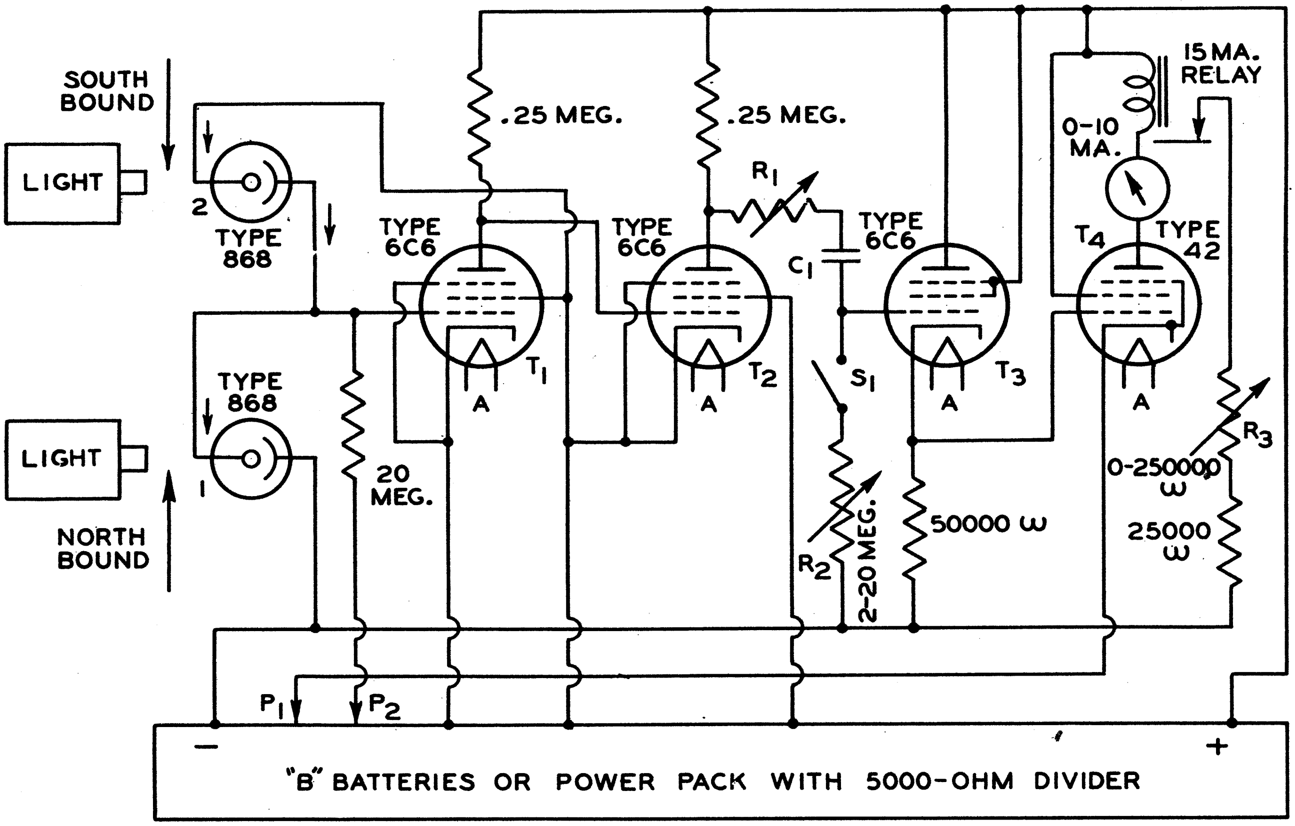


FIG. 7

Any charge accumulated by C_1 during the passage of a vehicle will leak off thru the grid-leak resistor R_3 and the device will be ready for the next passing vehicle. If the circuit constants of the device are properly set, it will be ready for the next vehicle even before the complete passage of the last vehicle.

Once adjusted and placed in operation, the device should require no attention other than an occasional check of battery voltages and of calibration.

Figure #7 shows a practical roadside-speed-indicator circuit. This circuit is more sensitive (that is, it operates on smaller amounts of light) than the circuit shown in figure #6 and is more easily adjusted. It will also indicate with equal accuracy the speed of vehicles passing in either direction. The operation of the circuit shown in figure #7 is traced thru step by step in the chart.

6. A HIGH-GAIN NON-MOTORBOATING AUDIO AMPLIFIER

All who have had occasion to build high-gain audio amplifiers have been confronted with difficulties from motorboating due to coupling from the output stages back thru the "B" supply to the input stages. This difficulty is often overcome by the use of very large filter condensers or by the use of separate "B" supplies for the various stages.

Figure #8 shows a stable high-gain resistance-capacity-coupled audio amplifier that has a voltage gain of more than 1,000,000 and which can be operated from a single poorly filtered, poorly regulated "B" supply. The stability of this amplifier circuit is due to the fact that it has a sharp low-frequency cut-off so that its individual "B" supply filters can effectively by-pass all the frequencies that are amplified, and so that the amplifier will not amplify any frequencies passed thru the "B" supply.

Figure $\#9_a$ shows the frequency characteristics of the amplifier as shown in figure #8. It is apparent that this amplifier has a sharp low-frequency cut-off. The sharp low-frequency cut-off of this amplifier is obtained by the combined effects of degeneration in the self-bias resistors, in the series-screen resistors, and in the coupling resistors. Figure 9_b illustrates how the gain of an amplifier stage varies with frequency when all of the supply voltages are fed from fixed voltage supplies except for the grid bias which is obtained from a self-bias resistor. As the frequency is lowered, the gain approaches a minimum which is the amount obtained when the self-bias resistor is totally unby-passed. As the frequency is increased the gain approaches a maximum. This is the value of gain that should be obtained using an infinite by-pass condenser or a fixed bias. This same curve is indicative of what happens when all the supply voltages are fixed, except for the screen voltage which is fed to the tube thru a series resistor which is by-passed to ground. The effect of the blocking-condenser-resistor combination is shown in figure $\#9_c$. When the combined effects of the self bias, the series screen, and coupling resistors are properly matched, a frequency-response curve such as that shown in Figure $\#9_a$ will be obtained. When circuit time constants are considered, the tube impedances,

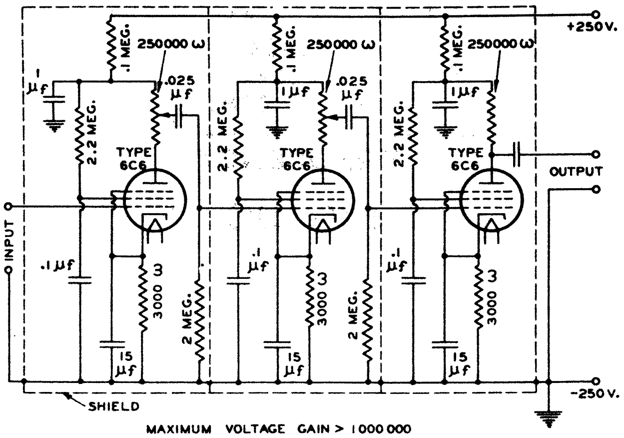
OPERATING DETAILS OF CIRCUIT SHOWN IN FIG.7

POSITION	CAR	PE No.1	PE No.2	GRID OF T_1	GRID OF T_2	PLATE OF T_2	CONDENSER C_1	GRIDS OF T_3 & T_4	OUTPUT CURRENT	RELAY Makes On 15 Ma. Releases Below 5 Ma.
1	North Bound Slow	Light On	Light On	Cut Off	Zero Bias	Definite Low Voltage	Normal Initial Charge	Normal Bias	10 Ma.	Maintains Position
2	North Bound Slow	Light Off	Light On	Zero Bias	Cut Off	Approaches Supply Voltage	Charging	Drawing Current	50 Ma.	Closed
3	North Bound Slow	Light Off	Light Off	Cut Off	Zero Bias	Definite Low Voltage	Normal Charge + Accumulated Charge	Increased Negative Bias	Below 5 Ma.	Open
4	North Bound Slow	Light On	Light Off	Cut Off	Zero Bias	Definite Low Voltage	Accumulated Charge Leaking Off	Bias Returning To Normal	Approaching 10 Ma.	Maintains Position
5	North Bound Slow	Light On	Light On	Cut Off	Zero Bias	Definite Low Voltage	Normal Initial Charge	Normal Bias	10 Ma.	Maintains Position
1	North Bound Fast	Light On	Light On	Cut Off	Zero Bias	Definite Low Voltage	Normal Initial Charge	Normal Bias	10 Ma.	Maintains Position
2	North Bound Fast	Light Off	Light On	Zero Bias	Cut Off	Approaches Supply Voltage	Charging	Drawing Current	50 Ma.	Closed
3	North Bound Fast	Light Off	Light Off	Cut Off	Zero Bias	Definite Low Voltage	Normal Charge + Accumulated Charge	Increased Negative Bias	Between 5 & 10 Ma.	Closed
4	North Bound Fast	Light On	Light Off	Cut Off	Zero Bias	Definite Low Voltage	Accumulated Charge Leaking Off	Bias Returning To Normal	Approaching 10 Ma.	Maintains Position
5	North Bound Fast	Light On	Light On	Cut Off	Zero Bias	Definite Low Voltage	Normal Initial Charge	Normal Bias	10 Ma.	Maintains Position
1	South Bound Slow	Light On	Light On	Cut Off	Zero Bias	Definite Low Voltage	Normal Initial Charge	Normal Bias	10 Ma.	Maintains Position
2	South Bound Slow	Light On	Light Off	Cut Off	Zero Bias	Definite Low Voltage	Normal Initial Charge	Normal Bias	10 Ma.	Maintains Position
3	South Bound Slow	Light Off	Light Off	Cut Off	Zero Bias	Definite Low Voltage	Normal Initial Charge	Normal Bias	10 Ma.	Maintains Position
4	South Bound Slow	Light Off	Light On	Zero Bias	Cut Off	Approaches Supply Voltage	Charging	Drawing Current	50 Ma.	Closed
5	South Bound Slow	Light On	Light On	Cut Off	Zero Bias	Definite Low Voltage	Normal Charge + Accumulated Charge	Increased Negative Bias	Below 5 Ma.	Open
6	South Bound Slow	Light On	Light On	Cut Off	Zero Bias	Definite Low Voltage	Normal Initial Charge	Normal Bias	10 Ma.	Maintains Position
1	South Bound Fast	Light On	Light On	Cut Off	Zero Bias	Definite Low Voltage	Normal Initial Charge	Normal Bias	10 Ma.	Maintains Position
2	South Bound Fast	Light On	Light Off	Cut Off	Zero Bias	Definite Low Voltage	Normal Initial Charge	Normal Bias	10 Ma.	Maintains Position
3	South Bound Fast	Light Off	Light Off	Cut Off	Zero Bias	Definite Low Voltage	Normal Initial Charge	Normal Bias	10 Ma.	Maintains Position
4	South Bound Fast	Light Off	Light On	Zero Bias	Cut Off	Approaches Supply Voltage	Charging	Drawing Current	50 Ma.	Closed
5	South Bound Fast	Light On	Light On	Cut Off	Zero Bias	Definite Low Voltage	Normal Charge + Accumulated Charge	Increased Negative Bias	Between 5 & 10 Ma.	Closed
6	South Bound Fast	Light On	Light On	Cut Off	Zero Bias	Definite Low Voltage	Normal Initial Charge	Normal Bias	10 Ma.	Maintains Position

which in this case are considerably less than the external resistors, must also be considered. Because there is no convenient means of knowing exactly what these tube impedances are under the particular operating conditions, it is most convenient to determine the time constants or condenser values in these circuits experimentally. For instance, the curves shown by figures 9_b and 9_c can be made to cut-off or attenuate the gain of the amplifier at the same point. If these circuits are not perfectly matched, that is, if one starts to attenuate before the other, the resultant effect will be somewhat like that shown in figure 9_d. As the low-frequency cut-off of 9_d is not particularly sharp, it will be difficult to provide proper plate-supply filters to stop motorboating in an amplifier having the desired low-frequency gain.

The use of series-screen and self-bias resistors make this amplifier much less affected by possible variations in tube characteristics and by small variations of the circuit-resistor values than conventional circuits using fixed-supply voltages to all the tube elements.

HIGH-GAIN NON-MOTORBOATING AUDIO AMPLIFIER



MAXIMUM VOLTAGE GAIN > 1000000

FIG. 8

FREQUENCY CHARACTERISTICS OF AMPLIFIER
SHOWN IN FIG. 8

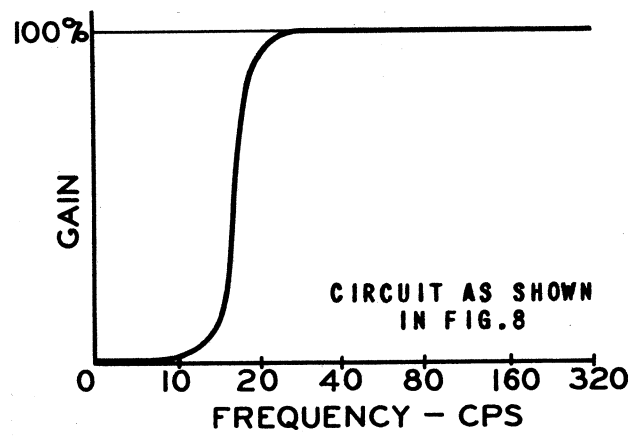


FIG. 9A

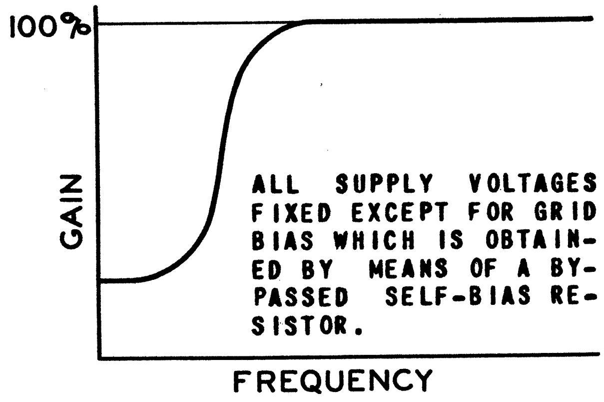


FIG. 9B

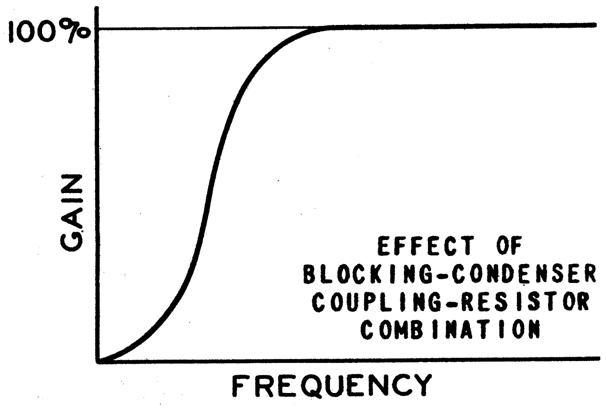


FIG. 9C

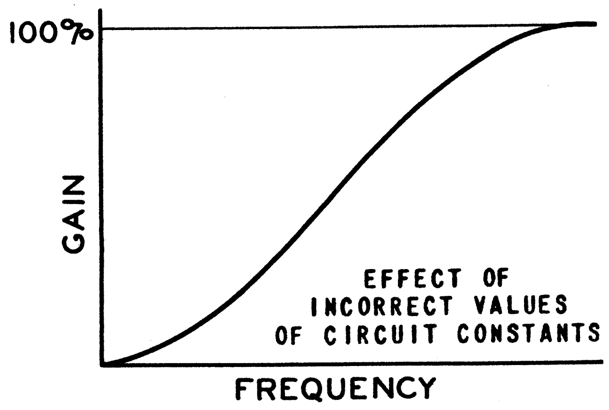


FIG. 9D

R. F. TRANSMISSION LINES

The December meeting, held on December 13th, was devoted to a symposium on radio-frequency transmission lines. Brief papers on several aspects of this extremely broad subject were read by Mr. C. W. Horn of the National Broadcasting Company, Mr. W. C. Tinus of the Bell Telephone Laboratories, Mr. Hugo Romander of the Kaltman-Romander Company and Mr. C. J. Franks of the Boonton Radio Laboratories.

Mr. Horn provided a brief paper on the historical aspects of the development of transmission lines in connection with broadcasting station design and operation; and his paper was, of course, replete with his usual and delightful reminiscences and philosophical digressions.

Mr. Tinus described in considerable detail the development and the practical form which is taken by lines and antennas for use in the ultra-high-frequency band, as typified by the newly installed police transmitter at Newark, New Jersey. Of especial interest was his brief story of the evolution of the antenna system there employed, and the samples of highly efficient, yet simple and economical, transmission lines for both low and high powers.

Mr. Romander discussed the matter of transmission lines from the standpoint of the amateur and supplied some exceedingly interesting estimates of the power distribution throughout a conventional system of antenna and line of the type commonly employed by the amateur. His review of the evolution and the reasons for the continued use of those types of antenna and line by the amateur, gave a most interesting picture not only of the state of the art in that field, but the fundamental economic and technical soundness of the methods used by the amateur.

Mr. C. J. Franks provided a short paper on the adaptation of the transmission line to the type of receiving system commonly employed in broadcast and all-wave receivers. His exposition of the details of the design of the several transmission lines--both R.F. and I.F.--in a remote-tuning type of receiver, for the design of which he was largely responsible some little time ago, was especially interesting.

The discussion brought out the fact that while the basic mathematical disclosure of the possibility of the propogation of waves along conductors was about at least as old as the practical disclosure of the means for the propogation of space waves, there appeared to be no simple explanation for the reason for the delay in applying the well-established fundamentals of the high-frequency transmission line theory to practical radio problems. It was suggested that, perhaps, the fact that much of the early development had been so largely in the hands of experimentalist might explain this condition in part, and the fact that both the instruction in and study of the propogation of waves on wires was so long in the hands of the pure physicists might explain that the now obvious simplifications both in the mathematics and physical concepts involved, resulting from the application of the rigorous analysis long available to the problem of high-frequency transmission lines, had been hidden from the engineer. It was, additionally, and more specifically, pointed out that for frequencies in and above the conventional broadcast range, the mathematical complications that may have retarded the adaptation of the transmission line to practical radio problems disappear when consideration is limited to transmission lines which are mechanically and otherwise suitable, and that once this simplification is thoroughly realized--as it is now only partially realized--their even more general adoption will doubtlessly result. Of especial interest was the point that with the simplifications of the mathematical relations, resulting from limiting considerations to high frequencies and to lines of conveniently large conductors, the engineer needs little more in the way of mathematics than simple trigonometry and the simplest of vector relationships to allow him to solve most of the problems of simple lines and antennas. It was urged that the membership investigate this possibility for themselves, and thus make themselves familiar not only with the simple mathematics of these useful electrical structures, but to note how completely the physics of their operations are revealed thereby.

It was further agreed that the difficulty of adjusting any system in which the frequency-determining circuit is directly connected to the transmission line may well have accounted for much of the delay in the adoption of transmission lines to practical radio problems and, in fact, have forced the adoption of the transmission line to wait upon the development and general use of the master-oscillator type of transmitter circuit.

Some objection was raised to the inference that the use of the transmission line in radio transmitters is of wholly recent origin, it being pointed out that within the experience of those present certain uses of lines had been made even before the advent of modern broadcasting. In the case of the early work with KDKA, as described by Mr. Horn, it was found, largely by accident, that the use of a relatively remote antenna connected to receiving equipment through a pair of wires, rather than through a single connecting wire, gave certain operational advantages; the reason for which was not clear at the time but appears now to have been a result of the limitation of true antenna effect to the remote structure and the provision of relatively efficient transmission in the connecting lines. In advance of these uses of transmission lines, however, it was noted that the location of transmitters on the lower levels of certain of our battle cruisers early in the late war, and the provision of antenna down-leads through large concentric shielding cylinders provided what was probably another partially, at least, inadvertent adaptation of the transmission principle. But earlier, by far, than these was the application described by the oldest member of the Club, Mr. Robert Marriot, in his work at Jersey City in 1910, in which the housing of the radio-frequency generator remote from much of the associated high-frequency apparatus forced the employment of a two-wire connection between the two in accordance with what was then known as the Shoemaker system which, in the light of subsequent developments, probably constituted the forerunner of a carefully adjusted, efficient, modern transmission line.

Whatever the cause of the slowness of the general adoption of transmission lines to radio transmitter problems, it was generally agreed that their introduction had freed the whole problem of transmitter operation from some of the most severe limitations. Without the use of transmission lines the elimination of the influence on transmitters of the intense fields directly under an antenna would, of course, have been difficult, if no economically impossible; and without its general use the devising and use of many of the extremely useful and effective directional arrays would have been made intensely difficult, if not downright impossible; and without its general use the highly desirable disassociation of the fragile, care-requiring, transmitting equipment from the rugged, weather-proof antenna structures would have been impossible, and the economic advantages of such a disassociation would doubtlessly have delayed the rapid development of all sorts of transmitting systems to a tremendous degree.

Much interest was shown in the description of the evolution of the UHF transmitting antennas as are used especially in police work. It was pointed out that one of the fundamental advantages of the ultra-high-frequency type of transmission is the fact that highly efficient antenna are economically possible; that is, that antennas having efficiencies of radiation quite without economic justification in the broadcasting service, because of the tremendous size and cost which are necessary, are readily possible in the UHF range because of the small size and cost of the radiating structure. Thus in the usual UHF transmission system, such as the police transmitter discussed, a half-wave radiator with its extremely high efficiency of radiation consists of about fifteen feet of copper, or brass, tubing of such dimensions as make it ruggedly self-supporting. There is, however, left a considerable problem in the devising of the line for the feeding of such an antenna since the very nature of the quasi-optical transmission in the UHF band requires that the antenna be located at the highest possible level in order that its horizon be as remote as possible. It was pointed out, however, that the half-wave radiator offers a pure resistance to a line which feeds it at any point along its length and thus provides the essential requirement for the use of a transmission line with minimum losses. Thus, such a half-wave radiator might be fed by a line at its center by the proper choice of line constants to provide for a matching of the characteristic impedance of the line and the resistance of the antennas as viewed from the point of attachment of the line. Such a structure includes a serious and difficult mechanical and electrical problem in the attachment of the line to the antenna at any point other than an end, and makes desirable the devising of means for providing for such an end attachment. Such an attachment, however, while solving the mechanical problems involved, in that it provides for the antenna being essentially a mechanical extension of the line proper, and thereby provides a simple and rugged structure, is complicated by the fact that where the size of the line and the antenna are approximately the same--as is mechanically desirable--the resultant lack of impedance match between the characteristic impedance of the line and the resonant end impedance of the antenna requires that some special expedient be resorted to to bring about proper matching. Such a matching can, it was shown, be brought about by taking advantage of the especial properties of half- and quarter-wave lines.

More specifically, it was indicated that a half-wave line of sufficiently low attenuation as is simply and practically possible, when terminated in any resistance, will provide at its unloaded terminals substantially the same value of impedance as constitutes its termination at its loaded terminals. While, in the case of the quarter-wave line, it was indicated that a suitably low-loss line terminating in a resistance, and fed by a transmission line will provide against reflection back into the line, and hence give greatest efficiency of transmission if the characteristic impedance of the quarter-wave line is the geometric mean between the loading resistance and the impedance of the transmission line proper.

This latter provides a workable solution to the UHF antenna problem. In practice, the antenna consists of a half-wave radiator which is structurally a part of one portion of the transmission line, while the other side of the line extends downward from the lower end of the antenna proper for a quarter-wave length at which point both sides of the quarter-wave line join the transmission line which makes connection with the transmitter. It is, of course, an essential element of this arrangement that the physical size of all the elements be so chosen as to give the required relationship between the several impedances.

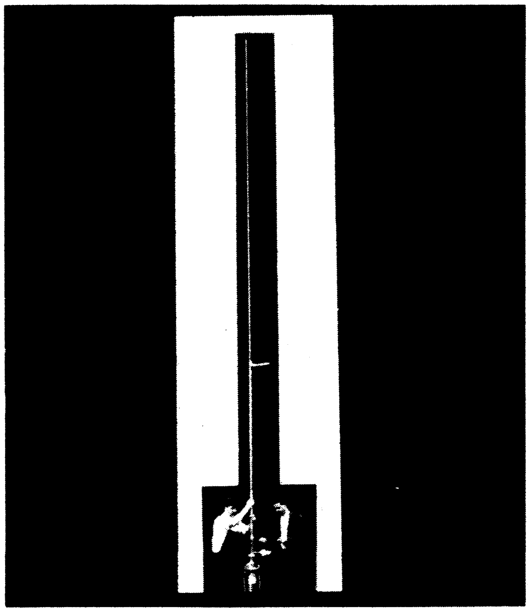


Fig. A

In Fig. A is shown a photograph of the actual arrangement used in Newark, New Jersey, where the 500-watt police transmitter operates at 30.1 megacycles. From this will be noted the physical sizes of the several parts of the system; it being, perhaps, necessary to point out, however, that the flag pole on which the antenna is located, provides the housing for the transmission line proper and above which is mounted the antenna itself.

Somewhat similar arrangements were reported to be in use in connection with the 60-megacycle transmitter atop the Empire State Building. In this case, further emphasis was placed on the point that in the UHF range the need for highest possible elevation and the unavoidable climatic hazards accompanying such location, bring with them the need for consideration of the mechanical details with care and completeness quite coordinate with the consideration required by the purely electrical aspects of the problem.

Samples of several standardized forms of transmission lines were shown. These consist essentially of copper tubing through which pass a concentrically located conductor of considerable size, contact between the two conducting members being provided against and the continued central location of the inner conductor being assured by the use of low-loss ceramic beads at frequent intervals along the length of the inner conductor, the beads being held in place along the inner conductor by slight deformation of the conductor proper, thus resulting in a combination conductor that can be bent and manipulated without damage to its operating constants. Where, however, something more closely approaching the flexibility of the conventional armored cable of the power-circuit practise is required, an alternate form of concentric conductor employing a braided covering of copper and including the ceramic beads is available. Samples of this were also shown.

Much of the discussion centered on the alternate possible forms which might be employed for the radiator and its association with the line--all of which further emphasized the need for the complete coordination of the mechanical and electrical details of the design of the antenna, line and supporting structure. An interesting form of antenna employing no matching elements was suggested for discussion.

It was pointed out that since the half-wave antenna offered a pure resistance at any point along its length--including its end--and since the characteristic impedance of a single-wire transmission line and the end impedance of the antenna were both simple functions of the diameter of structures constituting them, it should be possible to provide an antenna of so large a diameter that the end impedance of the antenna and the characteristic impedance of the line are substantially equal and so obtain a suitable match. Objection was raised to the usefulness of such a structure, in that it was felt that the large diameter of the antenna required to give an end impedance sufficiently low to match any otherwise useful line, would seriously interfere with the radio effectiveness of the antenna proper (or, as the speaker facetiously but tersely put it, "the standing waves on the antenna would not know which way to stand") although it was equally strongly felt that this was probably not of serious importance. The problem of the attachment of the line with a sufficiently sharp discontinuity in the physical structure to limit the standing waves to the antenna proper might, it was thought, offer some difficulties.

It was implied that the economic advantages of the short, cheap, highly efficient radiator of the UHF range were largely off-set by the quasi-optical characteristics of the radiation therefrom, which require an extremely great elevation of the antenna from the ground in order to secure a usefully distant horizon and an area of coverage of such magnitude as to justify the cost of the transmitting equipment. As against this, however, it was pointed out that it seems to be a characteristic of American cities that the population distribution with respect to the area of their tallest buildings is largely identical, and in addition, the relationship between the height of the tallest buildings and the population is fairly constant with the result that there is almost invariably already available in almost any of our larger cities a perfectly suitable antenna support in the form of the larger office buildings. Thus, much of the cost of the supporting structure required by the UHF antenna has already been absorbed in the cost of the available buildings. It was noted also, however, that without the availability of efficient transmission lines to provide for the location of the antenna at the topmost point of such buildings, while providing for the location of the remainder of the transmitting equipment at some other and more suitable point, much of the inherent advantage of these fortunate conditions would be lost.

In contradistinction to the niceties of design and construction which characterize the antennas and lines referred to in the preceding is the adaptations which the amateurs have made of the fundamental principles already discussed to their specific problems within the severe limitation, both technical and economic, under which, for the most part, they operate. For purely amateur uses it is obvious that any arrangement must inevitably be of low cost, easy of construction, adjustment and operation, and as efficient and reliable as is consistent with these requirements. For the most part the non-resonant transmission line finds little application in the amateur field because of the precision of construction and adjustment required for its successful use. And, in addition, the fact that the amateur almost invariably requires his transmitting system to operate on two or more of the amateur bands of frequencies, in addition to easy adjustment to the entire range within these bands, further points to the lack of suitability of the conventional types of matched lines. In addition to these completely rational reasons for the need for something other than the conventionally designed arrangements, it is probable that tradition which so largely determines the forms taken by amateur apparatus has had its influence in bringing into general use the so-called "Zep"- type of combination antenna and feed-line. It is something of a question as to whether the use of the approximately quarter-wave line, with one side extended beyond the other by an additional half-wave, was really introduced to the radio art in connection with radio transmission from lighter-than-air craft such as the Zepplins but, whatever the origin of the name, this type of antenna system, has found extremely wide-spread use and its description serves to indicate the form of structure commonly used by amateurs throughout the world.

In general, the amateur finds it quite impossible to provide himself with a mast or other supporting structure which will allow him to equip himself with a vertical antenna, notwithstanding the obvious advantages of this form of antenna as against the horizontal type he usually employs. This latter type requires only that it be attached to such supporting structures as are available to him--as for instance the roof-tops of his own home and that of his neighbors--and that it be fed in some manner that will deliver most of the output of his transmitter to the radiator. He usually chooses to make the length of the horizontal antenna a half-wave length for one of the lower frequencies of the amateur assignments using the same structure as a grounded antenna for the lowest wavelengths on which he operates and resorting to such expedients as are found necessary and workable to provide for operation at higher frequencies. The transmission line, or better, perhaps, the feed-line, is then chosen to be approximately a quarter-wavelength long and effort is made to supply it out of an impedance which matches the combination of half-wave antenna and quarter-wave line, with provision being made for the resonating of the reactance of such coupling as may be used and, incidentally, resonating the line to whatever degree may be necessary in view of the range of frequencies over which it is to be used within any one of the assigned bands.

Such a line-antenna combination results in approximately the same relationships attributed to the UHF antenna referred to previously, in that the characteristic impedance of the line is approximately the geometric mean of the terminating impedances. Or, more intelligibly, the combination of line and antenna results in a terminal impedance at its supply end determined by the ratio of the square of the characteristic impedance of the feed-line to the end impedance of the antenna. These simple relationships are, for several reasons, only approximately realized; but they serve to indicate the magnitude of the quantities involved. Thus, for the conventional 600-ohm line and an antenna having an end impedance of 10,000 to 15,000 ohms, a supply-end impedence of the order of 25 ohms results. This is an especially happy choice for the amateur, not only because the low value of the impedance makes the transfer of power to the line easily and conveniently possible, but also, which is equally important, it results in input currents of such relatively high value (in view of the powers commonly used) as to make measurement during adjustment easy with relatively simple, rugged and cheap instruments, and provide that stimulation to the operator which results only from the evidence of sizable and generally impressive values of current.

It is without point to neglect the significance of these purely psychological factors, since it is just such factors as these as have stirred the imagination and the ambition of the amateurs to strike out into new and previously little-explored fields, and thus to blaze the way for the more highly skilled, but perhaps less enthusiastic and persistent, professionals who fill the voids left in the work of the amateurs, and building upon this joint foundation, rear the precisely organized structure upon which commercial radio depends.

Nor is it to the point to be too critical of the amateur antenna system, even from the purely technical viewpoint; since, as was shown by the illustration given by Mr. Romander, it has little to apologize for even from the standpoint of the efficiency of operation.

More specifically, a set of data was supplied and is given in the following table, showing something of the power loss in the usual amateur antenna and in the com form of "tuned" line used therewith.

Frequency	Loss	Size	Efficiency
1.8 mc	2.35%	#10	(.935)N
1.8 mc	4.8 %	#16	(.875)N
14.2 mc	0.82%	#10	(.975)N
14.2 mc	1.66%	#16	(.953)N
58 mc	0.4 %	#10	(.988)N
58 mc	0.8 %	#16	(.976)N

$$(N = \frac{4L}{\lambda}.)$$

These sets of data are the result of careful computation, based on several simplifying assumptions. The second column shows the ohmic power loss in the antennas as compared to the power radiated, and is, in fact, the ratio of the computed high-frequency resistance of a half-wavelength wire properly weighted in accordance with the sinusoidal current distribution to the 75 ohms which is commonly accepted as the radiation resistance of such a wire. It is especially to be noted that, in all cases, the power lost in the conductor proper is only a few per cent of the total power lost in the antenna and, of even more importance, it is to be noted how little is lost through the use of what would probably be classed as a commercially unsuitably small wire size as compared with the larger wire sizes.

In the fourth column is given the results of a similar set of calculations involving, however, the transmission line and expressed as the efficiency of the lines. The figures given are such as to provide for the direct application to lines of more than a quarter-wave in length, since N is merely the ratio of four times the line length to the wavelength. Here again, it will be noted that the efficiency of transmissions shows itself to be strikingly high. And, in general, it is to be concluded that the apparently crude structures which are typified are, after all, quite respectable in their operating characteristics.

In the course of the discussion it was objected that no losses had been charged off against such insulating spacing members as might be included in the line structure and that, perhaps, even the radiation losses of the line might be an appreciable portion of the power loss. It was felt, however, that in view of the amateur's less rigorous requirements as to precise line spacing and the relatively few line spacers commonly employed, that the di-electric losses in the line structure might without serious error be neglected. And that, in general, the radiation losses from the lines were not of such serious magnitude at even the highest frequencies as to require inclusion in these admittedly unprecise but, withal, interesting and significant figures.

It is not, however, to be assumed, that only the "Zep"-type of antenna is employed by the amateurs since, as was pointed out, the center-fed, open doublet does find considerable use. In this case the dimensions which characterize the previously discussed structure provide two quarter-wave antennas feeding from opposite sides of the line which itself is usually made the equivalent of half-wave in length, and thus provides at its input terminals approximately the 75 ohms provided by the antenna which loads the other end of the line. This value of impedance is sufficiently low to meet the technical as well as the purely psychological needs of the amateur, and is found to serve quite well.

MEETING NOTES

January Meeting:

The meeting on January 10 was devoted to a paper by Mr. S. Y. White on the subject of signal-seeking circuits. Such circuits are characterized by the fact that when the system including them is tuned by the usual manipulation to be in only approximate tune with the signal that it is desired to receive, the automatic action of the circuits bring the system into more precise tune with no further manual adjustment. Many possibly useful schemes, both mechanical and electrical were described by Mr. White, amongst them a purely electrical one which he had developed and demonstrated, showing the operating characteristics of that type of automatic action.

The extended discussion that followed the presentation of the paper indicated the keen interest of the attendants in this type of circuit arrangement and, in addition, brought out the fact that work on arrangements of similar function had been in progress for some time both here and abroad.

February Meeting:

The meeting of February 14 was devoted to a paper by Mr. Glen F. Gillette on the subject of "Theoretical and Practical Aspects of Station Coverage as an Engineer Sees Them." It will be remembered that Mr. Gillette had devoted the last several years to the measurement of the transmission characteristics of a large number of American broadcasting stations, and on the basis of data so gathered was able to offer a most interesting summary of this data as well as certain conclusions as to the means that might be employed in the predetermination of these characteristics as well as for their general improvement.

While unusual preparation has been made for the formulation of Mr. Gillette's paper for publication, it has not yet been possible to complete it for that purpose. It is expected, however, that it will be available for the September issue of the Proceedings and will there be published.

March Meeting:

The meeting of March 14 was devoted to a paper by Mr. John F. Rider on the subject of "Engineering Developments in the Service Field for the Future". Mr. Rider pointed out at considerable length the need for providing for the servicing of radio receivers such apparatus as will make analysis of the causes for receiver failure---both partial and complete---more easily and expeditiously possible. For this purpose he proposed the use of two cathode-ray tubes in a particular circuit relation which he described and discussed. The discussion of Mr. Rider's paper directed itself as much to the educational and economic problems of the servicing of radio receivers as to the purely technical problems involved.

April Meeting:

The meeting of April 10 was held in the special auditorium of the General Electric Building in New York City and was devoted to the series of electrical and optical demonstrations that are commonly there given under the intriguing title of the "House of Magic". While the several demonstrations were unusually well prepared and generally interesting, it was most unfortunate that the formal lecture accompanying them was obviously designed for the non-technician and the willing-to-be-mystified, and of little, if any, interest to the attendants. Happily, however, the latter portion of the meeting was enlivened by a discussion of the then newly-announced all-metal tubes, of which a series of samples were available for examination.