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THE BEHAVIOR OF GASEOUS DISCHARGE TELEVISION LAMPS AT HIGH FREQUENCIES

By
H. J. Brown*

Probably the most common source of light used for the reception of television images is a gaseous discharge known to the physicist as a glow. The discharge is usually thru one of the noble gases as argon or neon in a sealed glass envelope at a low pressure. The light output of a lamp so constituted is capable of rapid changes and while it is far from ideal in color the simplicity and ease of construction of such lamps and the convenience of their application has given them wide use in mechanical scanning systems.

In discussing the elements of a mechanically scanned television system it is relavent at the start to mention one important feature of the system as a whole.

While it is probably true that a mechanically scanned television system can only with great cost and complication realize the same large number of picture elements that are readily possible with the cathode ray type of scanning system, the ease with which precise spot placement and spot size may be realized in the mechanical type of system off-sets this advantage of the alternate type of system to a degree that has been estimated to be as high as fifty per cent.

In view of these facts and in view also of the fact that the mechanical difficulties in the mechanical systems are probably not without their counterparts in the electrical problems involved in the cathode ray type of system, it is felt that there is still a considerable justification for the investigation of the properties of the glow lamp with their application to the problems of television in mind as is herein reported.

The glow lamps discussed in this paper were of two distinct types. One, suitable for use with aperture disc, included flat plate cathodes 1½" square while the other was of the "crater" type with a circular cathode 0.060" in diameter. The gaseous atmosphere of the lamps was neon in both cases, at pressures giving a breakdown voltage of about 175 volts. The current rating of both lamps was about 30 milliamperes so that the current density at the cathode of the crater lamp was many times that of the other lamp. The emitted light in both cases came from the negative glow region of the discharge and was identical in appearance.

In a glow discharge as employed in the lamps here discussed the negative glow is a region characterized by high ion density, small net space charge and low electric field intensity. The dark region between the glow and the cathode has a high space charge, and a much greater field intensity. In fact substantially the entire voltage impressed upon the lamp appears across this cathode dark space, the electrons gaining velocity from this field to plunge them into the negative region with sufficient energy to create positive ions and to excite atoms with a consequent production of light. In Fig. 1 is shown the static characteristics of the two types of glow

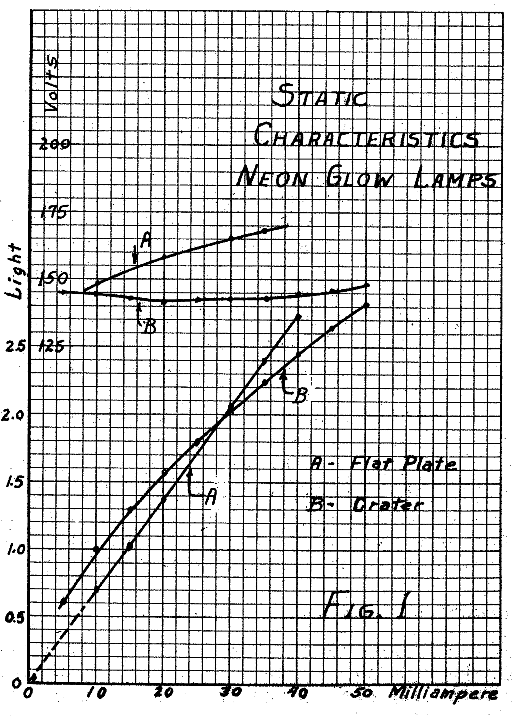

Fig. 1

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lamps under test where it may be seen that the production of light is a simple, direct function of the current thru the lamp and is largely independent of the voltage across the lamp, from which it is obvious that the practical and important characteristic of these lamps is their current-light relation particularly in so far as this characteristic is related to the frequency of the current exciting the lamp.

When operating in a conventional television system, the current thru the lamp is a modulated direct current. This is equivalent, of course, to an unvarying current with an alternating current superimposed. The alternating component of the current should provide an alternating component of the emitted light if the lamp is to be suitable for television purposes, and a lamp of such characteristic may then be considered as a transducer between current and light and as such requires that consideration be given to the following important characteristics.

Frequency Discrimination.

If the degree to which the light is modulated for any degree of current modulation is not substantially the same at all useful frequencies of current modulation the light output of the lamp will not truly represent the wave form of the current and will, of course, emphasize certain frequencies or ranges of frequency and discriminate against other ranges of frequencies.

Phase Shift.

If the light output of the lamp is not in precise time agreement with the current thru the lamp thruout the cyclic variation of both, there is, a phase difference between the light and the current. Such a phase difference between current and light output is obviously present in the filament type of lamp as a result of its thermal inertia and in which the light lags behind the current in time relationship. In the gaseous conduction lamp, however, the light will often lead the current as is shown in what follows.

Harmonic Distortion.

The dynamic light-current characteristic may depart from strict linearity in which event harmonics in the light output will be present over and above such harmonic content as may be present in the lamp current thus giving rise to harmonic distortion of the light output.

If these characteristics of a current-light transducer such as the lamps here considered are known and found to be satisfactory, only a knowledge of the characteristic impedance of the lamp is required to serve as a basis for the rational choice of the equipment to be associated with the lamp and for the prediction of the general operating properties of the system employing these several elements.

And if there is a reasonable degree of linearity between voltage and current, and light and current, a vector diagram may be drawn for any particular frequency showing the relative magnitudes and phases of these three variables. If any correlation exists between these variables a series of diagrams for different frequencies should tend to bring it out.

Measurement of Lamp as Transducer:

The obvious way to measure the light output of a lamp whose color is nearly invariable is to use a photo-cell. The electron emission from a photo-cell's cathode is strictly proportional to the quantity of light of fixed frequency impinging on it. Thus if saturation voltage is applied to the cell anode a current will flow, the magnitude of which is proportional to the light falling on the cell. In high vacuum cells there will be few collisions between electrons and gas molecules so that we need expect no internal effects, other than those due to the geometrical capacity between elements, tending to prevent the space current of the cell from following the comparatively slow flucuations of light encountered in these experiments. The external characteristic of the cell (Fig. 2) for constant impressed light shows a definite Schottky effect but it hardly suggests the presence of ionization by collision, the curve being concave downward up to 135 volts. In our experiments we used a cell voltage of 40, large enough to insure saturation, and small enough to prevent appreciable ionization current.

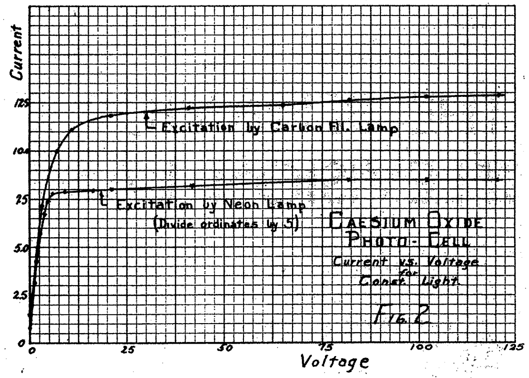
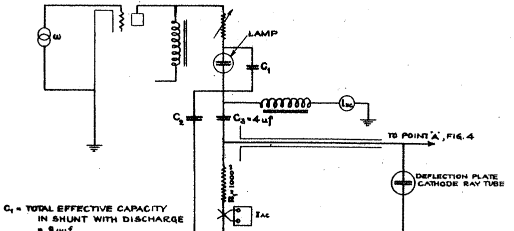


Fig. 2

It is especially interesting to note the difference between excitation by a line spectrum (neon lamp) and a continuous spectrum (filament lamp) in the sharpness of cutoff, as shown in Fig. 2.

The A.C. component of the photocell current must of course be built up to a value sufficient for measurement of magnitude, of phase, and of wave form. There must be no question of fact that this transfer takes place with a known degree of accuracy, and for this reason, the comparison method of measurement was used as indicated in Fig. 3 and 4.

LAMP DRIVING CIRCUIT



C_1 = TOTAL EFFECTIVE CAPACITY IN SHUNT WITH DISCHARGE = 9 uuf

C_2 = TOTAL EFFECTIVE CAPACITIY IN SHUNT WITH R_1 = 28 uuf

Fig. 3

The lamp driving circuit (Fig. 3) is arranged to superimpose an alternating current relatively free from harmonics on the steady direct current thru the lamp. This alternating current, flowing thru R_1 actuates one pair of deflection plates of a cathode ray tube and provides a calibrating voltage for the amplifier shown in Fig. 4, the magnitude of this current being measured by a thermocouple. The attenuator (Fig. 4) is so adjusted that the voltage introduced at the input of the amplifier is approximately the same as the A.C. voltage generated across R by the photocell. The output voltage from the amplifier actuates the voltmeter V_0 and the second pair of deflection plates of the cathode ray tube. With the photo-cell hooded, the voltage V_{ac} (proportional to the A.C. component of the lamp current) is introduced into the amplifier which is then adjusted for unit output and zero phase shift. Point A is then disconnected and grounded and the cell is unhooded. The resultant current-light excursion on

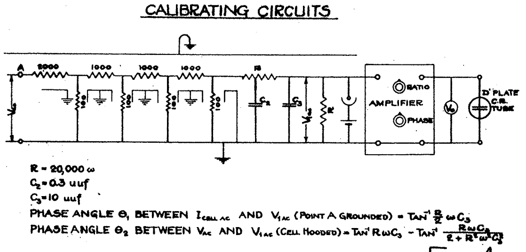


FIG. 4

the cathode ray tube will show the phase shift and any harmonics present. The voltmeter reading will tell the relative response.

In making these measurements a multistage wide range amplifier was used. Altho the measured response of the fundamental frequency in the light output is independent of the amplifier characteristics, to obtain a true current-light excursion the amplifier and input circuit must be distortionless thru the range of harmonics encountered in the light output. It is a simple matter to extend the distortionless range of the amplifier by increasing the number of stages while cutting down the gain per stage. But to increase the range of the input circuit it is necessary to reduce the value of resistor R. Random noises in the input circuit will tend to encroach on the signal as R is reduced making the measurements less satisfactory and for this reason a minimum value of 20,000 ohms was chosen for R. This gives a conservative upper limit of 160 k.c. for the calibration for the fundamental frequency and a lower value, depending on the harmonic content in the light output, for an accurate excursion. As it happens, however, the harmonics in the lower region are not noticeable and in the upper region are not qualitatively indicated on the excursion, so their effect will be neglected in the measurements.

The resistors used in the calibrating circuits and in the measurement of the lamp current are of the metallic film type. These elements have only easily calculable and measurable geometrical capacitances to affect their impedance. It is, therefore, a simple matter to choose values that will be substantially non-reactive. Only in the case of R (Fig. 4) was it necessary to supply especial mountings to reduce and establish this capacitance as represented by C_2. In the attenuator the effective capacitance in shunt with the resistors is largely negligible because of their low values and is eliminated from R by shielding.

Experimental Results;

Light vs. Current, Amplitude Response and Phase Shift:

The frequency response curves as a current-light transducer are shown in Fig. 5 for the two lamps whose static characteristics were given in Fig. 1. At low frequencies the excursion for both lamps has the same general form as the static characteristic and a very uniform response. In the case of the crater lamp, the response after falling to a minimum around 10,000 cycles slowly rises with frequency until at the upper limit of our measurements it is about 50 per cent greater than the low frequency value. The flat plate lamp has a 20 per cent increase in response to 40 k.c. where there is a sharp discontinuity. It then falls to a value at 160 k.c. not markedly different from its low frequency response.

While the above results are strictly true only for a degree of modulation of about 50 per cent, they are characteristic of the behavior of these lamps over wide ranges of modulation and polarizing current, with the exception of the break in the curve

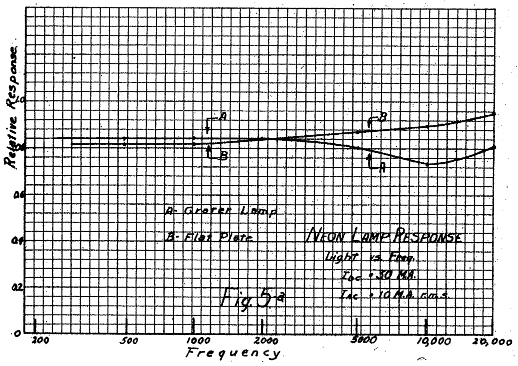


Fig. 5-a

of the flat plate lamp. This break is accompanied by so high a circuit impedance that it is impossible to force alternating current thru the lamp, and it is a property of this particular lamp for a narrow band of frequencies between 39 and 41 k.c.

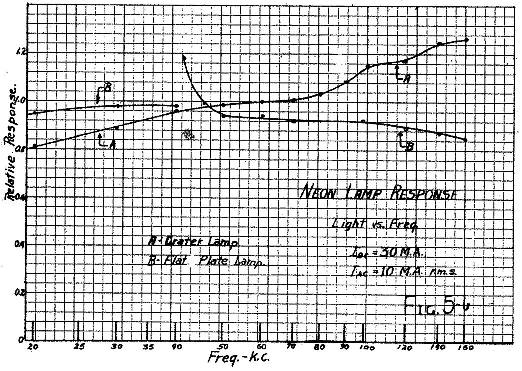


FIG. 5-b

There is a marked difference in the performance of the two types of lamps with respect to phase shift. All crater lamps tested having a small enclosed cathode showed a leading angle for the light with respect to the current while there was no observable phase shift with flat plate lamps. The angle of lead for the crater lamp whose response is plotted above is about 15 degrees for the above conditions at 50 k.c. It is proportional to frequency from zero to 90 k.c. after which tends to be constant. It is independent of the degree of modulation and decreases with increasing polarizing current.

Lamp Impedance:

The measured values of lamp impedance affords an interesting correlation with their observed light response. As with all instances of gaseous conduction, there is a time lag between ionization and the ionizing agent. In general it would be expected that devices such as these lamps, which depend on the creation of ions by collision to provide for the passage of current, would present inductive reactance to alternating currents. In Fig. 6 and 7 is shown the equivalent self inductance for the crater lamp as a function of frequency and current. This self inductance provides substantially the entire impedance of the lamp, the resistance component being small or negative. For high frequencies the inductance tends to approach a constant value determined only by the polarizing current. Thus, the alternating current lags the voltage by a large angle.

The flat plate lamp also shows self inductance. It tends to have a constant reactance

(Fig. 8) rather than a constant inductance; but as the resistance component is large and increasing

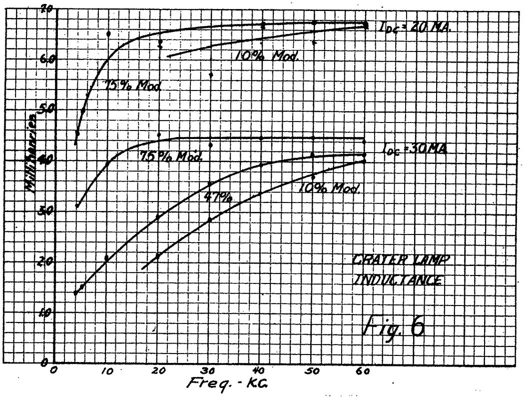


Fig. 6

with frequency, this lamp has a very much smaller phase angle between the applied current and voltage.

In Fig. 9 are given vector diagrams showing the relationship between the factors of impedance and light characteristics. It is definitely suggested

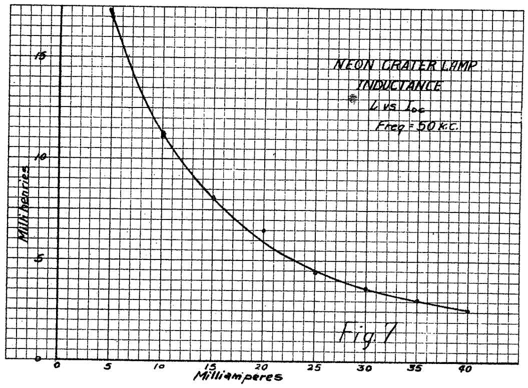


Fig. 7

by these diagrams and the response curves that the increasing voltage variation across the lamps is responsible for the rise in the light response with frequency. It will also be noticed that a small phase angle between current and voltage is associated with a negligible phase angle between current and light, while the large voltage-current angle of the crater lamp has with it a light, current phase shift.

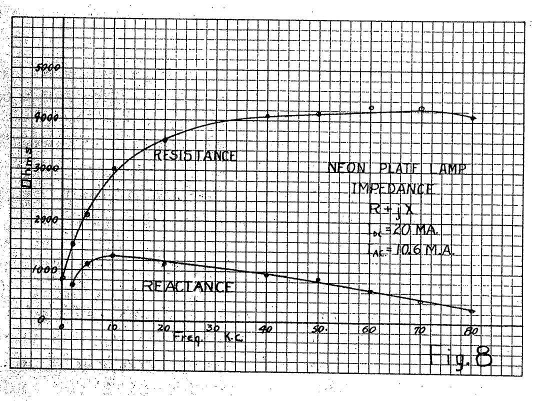


Fig. 8

The impedance variation also parallels the variation of the light response for the two lamps. The continuously rising impedance of the crater lamp has with it a continuous rise in the light response. The impedance of the flat plate lamp tends to approach a maximum in the same range as does the light response.

Circuit Application:

The circuit application of neon glow lamps is very simple. They should be driven thru a sufficiently high impedance circuit to minimize the effects of non-linearity, frequency discrimination, and phase shift inherent in the impedance characteristics. The pentode type of output tube with a plate resistance of the order of 100,000 ohms has shown itself to be satisfactory. A simple series connection of the lamp, tube plate and power supply is preferable to a shunt feed in that it provides a lower capacity shunting the lamp. This is very desirable as the crater lamp at high frequencies has a self inductance inversely proportional to the current. For a sinusoidal current thru the lamp there will be by necessity harmonics in the voltage. Shunt capacity around the lamp will decrease the voltage harmonics with a corresponding increase in the current harmonics flowing thru the lamp, as well lower the actual response. The upper limit of response of the crater lamp will obviously be limited by its inductance and its shunting capacity. With a series feed, this capacity need not be greater than 25 uuf. including the plate to ground capacity of the tube. As the lamp inductance is around 4 millihenrys, it may be safely said that, to the upper limit of the current-light response measurements, this lamp will cause little loss in picture quality.

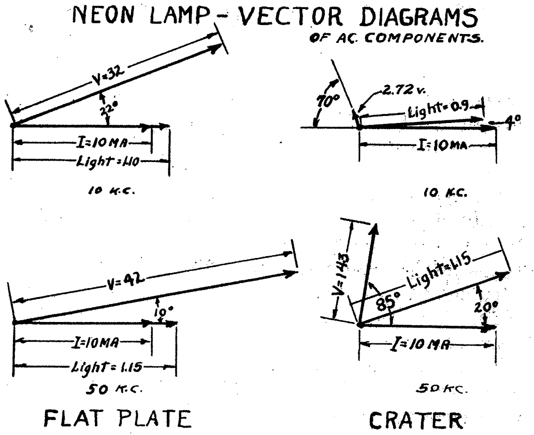


FIG. 9

Conclusions:

It is believed that the data here given shows quite positively that a crater lamp of conventional design will be found completely satisfactory for television systems employing 120 lines per frame and 25 pictures per second. And it is quite likely that they will be found useful for systems requiring even greater detail than this. Since no theoretical basis has been evolved to rationalize the results here reported, it is not possible to make any estimate of the limit of response of the behavior of lamps of other physical characteristics. However, in view of the fact that the interesting characteristics herein reported were found in lamps which had been built without any attempt at design for any special characteristics and without any understanding of the factors involved in the high frequency characteristics, it is believed that glow lamps can be developed that will provide satisfactory performance in any otherwise practical television system.

In closing I wish to acknowledge with sincere thanks the advice and assistance of Mr. J.B. Russell of Columbia University.

THE DESIGN OF RESISTANCE ATTENUATORS FOR RADIO FREQUENCY USE

By
Malcolm Ferris*

Resistance attenuators have recently been very widely used for radio frequencies up to about 20,000 kilocycles, especially in signal generators and similar apparatus.

The resistances used as elements in such attenuators must be so designed that skin effect, series inductance, and shunt capacity do not introduce appreciable error. I have found that wire wound resistors of the bifilar type are most satisfactory, as this type of winding has the lowest inductance. It is true that it also has high shunt capacity, but this can be held to values that are negligable even at 20,000 kilocycles, for resistances up to 25 ohms. For higher values of resistance, two or more 25 ohm resistors can be used in series. An attempt to wind a bifilar resistance of several hundred ohms in one unit would of course result in failure, due to high shunt capacity. This does not show, however, that the bifilar type of winding is unsuitable for use at high frequencies, but merely that suitable care must be exercised in using it.

Resistances of 5 to 100 ohms are the most practical to construct. Below 5 ohms, very careful design is necessary if the inductance of the leads is not to cause error, and above 100 ohms, shunt capacity becomes more troublesome.

Far more troublesome than the effect of inductance or capacity in the individual resistances, is the effect of mutual inductance, or capacity between sections of the attenuator which are operating at widely different voltage levels. Before considering these effects in detail, one factor that is of greatest importance should be especially noted.

Resistance and inductive reactance in series do not add algebraically, but combine vectorially in quadrature. For instance, a resistance of ten ohms and an inductive reactance of one ohm connected in series have a total impedance of 10.05 ohms, and NOT 11 ohms. This means that an inductive reactance of one ohm in series with a ten ohm resistor, will cause only one half of one per cent error, not ten per cent error, as might be expected. This is one of the important advantages of a resistance attenuator, and undoubtedly is one of the most important reasons for its extensive use.

Every engineer who has considered resistance attenuators has of course realized that undesired inductance and capacity may cause serious errors. A suggestion that has often been made is that two condensers in series would form an ideal voltage divider, free from frequency error. This would be true if it were possible to have such an arrangement entirely free from inductance. Unfortunately, this is impossible, and, as mentioned above, the undesired inductance causes a much more serious error than it would in a resistance attenuator.

The arrangement of apparatus shown schematically in the diagram of figure 1 is for the purpose of illustrating this effect. If the slider is moved along the inductance L, a nodal point will be found where the input to the receiver falls almost to zero. The photograph of figure 2 shows the actual arrangement of this apparatus, and the point of special

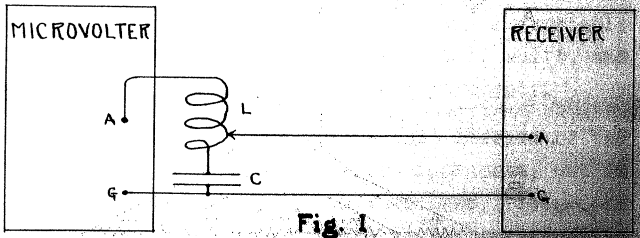


Fig. 1

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*Ferris Instrument Co., Boonton, N. J.

interest is the actual physical appearance of the inductance. It will be noted that this inductance is merely a short length of wire, two or three inches long. At 12,500 kilocycles, the nodal point occurs with the slider about one inch from the condenser terminal. At 15,000 kilocycles, the nodal point is practically at the condenser terminal. In other words, at 15,000 kilocycles, the inductance present in the condenser itself, plus the mutual inductance in the leads, is sufficient to cause one hundred per cent error. It can be seen that it would be almost impossible to make any arrangement of this apparatus which would reduce the inductance enough to make the scheme useful at frequencies of the order of 10,000 to 15,000 kilocycles, and even at frequencies of the order of 1,000 kilocycles great care is required to avoid such errors. (The condenser used in the above test was a .002 molded type)

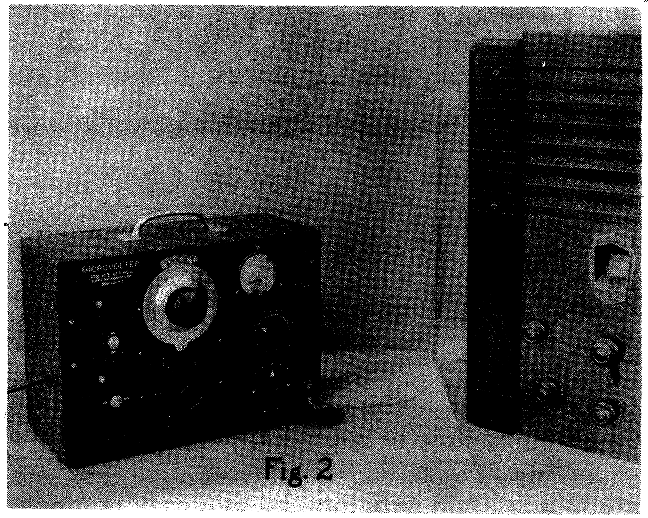
Fig. 2

Remembering that stray voltages due to undesired inductance and capacity effects combine vectorially in quadrature, we can consider some specific cases, and see to what limits these undesired inductances and capacities must be held. Figure 3 is drawn to illustrate two of the most important sources of trouble which must be considered. The attenuator shown has a five ohm impedance on each point, and, with 100 M.A. input, has 500,000 microvolts at its first point, and 5 microvolts at its output end.

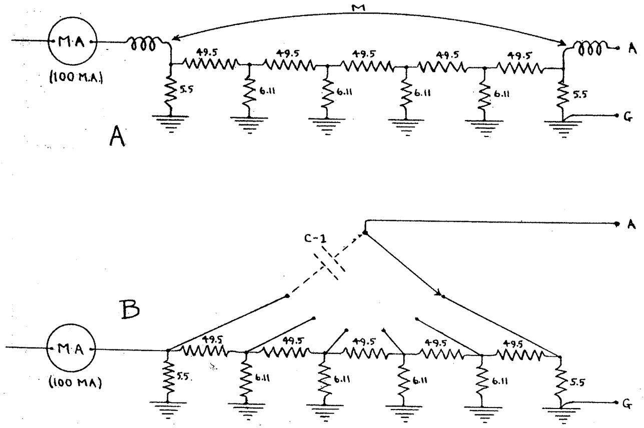

Fig. 3

Consider the mutual inductance indicated in figure 3(a). If we limit the voltage introduced into the output circuit by this mutual inductance to one half microvolt, which, combining in quadrature with the five microvolt output of the attenuator, would produce only one half of one per cent error, then the mutual reactance must not exceed 1/200,000 ohm. Since at 10,000 kilocycles one microhenry has a reactance of 62.5 ohms, this mutual inductance must not exceed one thirteen millionth part of a microhenry, if the above conditions are to be met at 10,000 kilocycles.

In practice, the only way in which such a low value of mutual inductance can be obtained is by means of very effective shielding between the attenuator input and output circuits.

Figure 3(b) is arranged to show another type of effect which will cause serious error unless properly considered in the design. The attenuator in this case is the same as in figure 3(a), but a switch is shown by which the output lead can be connected to any point on the attenuator. A condenser C-1 is shown to represent the capacity existing between the switch point which connects to the high end of the attenuator and the switch arm, which in the figure is shown connected to the output end of the attenuator. For the same conditions as above, the current flowing thru C-1 must not exceed one tenth microampere, and since the driving voltage is 500,000 microvolts, this means that its reactance must be at least 5,000,000 ohms, which at 10,000 Kcs. means a condenser not greater than 3/1000 of a micro-microfarad.

The permissible value of mutual inductance and capacity as computed above are of interest mainly to show the order of magnitude within which these factors must be held. It is of course impossible to measure one thirteen millionth of a microhenry by any of the usual methods of measuring inductance. Tests of the attenuator for "leakage" and accuracy usually show whether these values are within the desired limits.

Figure 4 shows two attenuators which differ only in the switching arrangement, the input being switched in figure 4(a), and the output in figure 4(b). As shown, there is little to chose between these two methods of switching.

The attenuators of figure 4 have a constant impedance of five ohms at any point, but give only five fixed values of output, namely 500,000, 50,000, 5,000, 500 and 50 microvolts. For practical use, this is not sufficient, and some scheme must be used to provide either continuous variation of output, or else many more steps. Two schemes for this purpose are in common use, and both methods have their own disadvantages as well as advantages. These two schemes are:

(a) Variation of the input current to the attenuator.
(b) Substitution of a calibrated potentiometer for one of the resistances of the attenuator.

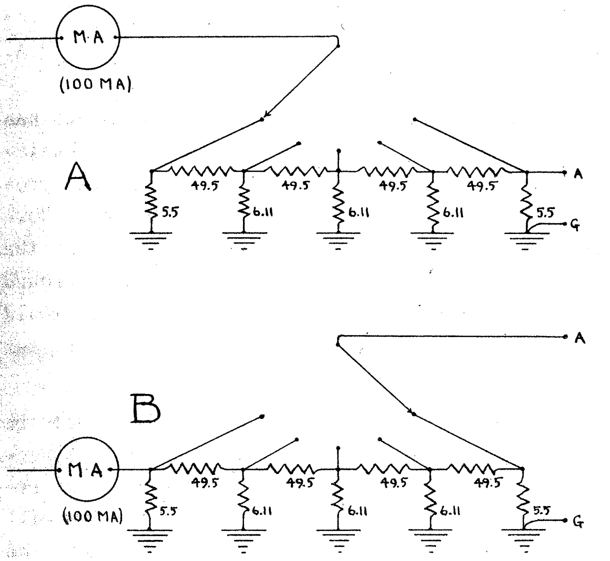

Fig. 4

Variation of the input current to the attenuator is almost certain to react on the frequency of the oscillator, unless a master oscillator-power amplifier type of circuit is used. This reaction is most serious when a heavy load must be drawn from the oscillator. Careful design of the oscillator circuit will reduce this reaction, but never entirely eliminate it.

Unfortunately, thermo ammeters and other types of meters suitable for measuring attenuator input have a deflection which varies with the square of the current. This means that about one third of full scale current is about the lowest value that can be read practically, and even at this value the accuracy of reading is very poor. It is therefore necessary to design an attenuator with voltage steps, having roughly a three to one ratio, instead of a ten to one ratio, thus making necessary many more steps in the attenuator, and also making necessary a multiplication of the meter reading by a value other than a multiple of ten, so that it can no longer be considered direct reading. It has been common practice to employ multiplying factors of 1, 2, 5, 10, 20, 50 etc., or 1, 3, 10, 30, 100 etc.

The use of a calibrated potentiometer overcomes the above disadvantages, since the input current need not be varied, and the potentiometer scale can be calibrated directly in microvolts, with multiplying factors of 1, 10, 100 etc. On the other hand, it introduces disadvantages of its own. It may be subject to wear, and change in calibration, so that it must be renewed after a period of service. Also, while suitable potentiometers of fairly high resistance are easily made, a low resistance potentiometer which is sufficiently free from inductance is quite expensive to make.

Practical attenuators involve various combinations of the above features, and may perhaps best be discussed by examining some specific designs, and discussing the features involved.

The diagram of figure 5 shows an attenuator quite similar to that shown in figure 3(b). It differs from that of figure 3(b) in the following particulars:

(1) It has one less section of attenuation
(2) It has a calibrated potentiometer for the final resistance
(3) The input is switched, instead of the output.

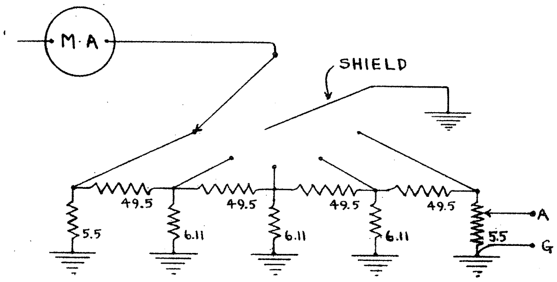

Fig. 5

Using a calibrated potentiometer for the output resistance of course makes it impossible to switch the output, and it has been necessary therefore to switch the input. As the attenuator has one less section than the one shown in figure 3, the effects of undesired inductance and capacity or only one tenth as serious. In the actual construction, it was found possible to use a conventional type switch, with only the precaution of a shield run thru a slot in the bakelite panel to lower capacity between the switch arm and the switch points.

The output potentiometer of this attenuator carries a dial which is calibrated directly in microvolts, from zero to fifty. The attenuator switch provides multiplying factors of 1, 10, 100, 1000 and 10,000. The output is therefore continuously variable from zero to 500,000 microvolts (one half volt), and the smallest scale division is one microvolt.

It will be noted that in this attenuator the output resistance is never over five ohms, but is always variable from zero to five ohms. There are some conditions, such as tests on highly regenerative receivers, where such a variable output resistance is undesirable.

Figure 6 shows a very different type of attenuator, and the photograph of figure 7 shows the actual appearance of three different attenuators. In this photograph, (a) is the attenuator of figure 6(b), (b) is the attenuator of figure 5 above, and (c) is the attenuator shown in figure 9 below, in one of its early experimental forms.

The arrangements shown in figure 6(a) and (b) differ only in the switching scheme. It will be noted that both switch arrangements give the same schematic connections, but the somewhat more complicated arrangement shown at (b) has to be used in practice to avoid trouble due to capacity across the switch, as illustrated in figure 3(b). This trouble is avoided by dividing the switch into two sections, so that the extreme difference in voltage levels does not occur in one section. Another method of eliminating this trouble would be very careful shielding of the switch, as has been done in the case of the attenuator shown in figure 7(c).

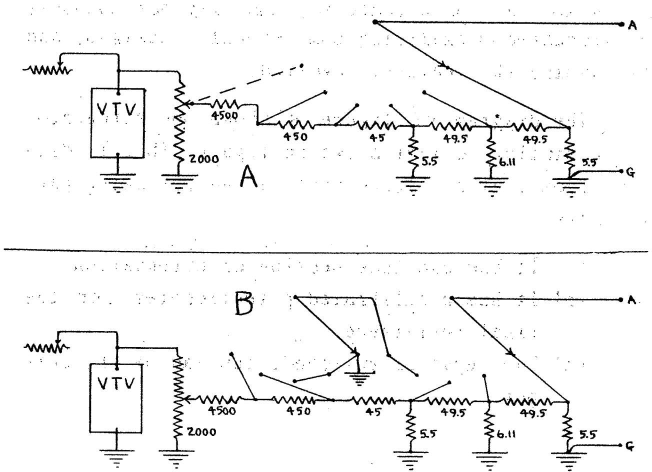

Fig. 6

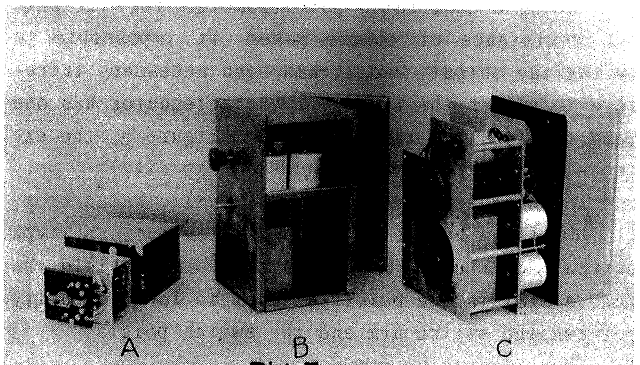

Fig. 7

The attenuator of figure 6 has for its first resistance a 2,000 ohm calibrated potentiometer. A radio frequency voltage of one volt is maintained across the terminals of this potentiometer. The rheostat shown at the left is adjusted until the vacuum tube voltmeter shows just one volt across the potentiometer. The potentiometer dial carries a scale marked from zero to ten microvolts, with a division every one fifth microvolt, and the attenuator switch provides multiplying factors of 1, 10, 100, 1,000 and 10,000.

It should be especially noted that the input current to the attenuator shown in figure 6 is only ½ M.A., as compared with 100 M.A. in the attenuator of figure 3. Therefore, for the same permissable stray field in the output circuit, the undesired mutual inductance as shown in figure 3(a) can be 200 times as great. Stated in other words, the shielding problem is much less severe. What this means in actual structure can be readily seen by comparing the attenuator at (a) in figure 7, which has ½ M.A. input, with those at (b) and (c), which have 100 M.A. input.

In figure 6(a) a sixth point on the switch has been shown dotted, connected direct to the potentiometer slider. If this point were used, it would provide output up to 1 volt, instead of 1/10 volt. However, it would require much more shielding of the switch, and in addition, the extra capacity to ground from this point which the unavoidable leads would add would cause attenuator inaccuracies at the higher frequencies.

One very definite sacrifice has been made in the attenuator of figure 6 to make a simple construction possible. This is the use of high output resistance for the higher output voltages. It will be noted that the output resistance is five ohms on the first three points (Multiply by 1, 10 and 100 - that is, output voltages up to 1,000 microvolts) On the fourth point (output up to 10,000 microvolts) the resistance is 50 ohms, while on the final point it is 500 ohms.

In general, resistances of 50 and 500 ohms cannot be introduced into a receiver antenna circuit without causing appreciable error. The amount of this error will of course depend on the particular receiver. In one receiver recently tested, which was a broadcast receiver of conventional type, at 600 Kcs., fifty ohms in the antenna made a negligable difference, and even 500 ohms made a very slight difference. On the same receiver, at 1400 Kcs., 50 ohms made a slight difference, but 500 ohms caused an error of about 20 per cent.

The attenuator of figure 6 provides 5 ohm output resistance up to 1,000 microvolts, and all sensitivity readings will normally fall below this value. If an attenuator of this type is used for taking selectivity readings, higher values of output will be required, and a check must be made to see what effect the added resistance will have on the results, so that a correction can be made if necessary.

Of course, the ideal attenuator would have low output resistance, even for the highest output voltages. As mentioned above, this means a more elaborate shielding structure, and therefore a more expensive arrangement. Also, it requires more power from the oscillator, which also complicates the design problem. For these reasons, most commercial attenuators use higher output resistance for high output voltages, and the user must bear in mind the limitations thus imposed.

Figure 8 shows an attenuator designed for obtaining continuous variation of output by varying the input current, instead of using a calibrated potentiometer. It will be noted that a great many more steps are necessary in the attenuator. The thermo element used with this attenuator is a high resistance one, and is connected to measure the voltage input to the attenuator, instead of the current. For the design as shown, the maximum voltage at the input terminals is two volts, and the meter scale is calibrated from zero to five microvolts. Multiplier settings are 1, 3, 10, 30, 100 etc., up to 100,000, and then the final one is 400,000.

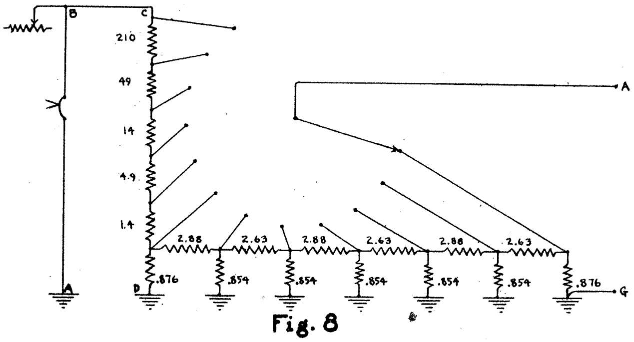

Fig. 8

This arrangement is intermediate between those shown previously in the matter of output resistance. It does have high resistance for the highest output, but has only 7 ohms at 50,000 microvolts, and 21 ohms at 150,000 microvolts. It uses very low values of resistance, which are very difficult to make free from trouble due to series inductance. The diagram does not show the shielding necessary around the switch, which is of course necessary to prevent serious errors.

It might be mentioned that the attenuator of figures 6 and 8 show meters for measuring voltage input to the attenuator, while the one in figure 5 measures current input. Current measurement is usually more suitable for attenuators of low input resistance, while voltage measurement is often better when the input resistance is high. Both methods have possibilities of error, which must be reduced by careful design in particular cases. Referring to figure 8, any voltage induced in the loop ABCD will cause error, as it will introduce into the circuit voltage additional to that measured by the element. With a high resistance, low current input, it is usually easy to arrange the parts so that no appreciable magnetic field is picked up by the loop ABCD. With the method of measuring current input, as shown in figure 5, capacity to ground might cause error, as this would by-pass part of the current, and the entire current as measured would not pass thru the attenuator. With a high resistance attenuator, this error could easily be serious, but with an attenuator of five ohms input, as shown in figure 5, it would require a capacity over 150 micro-microfarads to cause error even at 20,000 kcs., and the capacity can very easily be kept below this value. (With a 200 ohm input attenuator, this permissable capacity would be reduced to less than 4 micro-microfarads, and this would be difficult to obtain.)

Figure 9 shows another arrangement, which combines some of the features of both methods of continuous variation. The right hand part of it is similar to figure 5, except that it contains an additional step of attenuation, and the calibrated potentiometer is at the beginning instead of the end of the attenuator, thus making it necessary to switch the output instead of the input. This arrangement provides a fixed five ohm output resistance up to 50,000 microvolts, and a variable, zero to five ohms, from 50,000 to 500,000 microvolts. Above this, there are fixed taps at one volt and two volts, across ten and twenty ohms respectively, and intermediate values can be obtained by varying the current input. This arrangement provides output up to two volts across resistance low enough to be inserted directly in the usual antenna circuit, and does not require variation of the current input, except for values above one half volt. It does, of course, require extensive shielding, and draw heavy power from the oscillator. It might be mentioned that one advantage that goes with this is that a much more satisfactory type of meter can be used than where less power is available for the meter.

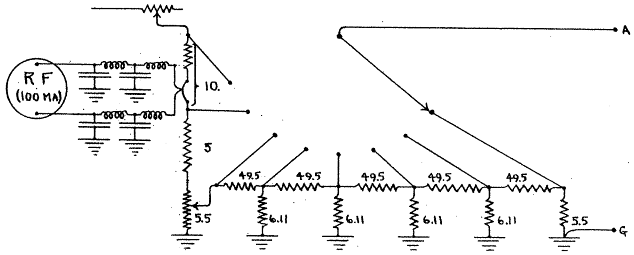

Fig. 9

Figure 7(c) shows the appearance of an experimental attenuator of the kind shown in figure 9. It may be noticed that only a single switch is used, but that very elaborate shielding of the switch is necessary in this case.

Examples of attenuator design could be continued indefinitely, but it is believed that those described above are sufficient to illustrate many of the factors involved in practical designs.