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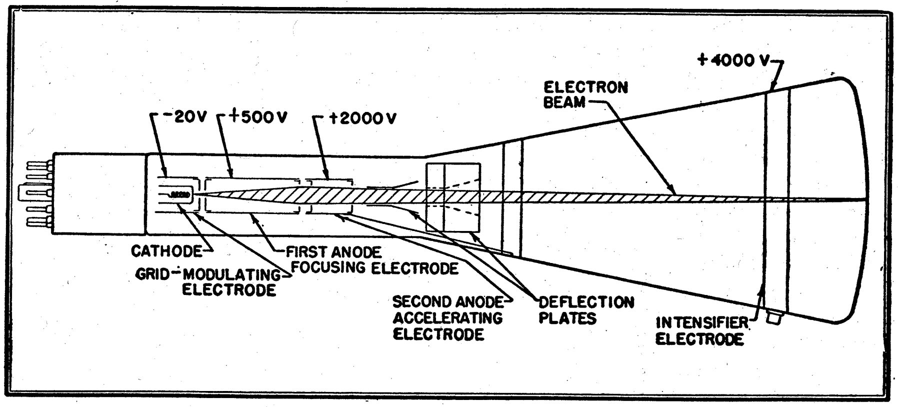

FIG. 1. ARRANGEMENT OF THE ELECTRODES IN A TYPICAL ELECTROSTATIC TYPE OF CATHODE-RAY TUBE

APPLICATION TECHNIQUES FOR CATHODE-RAY TUBES

Basic Requirements for Operation of Cathode-Ray Tubes, and Use of Published Specifications

BY DR. P. S. CHRISTALDI AND I. E. LEMPERT[*]

1. Introduction

THE tremendous increase in the use of cathode-ray tubes in the war effort has created a need for practical design information to promote efficient utilization of commercial cathode-ray tubes. It is the purpose of this paper to discuss the basic requirements for operating cathode-ray tubes, the provisions needed in equipment to assure proper operation of mass-production cathode-ray tubes, and some of the more important operating circuits. Particular emphasis will be placed upon the use of published specifications in designing equipment.

2. Operational Description of CRT

A TYPICAL cathode-ray tube arrangement is shown in Fig. 1, which also shows representative electrode voltages.

The indirectly-heated oxide cathode provides electron emission, and the structure in the region of the grid forms a diverging electron beam which is focused at the screen by the field between the first and second anodes. The amount of current in the beam may be varied from zero to the maximum current available by varying the grid voltage from the cutoff potential to zero potential.[1]

The spot is focused by varying the first-anode voltage. The second-anode voltage is fixed. The focused spot is deflected to any point of the screen by the application of suitable voltages to the two mutually perpendicular pairs of deflection plates.

Most modern electrostatic cathode-ray tubes employ an intensifier electrode after the deflection plates to increase the voltage of the electron beam, thus giving greater brightness with relatively little effect upon deflection sensitivity.

Fig. 2 shows a cathode-ray tube employing magnetic focusing and deflection. The first part of the gun of the magnetic tube is basically the same as that of the electrostatic tube, but the focusing is accomplished by an axial magnetic field and the deflection by two mutually perpendicular magnetic fields. Magnetic deflection has also been used with electric focusing.

It will be seen from the foregoing that the essential equipment needed to operate a cathode-ray tube are the following:

1. A source of heater voltage
2. A source of grid voltage variable from zero to cutoff
3. A variable source of first-anode voltage
4. A source of second-anode voltage (fixed potential)
5. A source of intensifier voltage (fixed potential)
6. Suitable sources of deflection voltages.

In the case of magnetically-focused tubes, a variable focus current must be available instead of the variable first-anode voltage.

Use of CRT Specifications ★ In the not-too-distant past, the practice in designing equipment to operate a given type of cathode-ray tube was to obtain a sample of the tube, build up a sample unit to give approximately the right voltages, then adjust the circuit components so that there would be enough negative grid-voltage to cut the beam off, and so that the first-anode voltage-control brought the tube to a focus at some point in its range and defocused it to some extent on both sides of the focus point. As might have been expected, the result of this type of design procedure was that when the equipment got into production tubes other than the original sample often would not work in the units due to production variations in individual tubes and to variations between the characteristics of tubes made by different manufacturers. This condition led to the formulation of specifications for the various tube types by the RMA and the Army and Navy, the use of which, together with regard for certain principles of design which have been formulated over a period of time by those in the cathode-ray field, make it possible to design equipment for a given tube type that will operate properly with any tube of that type made by any manufacturer.

A typical cathode-ray tube specification and outline drawing (for the 5CP1 tube) are shown in Figs. 3A and 3B respectively. It will be observed that the rated heater voltage is 6.3 volts, and that this voltage should not vary from 6.3 volts by more than 10%. Neglect of this specification will result in reduced performance and/or life.

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[*] Respectively Chief Engineer and Head of Tube Engineering Dept., Allen B. DuMont Laboratories, Inc., Passaic, N. J. Paper presented at the October 14, 1943 meeting of the Radio Club of America, New York City.

[1] In referring to potentials, it is understood that they are measured with respect to cathode, unless otherwise specified.

Referring to the grid-cutoff voltage specification F-8j, it will be observed that a minimum, bogie, and a maximum value are specified. "Bogie" is the tube manufacturer's term for a design point, a value which he attempts to hold in production; it is not necessarily an average. The important specification here, to the equipment manufacturer, is the maximum value (67.5 volts in this case). Since the intensity control which provides variable grid voltage nearly always provides a voltage between zero and some negative value, it is only necessary to design so that at least —67.5 volts are always available at one extreme of the control, in order to assure that the equipment will be capable of varying the intensity of any 5CP1 tube from maximum to cutoff; the tube specification tells him that no tubes are to have cutoff voltages higher than 67.5 volts. An exception to the above design procedure is found when positive pulsing of the grid is employed in the circuit, and it is desired to be able to cut off the beam entirely during pulsing. In that case, an additional negative voltage must be available to cut off the grid while it is being pulsed. If a 40-volt grid pulse is applied, for example, then a negative DC voltage of 40 + 67 = 107 volts should be available to assure being able to cut off the tube. The value of maximum cutoff voltage given on the tube specification sheet applies, of course, only for the operating condition with 1500 volts on the second anode. The maximum cutoff voltage for any other second-anode voltage is readily found, however, as it is proportional to the second-anode voltage.

Referring to the specification for first-anode voltage, it will be observed that, over the entire operating range of the tube, the first-anode voltage for focus of any tube must remain within the range from 302 to 518 volts. Thus, the focus control must provide for this range of voltages. Again, the limits given apply only for a second-anode voltage of 1500 volts, but are directly proportional to the second-anode voltage. It should also be pointed out that the divider must be such as to provide the necessary range of voltages for first-anode currents between zero and the maximum value specified under F-8b (1).

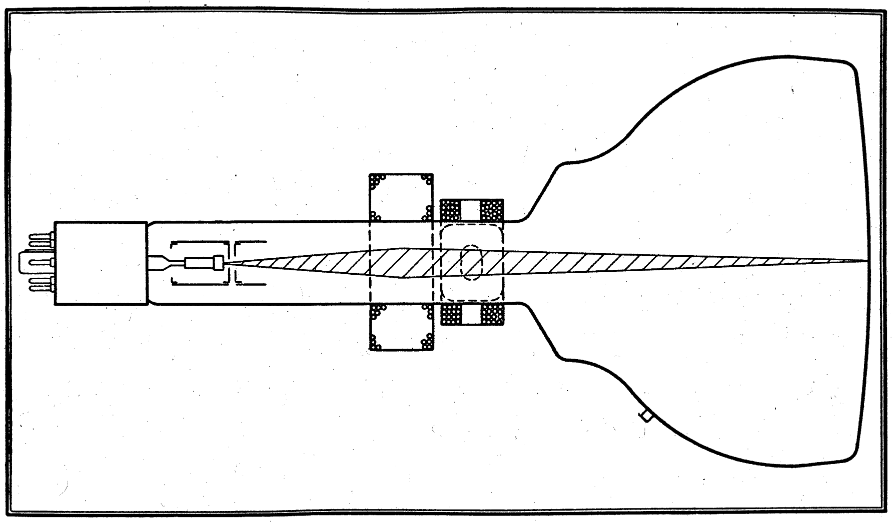

FIG. 2. ARRANGEMENT OF ELECTRODES, FOCUS COIL, AND DEFLECTION COILS IN A TYPICAL MAGNETIC TYPE OF CATHODE-RAY TUBE

The second-anode voltage and intensifier voltage used depend upon the brightness and line-width requirements for the particular application, but in no case should they exceed the maximum ratings indicated. In addition, the ratio of intensifier voltage to second-anode voltage $\frac{(E_{b3})}{(E_{b2})}$ must not exceed the specified maximum value; otherwise spot distortion and/or reduction of the usable screen area may occur. Line width for a given brightness will decrease as the overall voltage goes up, and the brightness attainable will go up. For the range of voltages from 0 to 4000, the brightness for a given beam current can be considered to increase as the square of the overall voltage.

The deflection-voltage sources must be so designed as to provide suitable deflection in spite of the range of deflection sensitivity over which tubes may vary. For circuits having deflection-amplitude controls which vary the deflection voltages from zero to maximum, it is necessary to be sure that there is sufficient voltage to produce the required deflection for tubes having the maximum allowable deflection factor (least allowable sensitivity). Again, the values of deflection factors given apply only for the specified second-anode and intensifier voltages, but are proportional to the second-anode voltage so long as the ratio $\frac{E_{b3}}{E_{b2}}$ is constant. For ratios other than the two given $\left(\frac{E_{b3}}{E_{b2}} = 1, 2\right)$ the deflection factors can be estimated roughly

FIG. 3A. 5CP1 TUBE SPECIFICATIONS

Ratings	Min.	Max.	Ratings	Min.	Max.
E_f		6.3 V ± 10%	E_{b3}	1500 V, DC	4400 V, DC
E_{c1}	−125 V, DC	0	R_g	- - -	1.5 Meg.
e_d	- - -	550 V	Z_d	- - -	1.0 Meg.
E_{b1}	- - -	1100 V, DC	E_{hk}	- - -	−125 V, DC
E_{b2}	1500 V, DC	2200 V, DC	E_{b3}/E_{b2}	- - -	2.3

Ref.	Test	Conditions	Min.	Bogie	Max.
F-6i	Heater current		540	600	660 mA
F-8b (1)	1st anode current	Light 3 ft. L.	−50	0	500 uA, DC
F-8b (1)	Cathode current	Light 3 ft. L.	- -	0	1000 uA, DC
F-8d (1)	Terminal alignment	1D2, pin No. 5	- -	0	10°
F-8d (2)	Angle between traces		87	90	93°
F-8d (3)	Base & neck alignment		- -	0	2°
F-8d (4)	Neck & bulb alignment		- -	- -	2.25 ins.
F-8d (5)	Side terminal alignment	1D2	- -	0	10°
F-8f (4)	Light output		3.0	- -	- - ft. L.
F-8h (3)	Leakage spot displacement	10 meg.	- -	- -	10 mm.
F-8h (2)	Position of spot		within 25 by 25 mm.		
F-8j	Grid cut-off voltage		−22.5	−45	−67.5 vDC
F-8n	Deflection uniformity		- -	0	5%
F-8p (1)	Heater cathode leakage	E_{hk} −125 V, DC	- -	- -	30 uA, DC
F-8p (2)	Grid leak	$E_c = E_{co}$	- -	- -	5 uA, DC
F-8p (3)	1st anode leakage	$E_c = E_{co}$	- -	- -	15 uA, DC

The following symbols are used in cathode-ray tube specifications:

e_d = voltage peak between 2nd anode and any deflecting plate
E_{b1} = 1st anode voltage
E_{b2} = 2nd anode voltage
E_{b3} = intensifier voltage
E_{co} = grid cut-off voltage
E_{c1} = modulating voltage
E_f = filament (or heater) voltage
E_{hk} = heater-cathode voltage (sign indicates polarity of filament with respect to cathode)
I_{b1} = 1st anode current
I_f = filament (or heater) current
I_k = cathode current
mA, DC = milliamperes, direct current
R_g = grid circuit resistance
uA, DC = microamperes, direct current
Z_d = impedance of deflection plate circuit at power supply frequency

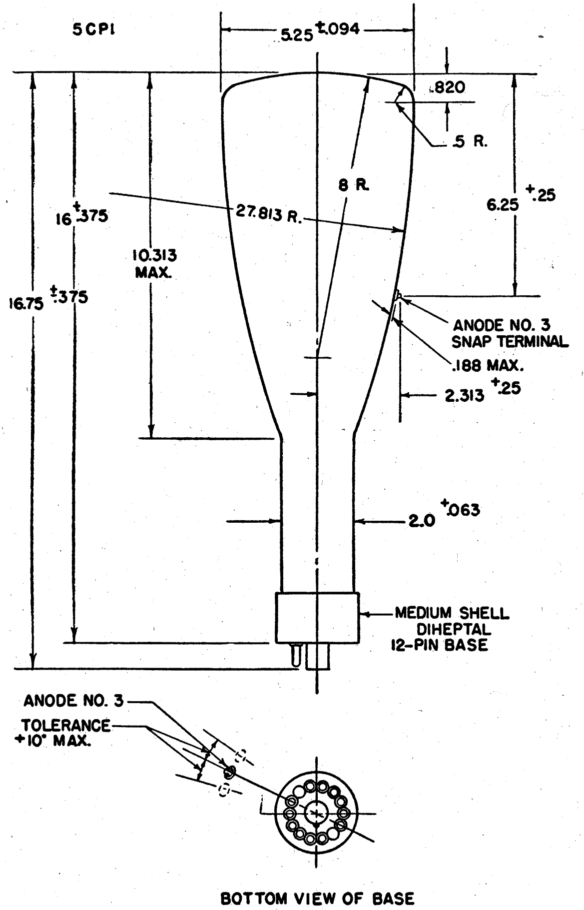

FIG. 3B. TYPICAL ELECTROSTATIC CATHODE-RAY TUBE, SHOWING DIMENSIONS IN INCHES

from the effect of changing from $\frac{E_{b3}}{E_{b2}} = 1$ to $\frac{E_{b3}}{E_{b2}} = 2$.

In the case of magnetic tubes, the focus and deflection requirements are complicated by the fact that components external to the tube itself affect the current requirements. Specifications of focusing current for magnetic tubes are based upon currents obtained in standardized focus coils. The equipment designer, who ordinarily will not intend to use the standard focus coil will, therefore, have no way of knowing what current range he should provide with his coil. The most practical way to proceed in this case will probably be to obtain a calibrated tube from a manufacturer. From the current reading obtained under standard conditions, the equipment designer will know by what percentage the calibrated tube deviates from bogie, and can, therefore, estimate the range of focus current required in this equipment from a reading obtained on his equipment for the calibrated tube.

Deflection sensitivity of magnetic tubes depends upon the deflection yoke, of course, and is not specified at all. The only tube variation which would affect deflection sensitivity would be variations of the reference line (see Fig. 4). with respect to the face. This assumes that the deflection yoke is located with respect to the reference line, as it usually is, the yoke being pushed forward as far as it will go. It can be assumed, as a good approximation, that the deflection sensitivity will be proportional to the distance from the center of the yoke to the face of the tube, for a given yoke and anode voltage.

The specifications which have been discussed in the foregoing are the ones which past experience has shown to be most important. Other parts of the tube specifications will now be discussed briefly. It goes without saying, of course, that all maximum voltage ratings should be adhered to strictly. The minimum rating specified for E_{c1} is of the nature of a maximum rating, and is given as a minimum merely because it happens to be negative. The minimum values of E_{b2} and E_{b3} are the minimum values recommended for operation of the cathode-ray tube. When operated at voltages below these values, brightness and spot size may not be satisfactory. The maximum value of R_g is the maximum DC grid resistance recommended for use with the cathode-ray tube.

If the resistance of the grid circuit is made too high, it will result in an increase in the apparent cutoff bias due to grid leakage. It might be noted at this time

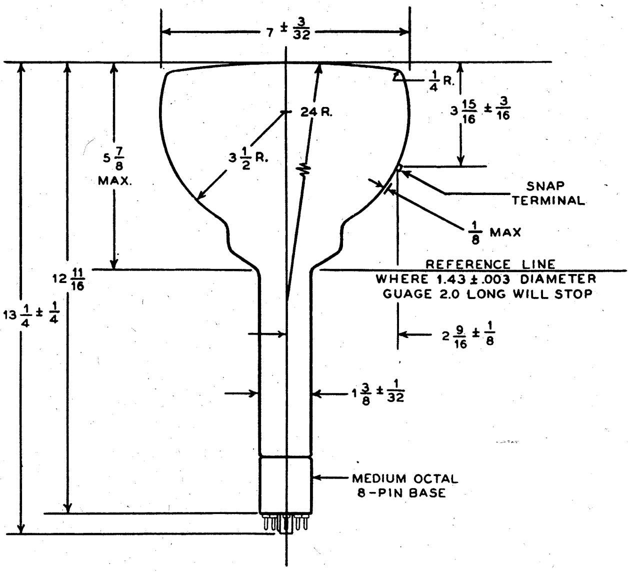

FIG. 4. TYPICAL MAGNETIC TYPE TUBE, SHOWING DIMENSIONS IN INCHES

that, in making plans to provide sufficient voltage for grid cutoff in cases where there is a resistance in series with the grid, provision should be made so that the required voltage will actually be present at the grid when the grid leakage has its maximum specified value (5uA in the case of the 5CP1). The maximum value Z_d (1 megohm in the case of the 5CP1) is the maximum impedance at heater-supply frequency which should be used in the deflection-plate circuit. If this value is exceeded, ripple voltages at power-supply frequency may build up at the deflection plates. It is to be noted that this is an AC impedance; a DC return of higher resistance can be used.

In addition to the tests listed here, there are many others that are of no particular interest to the equipment designer.

F-6i gives the heater current which must be supplied to the tube at 6.3 volts. F-8b(1) gives the maximum first-anode current which the bleeder will be called upon to supply in order for the tube to deliver its minimum specified light output. The specification of maximum cathode current gives the maximum current which the power supply will be required to supply at the minimum specified light output. The voltage breakdown test emphasizes the fact that the maximum ratings are absolute maximums beyond which the tubes are not necessarily tested, and are not to be expected to operate satisfactorily. Equipment in which voltages are expected to fluctuate should be so designed that the greatest fluctuation will not cause maximum ratings to be exceeded.

F-8d(1) and F-8d(5) indicate the misalignment of base and side contact with respect to the traces which must be provided for by suitable arrangements in the mechanical design of the equipment. F-8d(2) indicates the deviation from right angles which may be expected between traces, and this specification indicates that equipment should not be designed for use with a standard 5CP1 which will not tolerate a departure of 3° from right angular alignment. F-8d(3) is a specification of straightness of the base with respect to the neck and usually does not have to be given much consideration. F-8d(4) is a specification intended to limit crooked necks. As a practical matter, it has been found that it is of little importance in connection with electrostatic tubes but of great importance in connection with magnetic tubes where the tube must fit into a deflection-yoke and focus-coil structure, as well as into a socket and face-support structure. The reference F-8d(4) in the JAN-1A[2] specification describes this test very precisely, but as a practical matter the specification means that, with the base and face supported rigidly, the neck is required to be straight enough so that it will pass through a circle of specified diameter concentric with a line through the center of the base and through the center of the face. This means that either the diameter of the focus coil and deflection yoke must be as great as the maximum dimension given, or else provision must be made for motion of the focus coil and deflection-yoke structure. In the latter case, the inside diameter of the deflection yoke and focus coil need only be sufficient to pass a tube having the maximum neck diameter indicated on the outline drawing.

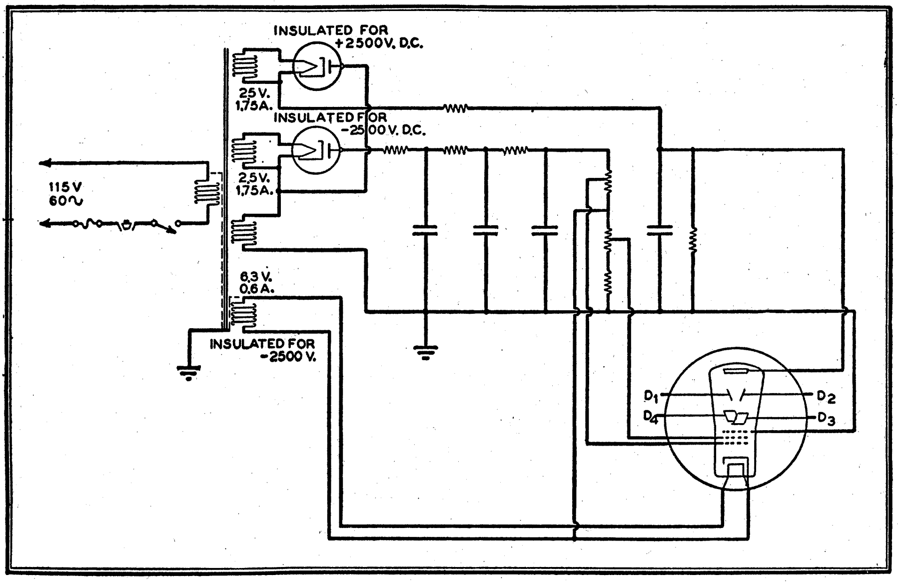

FIG. 5. TYPICAL POWER SUPPLY FOR ELECTROSTATIC TYPE CATHODE-RAY TUBE

F-8f(4) specifies the minimum light output of 5CP1's as measured by the standard RMA method, using a 2- by 2-in. raster and a foot-candle meter in close contact with the face of the tube. Greater light output than the minimum specified value should not be counted upon at the test voltage ($E_{b2} = 1500$ V, $E_{b3} = 3000$ V in this case) when designing equipment. As stated previously, the light output at a given beam current will vary approximately as the square of the over-all voltage (E_{b3}) up to 4000 volts. In addition, the maximum beam current available will increase approximately as the 1.4 power of the second-anode voltage for tubes such as the 5CP1 which do not have a constant voltage electrode next to the grid.

In tubes which have an extra electrode next to the grid, the voltage of which is not dependent upon the second-anode potential (as in most presently available magnetic tubes), the maximum beam current available will vary with the voltage of this electrode. It will be necessary, of course, to determine what light output, as measured by the standard method, is required for individual applications.

F-8h(2) indicates the maximum deviation of the spot from the center with no deflection voltages applied, due to misalignments of the gun structure. In the case of the 5CP1, the specification states that the undeflected spot will fall within a 25- by 25-mm. square centered with respect to the tube face. Sufficient positioning voltage must be supplied by the equipment designer to bring the spot back to the center of the face. It is to be noted that this deviation is for the case where the tube is shielded from the earth's magnetic field and that the vertical component of the earth's magnetic field may produce a horizontal deflection of the order of ½ in. when the tube is operated horizontally. In the event that the tube is not shielded magnetically, additional positioning voltage should be provided to take care of this deflection.

F-8h(3) is really a deflection-plate leakage test. It indicates the amount of deflection which may be produced by the voltage built up across a 10-megohm resistor in the deflection-plate circuit. In the event that the resistance in the plate circuit is other than 10 megohms, the maximum allowable displacement will be in proportion to the resistance. Sufficient positioning voltage should be available to take care of this displacement in addition to the others.

F-8n is a specification of deflection linearity which is explained in the JAN-1A[2] reference.

F-8p(1) specifies the maximum heater-cathode leakage which may occur and, when the cathode is not connected to one side of the heater, care should be taken to see that the resistance of the cathode circuit is low enough so that 30 microam-

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[2] Joint Army-Navy Specification JAN-1A for radio electron tubes.

peres will not produce objectionable voltage drops.

The same considerations apply to F-8p-(2) grid leakage. F-8p(3) will not generally be of much interest to the designer as he must provide for much heavier currents in the first-anode circuit anyway.

3. Cathode-Ray Tube Circuits

Power Supply ★ In the greatest number of installations, power for operating cathode-ray equipment is obtained from 115-volt, 60-cycle lines, and such a source will be assumed in the following discussion, although it is perfectly feasible to use sources of other frequencies or batteries in conjunction with vibrators or inverters. Whatever the source may be, it is necessary to maintain the voltage within ± 10% of its nominal value if the voltage rating of the cathode-ray tube heater is not to be exceeded.

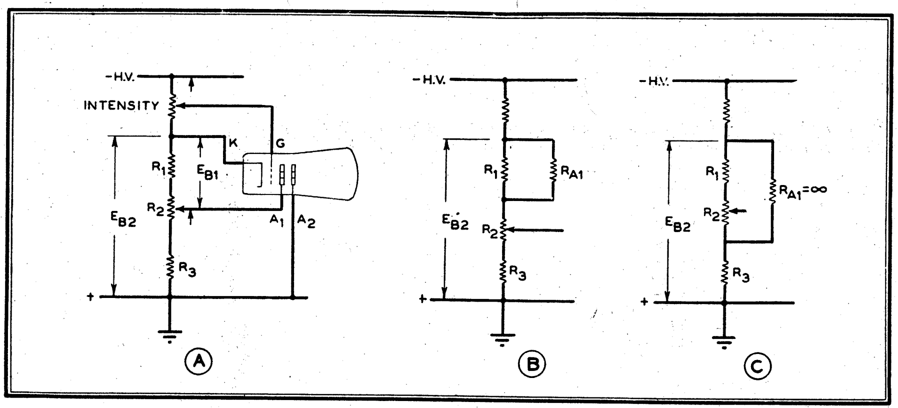

FIG. 6. A: TYPICAL BLEEDER CIRCUIT. B: EQUIVALENT CIRCUIT FOR DETERMINING MAXIMUM 1ST ANODE CURRENT AT MINIMUM REQUIRED BRIGHTNESS. C: EQUIVALENT CIRCUIT FOR CUT-OFF BIAS

The power transformer used to step up voltage to the 1,500 volts or more used to accelerate the electron beam may be separate from that required to operate associated circuits, or an extension of low-voltage windings may be used. In either case, it is good practice to insulate windings from each other and from the core to withstand twice the rated voltages plus 1000 volts. When voltages above 4000 or 5000 volts are used, precautions should be observed to prevent corona discharge, which often results in erratic deflections or changes in intensity of the electron beam.

The size of transformers supplying cathode-ray tube equipment is usually considerably larger than that of units of similar power used in other applications, for a number of reasons. The core is usually made larger than normally required for the supply frequency used in order to reduce external magnetic fields, which might deflect the beam; extra magnetic shielding of the transformer is often used. The higher voltages require more insulation and, therefore, more space. Finally, it is good practice to use electrostatic shields around both primary and cathode-ray tube heater windings, particularly when the heater is not grounded, to prevent the induction of voltages in those windings from the high-voltage secondary. Induced voltages in the primary may be dangerous, while those in the heater winding may result in objectionable modulation of beam intensity.

The current rating of the high-voltage winding is generally governed by the wire size used, since the total current drain is only a few milliamperes for conventional circuits. It is desirable to have relatively good voltage regulation in order to minimize defocusing and change of pattern size with variations of intensity, and this is usually accomplished by using a bleeder current of from 1 to 5 milliamperes, depending on the current variations to be expected in the electron gun. The bleeder is used as a voltage divider to provide other operating potentials for the gun.

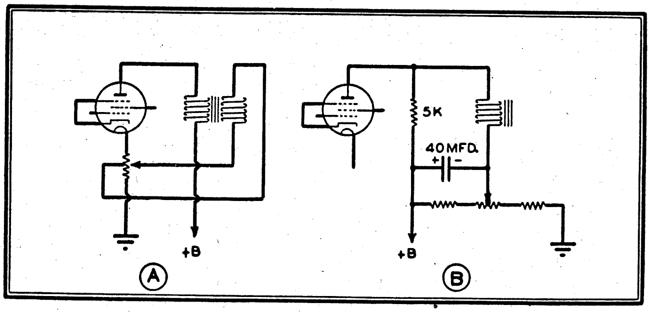

FIG. 7. POSITIONING CIRCUITS FOR MAGNETIC DEFLECTION USING, A: TRANSFORMER COUPLING, AND B: DIRECT COUPLING

A half-wave rectifier circuit is generally used, since the load current is small. In cases where an intensifier electrode is used, it is advantageous to use a voltage-doubling circuit. In the latter case, the rectifier heater windings should be insulated from each other to withstand twice the voltage to ground of either of them. Since in most applications the deflection plates operate at or near ground potential, that part of the high-voltage supply used to operate the gun is operated with its positive side grounded.

The filter is generally of the resistance-capacitance type using one or more sections, depending upon the degree of filtering required. When modulation of beam intensity is to be used, at least two and usually three sections will be found necessary, while otherwise one section, with the addition of a by-pass capacitor between cathode-ray tube grid and cathode, will suffice. Only one section is required for the intensifier supply.

The voltage ratings should be adequate to permit operation at the peak value of the voltage delivered by the transformer, since the load is small, and allowance should be made for variations in line voltage above the design-center value. Peak values of current through the first filter capacitor should be limited by using input resistance, although this will result in a loss of useful voltage across the bleeder. With such a filter there will be, in a typical case, a loss in voltage of approximately two hundred volts. Since there will be a further loss of a hundred volts or so across the rectifier tube, the voltage rating of the transformer must be somewhat higher than the quotient of the desired output voltage by the factor 1.414.

Fig. 5 is representative of the type of power supply used to operate electrostatic-type cathode-ray tubes.

The bleeder is used as a voltage divider to provide variable grid bias and variable focusing electrode potentials. In its design it is necessary to know not only the range of cutoff bias permitted by the specification on the particular type of cathode-ray tube to be used, but also the range of focusing electrode voltages and currents that must be provided.

Having decided upon the bleeder current to be used, the total resistance of the bleeder string can be determined and from it, by simple proportion, the resistance of the grid-bias potentiometer to provide the required range of voltages, based upon the specified maximum cutoff bias, plus peak modulation voltages, when they are to be used. It should be remembered that allowance must be made for the tolerances of resistors and potentiometers, as well as those of electrode potentials.

In determining the value of the focusing electrode potentiometer for electrostatic focus tubes, it is convenient to replace the path from focusing electrode to cathode by equivalent resistances, one determined for maximum first-anode current, for which there is specified a value at minimum required brightness, and the other for zero current (cutoff grid bias). For the first case, the minimum specified value of focusing voltage should be used, corresponding to minimum shunt resistance. A comparison of Figs. 6a and 6b will illustrate the method used. Fig. 6c, showing the case for grid bias at the cutoff value, is equivalent to the bleeder alone without additional shunt resistance.

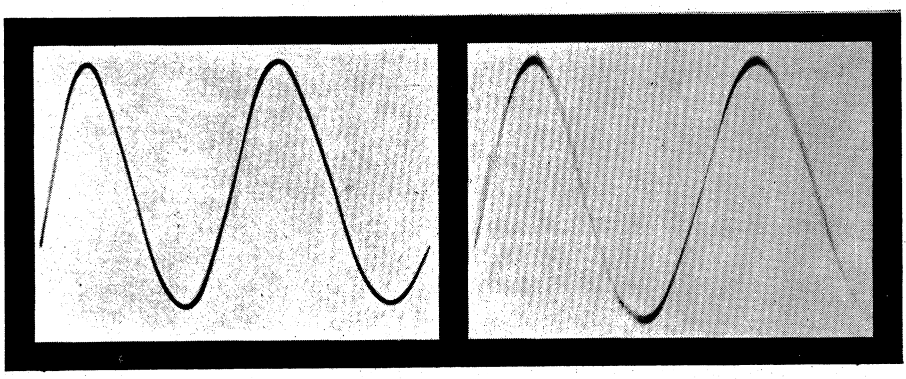

FIG. 8. ILLUSTRATING EFFECT OF UNBALANCED DEFLECTION. LEFT, ALL PLATES RETURNED TO GROUND. RIGHT, -148 VOLTS ON VERTICAL PLATES

Magnetic Focus and Deflection ★ In the case of magnetic-focus tubes, the focusing coil may be connected across a power supply of suitable voltage and current rating or, if the load is sufficiently constant, in series with it. In the first case, the focus coil will have relatively high resistance and, as the coil heats up, changes in its resistance will cause changes in focus current which will require compensation. In the case of series coils, the coil resistance is usually small compared to the load resistance, so that current through it is largely dependent upon the characteristics of the load. As it was pointed out above, specifications are written in terms of a standard focus coil, with a specified range of focusing currents required for a particular tube type and for a definite position of the focusing coil. While the exact values depend upon the design of both coil and gun, a typical value of focusing ampere-turns for a tube operated at 7000 volts is 100 milliamperes.

The same general comments apply to deflection-coil requirements for tubes using magnetic deflection as were made concerning focusing.

The design of magnetic deflection circuits is somewhat more complicated than that of electrostatic circuits because of the requirements that sawtooth currents or other special wave shapes rather than voltages must be produced, and that these currents have to be produced in inductive loads. The wave-forms required to produce sawtooth currents in partially inductive and partially resistive loads have been discussed fully elsewhere, and will not be taken up here.

As a practical matter, to obtain deflection at a uniform rate, e.g., a linear time base, the usual arrangement is to use a source of sawtooth voltage which has been modified to produce a short negative pulse just before the positive rise of the sawtooth. Such a voltage, with the amplitudes of pulse and sawtooth voltages in proper proportion, will result in a sawtooth current through a load made up of resistance and inductance.

The practical problems encountered in magnetic-deflection circuits are quite different for low-frequency circuits, of the order of 60 cycles, and for high-frequency circuits of the order of 5,000 to 15,000 cycles. In the case of high-frequency circuits, transformer coupling is usually used so as to reduce the effect of the capacitance of the leads to the deflection yoke and to transfer insulation problems from the yoke to the transformer.

In discussing high-frequency drive circuits, we will consider the load as being driven by the amplifier without regard to whether or not there is a transformer present. In either case, the impedance presented to the tube plate will be about the same. The problems in the case of high-frequency circuits are to so design the amplifier driving the deflection coil as to accomplish the following:

1. Provide sufficient voltage to take up the $L\frac{di}{dt}$ drop occurring across the inductance during the forward sweep and still leave a sufficient voltage at the plate of the tube. The use of a pentode amplifier is advantageous in this respect as the plate voltage can drop considerably lower without appreciably affecting the tube's current supply characteristics than in the case of a triode.

2. Sufficient insulation must be provided so that the high voltage which occurs across the coil when the current is suddenly stopped during a return sweep will not cause breakdown. In this connection, it should be pointed out that, for sweeps of the order of 15 kc. with return time of 10% or thereabouts, voltages of 2,000 to 4,000 volts will build up during the return time. It is important to bear in mind that the polarity of operation of the output tube cannot be chosen indiscriminately because it would be impossible for the power unit to supply the high voltage that would be required to return the sweep if this return sweep were produced by an increase of current through the coil. Thus such output amplifiers must always operate with the forward sweep produced by increasing plate current.

3. Suitable damping must be provided to prevent shock oscillations from occurring after the return sweep. The method of damping and values of constants are usually determined experimentally for particular cases.

4. The design of the transformer and coil system must be such as to permit the required speed of return. This requirement, of course, means keeping capacitances down as much as possible, as well as giving attention to certain specialized problems which depend upon the type of circuit used.

In connection with low-frequency circuits, the problem is usually that of obtaining satisfactory linearity. When transformer coupling is used at low frequencies, it will be found that, in order to produce a sawtooth current in the secondary, it is necessary to provide a parabolic waveform in the primary. If the current in the primary is a sawtooth, the secondary current will be a saturating exponential instead of sawtooth.

The reason that this occurs in low-frequency transformers and not in high is that it is a function of Q, and Q cannot be made high enough to prevent the effect at the lower frequencies. Various circuits have been devised for correcting this condition, but none of them has been found to be entirely satisfactory. The preferred method is to drive low-frequency deflection coils directly from a tube plate, using resistance coupling. The problem then becomes merely that of providing sufficient capacitance in a coupling capacitor. A higher-sensitivity coil, of course, is required than if transformer coupling is used.

Positioning can be accomplished in transformer-coupled circuits as indicated in Fig. 7a, and, in the case of direct-coupled circuits, positioning can be accomplished as shown in Fig. 7b.

Deflection in Electrostatic Tubes ★ Deflection of the beam in electrostatic cathode-ray tubes generally requires voltages of the order of 500 volts peak-to-peak or higher. Often such voltages exist in the circuits being studied, but more frequently it is necessary to provide amplifiers to permit indication with reasonable pattern sizes of signals of a few volts of amplitude. It is often useful to provide for the connection of signals directly to the deflection plates in order to eliminate any effects on waveform that the use of an amplifier might produce. One of these effects is a restriction of frequency range, since an amplifier is equivalent to a band-pass filter; the other is the effect of input impedance, which is generally higher for the deflection plates of a cathode-ray tube than for the input circuit of an amplifier.

The signal voltages applied to the deflection plates should preferably be balanced, whether or not an amplifier is used, and the potential about which they are balanced should be that of the second anode. Adherence to this principle of design will result in a minimum of astigmatism, which is evidenced by a spot of other than round shape, and of trapezoidal distortion, which appears as a non-linearity of deflection sensitivity on one axis dependent upon position along the other axis. Both of these defects have been discussed at some length in textbooks and manuals. Fig. 8 illustrates the effect of balanced deflection potentials. Here, with second anode grounded, the average potential of both pairs of deflection plates was first made zero, resulting in good, uniform focus. Then the average potential of the vertical pair was increased to +148 volts, with considerable defocusing resulting.

From the design standpoint, the characteristics of greatest importance are deflection-plate capacitance, deflection factor, and leakage. Unless wide-band or tuned amplifiers are required, the capacitances can be neglected, since they are generally less than 10 uuf. and, therefore, small by comparison with other circuit capacitances. If they cannot be neglected, then some provision must be made to compensate for variation of capacitance from tube to tube. This often is in the form of variable iron-core inductances in wide-band shunt-compensated amplifiers, or of trimmer capacitances when the circuits are tuned.

The deflection factor determines not only how much gain is required when the input signal level is known, but also how much deflection-signal voltage must be developed. This latter requirement influences the design of the amplifier power supply. The use of balanced, or symmetrical, deflection permits a 2-to-1 reduction in amplifier power-supply voltage, when this is a limiting factor, as well as improving focus and linearity. In any event, deflection factors may be expected to vary ±20%, and this tolerance, together with the tolerances of plate-load resistors and amplifier-tube characteristics, must be provided.

Limitations of deflection-plate impedance may be of importance where it is desired to make the time constants of coupling circuits as long as possible, in order to provide good low-frequency response, yet keep the physical size of coupling capacitors small to minimize shunt capacitance. Wherever the maximum rated impedance threatens to impair performance, direct coupling to the deflection plates may be considered.

Other circuits are used in connection with the deflection amplifiers. A typical example is the linear-time-base generator. Such circuits, however, do not depend upon the characteristics and ratings of the cathode-ray tube to as great an extent as do the deflection amplifiers, so they will not be considered here.

Intensity Modulation ★ One type of circuit which is affected by cathode-ray tube characteristics and which, therefore, requires consideration of them is that used for modulation of the intensity of the spot. Variations of this type are produced by applying signals between the grid and cathode of the tube. Thus a knowledge of cutoff bias rating, grid-cathode capacitance, and grid-cathode leakage rating are essential, particularly where circuit design must be carried to the limit to obtain the required performance. The range of cutoff bias fixes the value of grid-drive voltage required, for sufficient voltage should be available to drive from the minimum cutoff value to zero bias. Provision should be made to prevent the grid from going positive under any conditions of operation. It is desirable to have means available for controlling the level of the intensity-modulation signal voltage.

Grid capacitance and grid leakage have comparable effects on grid modulating circuits to those of deflection-plate capacitance and leakage on deflection circuits, and they must be taken into consideration in designing the circuit in much the same way.

The Fluorescent Spot ★ The fluorescent spot of a cathode-ray tube has several important characteristics other than those of motion and relative intensity. Most important of these characteristics are size, color, brightness, and persistence.

The usefulness of a cathode-ray tube depends upon its presenting an indication or a record. Thus the light output, or brightness, is of importance. Since one of the factors influencing it is accelerating potential, which also controls deflection factors, the choice of both tube type and operating conditions will depend on the particular applications involved. The brightness and the spot size are interrelated, the spot size generally increasing with brightness, and this must be considered in determining the suitability of a tube type.

In the specifications, the maximum spot size for a given accelerating potential and for a given required minimum brightness is given, and the test method takes account of astigmatism of the spot as well as of actual dimensions. In designing equipment, the specified values should be anticipated, although in many cases actual performance will be found to be better.

The color of the spot is usually relatively unimportant, although in most cases fluorescent screens providing a blue spot are superior for photographic work to those giving other colors. Generally the color is incidental to the persistence characteristic, which is ordinarily classified as short, medium, or long. Short-persistence screens are generally required only for photography on moving film, while those of medium persistence are best suited to visual observation of phenomena recurring at rates not less than fifteen times a second. Where repetition rates are lower than this, or for the study of transient phenomena, long-persistence screens should be used.

4. Conclusion

In the application of cathode-ray tubes, the first step in the design of equipment is to determine the type of tube which can provide the performance required, as determined from its specifications and ratings. It is then necessary to design the equipment not from a sample of that tube type but rather from the specifications, in order to ensure that in the course of production and maintenance the equipment will operate satisfactorily and interchangeably with all tubes falling within the specified tolerances.

SUMMARIES OF PAPERS GIVEN BEFORE THE RADIO CLUB OF AMERICA, Inc.

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On March 17, 1943, at the N.B.C. Studio 6A, 49 West 49th Street, New York City, Mr. Frederick G. Knopfke, Manager of Sound Effects for the National Broadcasting Company, spoke on the production of sound effects in radio broadcasting. An excellent insight into the backstage of radio was given. The technique of the production of both simple and difficult effects was explained. Sound effects equipment were displayed and demonstrated in normal and unorthodox operations.

Mr. Leo A. Weiss, Instrument Design Supervisor of Simmonds Aerocessories, Inc., on April 8, 1943 delivered a paper on the Radiosonde at Havemeyer Hall, Columbia University. The wealth of practical scientific development lying behind all of the radio achievements in the very new and long range weather forecasting, based upon mass air analysis, was discussed. The Radiosonde had been made practical only recently for basic results and had been hitherto an essentially theoretical approach. The subject of Radiosonde instrumentation, including the very definite cleavage between meteorological portions and the radio transmission and reception portions, were covered in detail.

At Havemeyer Hall, Columbia University, New York City, on May 13, 1943, Mr. A. G. Kandoian of Federal Telephone and Radio Laboratories, and Mr. Robert F. Lewis, Columbia Broadcasting Co., gave an excellent talk on ultra-high frequency measuring technique. Transmission line measurements at very high frequencies and the lower ultra-high frequency design of probe type detectors for voltage, current, and power measurements were discussed. Applications of the instruments to specific measurement problems, including characteristics of solid dielectric transmission lines of co-axial and balanced type, antenna impedances, etc., were fully covered.

Mr. S. Young White, Consulting Engineer, formerly with the General Communication Co., on February 10, 1944 delivered a paper before the Club on the comparison of various tuning systems at V.H.F. The paper covered both theory and economics in tuning by parallel and concentric lines, cups, sliding contact coils, variable condensers of special design and core tuning by iron and conductive cores in relation to their performance under temperature, voltage, humidity and vibration condition. Special instrumentation required in these investigations and the range of 50 to 500 M.C. was discussed with emphasis on post-war problems.

Dr. C. H. Bachman from the Electronics Laboratory of the General Electric Company, Schenectady, N. Y., on March 9, 1944, spoke before the Club on the Electrostatic Electron Microscope. The speaker described the problems encountered in electron microscope design and traced the development of the instrument up to present day models. The relative advantages and disadvantages of electrostatic and electro-magnetic lenses were discussed along with some applications of the instruments. Guests had the opportunity to view an image through an electron microscope which the speaker had on hand.

A talk on the use of high frequency in wooden aircraft manufacture was given before the Club on January 13, 1944 by Mr. John F. Dreyer, Jr., Chief of Electrical Research, Duramold Division, and Edward W. Stone, Project Engineer, Burlington Division, Fairchild Engine and Airplane Corporation. The desirability of the high frequency process for the bonding of wood and the nature of the process were thoroughly covered. Available generating equipment was described and the direction for improved designs pointed out. Methods of matching the load to the generator and some of the measurement problems encountered were discussed, as well as some of the problems which arise in production. A demonstration of high frequency gluing was given and a considerable number of lantern slides were shown.

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