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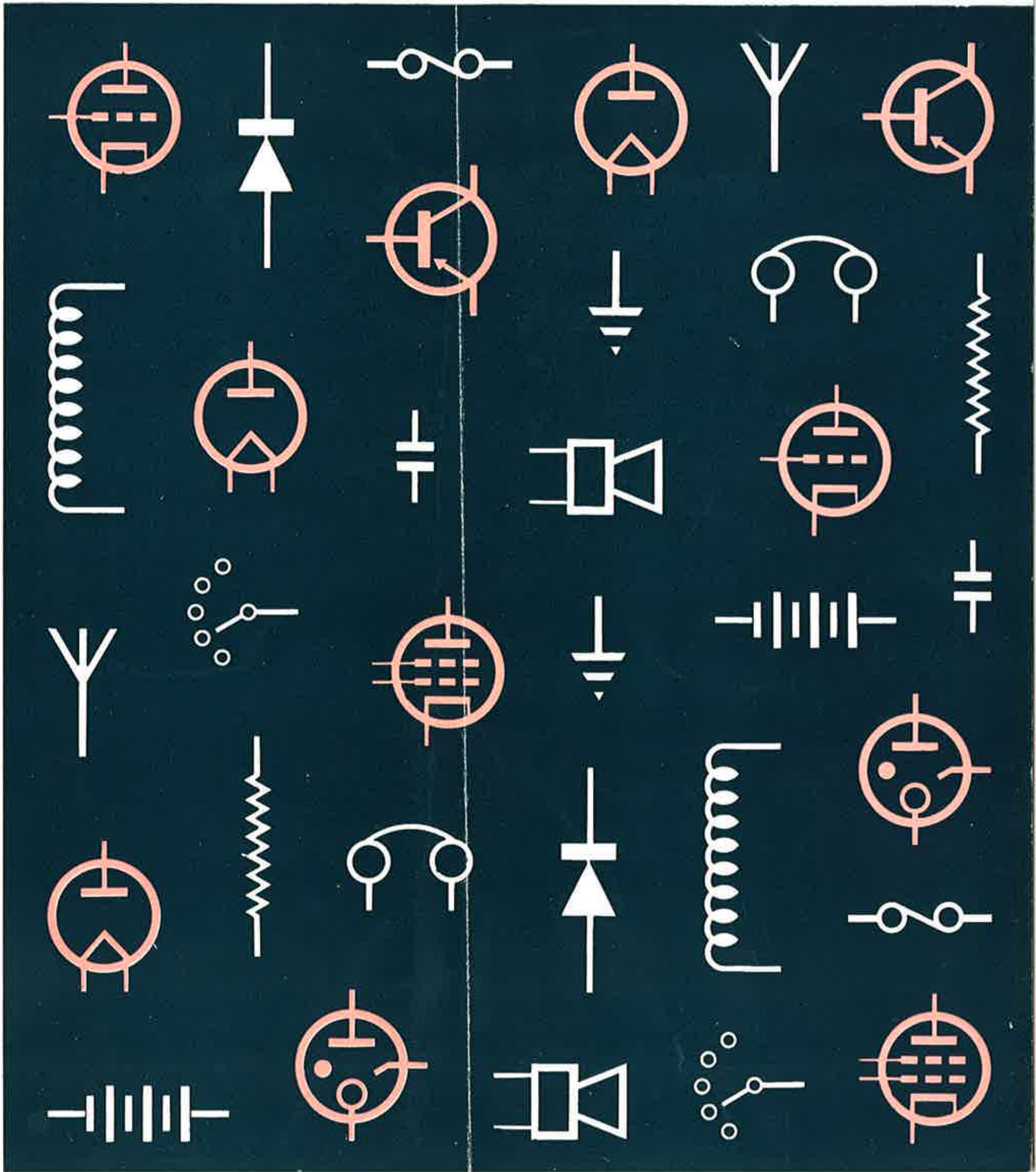

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THE SYNTHESIS OF BLACK AND WHITE TELEVISION IMAGES FROM COLOURED PICTURE TUBE PHOSPHORS

by C. H. Laurence, B.Sc.

Summary

The colour of a picture tube screen must be carefully chosen, as the eye is extremely sensitive as a colour-comparison device and colour perception of an object is influenced by its surroundings. Thus, during manufacture it is necessary to control the final colour by measurement to a tolerance corresponding to the critical nature of human colour perception.

The screen of a black and white picture tube is composed of two or more phosphors, chemical materials capable of giving coloured luminescence when excited by an electron beam. By suitable choice of phosphors a screen colour is achieved which can be closely duplicated from batch to batch. The CIE* system of colour specification and the black body curve on the CIE diagram are used extensively in phosphor blending.

Several aspects of actual screen application such as body colour of the phosphor, thickness of the screen and impurities in the settling water, can cause colour shifts.

Introduction

In monochrome television there is no technical reason for using a white fluorescent screen; the information conveyed by the picture is unaffected by its colour. Although a yellow screen is supposed to be the best from a fatigue point of view, the public from the start preferred a white screen. This may have been due to many years' familiarity with black and white photographs and films, or a natural choice due to the fact that certain objects look ludicrous when portrayed in an unusual colour.

But, whatever colour is used, the usefulness of a television picture tube depends upon its ability to present a visual pattern on its screen. The process of producing light by electron bombardment of the screen material or phosphor involves the mechanism advanced by quantum physicists to explain the phenomenon of luminescence. Electrons raised from their stable energy state by instant electron bombardment give forth radiation equivalent to the energy lost in returning from this higher energy state to their stable state. Besides the straightout return of an excited electron to its normal state, there is also a probability of it being trapped in a metastable or temporary state, from which it can return to the stable state only after an auxiliary excitation which may be thermal in nature.

The two different types of electron return combine to give the overall luminescence, which can be considered as two distinct processes, fluorescence caused by the first type of electron return (and which ceases almost immediately

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*Commission Internationale de l'Eclairage.

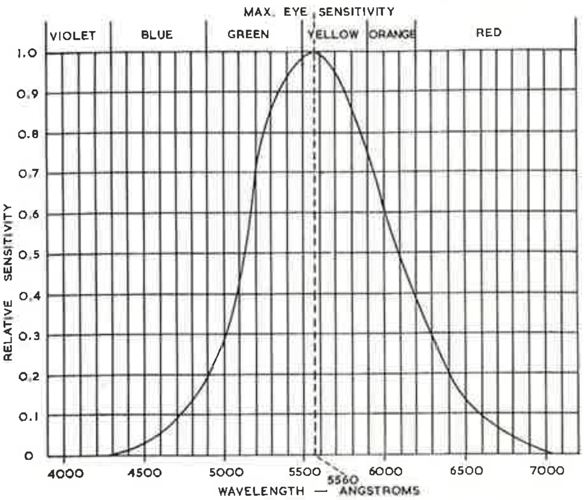

Fig. 1. — Relative sensitivity of the Eye to Different Wavelengths of the Visible Spectrum.

upon removal of the excitation), and phosphorescence which persists after the excitation is removed. It is difficult to differentiate between the two types of luminescence; a commonly used time limit for the duration of fluorescence after cessation of excitation is 10^{-8} seconds. After that time the radiation is termed phosphorescence.

Before discussing the luminescent colour and characteristics of actual picture tube phosphors a characteristic of human vision which is of great significance in television should be mentioned. The eye does not have the same response to light of different frequencies. If one were to look at monochromatic lights of the same intensity from one end of the spectrum to the other, the relative brightness of each colour would seem to increase to a maximum and then decrease.

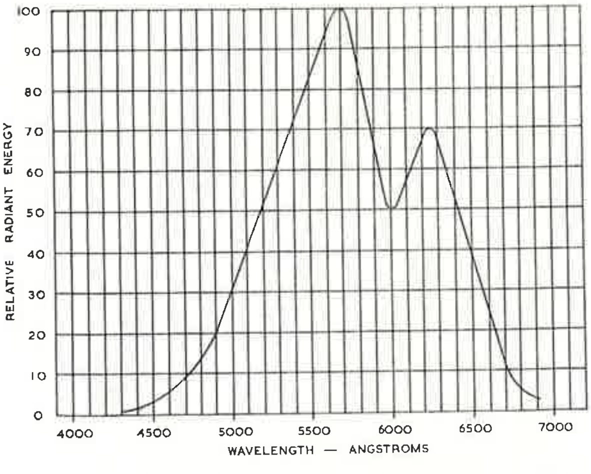

Fig. 2. — Spectral Characteristic Curve of a Phosphor Blend.

This is shown in Fig. 1, where the maximum visual response occurs at a wavelength of 5,560 angstroms. The luminosity of monochromatic light of this wavelength has a value of 680 lumens per watt.

As previously mentioned energy radiated from a phosphor screen covers a range of wavelengths and it is found that the intensity is not the same for different wavelengths. A typical intensity versus wavelength curve is given in Fig. 2. Such a curve of course, refers to a specific set of conditions; the two peaks are typical of a mixture of two phosphors.

The visual spectral characteristic of a phosphor screen is obtained by a combination of the two previous curves. A new curve is drawn with new ordinates obtained by multiplying the two previous ordinates together (for each wavelength).

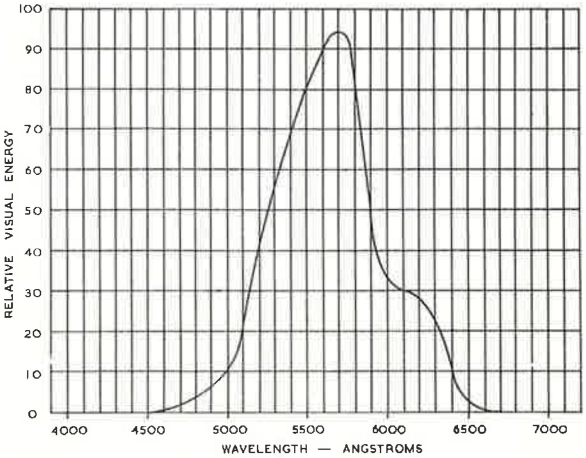

Fig. 3. — Visual Spectral Characteristic of the Blend shown in Fig. 2.

The difference in area between Figs. 2 and 3 gives an idea of the visual efficiency of the phosphor. In this case, Fig. 3 is about 70% of Fig. 2, quite an efficient phosphor.

The CIE Colour System

Emphasis placed on the colour of the post-war television picture tube made accurate control of colour a necessity. In the pre-war period the factory method for measuring and defining the colour of TV phosphors was a visual comparison of the tube with various coloured light sources. Visual comparison, in addition to being subjective was basically inadequate, since the colours of even these light sources were undefined.

Today the CIE colour specification system is used. This system developed from the fact that

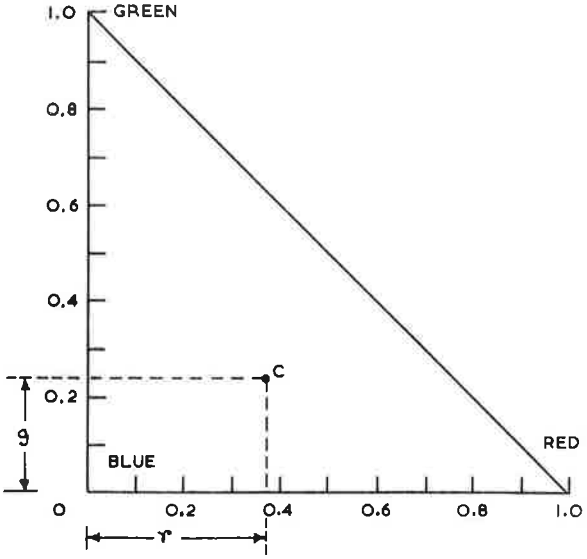

Fig. 4. — Chromaticity Diagram Relating to Reference Stimuli R, G and B.

any colour could be matched by a suitable mixture of three radiations such as red, green and blue. If the amounts of red, green and blue required to match a colour represented by the symbol C° are respectively u, v, and w, as measured in some convenient unit, then C° can be expressed algebraically by the equation:

$$C^\circ = uR^\circ + vG^\circ + wB^\circ$$

If the nature of R°, G°, and B° (i.e. the red, green and blue radiations) is known, e.g., by their wavelengths or energy distributions, and if the units in which they are measured, e.g., energy units or units of light flux, can be stated, then the equation for C° provides an exact and unique specification for the colour.

The basic system established by the CIE used three primaries R, G, and B ($\lambda_R = 700$, $\lambda_G = 546.1$, $\lambda_B = 435.8$mμ).* It has become the practice to base the units of R, G, and B on a match of a white of some defined quality. It is assumed that equal amounts of R, G, and B are required to match an equal energy white, that is, a source radiating equal power at all wavelengths. This involves the relative luminosities of R, G, and B. For unit quantities of the stimuli, the relative luminosities L_R, L_G, and L_B were found as

$$L_R : L_G : L_B :: 1 : 4.59 : 0.06$$

On these units we can say that a definite amount of C, say 'c' is given by the equation:

$$cC = r_1R + g_1G + b_1B$$

where r_1 g_1 and b_1 are known as tristimulus coefficients. The unit amount of C is defined as the amount of C represented by the equation whose coefficients add up to unity.

$$\text{e.g. } C = rB + gG + bB \text{ where } r = \frac{r_1}{r_1 + g_1 + b_1}$$

g and b similarly.

Here, r, g, and b are known as trichromatic coefficients. Also, $c = r_1 + g_1 + b_1$ so that the amount of C is given by the sum of the three tristimulus coefficients.

In the unit trichromatic equation, provided that any two of the three coefficients are known, the third can be found as the difference between unity and the sum of the other two. C can then be represented on a plane diagram as in Fig. 4, known as a chromaticity diagram.

To obtain the trichromatic units on the R, G, and B system for an arbitrary light source, certain methods are well established. First the tristimulus coefficients are obtained, then the trichromatic coefficients. Unfortunately on the R, G, and B system the conception of negative colour is involved. This simply means that not all colours can be matched by the addition of certain amounts of the R, G and B stimuli. Often one stimulus has to be added to the sample to match a blend of the other two.

To eliminate this the technical measurement of colour is done using three specially selected

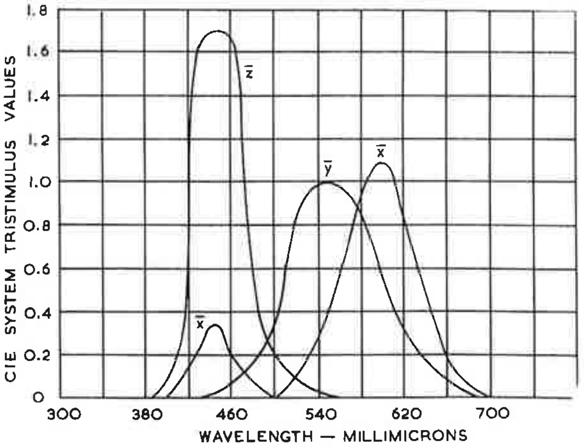

Fig. 5. — Distribution Curves Giving the Tristimulus Values $\bar{x}$, $\bar{y}$ and $\bar{z}$ in Trichromatic Units of the XYZ Stimuli for the Equal Energy Spectrum.

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*Wavelengths of light are customarily expressed in either angstrom units or microns (mμ). An angstrom unit equals 1×10^{-10} metre, one micron equals 1×10^{-6} metre, so that one micron equals 1×10^{4} angstrom units.

stimuli X, Y, and Z. These are not real colours, but mathematically possible although physiologically non-existent. Any colour can be matched by positive amounts of these stimuli. X, Y and Z are defined by reference to the R, G and B spectral stimuli.

To assist in the measuring of an arbitrary light source, the CIE standardized experimentally-determined quantities of X, Y and Z required to match a constant power of each wavelength throughout the equal energy spectrum. The values obtained $\bar{x}$, $\bar{y}$ and $\bar{z}$, are referred to as "tristimulus values" or "distribution coefficients" since, when plotted against wavelength, they show the distribution of X, Y and Z the equal energy spectrum. The standardized curve is shown in Fig. 5.

The values of the distribution coefficients can be used to evaluate the tristimulus equation for an arbitrary light source defined by its energy distribution. From this data a chromaticity diagram can be constructed, similar to that shown in Fig. 4, except that x, y and z are substituted for red, green and blue respectively.

The pure spectral (monochromatic) colours can be located in the triangle by a direct application of the tristimulus value curves. The locus of the chromaticities of the spectral colours is a horseshoe-shaped curve. Along the straight line joining the ends are the purples which are not spectral colours. The locus is shown in Fig. 6.

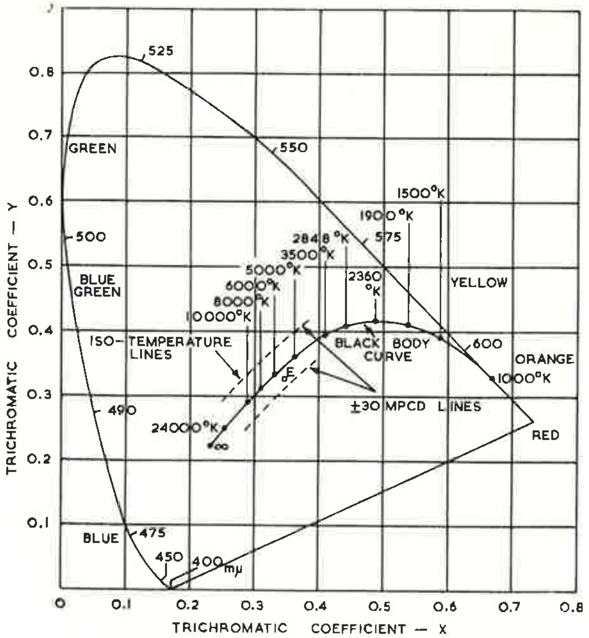


Fig. 6. — Locus of the Spectrum Colours in the XYZ Chromaticity Diagram and the Planckian Locus or Black Body Curve.

For ordinary illuminants, it has long been the practice to specify colour in terms of colour temperature. This temperature identifies the colour of light which would be emitted by a perfect "black body" raised to the specified temperature. The locus of such colours can be plotted on the CIE diagram and is known as the Planckian Locus or "black body" curve. It so happens we are accustomed to illumination of colours fairly close to this curve, though ranging along it for a considerable distance. We also consider a large portion of it to represent "white." Note that in colour-temperature work, the Kelvin or absolute scale of temperature is used. See "Radiotronics," Vol. 24, No. 12, December, 1959, page 318.

No such tolerance is allowed normal to the black-body curve; a comparatively slight deviation upward on the CIE diagram represents colours which are immediately recognised as being greenish and similarly a shift downward produces colours which are classed as purplish. Iso-temperature lines can be drawn across the black-body curve. These lines do not cross the black-body curve at right angles.

Another helpful adjunct on the diagram are the MPCD lines, lines of minimum perceptible colour difference. The size of the MPCD unit varies with colour so that the lines of constant MPCD values converge toward the black body line at high colour temperature.

Thus, we have an alternative way of specifying a colour, e.g. we can say the colour is x = 0.305, y = 0.320, or we can state that the colour is 7000°K + 5 MPCD. One extremely useful property of the CIE system is that a straight line between any two points on the diagram represents all the colours that may be obtained by colour addition; that is, by mechanically mixing two luminescent materials.

So that, as shown in Fig. 7 the colour of any mixture of Y2 and B2 will fall along the line joining the two points. The proportion of each colour may be such as to produce a white of 7000°K. If too much of Y2 is used the resultant colour will be pale orange, and if too much of B2 the resultant colour will be bluish. Actually, a straight line is obtained only with materials which are normally white in colour. If one of the materials shows selective absorption in the visible spectrum, a bulge will appear on the straight line.

Practical Phosphors

Certain phosphors have white light emission but their formulae are involved and their efficiency very poor. It is usual in modern television screens to use two phosphors of complementary colours;

a blue emitting material is generally mixed with yellow emitting material. If these are white crystalline materials, such as zinc sulphide or zinc beryllium silicate, the colours of the two components are chosen so that the straight line joining them passes through the point of desired white and in addition is as parallel as possible to the black body curve. Thus, deviations in different batches from the average colour, for example by a slight change in the efficiency of one phosphor, which will occur along the straight line joining the two colours, will give colours at the same distance from the black body curve as the bogey colour. These colours will be more acceptable than those resulting from comparable deviations in the green or purple direction which would occur if the phosphor line lay at a considerable angle to the black body line. It is a characteristic of human vision that a much greater shift of colour can be tolerated along the black body curve rather than across it.

Because of the better efficiency of the zinc cadmium sulphides as compared to the zinc beryllium silicates, the former are now used in television tubes, thus giving an all-sulphide screen. Zinc sulphide and zinc cadmium sulphide phosphors constitute very efficient cathodo-luminescent materials. Under normal conditions zinc cadmium sulphide screens activated with silver, at bombarding voltages of 6 to 10 kilovolts, yield luminous outputs of 35 to 50 lumens per watt. Converting one watt of energy into radiation producing maximum visual response will give rise to about 680 lumens of light, and if converted into radiation with the spectral response of zinc cadmium sulphide, approximately 500 lumens. This means the actual efficiency of the zinc cadmium sulphide is only about 10%.

The all-sulphide screen material has body colour due to the yellow of the zinc cadmium sulphide so that the screen must now be considered as a filter as well as an emitter. The spectral transmission of this filter varies as the proportion of blue to yellow components changes, effectively shifting the blue source towards longer wavelengths. Thus the phosphor line for the zinc sulphide, zinc cadmium sulphide mixture curves slightly upwards from the straight line connecting the CIE points, producing a greener white than expected. If Y2 in Fig. 7 had a yellow body colour, the resultant mixture colours with B2 would not lie on the line Y2B2, but for colours near the centre of the diagram rather on the dotted line Y2B2a.

The screen brightness of a television tube is related to the luminosities of the yellow and blue phosphors and the relative amounts used. Since the luminosity of the yellow is many times that of the blue and the amounts about equal, most of the visual efficiency of a television screen comes from the yellow components.

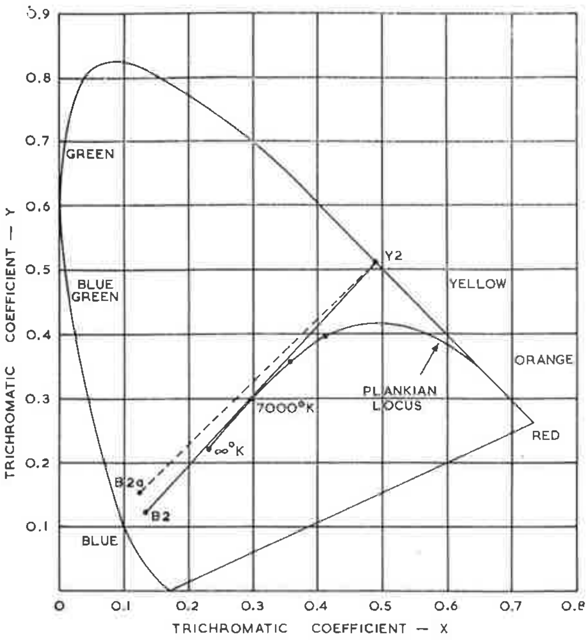


Fig. 7. — Mixture Diagram for Phosphor Blends using a Yellow Component Y2 and a Blue Component B2.

In spite of the luminous efficiencies of the two phosphors their phosphorescent decay period or persistence characteristics are similar and quite short. The curve for a zinc sulphide phosphor, for example, shows that light output falls to less than 0.1% in one picture period.

As mentioned earlier, luminescence produced by the electron bombardment is of two sorts, fluorescence and phosphorescence. Upon removal of the excitation fluorescence stops abruptly (within 10^{-8} seconds) whereas phosphorescence persists. The latter is the radiation of excited electrons which have been delayed, by being caught in "traps" in the crystal lattice, in dropping back to a stable state.

In a picture tube the beam which serves as excitation is on a given area for a length of time equal to about 0.1 to 0.2 microseconds. The light persists for several hundredths of a second, so that it is the phosphorescence of the material which gives most of the light. The total light energy released, i.e., the light intensity integrated over the time it persists is approximately proportional to the energy supplied rather than to the instantaneous power. That is, ten microamps for 10^{-6} seconds averaged over two-hundredths of a second will give approximately the same light as 100 microamps for 10^{-7} seconds.

As a matter of interest, if we consider the electron beam to have a spot size of about 1 mm total diameter (the actual brightness through the spot is a bell distribution) and the scanning width to be 500 mm then the speed of the spot in mm/sec is $500 \times 625 \times 25$ since the spot sweeps across the screen $625 \times 25 = 15{,}625$ times per second.

$\therefore$ Time to pass 1 mm =

$$\frac{1}{500 \times 625 \times 25} = 1.3 \times 10^{-7} \text{ sec}$$

So that the total excitation time in 1000 hours operation is only $1.3 \times 10^{-7} \times 25 \times 60 \times 60 \times 1000 = 12$ sec approximately, but the power

$$= \frac{\text{Ultor Volts} \times \text{Beam Current}}{\text{area}}$$

equals some hundreds of watts per square centimetre which is the reason we get electron burns from stationary spots. For comparison the power radiated in watts per square centimetre for an oxide coated cathode operating at 1100°K is 2.7 and for a 100 watt incandescent lamp with the tungsten filament at about 2900°K the figure is 140 watts per square centimetre.

Returning to the all-sulphide phosphor screen, a figure of 7000°K was the original tentative choice for a "best white." Screens yellower than this exhibit sepia tones in the shadows which were considered objectionable; the bluish screens appear truly black in the dark areas and seem to have more contrast. Since then screens have tended to become more and more blue due to customer preference, first to 8300°K, then 9300°K with 11,000°K now becoming very popular.

The actual making of a blend of P4 phosphor starts with the preparation of the two main components, for example, the blue emitting zinc sulphide ($x = .152$, $y = .108$) and the yellow emitting zinc cadmium sulphide ($x = .453$, $y = .521$). The phosphors are prepared separately and each is tested under standard conditions in two different ways, firstly for obvious things such as grain size, colour, efficiency, etc., and secondly for the ability to settle as a screen, able to withstand normal processing as required of a television picture tube.

Having passed both series of tests and with the colour located on the CIE diagram, calculations are made as to the approximate amounts of each required to give the desired white. A trial blend is then prepared and tested for colour. It will be remembered that because of the yellow body-colour of the phosphor, the colour of the blend will be a little greener than calculated; in effect a few MPCD's higher from the black body curve, provided the straight line joining the position of the two colours was tangent to or above the black body curve. This matter of MPCD's is most important if specifying the colour temperature in degrees Kelvin. A colour of say 9300°K + 5 MPCD looks purple when compared with another white 9300°K + 30 MPCD.

If one wishes to make the latter from two components which normally give the former, small adjustments are made to the amounts of the major components and a third component (in this case a green emitting zinc cadmium sulphide) added in amounts of up to 3 per cent. This effectively increases the MPCD distance from the black body curve. For the reverse, to bring a blend closer to the black body line, a red emitting phosphor is added as a third component.

The actual measurement of colour was mentioned before for a source defined by its energy distribution found. Due to the small amount of components and final blend, either actual tubes are made using the phosphor concerned, or small glass test pieces containing a layer of phosphor are fixed in a demountable vacuum device containing an electron gun. In each case the weight of phosphor per square centimetre is closely controlled.

The screen or test piece is scanned in the usual way, under specified conditions and the spectral distribution found, due to the small amount of light available a spectroradiometer is necessary; this is a laboratory instrument, large and delicate. The relative energy values for the light emitted are measured over a wavelength range 400-700mμ Readings are generally made in steps of 10mμ. The CIE colour can then be calculated from the distribution coefficients given in Fig. 5.

Another method is to use a colorimeter. Although the instrument requires a rather sensitive current meter for the light intensities involved, it is suitable for use in production. One popular instrument uses a single photocell and three filters, green, amber and blue on a disc. The instrument must be calibrated by means of a standard television picture tube (standardised with a spectroradiometer) of about bogey colour value and using a similar phosphor mixture to the production samples. To obtain the colour of a sample the deflections for each of the three filters are obtained and the chromaticity computed from equations given with the instrument.

It should be emphasised that for colour measurements the brightness of the screen must be standardised and also the appropriate operating conditions. This is because the relative efficiencies of the blue and yellow materials are not consistent for changes in excitation conditions, that is, changes in exciting current and voltage.

A shift to a higher colour temperature will result if either the current or ultor voltage is increased and, conversely, to a lower colour temperature if either the current or ultor voltage is decreased. Also, as a matter of interest, defocusing will lower the colour temperature since it decreases the current density per luminescent centre. These changes in colour temperature are of no importance in television receivers, for example the eye sees only a change in brightness as the current is changed, but the effects are important in laboratory control.

Developing the final colour on paper is relatively simple: getting the colour on the screen of a television picture tube is rather more of a problem. Settling conditions, screen bake-out conditions, aluminizing of the screen, all play a part. For example, the reduced beam currents used in aluminized tubes enhance the relative brightness of the yellow component, so that a phosphor for an aluminized tube has relatively more blue component than a phosphor to be used in a non-aluminized tube, even though both tubes have the same screen colour at identical operating conditions of light output and ultor voltage. Traces of impurities in the water used for settling the screen can affect the screen colour. An amount of copper less than one part in a million in the water, will cause a greening of the screen, visible only at final test.

The colour of different blends is held to within narrow limits. Variation due to settling is at least three times the blend to blend variation. The principal cause is screen weight variations — a change in weight of ten per cent equals a colour change of about 600°K at an average weight of 4 mgm per square centimetre.

It has been shown that modern manufacturing methods can produce television picture tubes whose screens are of a specified colour. The actual colour desired, however, is purely a matter of choice—it is very subjective. The quality and picture information are not affected by the ultimate colour chosen but over a period, the trend, dictated by customer demand, has been to a bluer screen. It is well known that the ambient lighting is of great importance. A screen which appears bluish in incandescent light may seem yellowish in daylight and one which is quite blue initially may appear to be a good white when viewed for some minutes. It seems likely that the bluer screen with its stark blue-green whites, shows out very well in the showroom and is most pleasing when viewed under normal conditions in the home.

This article is a condensed version of a paper prepared by the author for the 1959 IRE Radio Engineering Convention, and subsequently printed in the Proceedings of the Institution of Radio Engineers, Australia. The condensation has been prepared and is presented here by kind permission of the Institution.

AUTOMOBILE TEMPERATURES

We all know how hot a car will get when left in the sun, but how many realise that this will have a most decided effect on the performance and life of any electronic equipment installed in the car? Equipment ratings invariably include a maximum operating temperature which must not be exceeded. This is particularly true of transistorized equipment, whether a complete transistor radio or a hybrid unit with transistor output stage or power supply.

In view of the maximum operating temperature of 90°C for most germanium power transistors, it is interesting to note the results of some temperature measurements made recently in the U.S.A. In these tests, temperatures were measured in a car under severe ambient temperature conditions. The car was dark in colour, facing the sun, and with all windows, doors and air vents closed.

After exposure to the sun for four hours at ambient air temperatures of the order of 110°F (43°C), the following temperatures were measured:

Under the dash	150°F	(65°C)
Engine side of firewall, engine off	140°F	(60°C)
Engine side of firewall, engine idling	180°F	(82°C)
Luggage compartment	130°F	(54°C)

With electronic equipment operating under these conditions it will in some cases require only a small temperature rise in the equipment itself to produce an intolerably-high and destructive temperature in the equipment. The sun-temperature of 110°F under which the tests were carried out is frequently exceeded in Australia, and these facts must be remembered when installing equipment in vehicles.

The 7199 in High-Fidelity Audio Equipment

This article describes the special features of the 7199 triode-pentode, and discusses its application in "hi-fi" audio equipment. The 7199 is a 9-pin miniature type containing a medium-mu triode and a sharp-cutoff high-transconductance pentode, and having very low hum, leakage noise, and microphonism. It is specially designed and controlled for use in high-fidelity audio equipment in stages operating at signal levels in the order of 100 millivolts. It is particularly useful in direct-coupled voltage-amplifier phase-splitter circuits, and in tone-control circuits.

Two circuits are given in which the 7199 is used as a direct-coupled voltage amplifier and phase splitter, and one in which the pentode unit is used as a general-purpose voltage amplifier. It also discusses the advantages to be gained by operation of voltage-amplifier pentodes at low plate and grid-No. 2 voltages, and gives graphs and calculations showing how these advantages may be achieved for the pentode unit of the 7199.

Design Features and Characteristics

The 7199 utilizes a specially designed cage assembly and stem which make it much less susceptible than other triode-pentodes to microphonics. These features also provide a rugged structure and minimize leakage noise. The heaters of the two units are specially designed to produce very low magnetic hum. Median values of hum and noise, expressed as equivalent voltages at the control grids, are 35 microvolts for the pentode unit and 10 microvolts for the triode unit. Maximum values are 100 microvolts for the pentode unit and 150 microvolts for the triode unit. These equivalent hum-and-noise voltages are for grid-circuit resistances of 50,000 ohms.

Because of its high transconductance (7,000 μmhos), the pentode unit of the 7199 can provide large voltage gains (values of 100 to 350 are typical). It can also deliver output signals as large as 90 volts peak-to-peak with low distortion. The triode unit has a mu of 17 and can handle large signal voltages. This combination of characteristics, together with its low hum and noise, makes the 7199 especially suitable for use as a voltage amplifier and cathode follower, or a voltage amplifier and phase splitter (the phase splitter is a form of cathode follower).

Hum and Noise Performance

The hum-and-noise performance that can be expected from the 7199 when precautions are taken in circuit layout and wiring to eliminate hum and noise from other sources is illustrated by the following example:

Assume that the pentode unit of the 7199 is to be used in the input stage of an amplifier having a sensitivity of 100 millivolts rms. (The rated power output or voltage output of the amplifier need not be specified.) The amplifier has an input resistance of 50,000 ohms. Based on the maximum value of hum and noise for the pentode unit (100 microvolts), the minimum signal-to-noise ratio at the amplifier input in decibels will be

$$20 \log \frac{0.1}{0.0001} = 20 \log 1{,}000, \text{ or } 60 \text{ db.}$$

Based on the median value of hum and noise for the pentode unit (35 microvolts), this ratio will be

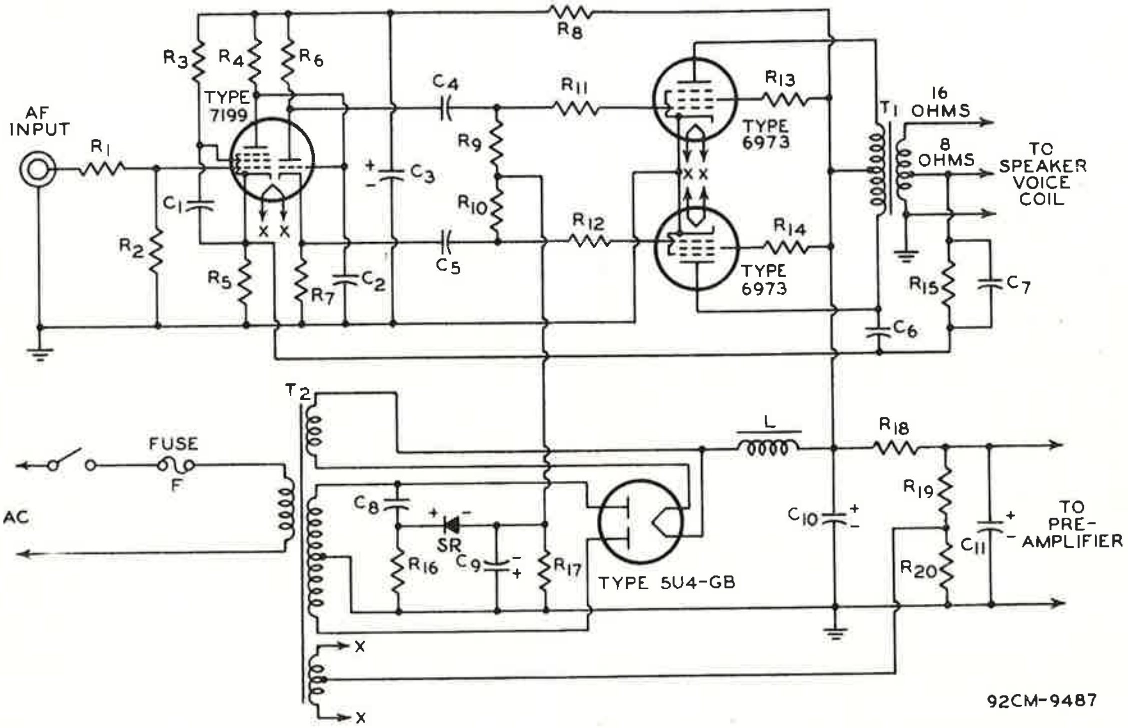
$$20 \log \frac{0.1}{0.000035} = 20 \log 2{,}850$$, or approximately 69 db.

If the input stage has a gain of at least 20 db (a voltage gain of 10), hum and noise originating in the grid circuits of succeeding stages can be neglected, and the signal-to-noise ratio at the amplifier output will be the same as that at the input. Because the pentode unit of the 7199 can easily provide voltage gains of more than 100, these conditions are easily realized. Hum and noise at the output of the amplifier, therefore, will be at least 60 db below rated output.

It is evident from the foregoing example that if the pentode unit of the 7199 is used in the input stage of a preamplifier, or in any other application where the input signal level is only a few millivolts, the hum and noise at the output of the following amplifier may be substantially less than 60 db below rated output. For high-fidelity reproduction, therefore, the pentode unit of the 7199 should not be used in any stage where the input signal level is substantially less than 100 millivolts.

Applications

An example of the use of the 7199 as a voltage amplifier and phase splitter is shown in Fig. 1. In this high-fidelity, 15-watt, power amplifier, the pentode unit of the 7199 is direct-coupled to the triode unit, which drives a pair of 6973 high-fidelity beam power valves operating in class AB$_1$ with fixed bias. The amplifier uses 18 db of



C_1: 0.25 µf, 600 v., paper

C_2: 3.3 µµf, 400 v., mica or ceramic

C_3, C_{11}: 40 µf, 450 v., electrolytic

C_4, C_5: 0.25 µf, 600 v., paper

C_6: 3.3 µµf, 600 v., mica or ceramic

C_7: 150 µµf, 400 v., mica or ceramic

C_8: 0.02 µf, 600 v., paper

C_9: 100 µf, 50 v., electrolytic

C_{10}: 80 µf, 450 v., electrolytic

F: Fuse, 3 amperes, 150 volts

L: Filter choke, 3 henries, 160 ma., 75 ohms,

R_1: 10,000 ohms, 0.5 watt

R_2: 470,000 ohms, 0.5 watt

R_3: 820,000 ohms, 0.5 watt

R_4: 220,000 ohms, 0.5 watt

R_5: 820 ohms, 0.5 watt

R_6, R_7: 15,000 ohms ± 5%, 2 watts

R_8: 3900 ohms, 2 watts

R_9, R_{10}: 100,000 ohms, 0.5 watt

R_{11} R_{12}: 1000 ohms, 0.5 watt

R_{13}, R_{14}: 100 ohms, 0.5 watt

R_{15}: 8200 ohms, 0.5 watt

R_{16}: 15,000 ohms, 1 watt

R_{17}: 68,000 ohms, 0.5 watt

R_{18}: 4700 ohms, 2 watts

R_{19}: 270,000 ohms, 1 watt

R_{20}: 47,000 ohms, 0.5 watt

SR: Selenium rectifier, 20 ma., 135 volts rms

T_1: Output transformer for matching speaker voice-coil impedance to 6600-ohm plate-to-plate

T_2: Power transformer, 360-0-360 volts rms, 120 ma.,

Fig. 1 — High-fidelity Power Amplifier using the 7199 Triode-pentode as a High-Gain Voltage Amplifier and Phase Splitter.

degenerative feedback between the voice-coil connection and the voltage-amplifier cathode. At 15 watts output, total harmonic distortion (measured at 1,000 cps) is less than 0.5 per cent, and intermodulation distortion is less than 0.5 per cent. Hum and noise with input shorted are 84 db below rated output. As shown in Fig. 2, the frequency response of the amplifier at 4 watts output is flat over the entire audio spectrum and down less than 2 db at 10 cps and 60,000 cps. At 15 watts output, the frequency response is flat from 20 cps to 15,000 cps, and down less than 1 db at 15 cps and 20,000 cps. The amplifier has a sensitivity of 1.2 volts rms, and a damping factor of 12.

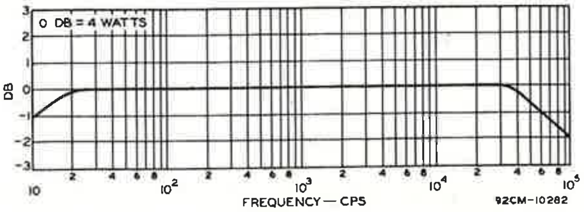


Fig. 2 — Frequency-response Characteristics of the Amplifier shown in Fig. 1.

A slightly different voltage-amplifier/phase-splitter circuit which also is capable of very good performance is shown in Fig. 3. In this circuit, grid-No. 2 voltage for the pentode unit of 7199 is obtained through a 220,000-ohm resistor from the cathode of the triode unit. This arrangement provides regenerative feedback between the two units which can be used to obtain increased over-all gain at the lower audio frequencies.

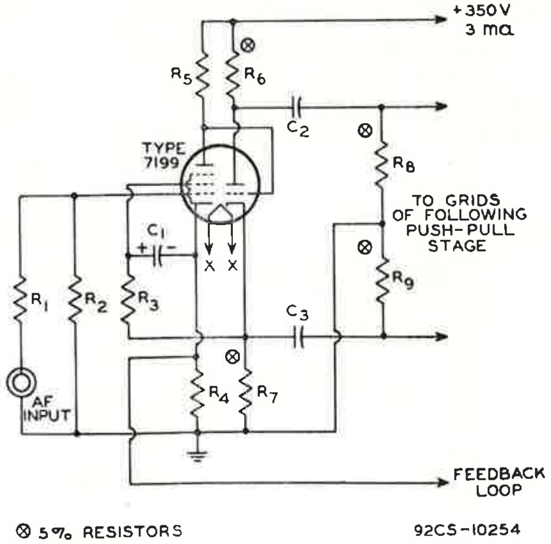


Fig. 3 — Voltage-amplifier/Phase-splitter Circuit using the 7199.

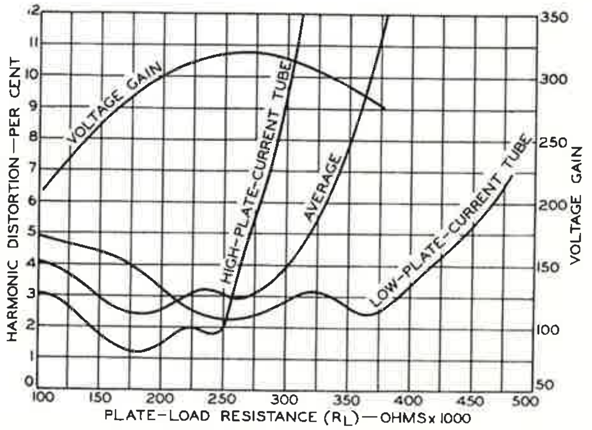


Fig. 4 — Total Harmonic Distortion and Voltage gain of the Pentode unit of a 7199 as a Function of Plate-load Resistance. Distortion Curves are for Typical Valves having High, Average, and Low Plate Currents; Gain Curve is for Typical Valve Having Average Plate Current.

The frequency at which this feedback becomes effective depends on the value of the grid-No. 2 bypass capacitor C_1. If C_1 has a small value, it may be necessary to use relatively heavy filtering in the B supply circuit to prevent motorboating.

The voltage-amplifier/phase-splitter circuits shown in Figs. 1 and 2 produce extremely low harmonic distortion, have frequency-response characteristics extending well beyond the audio range, and permit the use of relatively large amounts of over-all feedback. The phase-splitter stages are easily balanced at low frequencies by adjustment of the plate and cathode resistors, and have input impedances of several megohms, thus making it possible to achieve very high gains in the pentode stages.

Some of the special considerations involved in the use of such circuits are:

1. As the plate-load resistance for the pentode unit is increased, the distortion produced

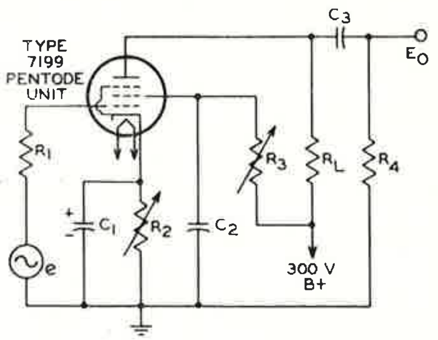


Fig. 5 — Amplifier Circuit used to Obtain data shown in Fig. 4. Cathode Resistor was Adjusted to Provide Grid-No. 1 bias of —1 volt.

by this unit increases more rapidly than its gain;

2. If the plate-supply voltage is low, the use of direct coupling between the pentode and triode units may result in undesirably low plate voltage for the pentode unit;

3. To obtain equal response at the higher audio frequencies in the two output circuits of the phase splitter, it may be necessary to equalize the capacitances to ground of the plate and cathode of the triode unit.

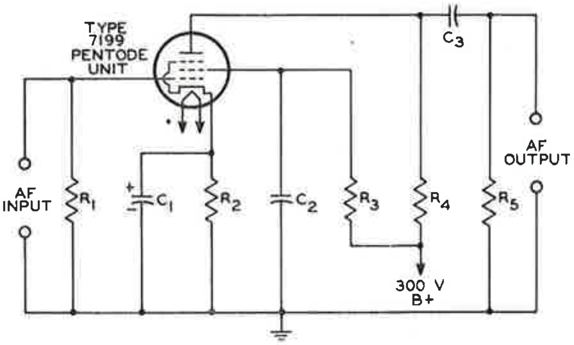


Fig. 6 — General-purpose Voltage-amplifier Circuit using the Pentode unit of a 7199.

Operation of Voltage-Amplifier Pentodes at Low Plate and Grid-No. 2 Voltages

There are two methods by which a pentode may be operated so as to produce low harmonic distortion. One is to operate the pentode over the most nearly linear region of its characteristic. The other is to select an operating point just above the "knee" of the characteristic, so that second-harmonic distortion is partially cancelled by third-harmonic distortion. Although the latter method provides the highest gain, and has recently been used by some circuit designers for that reason, it is not recommended for production equipment because of the initial adjustment required. Normal variations among pentodes of the same type are such that a quiescent point which is just above the "knee" for one valve may be on or under the "knee" for another, and thus result in low gain and very high distortion.

Although operation over the most nearly linear region of the characteristic provides less gain, it provides much more latitude for normal variations in valve characteristics, and, therefore, is the recommended method of operation for pentodes. To achieve maximum latitude in this method of operation, it is necessary to take into consideration the effects on harmonic distortion of normal variations in transconductance, plate resistance, amplification factor, cathode current, and plate-to-grid-No. 2 current ratio.

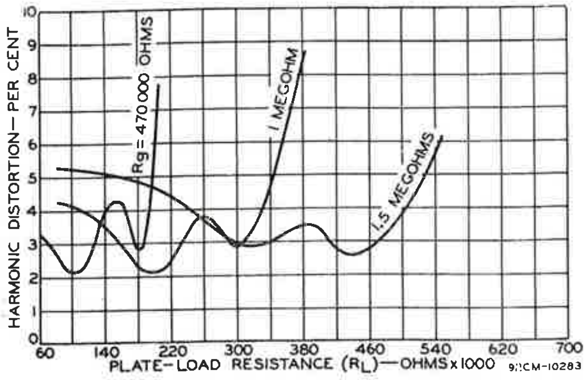


Fig. 7 — Total Harmonic Distortion of a typical 7199 Pentode unit as a Function of Plate-load Resistance and grid-No. 2 Resistance.

Fig. 4 shows the total harmonic distortion and voltage gain of the pentode unit of the 7199 as a function of plate-load resistance. The three distortion curves show the spread of this characteristic for valves having high, low, and average values of plate current. This figure also shows the voltage gain of a valve having average plate current as a function of plate-load resistance.

These curves were obtained with the valves operated in the circuit shown in Fig. 5, using a constant signal-input voltage of 0.1 volt (100 millivolts) rms, and with the cathode resistor adjusted to provide a grid-No. 1 bias of —1 volt. The average maximum output voltage obtained in this circuit was 32 volts rms (representing a gain of 320), or 90 volts peak-to-peak, which is sufficient to drive the largest audio-output valves.

The first minimum point on each distortion curve is that obtained by operation over the most nearly linear region of the valve characteristic. The second minimum point is for operation in the knee region, which is not recommended.

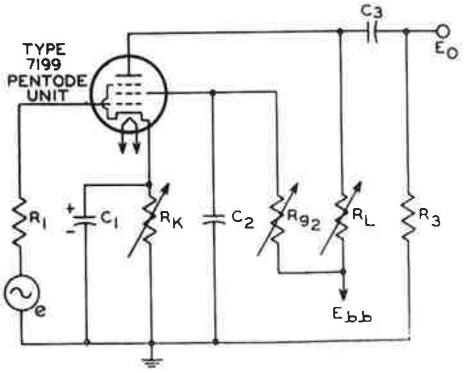


Fig. 8 — Amplifier Circuit used to Obtain data shown in Fig. 7.

It is evident from Fig. 4 that the optimum value of plate-load resistance under the conditions employed is between 180,000 and 240,000 ohms. (The average value of cathode resistance required to provide −1 volt of bias for this range of plate-load resistance values was 750 ohms.) The circuit of a general-purpose amplifier stage using the pentode unit of the 7199 with the recommended component values is shown in Fig. 6. In this circuit, the average grid-No. 2 voltage of the pentode is 35 volts.

The spread of a typical curve of distortion versus plate-load resistance, such as the curve for an average pentode shown in Fig. 4, can be broadened so as to make circuit performance less critical with respect to individual valve characteristics and component values by an increase in the value of the grid-No. 2 resistor. Fig. 7 shows the distortion of a typical 7199 pentode unit as a function of grid-No. 2 resistance and plate-load resistance. These data were obtained in the circuit shown in Fig. 8.

It is evident that as the grid-No. 2 resistance is made larger—i.e., as the grid-No. 2 voltage is reduced—the plate-load resistance for minimum distortion increases and becomes much less critical. This effect can be used to advantage in the design of direct-coupled pentode-triode circuits such as those shown in Figs. 1 and 3. In such circuits, the pentode unit must be operated at low plate voltage to provide proper bias for the triode unit, and, therefore, must also be operated with low grid-No. 2 voltage. The use of high-value plate-load and grid-No. 2 resistors of relatively wide tolerance satisfies these requirements, minimizes the sensitivity of the circuit to variations in valve characteristics and component values, and reduces manufacturing costs.

The curves in Fig. 7 also indicate that in any pentode amplifier application it is possible to achieve minimum distortion for any value of plate-load resistance by adjustment of the grid-No. 2 resistance. This feature makes it possible to optimize gain and distortion for any desired high-frequency "roll-off" characteristic.

(With acknowledgements to RCA)

MILLER EFFECT

Every so often the term "Miller Effect" is brought up in the explanation of circuit operation. It refers to the added input capacitance that is effectively introduced in a valve circuit by the charging of the input grid capacitance through the grid-to-plate capacitance of the valve. "Miller Effect" (sometimes referred to as "Miller capacitance") can affect the response of tuned circuits appreciably as the strength of the input signal varies.

In a pentode the additional input capacitance resulting from the "Miller Effect" is small because of the extremly low value of grid-to-plate capacitance (Cgp). In a triode however, the high value of grid-to-plate capacitance reflects back into the grid circuit, especially when the valve is used as an amplifier stage, greatly increasing the dynamic input capacitance. When the gain of a stage is very high, even a small amount of grid-to-plate capacitance can increase the input capacitance appreciably.

The degree of "Miller Effect" introduced in a circuit is also dependant to a great extent on grid bias, since its effect becomes greater as the stage gain increases. Unless compensated for, the shape of a response curve can change appreciably as the agc voltage in a television receiver is varied. In certain television receivers this is used to advantage by arranging the circuits to place the picture carrier higher up on the response curve when the signal is relatively weak and the circuits are functioning on low bias.

"Miller Effect" (capacitance) can be controlled by employing an unbypassed resistor in the cathode circuitry to provide enough degeneration to cancel out the regenerative voltage developed by the "Miller capacitance." Thus it is very important to remember that an incorrect value of resistance placed in a circuit intended for this purpose will result in either incomplete or over cancellation of the "Miller Effect."

In a mixer stage using a triode, an LC neutralizing circuit is often connected between plate and grid. The value and phase of voltage fed from the plate to the grid by the LC network cancels the regenerative voltage developed by the "Miller Effect." "Miller Effect" plays an important role in circuit operation, and though it is not apparent on the schematic diagram, it must not be forgotten.

THE TUNNEL DIODE

The germanium tunnel diode performs virtually all the functions of a standard low-power transistor, and applications are seen for it in computers and basic circuits. This device, of pinhead size, may lead to radical savings in the cost and complexity of basic electronic circuits, and is presently in the experimental stages in the RCA David Sarnoff Research Center at Princeton, New Jersey. The device was developed for potential applications in memory elements of ultra-high-speed computing systems, and as a new basic circuit device with a broad range of uses in amplifying electrical signals.

The RCA tunnel diode was described by Dr. Henry S. Sommers, Jnr., of the RCA Laboratories technical staff, at the Semiconductor Device Conference held recently at Cornell University. Dr. Sommers described the tunnel diode as an extremely simple and potentially cheap device that will be capable of operating over a wide range of frequencies in virtually any type of circuit that now employs low power valves or transistors. He stated that the experimental unit has been operated in the laboratory at frequencies higher than 1,000 megacycles — one billion cycles per second — with a potential range in the future to beyond 10,000 megacycles. The device employs a principle known as negative resistance, long known in the radio industry but not previously put to widespread practical application. The diode consists of a tiny piece of germanium crystal, only three-thousandths of an inch in diameter.

Dr. Sommers disclosed that the new tunnel diode has been applied experimentally in a new and simple type amplifier circuit developed at the David Sarnoff Research Center by Dr. K. K. N. Chang, of the RCA Laboratories technical staff. According to Dr. Chang, the experimental amplifier has performance characteristics similar to those of the parametric amplifier, a device now used for the amplification of weak signals in microwave and other communications equipment, but at the same time is far simpler in its circuitry than the parametric amplifier.

Recalling that RCA has recently demonstrated an experimental tunnel diode made of gallium arsenide, a newly developed compound material, Dr. Sommers pointed out that the development of a type employing germanium offers several advantages. A major one, he said, is the fact that germanium has long been a standard material for transistors, so that it is readily available and has properties familiar to electronics manufacturers. Discussing the principal advantages of the tunnel diode as a basic circuit device, Dr. Sommers emphasized its simplicity, low cost, and extremely low power requirements.

The tunnel diode is the industry's first gallium-arsenide device to generate high-frequency radio signals. Besides the promises of great simplicity in circuit design, high reliability and ability to operate at very high frequencies over a very wide temperature range, the bi-stable characteristic of the diode makes it particularly suitable for computer applications. The power requirement is of the order of 1,000th of that required for transistors in the same application.

The tunnel diode, a two-terminal device, is in many ways similar to a transistor, but employs a different principle of operation. The transistor, a three-terminal amplifying device, consists of an emitting electrode, a collecting electrode, and a third electrode which controls the signal. The speed at which such a device can operate is affected by the time taken by electrons or carriers to journey from the emitting to the collecting electrodes.

In both valves and transistors, this transit time is long compared with the time which would be taken for a signal to travel an equal distance along a metallic conductor. The reason is that the signal moves along a conductor by a charge-transfer process, rather than by the movement of a discrete group of electrons.

The tunnel diode, on the other hand, uses a principle similar to that applying in the case of the conductor, the charge-transfer process. The signal travels by a type of "bucket-brigade" system, in which each electron passes on a charge to the next and so on down the line. The electrons, like members of the team, remain substantially in the same place. The direction of travel is influenced of course by applied electric and magnetic fields.

Amplification is possible in the tunnel diode because it can, under certain conditions, exhibit negative resistance. In other words, under the correct conditions an increase in voltage results in a decrease in current.

The interesting name of the tunnel diode (all the new semiconductor devices seem to have intriguing names) is derived from the "tunnel effect", discovered by a Japanese scientist, Dr. Esaki, about a year ago. The term is used to describe the manner in which electric charges move through the diode under certain conditions, and in which a particle moves instantaneously from one side of a barrier to the other, although not possessing the energy to overcome the barrier. It is just as if a boy, unable to climb a wall, burrowed or tunnelled underneath it to get to the other side.

The barrier in the tunnel diode is the familiar space-charge depletion region. In an ordinary p-n junction diode, a charge is transmitted through the junction when the electrons comprising its field diffuse through the solid barrier of the semiconductor junction. The charge moves at a faster rate than in a valve, where actual migration of electrons takes place.

Heavy doping of the materials used in the tunnel diode thins the junction barrier (space-charge depletion region) to about one millionth of an inch. This extremely small dimension allows an under-powered particle to tunnel through the barrier and appear simultaneously on both sides of it. This quantum-mechanical tunnelling is equivalent to the charge passing through the tunnel diode junction at the speed of light, and effectively disposes of the problem of transit time.

Furthermore, as the density of the charge carriers in the junction is increased by doping, and the reverse breakdown voltage reaches zero, particles which tunnel through the barrier give rise to an additional current at a small forward bias. This current is called the Esaki current. Further doping will maintain the reverse breakdown condition even when a small forward bias is present, and in this way maintains the negative resistance characteristic of the diode.

It is hoped to present more data on the tunnel diode in the future.

STORED ELECTROLYTICS

When electrolytic capacitors are stored or left inactive for a period of time, they may become leaky and low in capacitance. Such capacitors will not function properly, particularly when used in low-voltage circuits. Therefore, before installing electrolytic capacitors in low-voltage circuits — such as those used in the ratio detector and agc filter circuits — it is wise to check them for leakage. This may be done by simply measuring the resistance across the capacitor with a meter and comparing the findings with the minimum resistance leakage permissible.

As a general rule the maximum current leakage permissible in low-voltage capacitors is one-quarter ($\frac{1}{4}$) milliampere per mfd at its maximum rated working voltage. This means that if a 2mfd capacitor is rated at 50 volts dc, the permissible current leakage through this capacitor when subjected to a potential of 50 volts is .5 milliamps (.25 x 2 = .5 milliamps at 50 volts). Knowing this a technician can determine the minimum resistance leakage permissible by using Ohms Law. For example, in the case of the 2mfd capacitor mentioned above 0.5 milliamps of leakage current is permissible at 50 volts. Using Ohms Law:

$$R = \frac{E}{I} = \frac{50}{.0005} = 100{,}000 \text{ ohms.}$$

Thus, 100,000 ohms is the minimum leakage resistance permissible.

Note: When measuring the resistance across the capacitor, use a meter of 20,000 ohms per volt sensitivity or better, and always attach the common (—) terminal of the meter to the negative lead of the capacitor.

In border-line cases use a biased supply or other source of dc and charge the capacitor at about one-half its rated voltage for a few minutes. Discharge the capacitor and check it again. If the leakage can be reduced below the limit, the capacitor can still be considered serviceable.

DIODE AVC IN TRANSISTOR PORTABLES

Notes on the Use of Germanium Diodes in AVC Circuits of Transistor Portable Receivers

By H. R. Wilshire, A.S.T.C., A.M.I.R.E., A.M.I.E. (Aust.)
(A.W.V. Application Laboratory)

Germanium diodes connected in a circuit which allows them to conduct when the signal increases beyond a particular level may be used to augment the normal control of gain and provide a very good avc characteristic. The control of gain produced by varying the bias current of rf or if transistors is achieved by varying both the current gain and the input and output impedances of the transistor. The mismatching brought about by the latter effect is probably the more important.

The germanium diodes help the control by placing a shunting resistance across one or more tuned circuits. The value of the shunt varies with the magnitude and the sign of the potential across the diode. For negative values of 2 volts or more the effective resistance may be greater than 0.5 megohm. As the potential decreases to zero the resistance may drop to as low as 10,000 ohms. An increase in the opposite direction i.e. the one of easy current flow, causes a very rapid drop in resistance. Fig. 1 illustrates the effect for a typical GEX34 diode.

It is necessary to differentiate between the dc resistance, which is the value obtained by measuring the current through the diode for a particular value of applied direct voltage, and the ac resistance or impedance, which is obtained for any particular point from the slope of the curve relating the direct voltage and current. The dc values will determine the distribution of direct current in the network while the ac impedance is the effective shunt on the if transformer. Each value of ac impedance plotted in Fig. 1 is the slope of the line which is tangent to the curve at the point considered, and is therefore accurate for a very small swing of signal voltage.

For large swings the effective shunting impedance will be lower.

In the case of a receiver using a converter and if amplifiers, only one diode is normally used to provide a shunt across the collector winding of the first if amplifier. When an rf stage precedes the converter a second diode may be connected across the rf collector circuit. It is essential that potentials be arranged to provide for diode shunting to take place before the signal level has reached a point where the transistor clips the peaks of the modulated signal. The clipping may be due to the collector current being driven either to saturation or to cutoff. The combined effect of

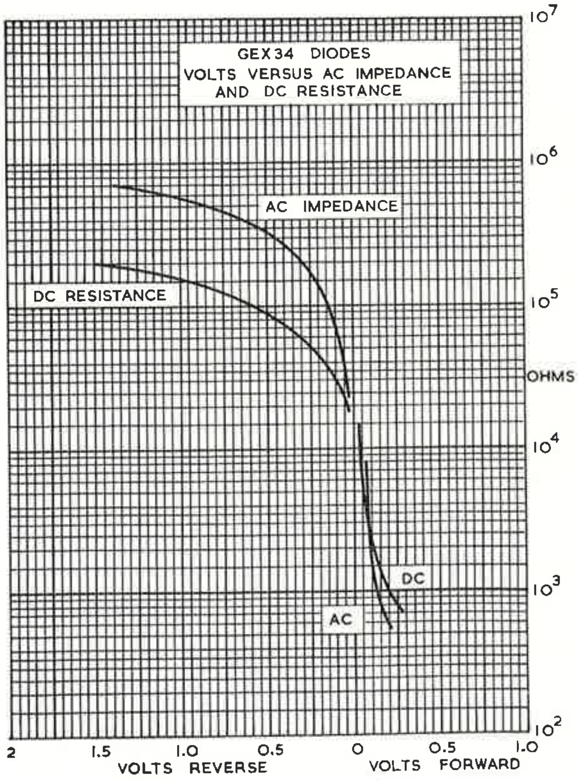


Fig. 1

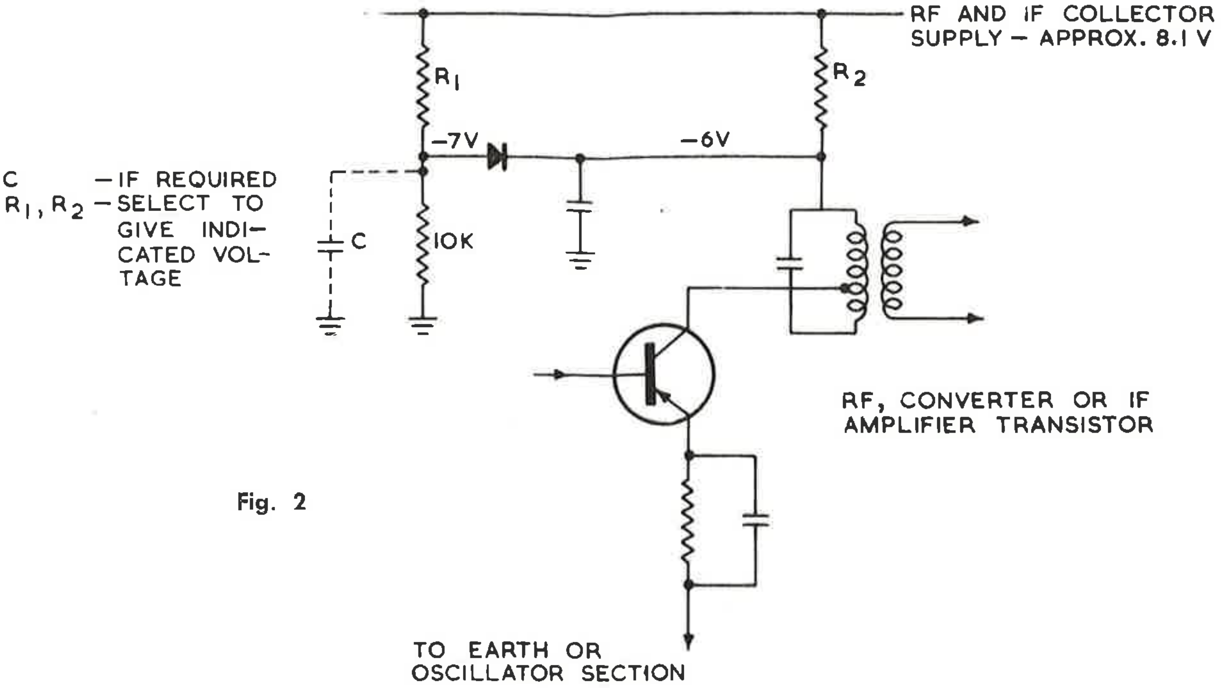


Fig. 2

both avc bias and diode shunting should be such as to restrict the peak signal swing to about 60-80% of the maximum collector excursion. In addition it is necessary to limit the variation of potential across the diode due to the avc bias changes. The maximum input signal which the receiver must handle without excessive distortion should not cause the dc voltage across the diode to reverse in sign. If this condition is allowed to develop the diode assumes a very low resistance in its forward conducting mode and will reduce the Q of the tuned circuit to a very low value, with consequent broadening of the selectivity curve.

When a cathode ray oscilloscope of high input impedance is connected across the tuned circuit which forms the load of the controlled transistor, clipping of the modulation peaks on one side of the modulated signal will be observed. This effect may be very severe if the diode is allowed to conduct in its forward direction. When conducting in this manner the diode resistance may drop to as low as a few hundred ohms and the clipping will be sufficient to flatten one side of the modulated wave. The clipping introduced this way does not necessarily result in high distortion since the following tuned circuits restore symmetry to the modulated signal. Generally however the diode clipping effect is superimposed on the clipping which is caused by the transistor and which may affect either side of the modulated signal. In this case high distortion will result.

A method of obtaining a suitable bias for the diode is shown in Fig. 2. In this circuit a divider is connected across the battery to provide a 7-volt source. The filter resistor in the collector of the controlled transistor is adjusted to provide approximately 6 volts at the collector. The shunt diode is then connected in its high resistance direction between the 7-volt point and the collector load, either at the collector or the top of the tuned circuit. The diode then exhibits a shunt of about 0.2 megohm with low signal input voltages, i.e., with a reverse bias of — 1 volt. As the input increases the bias across the diode falls towards zero with a consequent reduction in its resistance.

The use of such a diode will introduce at low signal inputs a loss in gain which will amount to approximately 2 db and 1 db for the if and rf stages respectively. Mistuning effects due to diode action will be negligible if the total tuning capacitances are maintained at the moderately high values which are normal in transistor circuit design.

Filter resistors placed in the collector circuits of controlled transistors will of course tend to reduce the effectiveness of the damping action. Their use is necessary however and values should be selected keeping in mind the points discussed.

A disadvantage of the diode control method is the worsening of selectivity which occurs for high signal levels. One possible method of reducing this effect is to use high-Q, high-impedance tuned circuits in all stages except that across which is connected the damping diode. This circuit should be of the low impedance type. The proper compromise in a number of factors must be reached to produce optimum gain, selectivity and avc characteristics.

TRANSFLUXORS

Ferrite materials are being widely used today in the electronic industry, and new uses are being constantly found for them. Ferrites are nonmetallic materials which have high resistivity and consequently low eddy-current losses. This characteristic enables them to be used at much higher frequencies than was previously possible with metallic magnetic materials of similar permeability.

The transfluxor utilizes a circular ferrite core having two or more apertures or holes. Data on interesting applications of ferrites has been released by RCA. These devices have an essentially rectangular hysteresis loop. They can control the transmission of ac power according to a level set by a single pulse and furnish an output determined by the stored pulse for an indefinite length of time. In addition, the transfluxor once "set" does not require the presence of an input command (dc or low-frequency as control current) as does a magnetic amplifier.

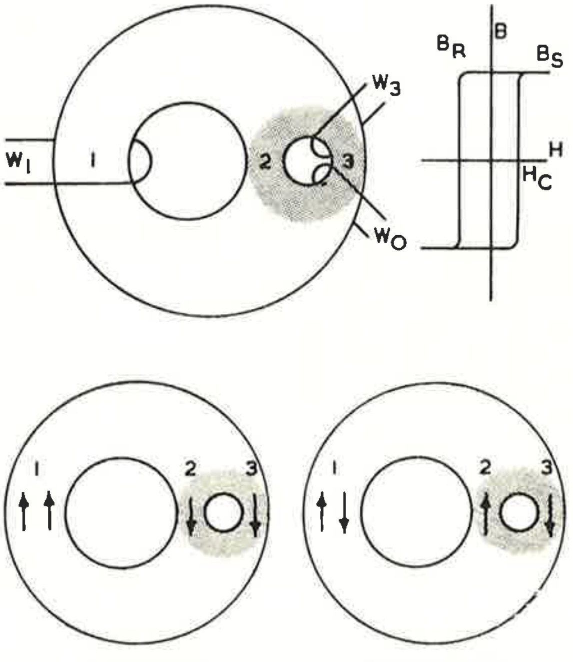
The basic principle of operation of the transfluxor is that the use of two or more apertures in a core creates 3 or more distinct flux paths or legs. The controlled transfer of flux between these legs provides the unique output characteristic of this device.

Fig. 1 illustrates a two-aperture ferrite core having an essentially rectangular hysteresis loop in which the remanent induction (Br) is substantially equal to the saturated induction (Bs). The diameters of the apertures are unequal. The cross-section areas of legs 2 and 3 are equal; the cross-section area of leg 1 is equal to, or greater than, the sum of the areas of leg 2 and leg 3.

Assume that a pulse current is applied to winding W_1. This pulse is in a direction and of sufficient magnitude to produce a clockwise flux flow which saturates legs 2 and 3. These legs will remain saturated after the termination of the pulse since the remanent induction and the saturated induction are almost equal.

If an alternating current is then applied to winding W_3, one phase of the ac will produce a magnetomotive force having a clockwise direction. This force will tend to increase the flux in leg 3 and decrease that in leg 2. However, since leg 3 is already saturated, no flux flow can take place. Similarly, during the opposite phase of the ac, a magnetomotive force is produced in a counterclockwise direction. This force tends to produce an increase in flux in leg 2. Since leg 2 is also saturated, no flux flow can occur. Under these conditions, the transfluxor is in a "blocked state" and no output can be induced in winding W_o.

With the transfluxor in its blocked state, consider the effect of a current pulse which produces a magnetomotive force through winding W_1 in a



BLOCKED

UNBLOCKED

Fig. 1 — Principles of Transfluxor Operation.

direction opposite to that of the blocking pulse. A magnetizing force (H) which is proportional to the current pulse is produced around the large aperture. This magnetizing force is greatest at the periphery of the aperture and varies inversely as the radius. It is possible to apply a current pulse large enough to produce a magnetizing force which exceeds the coercive force (Hc) in leg 2 but not large enough to exceed the coercive force in the more distant leg 3. This current pulse, called the "setting pulse", reverses the direction of magnetization in leg 2 but will not affect leg 3. Under these conditions, with leg 2 saturated in one direction and leg 3 saturated in the opposite direction, the transfluxor is in the unblocked or "maximum-set" state.

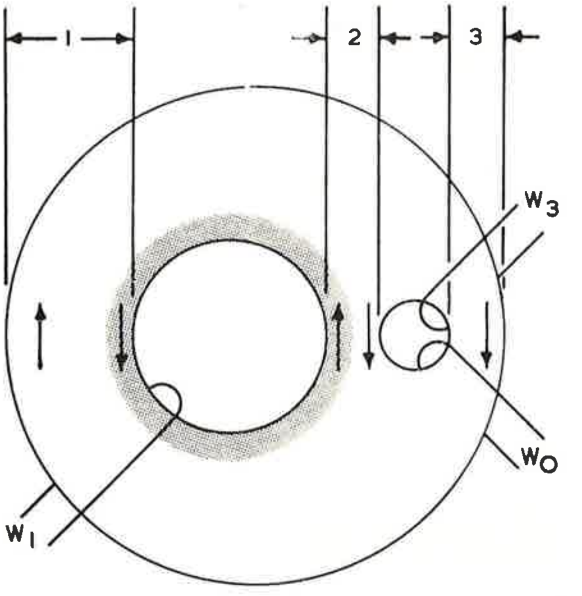


Fig. 2 State of Transfluxor for Continuous-Range Operation.

If the transfluxor is in its unblocked state, an alternating current applied to winding W_3 will now produce a corresponding alternating flux flow around the small aperture. The first counterclockwise phase of the ac will reverse the flux flow, the next clockwise phase will reverse it again. This alternating flux flow will induce a voltage in the output winding W_0 as long as the ac is present in winding W_3.

The transfluxor can also be set to any point between the blocked state and the unblocked state by means of a single-setting current pulse of the proper magnitude. Fig. 2 illustrates the condition of the transfluxor when it is not in its maximum-set state. The shaded portion of Fig. 2 represents the effect of the setting pulse on a transfluxor which was originally in its blocked state. That phase of the alternating current in winding W_3 which tends to produce a counterclockwise flow of flux can change only that part of the flux in leg 2 which is in a clockwise direction, i.e.: the flux produced by the setting pulse. Flux flows counterclockwise through leg 3 only until leg 2 becomes saturated in the counterclockwise direction. The clockwise flux field originally set into leg 2 may be thought of, as being transferred to leg 3. The next half-cycle of the alternating current which tends to produce a clockwise flow of flux in leg 3 reverses the process and retransfers the flux to leg 2. A succession of half cycles of alternating polarity on winding W_3, will cause an interchange of flux between legs 2 and 3 equal to that initially set into leg 2.

When leg 3 is saturated in a clockwise direction, there is a possibility that a sufficiently large ac, which will produce counterclockwise flux flow, could change the flux in leg 3 by transferring flux to leg 1. There is, therefore, a limit to the permissible amplitude of the energizing ac because of the possibility of "spurious unblocking". This amplitude is increased by the use of unequal aperture diameters which make the flux path through legs 1 and 3 much longer than the path through legs 2 and 3. There is no danger of spurious unblocking when the ac tends to produce a clockwise flux flow since leg 3 is already saturated in the clockwise direction. Asymmetric alternating current or a train of relatively large "driving" pulses (clockwise) and relatively small "priming" pulses (counterclockwise) may therefore be used to advantage. Large driving pulses, which cannot unblock the transfluxor, can provide substantial power to deliver high output currents. The priming pulses must be large enough to provide the required magnetizing force around the small aperture, but not large enough to provide it around both apertures.

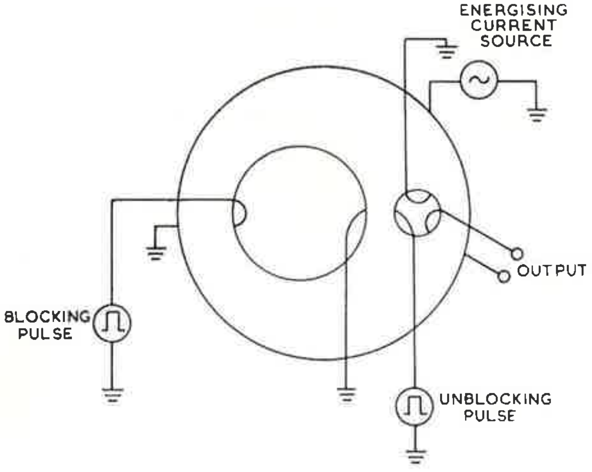


Fig. 3 — Test Setup for Determining Performance Data of Transfluxor.

Fig. 3 illustrates a simple test setup for measuring some of the more important characteristics of the RCA Transfluxors.

In this test the non-sinusoidal output voltages produced by a sinusoidal energizing current are observed on an oscilloscope, first when the transfluxor is in the blocked state and second, when the transfluxor is in the unblocked state. The amplitude of the energizing current, blocking current, and unblocking current are optimum values for an average unit. The ratio of the peak output voltage in the two states is referred to as the on-off discrimination ratio of sinusoidal energization.

The values of blocking and unblocking current obtained from this test may serve as an indication of the coercivity of the core material. The output voltage in the unblocked state is a measure of the maximum transferable flux in the output magnetic circuit. The discrimination ratio, which is essentially a figure of merit of the transfluxor, is also an indication of the rectangularity of the core material.

To give some idea of the capabilities of these devices it may be interesting to look at a couple of developmental designs and see what they can do. The first type is 0.14″ thick and 0.346″ in diameter; it is of the two-aperture type. The blocking current is 4 ampere-turns, the unblocking current 1.1 ampere-turns, and the ac driving current 1.2 ampere-turns peak-to-peak. The blocked output voltage is 3.5 millivolts per turn peak-to-peak, the unblocked output voltage 180 millivolts per turn peak-to-peak. This provides a discrimination ratio of 51.

A second transfluxor is of the five-aperture type; it is only 0.048″ thick and 0.1685″ in diameter. It has a blocking current value of 1.5 ampere-turns, and unblocking current value of 0.2 ampere-turns, and an ac driving current of 0.5 ampere-turns peak-to-peak. The blocked output voltage is 1.5 millivolts per turn peak-to-peak, the unblocked output voltage 45 millivolts per turn peak-to-peak. The discrimination ratio is 30.

(With acknowledgements to RCA)

THE JUNCTION TRANSISTOR

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