The Journal of

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" *To promote the advancement of radio, electronics and kindred subjects by the exchange of information in these branches of engineering.*"

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A ROYAL CHARTER OF INCORPORATION

IN Great Britain and throughout the Commonwealth the ambition of most voluntary associations is to deserve the honour of being granted a Royal Charter of Incorporation.

Although Royal Charters had been granted earlier, the Grant to the Royal Society by King Charles II in 1662 was—and remains—the most outstanding example of royal encouragement of an association formed to advance science. During the subsequent 300 years, industrial history has been well reflected by the Incorporation under Royal Charter of many Institutions whose principal objects include the advancement and application of science to particular branches of engineering.

The use of the word "engineer" was, in fact, first acknowledged in the Royal Charter of Incorporation granted to the Institution of Civil Engineers in 1828. This honour was secured only 10 years after that Institution had been founded and which, at that time, covered all branches of engineering. During the industrial revolution a number of other Institutions were founded, but ranking as a senior examining body is the Institution of Mechanical Engineers. Founded in 1847 in Birmingham, the Institution of Mechanical Engineers was granted a Royal Charter in 1930. Meanwhile, the Institution of Electrical Engineers had been formed in 1871 and was Incorporated by Royal Charter in 1921. Among other examples of societies who reflect major industrial activity, and who have been honoured with a Royal Charter, are the Royal Institute of Chemistry (founded in 1877 and Incorporated under Royal Charter in 1885) and the Institution of Structural Engineers (1908, 1934). More recently the Institution of Chemical Engineers (founded in 1922) has also been granted a Royal Charter of Incorporation.

Thus, in almost every scientific and engineering field of human endeavour, the efforts of British voluntary societies are devoted towards recognition of their work by the grant of a Royal Charter.

It may also be noted that not all Institutions are successful in obtaining a Charter on their first Petition. The honour requires such distinguishing factors as (a) the Institution being founded upon a distinct body of knowledge requiring a measure of skill in its application, and (b) that the members should have recognized responsibility for guarding and developing their particular branch of knowledge and for the educational process associated with it. As the *Times Review of Industry* once stated, there are also other important features which are looked for in a body requiring recognition by the State.*

In this respect where stands our own Institution? Has the Brit.I.R.E. fulfilled its declared objects sufficiently to justify lodging a Petition for a Royal Charter?

In its Annual Reports and elsewhere the Council of the Institution has frequently stated that its purpose is to fulfil the requirements of earning a Royal Charter of Incorporation. Next month, the corporate members of the Institution will be asked to consider a Special Resolution and their answer will enable the Officers of the Institution, acting as Petitioners, to further the aim which it is believed is shared by all radio and electronics engineers.

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* *J. Brit.I.R.E.*, **15**, page 65, February 1955.

INSTITUTION NOTICES

Countess Mountbatten of Burma

On behalf of all members the Council has conveyed a message of sympathy to the Institution's Vice-Patron, Admiral of the Fleet the Earl Mountbatten of Burma, K.G., on his bereavement.

The Countess Mountbatten of Burma, C.I., G.B.E., D.C.V.O., G.C.St.J., was a world figure and many members throughout the world had met her; her point of contact with so many members was often in connection with charitable work. This was more particularly revealed when, on the occasions of her attendance at Institution functions, she showed great interest in the work of the Benevolent Fund and the individual work of members interested in the education and other help given to orphan children.

Lady Mountbatten will always be remembered for her humanitarian work throughout the Commonwealth and the world.

"Collected Clerk Maxwell Memorial Lectures"

The Council has authorized the publication of a book containing the Clerk Maxwell Memorial Lectures. In addition to the four lectures given respectively by Professor G. W. O. Howe, Sir John Cockcroft, F.R.S., Sir Lawrence Bragg, F.R.S. and Dr. V. K. Zworykin, the book will also include the Presidential Address of Mr. L. H. Bedford. The establishment of the Memorial Lectures arose out of this Address which dealt in some detail with Clerk Maxwell's work.

Advance orders can now be taken for the "Collected Lectures" which will be published shortly, price 21s., post free.

Back Copies of the Journal

The Institution has received requests for the following issues of the *Journal* which are now out of print:—

January 1953,
March, June and July 1955,
July, August and October 1956.

Members who have copies of these issues, in good condition, for disposal, are invited to send them to the Brit.I.R.E. Publications Department, 9, Bedford Square, W.C.1.; a payment of 5s. per copy will be made.

New Year Honours

The Council of the Institution has congratulated Wing Commander H. E. Bennett, R.A.F., on his appointment as a Member of the Military Division of the Most Excellent Order of the British Empire which was announced in the New Year Honours List. Wing Commander Bennett, who was elected an Associate Member in 1955, is senior electronics plans officer at the Headquarters of Fighter Command.

Students' Essay Competition

The subject for this year's Students' Essay Competition is "The Future of Electronics in Industry." Registered Students and Graduates under the age of 23 years are reminded that their entries for this competition should be received by the Institution not later than the 31st March. The value of the prize for the most outstanding essay is £20, and the second and third prizes are £10 and £5 respectively; essays should be between 3,000 and 5,000 words in length.

The 1960 List of Members

The 8th issue of the List of Members of the Institution contains the names of all Corporate Members, Companions, Associates and Graduates, and will shortly be sent free of charge to these members. Registered students, whose names are *not* included in the List, may obtain copies from the Institution, price 5s. each. To facilitate despatch, Students are requested to complete the special order form included in this issue of the *Journal*.

"Flight Test Instrumentation" Symposium

The College of Aeronautics, Cranfield, is holding a three-day Symposium on Flight Test Instrumentation at the College on Thursday, 7th April—Saturday, 9th April. It is open to those connected with or interested in instrumentation for the flight testing of aircraft, and there will be a registration fee of 10s. 0d. A limited amount of residential accommodation is available in the College at an inclusive charge of £4 4s. 0d. per person. Further information may be obtained from Mr. M. A. Perry, Department of Flight, College of Aeronautics, Cranfield, Bletchley, Bucks.

High Transconductance Wide-band Cathode-Ray Gun†

by

EROS ATTI, PH.D.‡

Summary: The "screen-grid amplifier gun" is a combination of a conventional tetrode-type gun with an amplifier constituted in large measure by the gun's existing electrodes. In its simplest version the gun has, in fact, only one electrode more than conventional guns. The new gun has three grids participating in the beam modulation process: an auxiliary input grid and the two grids of the immersion lens. These latter grids are coupled together and operated 180° out of phase with respect to the input grid. Transconductance and resolution have been divorced from each other to a large extent in the screen grid amplifier gun. The low shunt capacitance makes the gun particularly suitable for wideband operation. Favourable possibilities are offered by this development for building guns with smaller "gamma" than hitherto possible. Analytical expressions correlating the gun's beam current to various types of gun drive, namely, combined screen and control grid drive, control grid drive and cathode drive are derived for cathode-ray guns of conventional design. An analytical expression for the gun's modulation constant is also given. Television guns possessing excellent resolution characteristics and transconductance in excess of 500 μmhos may be obtained rather simply. High transconductance guns and structures are shown.

1. Introduction

The control grid of a typical television gun at present requires about 50-70 volts of drive to vary the beam current from cutoff to 1500 microamperes. The gun's average transconductance in this current range lies, therefore, somewhere around 20-30 micromhos, a value two orders below that of electron devices which do not have resolution demands, ordinary radio tubes, for instance.

Resolution is a primary requirement of most cathode-ray guns. In existing electron optical systems it limits the cathode area utilized by the guns of television and other display tubes to less than one square millimetre, or roughly, to about one per cent. of the cathode area possibly available on the basis of heating power supplied to the cathode (≅ 3·8W). This extremely poor cathode utilization factor, both from the standpoint of power and area, accounts in a large degree for the unsatisfactory transconductance and relatively large shunt capacitance of present cathode-ray guns.

The many attempts made in the past to achieve high transconductance guns by other types of electron optical systems, or by other more or less ingenious schemes have been only partially successful, mainly on account of the limited resolution capabilities of the guns.

2. Screen-grid Amplifier Gun

The conflict between transconductance and resolution has been solved in the screen grid amplifier gun by separating the two main functions performed by the present immersion lens, namely the formation of the beam and the control of the beam's intensity. In the new gun beam formation remains the main function of the immersion lens while beam control is an additional function of the lens.

The beam forming and intensity control portion of the gun may be considered to be constituted of two distinct sections: an immersion lens of conventional design K, G_1, G_2 and an amplifier K, G_d, G_2 as shown in Fig. 1. The first accelerator electrode or screen grid, G_2, of the cathode-ray beam section is also at the same time the anode of the amplifier section.

A signal, therefore, applied to the input grid G_d of the gun appears amplified at the screen grid of the immersion lens. Since the control

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U.D.C. No. 621.385.832

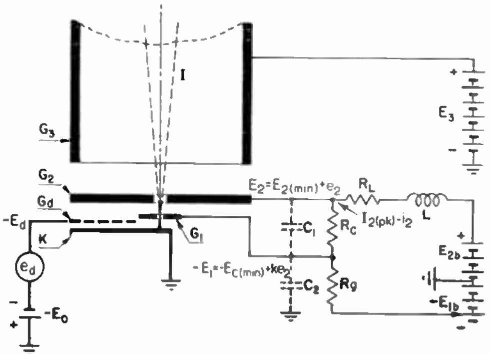

Fig. 1. High transconductance gun operation principle.

grid G_1 is coupled to the screen grid by means of a voltage dividing network R_c and R_g, any voltage change e_2 in the screen grid causes a voltage change $e_1 = k\,e_2$ in the control grid, where k is the coefficient of voltage coupling between the two grids expressed by: †

$$k = \frac{e_1}{e_2} = \frac{R_g}{R_c + R_g} \qquad \ldots\ldots\ldots(1)$$

As variations in potential of either one of these two electrodes cause the beam current to vary, the beam is controlled by a combined screen grid and control grid action. The two aperture grids G_2, G_1, converge the beam current into a small crossover which is then imaged upon the viewing screen, or target, by the lens system of the gun, only partially shown in Fig. 1.

The design of the immersion lens section K, G_1, G_2 is primarily dictated by resolution and beam current requirements of the gun.

The driver or input grid, G_d, of the amplifier is completely out of the beam path to avoid interfering with the electron optics of the gun. In combination with K and G_2 it basically constitutes the gun's amplifier section, a triode in this case. The screen grid current I_2, controlled by the driver grid, is emitted by a large cathode area and is relatively large compared to the beam current I.

The amplifier section is designed primarily on the basis of transconductance and gamma characteristics desired for the gun.

Cathode heating power remains the same as that of conventional guns.

Going into somewhat more detail let the screen grid, G_2, be biased at $E_{2(min)}$, the driver grid, G_d, at $-E_0$, and the control grid at $-E_{c(min)}$ potentials so that in absence of input signal e_d, the beam current I is at its cutoff point (Fig. 2). A negative input signal $e_d = e'_d$ applied to G_d or a positive one applied to K, causes a variation

$$i'_2 = I_{2(pk)} - I'_2 \qquad \ldots\ldots\ldots(2)$$

in the screen grid current I_2.

Consequently, due to the impedance Z of the screen grid circuit and to the coupling between grids, the screen and control grid potentials are increased respectively by $e'_2 = Z\,i'_2$ and $e'_1 = ke'_2$ volts, and the beam current I increases from zero to I'.

Arbitrary co-ordinates have been chosen for the plot of Fig. 2.

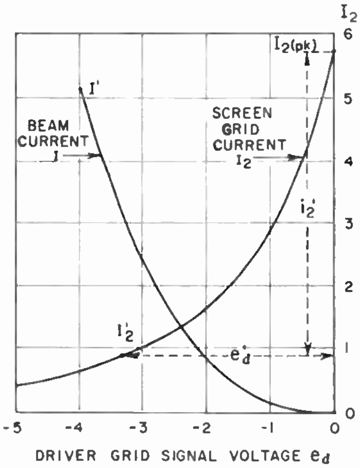

Fig. 2. Beam current and screen grid current versus input voltage e_d.

The screen grid load impedance Z is constituted by the load resistor R_L, the high frequency compensating inductance L and the total shunt capacitance C_t associated with the G_2, G_1 electrodes and respective circuits. The effect of the resistors R_c and R_g upon Z is neglected because R_c and R_g are assumed to be considerably larger than R_L.

The screen grid current I_2 and potential E_2, are plotted versus input voltage e_d in Fig. 3, in the particular case in which the amplifier section is operating along a linear portion of its transfer characteristic $I_2 = f(e_d)$. A somewhat different

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† A List of Symbols used in this paper is given in Appendix 1.

presentation than that of Fig. 2 has been used here. The positions of the positive and negative abcissae semiaxes have been reversed. In the same diagram the beam current I and the control grid potential $-E_1$ are also plotted against e_d, for an arbitrary value k of coupling between the screen and control grids G_2, G_1. The various quantities I_2, I, E_2, $-E_1$, are plotted against e_d, all co-ordinates being arbitrary.

The input voltage e_d required to produce I by the driver grid of a given gun, with an arbitrary coupling coefficient k between the G_2 and G_1 grids, can be established if the relationship

$$I = f(e_2, k) \qquad \ldots\ldots\ldots(3)$$

is known.

The voltage e_d, then, is simply e_2/G where G is the gain of the amplifier stage.

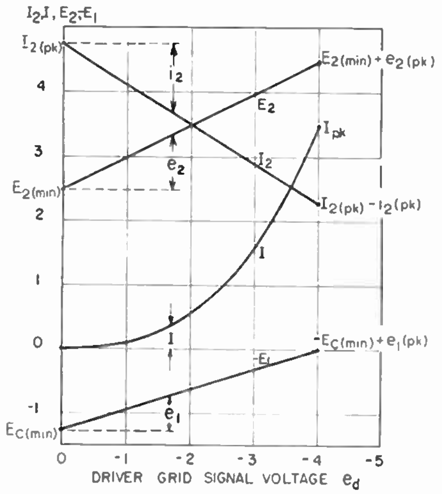

Fig. 3. Beam and screen grid currents I, I_2, screen grid and control grid voltages E_2, $-E_1$, versus input voltage e_d.

The total shunt capacitance C_t of the amplifier-immersion lens system together with the transconductance of the amplifier section determines the system's gain bandwidth product and thus, indirectly, the transconductance g_m of the gun.

3. Cathode-ray Beam Section

The beam modulation considerations which follow apply to the electron optical section of the screen-grid amplifier gun. Consequently, they are also valid for screen-grid guns of conventional design without the amplifier section.

3.1. *Beam Modulation by Combined Screen Grid and Control Grid Drive*

Let it be assumed that

(a) the coupling between screen and control grid is k

(b) the screen grid and control grid are biased respectively at $E_{2\,(min)}$ and $-E_{c\,(min)}$, so that the beam is at the cut-off point.

A screen-grid potential change from

$$E_2 = E_{2\,(min)} \qquad \ldots\ldots\ldots(4)$$

to

$$E_2 = E_{2\,(min)} + e_2 \qquad \ldots\ldots\ldots(5)$$

causes the control grid cut-off potential $-E_c$ to slide from

$$-E_c = -E_{c\,(min)} \qquad \ldots\ldots\ldots(6)$$

to

$$-E'_c = -(E_{c\,(min)} + \frac{1}{\mu}\, e_2) \qquad \ldots\ldots\ldots(7)$$

At the same time the control grid potential $-E_1$ slides from

$$-E_1 = -E_{c\,(min)} \qquad \ldots\ldots\ldots(8)$$

to

$$-E'_1 = -E_{c(min)} + k\, e_2 \qquad \ldots\ldots\ldots(9)$$

The resulting control grid potential above cut-off or drive voltage e_g is thus

$$e_g = E'_c - E'_1 = (k + \frac{1}{\mu})\, e_2 \qquad \ldots\ldots\ldots(10)$$

To determine the beam current I leaving the cathode under this condition, use will be made of the following approximate relation:

$$I = n\, e_g^{7/2} \,.\, E_c^{-2} \qquad \ldots\ldots\ldots(11)$$

provided by H. Moss[1], which applies to the case of a gun driven by its control grid alone, while the screen grid and the cathode are at fixed potentials. n is a constant dependent on gun geometry and E_c is the beam cut-off potential.

Introducing in (11) the corresponding expressions of E_c and e_g, as given by (7) and (10), the following explicit form of eqn. (3) is obtained:

$$I = n\,.\,(k + \frac{1}{\mu})^{7/2} \,.\, e_2^{7/2}\, (E_{c\,(min)} + \frac{1}{\mu}\, e_2)^{-2} \qquad \ldots(12)$$

Since in normal operation the control grid is not intended to be driven above cathode potential, the screen grid voltage swing e_2 cannot exceed the peak value $e_{2(pk)}$ which satisfies the relation:

$$-E_{1\,(pk)} = -E_{c\,(min)} + k\,e_{2(pk)} = 0 \quad \ldots(13)$$

or

$$e_{2\,(pk)} = \frac{E_{c\,(min)}}{k} \quad \ldots\ldots\ldots(14)$$

In such a case the peak beam current I_{pk} obtained at zero control grid potential is:

$$I_{pk} = n\,(k + \frac{1}{\mu})^{7/2} \,.\, e_{2(pk)}{}^{7/2}\,(E_{c(min)} + \frac{1}{\mu}\,e_{2(min)})^{-2} \quad \ldots\ldots\ldots(15)$$

which on account of (14) by elimination of $E_{c(min)}$ becomes

$$I_{pk} = n\,(k + \frac{1}{\mu})^{3/2} \,.\, e_{2\,(pk)}{}^{3/2} \quad \ldots\ldots\ldots(16)$$

or, by elimination of $e_{2\,(pk)}$ becomes:

$$I_{pk} = n\,.\,(1 + \frac{1}{k\mu})^{3/2} \,.\, E_{c\,(min)}{}^{3/2} \quad \ldots\ldots\ldots(17)$$

From eqn. (16), solving for $e_{2\,(pk)}$

$$e_{2\,(pk)} = \frac{1}{k + \frac{1}{\mu}}\left[\frac{I_{pk}}{n}\right]^{2/3} \quad \ldots\ldots\ldots(18)$$

The bias $E_{c\,(min)}$ according to (14), or to (17) is simply

$$E_{c\,(min)} = k\,e_{2\,(pk)} = \frac{1}{1 + \frac{1}{k\mu}}\left[\frac{I_{pk}}{n}\right]^{2/3} \quad \ldots\ldots(19)$$

By resolving with respect to $E_{2\,(min)}$ the following relation, which gives the cut-off potential $E_{c\,(min)}$ as a function of the potentials $E_{2\,(min)}$ applied to the screen grid and E_3 to the anode of the gun:

$$-E_c = -E_{c\,(min)} = -\left[\frac{E_{2\,(min)}}{\mu} + p\,E_3\right] \quad (20)$$

we obtain:

$$E_{2\,(min)} = \mu\,(E_{c\,(min)} - p\,E_3)$$

$$= \mu \left[\frac{1}{1 + \frac{1}{k\mu}}\left[\frac{I_{pk}}{n}\right]^{2/3} - p\,E_3\right] \quad \ldots\ldots\ldots(21)$$

which, for $p = 0$, reduces to:

$$E_{2\,(min)} = \mu\,E_{c\,(min)} = k\mu\,e_{2\,(pk)} = \frac{\mu}{1 + \frac{1}{k\mu}}\left[\frac{I_{pk}}{n}\right]^{2/3} \quad \ldots\ldots\ldots(22)$$

Relations (19), (21) and (18) allow calculation, for any coupling k, of the biasing potentials $E_{c\,(min)}$, $E_{2\,(min)}$ and the peak screen grid voltage swing $e_{2\,(pk)}$ required by the immersion lens of the gun to produce the peak beam current I_{pk}.

3.2. *Modulation Constant in relation to Gun Geometry*

As previously mentioned, the modulation constant n depends upon gun geometry. The following empirical expression was found to represent fairly well the relationship between the constant n and the geometry of the gun for a range of μ between 0·5 and 120:

$$n = \frac{3{\cdot}8}{1 + \frac{1}{\mu}} \quad \ldots\ldots\ldots(23)$$

The validity of expression (23) has not yet been tested outside the range of μ mentioned above.

A plot of n against μ is given in Fig. 4.

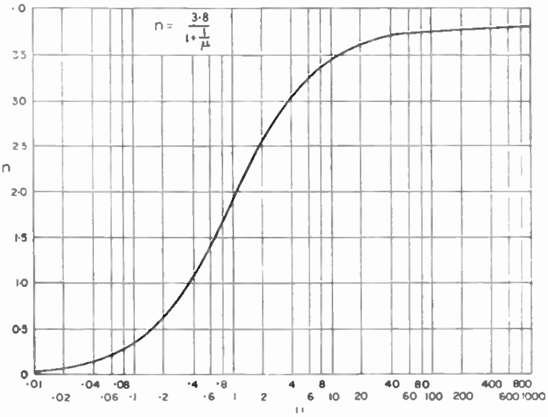

Fig. 4. Modulation constant n versus μ.

With the aid of (23) expressions (12), (16) and (18) become respectively:

$$I = \frac{3{\cdot}8}{1 + \frac{1}{\mu}}(k + \frac{1}{\mu})^{7/2}\,e_2{}^{7/2}\,(E_{c\,(min)} + \frac{1}{\mu}\,e_2)^{-2} \text{ microamps} \quad \ldots\ldots\ldots(24)$$

$$I_{pk} = \frac{3{\cdot}8}{1 + \frac{1}{\mu}}(k + \frac{1}{\mu})^{3/2}\,e_{2\,(pk)}{}^{3/2} \text{ microamps} \quad \ldots\ldots\ldots(25)$$

$$e_{2\,(pk)} = 0{\cdot}41\;(1 + \frac{1}{\mu})^{2/3} \,.\, \frac{1}{k + \frac{1}{\mu}} \,.\, I_{pk}{}^{2/3} \text{ volts} \quad \ldots\ldots\ldots(26)$$

The validity of all these various expressions is limited to that of the basic relation (11) from which they are derived.

3.3. *Screen and Control Grids A.C.-coupled*

Equation (26) shows that the minimum peak value of screen grid voltage $e_{2\,(\mathrm{pk})}$ required to produce I_{pk} is obtained when k is maximum or with unity coupling ($k = 1$). Unity coupling however, cannot be achieved in practice by means of the resistive or d.c.-coupling shown in Fig. 1 because the negative bias $-E_{1b}$ required to provide $-E_{c\,(\mathrm{min})}$ increases very rapidly as k approaches unity.

By simple algebraic manipulations one arrives at the following expression

$$E_{1b} = \frac{E_{c\,(\mathrm{min})} + kE_{2\,(\mathrm{min})}}{1-k} \qquad \ldots\ldots\ldots(27)$$

For such a reason practical values of k are not likely to be much above 0·5.

Capacitive coupling overcomes this limitation and permits us to achieve unity coupling. In Fig. 11, the coupling resistor R_c has been replaced by the capacitor C_c, the reactance of which must be negligible compared to R_g, throughout the desired beam modulation bandwidth. The d.c. component therefore, in such a case, can be conserved only by virtue of the beam modulation action carried out by the screen grid alone. Because of this, low-μ cathode-ray guns appear to be more suitable for capacitive coupling, than high-μ guns, whenever it is important to preserve as much of the signal's d.c. component as possible.

Values of $\mu \cong 1$ are possessed by some of the recent television guns built for operation at low screen-grid voltages, around 50-70 V, as compared with $\mu \cong 5$ typical of many 300 V screen-grid voltage guns in present use.

3.4. *Beam Modulation by Cathode Drive*

Expressions corresponding to (24), (25) and (26) may be easily obtained also for the case in which a beam modulating voltage e_c is applied to the cathode of the gun while both grids G_2, G_1 are at fixed potential.

In fact, the combined screen and control grid drive with unity coupling produces identical beam modulating effects as cathode drive because in both cases the potential differences between K, G_1, G_2 are the same. Polarities of e_2 and e_c are opposite however.

This equivalence is rigorously true only when the penetration factor $p = 0$. It is sufficiently exact as long as $e_2 \ll E_3$.

In the cathode drive case $E_{c\,(\mathrm{min})}$ is the potential to which the cathode must be raised above the control grid potential to cut the beam off.

The corresponding relations for cathode drive, obtained from (14), (24), (25), (26) by setting $k = 1$, are:

$$E_{c\,(\mathrm{min})} = e_{c\,(\mathrm{pk})} \qquad \ldots\ldots\ldots(28)$$

$$I = 3{\cdot}8\ \left(1 + \frac{1}{\mu}\right)^{5/2} . \, e_c^{7/2} . \left(E_{c\,(\mathrm{min})} + \frac{1}{\mu}\, e_c\right)^{-2} \text{ microamps} \qquad \ldots\ldots\ldots(29)$$

$$I_{\mathrm{pk}} = 3{\cdot}8\ \left(1 + \frac{1}{\mu}\right)^{1/2} . \, e_{c\,(\mathrm{pk})}^{3/2} \text{microamps} \qquad \ldots(30)$$

$$e_{c\,(\mathrm{pk})} = 0{\cdot}41\ \left(1 + \frac{1}{\mu}\right)^{-1/3} . \, I_{\mathrm{pk}} \text{ volts} \qquad \ldots\ldots\ldots(31)$$

3.5. *Beam Modulation by Control Grid Drive*

When the beam modulation voltage is applied to the control grid alone, while screen grid and cathode are at fixed potentials, expression (11) on account of (23) becomes

$$I = \frac{3{\cdot}8}{1 + \dfrac{1}{\mu}}\ e_g^{7/2} . \, E_c^{-2} \text{microamps} \qquad \ldots(32)$$

which for

$$e_g = e_{g\,(\mathrm{pk})} = E_c \qquad \ldots\ldots\ldots(33)$$

reduces to

$$I_{\mathrm{pk}} = \frac{3{\cdot}8}{1 + \dfrac{1}{\mu}} . \, e_{g\,(\mathrm{pk})}^{3/2} \text{ microamps} \qquad \ldots(34)$$

From this latter relation

$$e_{g\,(\mathrm{pk})} = 0{\cdot}41\ \left(1 + \frac{1}{\mu}\right)^{2/3} . \, I_{\mathrm{pk}}^{2/3} \text{ volts} \qquad \ldots\ldots\ldots(35)$$

is readily derived.

Relation (26), (31) and (35) specify the peak drive signal $e_{2\,(\mathrm{pk})}$, $e_{c\,(\mathrm{pk})}$, $e_{g\,(\mathrm{pk})}$, required by the same gun to produce the same peak current I_{pk} at zero control grid potential when the combined screen grid-control grid drive, cathode drive, and control grid drive are employed respectively.

In all three cases the screen grid is at the same potential $E_{2\,(\mathrm{pk})}$ volts above both the cathode and control grid potential when the beam current attains its peak level I_{pk}.

The ratios

$$\frac{e_{2\,(\mathrm{pk})}}{e_{g\,(\mathrm{pk})}} = \frac{1}{k+\dfrac{1}{\mu}} \qquad \ldots\ldots\ldots(36)$$

and

$$\frac{e_{2\,(\mathrm{pk})}}{e_{c\,(\mathrm{pk})}} = \frac{1+\dfrac{1}{\mu}}{k+\dfrac{1}{\mu}} \qquad \ldots\ldots\ldots(37)$$

are plotted versus μ with k as a parameter respectively in Figs. 5 and 6.

Finally, from eqns. (36) and (37)

$$\frac{e_{c\,(\mathrm{pk})}}{e_{g\,(\mathrm{pk})}} = \frac{1}{1+\dfrac{1}{\mu}} \qquad \ldots\ldots\ldots(38)$$

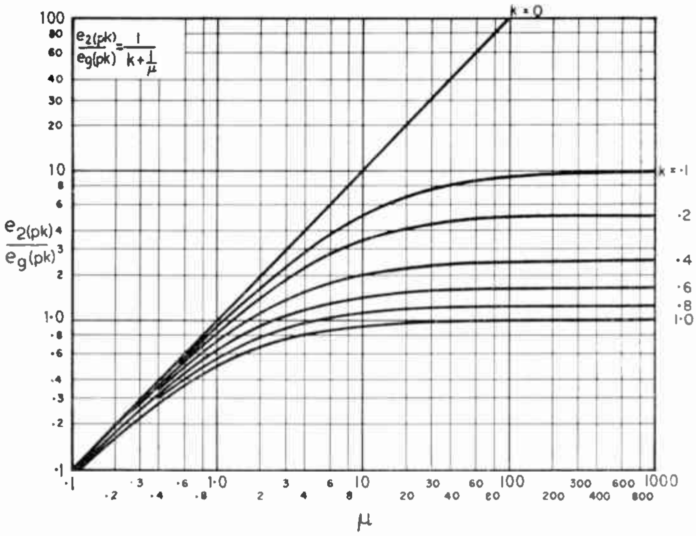

Fig. 5. Ratio $e_{2\,(\mathrm{pk})}/e_{g\,(\mathrm{pk})}$ versus μ (k as parameter).

4. Resolution

The resolution performance of the high g_m screen grid amplifier gun with unity coupling is substantially the same as that of its low g_m counterpart utilizing ordinary cathode drive.

Beam modulation by means of the screen grid, in combination with the control grid, may cause some variation in the strength of the prefocusing lens formed by the G_2 and G_3 electrodes, on account of the screen grid potential variations. The extent of this effect depends upon the part played by the prefocusing lens in relation to the total strength of the combined prefocusing and main lens of the gun.

The high g_m television gun C shown in Fig. 8 has a resolution performance of better than 1200 lines at 100 μA beam current when mounted in a 21 in. bulb.

The gun illustrated by Fig. 12 is the high g_m counterpart of a high resolution gun developed by G. L. Cox and A. E. Oberg. It will provide a spot diameter of 0·0015 in. or better than 600 lines per inch at about 10 μA beam current and 10 kV final anode voltage.

5. Amplifier Section

Conventional video amplifier considerations apply to the amplifier section of the gun. High transconductance and low capacitance are important, particularly in the case of large bandwidths. Beam modulation bandwidths 3 db down at 20 Mc/s are common in a number of applications involving high resolution displays.

Another important design factor is the curvature of the amplifier's transfer characteristic since it may be called upon to provide the proper $e_2 = \mathrm{f}\,(e_d)$ relationship which assures the desired beam transfer characteristic.

The amplifier section may be a simple triode, a tetrode or even a pentode, depending upon the particular gun characteristics considered to be the most important in each case. Triodes may be preferred for very wideband guns on account of their lower output capacitance and their low internal resistance which allows the use of large load resistors R_L. Also the smaller gain required in such a case makes less objectionable the increase in input capacitance due to the Miller effect. Tetrodes or pentodes, on the other hand may be preferred in those cases in which, for instance, minimum input capacitance is important.

6. Gun Gamma

As is well known the beam current I obeys approximately a power law of the form

$$I = a\,e^{\gamma} \qquad \ldots\ldots\ldots(39)$$

where e is the drive voltage applied to the gun, and a and γ are constants, dependent upon the gun geometry.

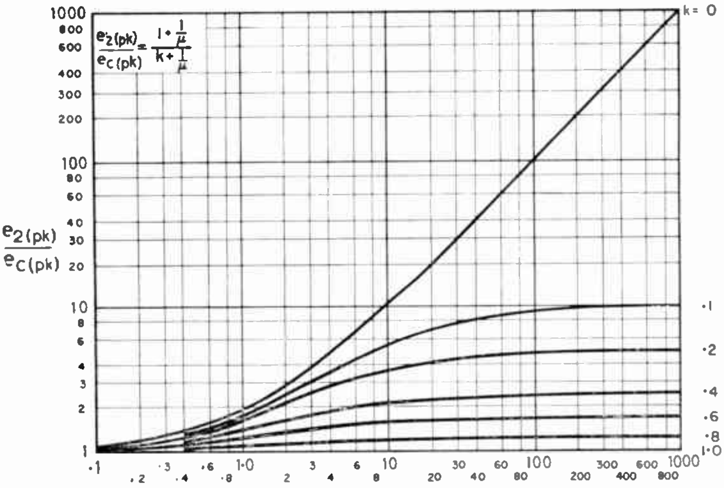

Fig. 6. Ratio $e_{2\,(pk)}/e_{c\,(pk)}$ versus μ (k as parameter).

In the case of grid drive, for instance, eqn. (32) supplies the following values of a and γ:

$$a = \frac{3{\cdot}8}{(1+\frac{1}{\mu})\,E_c^2}\ ;\ \gamma = 3{\cdot}5 \qquad \text{.........(40)}$$

Values of γ slightly smaller than 3·5 are given by eqns. (24) and (29), which refer to the combined screen grid-control grid drive and cathode drive respectively, on account of the presence of e_2 or e_c in the second factor of these equations.

Because of such power law dependence, the grey scale is severely compressed and the tonal rendition of the image suffers badly unless gamma-corrected signals are used to drive the gun.

The screen-grid amplifier gun offers interesting possibilities to make guns with gamma smaller than hitherto possible. The reason is quite apparent from Fig. 2. The curvature of the screen-grid transfer characteristic opposes that the beam current curve and this tends to make the beam current a more linear function of the input signal voltage e_d. If use could be made of a curved portion of the screen grid current transfer characteristic $I_2 = f\ (e_d)$ such that the screen grid current swing i_2 satisfies the relation

$$i_2 \propto e_d^{1/\gamma} \qquad \text{.........(41)}$$

an approximately linear relationship between I and e_d would be obtained.

In general, if

$$i_2 \propto e_d^{\gamma_1} \qquad \text{.........(42)}$$

the beam current I will approximately satisfy the relation

$$I = be_d^{\gamma\gamma_1} \qquad \text{.........(43)}$$

b being a constant.

Since the exponent γ_1 will always be smaller than unity, the gamma of a screen-grid amplifier gun will always be smaller than that of its conventional low g_m version.

All this is qualitatively illustrated by Fig. 7. In this graph the broken and solid lines represent the various quantities i_2, e_2, e_1, I, etc., with the gun operating along a linear and non-linear portion, respectively, of the screen-grid current transfer characteristic.

7. Gun Capacitance

The shunt capacitance of the screen grid amplifier gun is low because most of the amplifier section electrodes already exist in the gun's immersion lens system. A high g_m gun may

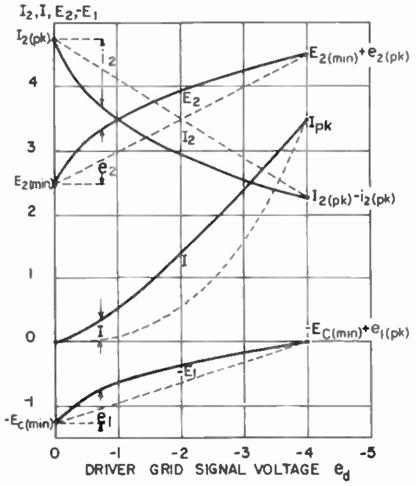

Fig. 7. Gamma compensation of gun's transfer characteristic.

possess a shunt capacitance about the same as the input capacitance of its equivalent low g_m conventional counterpart. Since the shunt capacitance associated with the immersion lens circuit may be also kept quite small, the small overall gun and circuit shunt capacitance C_t makes it possible to utilize high R_L values in the screen grid circuit.

The type and degree of coupling between the screen and control grids influences the total shunt capacitance C_t.

by the comparatively large coupling capacitor C_c.

A small variable capacitor of a few picofarads may have to be added in parallel to C_1 or C_2, depending upon k, to satisfy the condition

$$\frac{C_1}{C_2} = \frac{R_g}{R_c} = \frac{k}{1-k} \qquad \text{.........(44)}$$

where C_1 is the G_2 to G_1 interelectrode capacitance, which assures the constancy of the coupling factor k throughout the pass-band.

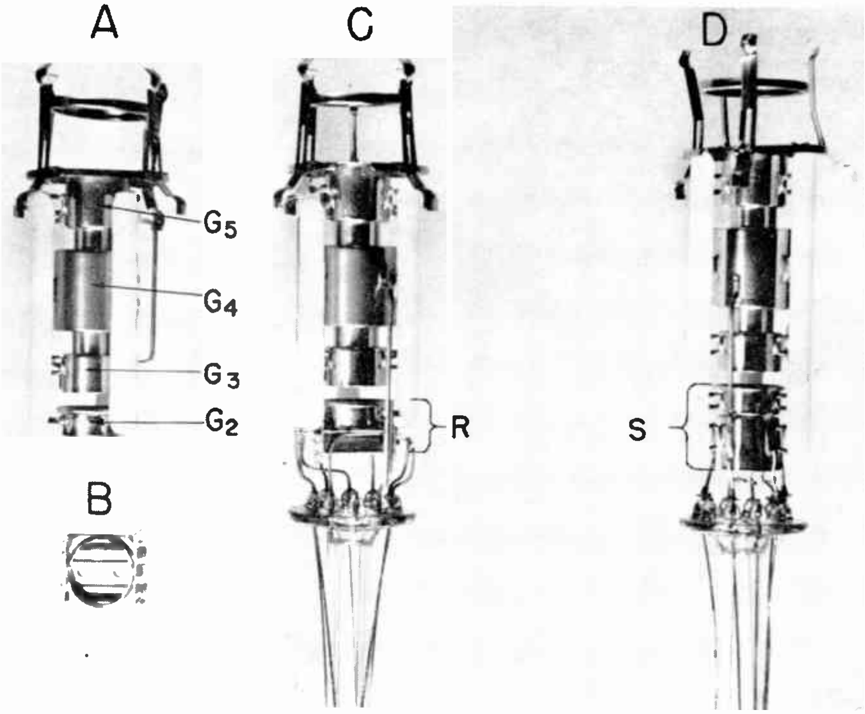

Fig. 8. Low voltage electrostatic focus television gun D (right) and corresponding high transconductance screen grid amplifier version C (left).

Resistive coupling offers a more favourable shunt capacitance situation than capacitive coupling, both from the gun and circuit point of view. There are two reasons for this:

(1) a fraction only, instead of all, of the shunt capacitance C_2 associated with G_1 is added to the amplifier's output capacitance (Fig. 1).

(2) the stray capacitance contributed to C_t by the coupling resistor R_c is substantially smaller than that contributed

The smaller total shunt capacitance C_t achieved with resistive coupling tends to offset some of the loss in gain caused by the below unity coupling values k allowed by this latter type of coupling.

8. Gun Structures

A high transconductance low voltage electrostatic focus television gun C is shown in Fig. 8. It is composed of two sub-assemblies A and B. The latter is the amplifier-immersion lens unit

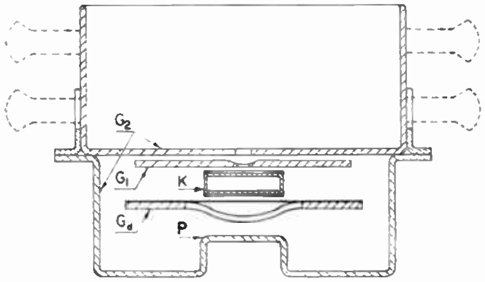

Fig. 9. Amplifier-immersion lens.

without the screen grid cup. Sub-assembly A comprises the screen grid cup G_2, the two high voltage anodes G_3, G_5 connected together, and the focusing electrode G_4. Because the amplifier-immersion lens unit R is appreciably shorter than the conventional low g_m immersion lens unit S presently used, the high g_m television gun C is shorter than its conventional low g_m television version D shown at right.

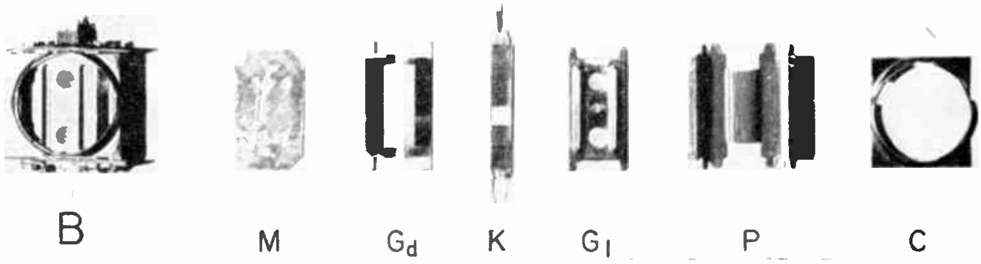

Fig. 10. Amplifier-immersion lens (without screen grid cup) B. and components.

The amplifier-immersion lens unit B is of the double-ended type illustrated by Fig. 9. The cathode K is perpendicular to the drawing sheet, has rectangular cross-section, and emits on both its wide sides. The upper surface, under the control-grid aperture, provides the cathode-ray beam while the lower side provides the screen current I_2 controlled by the driver grid G_d and collected by the portion P of the screen grid electrode.

The various electrodes which constitute B are shown in Fig. 10. Both the control grid G_1 and the driver grid G_d are planar. Part C receives the screen-grid G_2 cup with the rest of the gun attached to it, while part M is one of the two micas of the unit.

The total shunt capacitance of the gun is about 6–8pF. The circuit components add another 2·0+3·5 pF depending upon the type or degree of coupling employed. The total tube and circuit capacitance is about 8–12 pF as compared with the 20 to 38 pF of conventional arrangements[2] in which separate amplifier and picture tubes are used.

Since a "black positive" video signal is required by the driver grid of the gun, advantage may be taken of this fact to use the triode as a d.c. restorer by clamping the synchronization tips at the triode zero bias level (Fig. 11).

The input video signal required for operation of the high g_m gun at full television bandwidth from cut-off to zero bias has been found to range from two to four volts peak-to-peak for various combinations of triode characteristics, and coupling values k. Voltage gains up to 30 have been obtained, with a bandwidth 3 db down at 5 Mc/s using load resistors up to 18 kΩ. Average triode currents in the four to

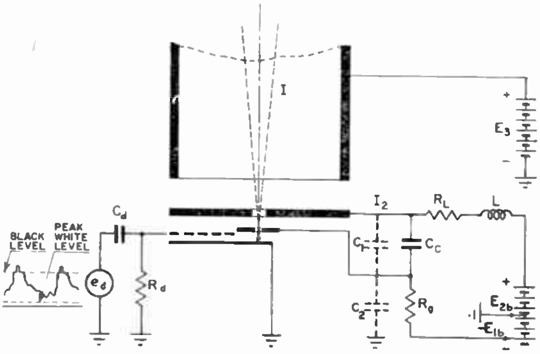

Fig. 11. High transconductance gun with capacitive unity coupling.

eight milliampere range make it possible to operate the amplifier from the television receiver boost supply, thereby maintaining a sufficiently high G_2 to cathode potential and, at the same time, providing adequate bias levels for the cathode-ray tube control grid.

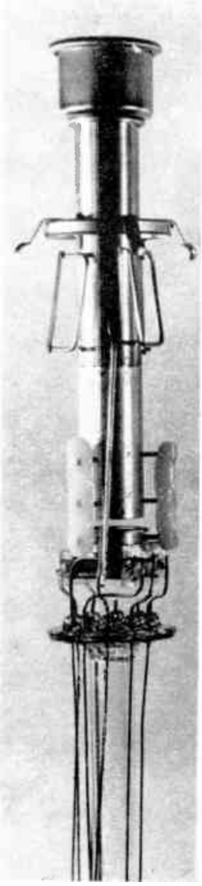

Fig. 12. Wideband high transconductance high resolution gun.

The high transconductance wideband special purpose gun shown in Fig. 12 requires a drive voltage below 10 volts for operation at bandwidths around 15–20 Mc/s.

9. Acknowledgments

The author extends his thanks and deep appreciation to: W. C. Johnson for his contribution in developing the amplifier section of the gun; W. Rial and L. E. White for their contribution in working out many of the circuit problems associated with the development; J. Lempert and J. Rima for the support given to the development.

10. References

1. Hilary Moss, "The electron gun of the cathode ray tube—Part II," *J. Brit.I.R.E.*, **6**, pp. 99-128, May-June 1946.
2. D. G. Fink, "Television Engineering Handbook" (McGraw-Hill, New York, 1957).

11. Appendix 1: List of Symbols

The following list of most frequently employed symbols and terms used throughout the paper are collected here for convenient reference.

$-E_d$, $-E_1$, E_2, E_3	Potentials respectively upon driver grid (G_d), control grid (G_1), screen grid (G_2), anode (G_3).
$-E_c$, $-E_{c\,(\mathrm{min})}$	Control grid bias to cut off beam I when screen grid is respectively at E_2 and $E_{2\,(\mathrm{min})}$.
I, I_{pk}	Beam current (at cathode) when control grid G_1 is respectively at $-E_1$ and at cathode potential (in μA).
I_2, i_2	Screen grid current and current swing respectively.
μ	Control grid relative to screen grid amplification factor, at cutoff: $\mu = -\left[\frac{\Delta E_2}{\Delta E_1}\right]_{I=0}$
p	Anode penetration factor, at cutoff: $p = \frac{1}{\mu_3} = -\left[\frac{\Delta E_1}{\Delta E_3}\right]_{I=0}$
e_2	Screen grid voltage swing.
e_1	Control grid voltage swing due to coupling to screen grid.
e_g	Control grid voltage drive from cutoff.
e_d	Driver grid input signal voltage.
k	Coefficient of voltage coupling between screen grid and control grid: $k = e_1/e_2$.

All potentials are in volts.

Automation of Television Programme Switching †

by

G. E. PARTINGTON, B.SC.TECH.‡

A paper read on 3rd July 1959 during the Institution's Convention in Cambridge.

Summary: The paper outlines a complete system under which nearly all the operations in programme switching are controlled by a punched paper tape derived directly from the preparation of the programme schedule. Simplified manual control facilities are provided for non-schedule operation. The term "Programmation" has been coined to describe this field.

1. Introduction

One of the most spectacular developments of recent years has been the increasing application of machine methods to perform complex operations. This has been most successful in such fields as machine tool operation, plant control, and accountancy. The application of automation has resulted in the following advantages:

(1) Higher accuracy of result.
(2) Greater speed of operation.
(3) Reduction of human errors.
(4) Automatic systems will operate continuously without fatigue.
(5) Release of staff from routine to more skilled operations.

Behind this work is the simple philosophy that where an operation is predetermined, then its execution is best performed, when the time comes, by a machine rather than by a human being who is apt to be nervous, tired or worried. In this way staff can be freed from much uninteresting routine, human operating errors can be reduced and in some respects it will be possible to improve the performance beyond that achieved by human operators and to extend the performance range.

A day's television programme is assembled from programme segments of various lengths. These usually follow the general pattern of extended transmissions from a studio, film or outside broadcast, interspersed with short periods during which several different sources may be used to make announcements, show time and station identification, and to advertise. Typically the real programme segments range from 10 to 90 minutes and the "break" periods use three or four sources in two minutes.

This programme assembly is usually handled by a team consisting of a programme controller, a vision mixer, a sound mixer, and possibly some assistants. Their life is peculiar in that during the extended periods of the main programme they have little or nothing to do but worry about the next break, during which they burst into co-ordinated activity when, to split-second timing, instructions are issued and buttons and faders operated.

The time at which various instructions have to be issued or controls operated is predetermined in the form of a programme schedule; although deviations from this are necessary due to inaccurate programme timing, breakdowns or last minute changes. The general development of automation has suggested to several organizations that this aspect of television is another field in which human drudgery can be alleviated. Conventionally the personnel involved behave, for the greater part of the time, as human servos reacting to the stimuli provided by reading the programme schedule and a clock. It is only during deviations from this that their faculties are fully extended. Accordingly it seems reasonable to devise a machine to carry out the routine operations. If, further, a simplification can be made in the manual control, there can when necessary then be a reduction in personnel, particularly as they will be relatively

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U.D.C. No. 621.397.61

rested by not having to deal with the main routine operations. Given a reliable machine, then operating errors will be considerably reduced, which is particularly important to commercial television when a single wrong operation can cost the company up to several thousand pounds in lost revenue.

At this time "Programmation" as this automated system has been termed, deals mainly with the integration of complete segments of the programme to form a continuous flow, and not with the means used to produce these individual segments such as a piece of film or a studio production. Consequently it is mainly concerned with the functions of Continuity, Master Control and the associated Announce Studios and Telecine.

The system is designed to parallel as closely as possible the present manual system in order to facilitate its introduction on a step-by-step basis with the minimum of dislocation. Eventually it may be advantageous to change operating techniques radically to make better use of Programmation but at the moment there seems no good reason to depart too far from the well established pattern.

The equipment relies on uniselectors and relays for its operation which may seem rather unglamorous in this age of ferrites, transistors, magnetic stores and other computer developments. However, an analysis of the system requirements has not shown the necessity of speeds in excess of those provided by uniselectors and relays. Consequently the system has been built up round these elements, which, having had a long development history, are now very reliable, easy to maintain and cheap.

2. General Problems of Programme Assembly and Switching

The Main Functions of Master Control, Presentation, Continuity, Dummy Mixer or Central Control are:

(1) To check that programme sources will be available as required.

(2) To take alternative action if they are not, or they cannot be transmitted.

(3) To put them on air as required (programme switching).

(4) Possibly to check technical quality.

The assembly of programmes involves previewing and prelistening to check their availability, giving warning cues, "on air" cues, "start telecine" cues, slide or caption changes, etc.

Programme switching, particularly in commercial television networks, is usually conducted according to a rigid time schedule; this is particularly true of a sequence of commercials in a break. At the moment operators react according to a predetermined pattern, in response to stimulus from a clock, often two or three operators in series. It therefore seems reasonable to replace the human servos with a machine which will do all that is necessary, and with great precision—until a fault condition arises beyond its perceptive powers but detectable by a human supervisor who then takes charge for as long as necessary.

It might be argued that a full crew will have to be present to deal with a non-scheduled event such as a programme overrunning, a last-minute change or a breakdown. This is not so provided the whole control system can be sufficiently simplified as to be within the compass of the Programme Supervisor who will be relatively rested after the machine has been doing the routine work.

The elements of programme switching are:

(1) *Storage* of scheduled information as to action to be taken and time of action.

(2) *Read-out* of the stored information at correct time, and translation to action.

(3) *Non-scheduled switching* to cover last-minute programme changes, timing errors or breakdowns.

A variety of programme switching systems can be formulated ranging from the introduction of some small aid to present systems up to completely automatic systems. The main divisions seem to be:

(a) Non-clock systems, where a sequence of changes is preset, but the time of change is controlled by the supervisor. The preset capacity can be sufficient to cover, say, a complete commercial break or can cover a day's operation.

(b) Clock systems, where the change itself is initiated automatically at the predetermined times. Such systems also have to be capable of reverting to supervisor control for last minute changes.

The system discussed below is designed as a fully automatic clock system in the belief that it is better to work out the final system and use parts of that to provide more limited facilities than to start with some interesting aids for selected problems and then try to integrate these into a complete system at a later date. In any case, it is believed that the equipment for fully automatic clock operation is so simple and economical that cost need not delay its introduction. The equipment can perform a substantially unlimited number of different operations and is easy to tailor to particular installations.

3. Storage of Programme Information

In present manual systems programme information is stored in the form of duplicated paper sheets similar to Fig. 1. The Programme Controller compares the scheduled time with the time indicated by a clock and instructs operators to make programme changes when these coincide. In addition, instructions are given to start telecine machines, and various cues are given. These are not generally written into the programme schedule, but can easily be derived from the schedule by the Programme Controller, according to the station's routine practices.

TIME	VISION	SOUND	PROGRAMME
21 59 50	SLIDE	-	STATION IDENTIFICATION
21 59 54	CLOCK	-	CLOCK
22 00 00	SOF/MARCONI 4		TS "UFIXIT" (0 08)
22 00 08	NET 2		SQUIZ KIDS Pt.1
21 14 00 (approx)	SOF/MARCONI 3		"UNEEDIT" (0 15) "WHEN" (0 15) "CLEAN MARG" (0 30)

Fig. 1. Normal programme schedule.

If the programme schedule is to be read by a machine, then it is preferable to put the information in such a form that a simple machine can read it and also to include that additional information normally added by the Programme Controller, such as the requirements of starting a film projector a specific time before it goes on the air. For present purposes each instruction or action normally initiated by the Programme Controller or one of his assistants is called an "operation," and put into the programme schedule as an "operate code."

In very simple systems it would be possible to use a single character, but this would limit the number of different operate codes to forty or fifty, made up of, say, twenty-six letters, nine figures, and other symbols. Such a coding system would also have the disadvantage that it would not be possible to have an easily remembered code unless the requirements were simple, so that, say, studios were given numbers, telecine projectors letters, and the rest covered by a few symbols. For general use a two-character code meets all requirements. Each character can be either a letter or a figure so that S3 can be Studio 3, N2 Network 2, etc., making an easily remembered code system. With two characters several hundred different codes are possible.

Using two characters, an operate code system can be devised, such as shown below, in which the first character denotes the class of operation and the second character subdivides that class.

In devising this code, the following assumptions are made:

(1) As in current systems the routine is to preview and prelisten the next programme, and then switch this on air at the appropriate moment.

(2) The sound and vision of a programme source will normally be switched together. The exception to this is the sound from announcer or gramophones or tape which may be required with any picture source and may be mixed with the sound of those sources.

If required, separate codes could be used for sound and vision switching but this seems to be an unnecessary complication.

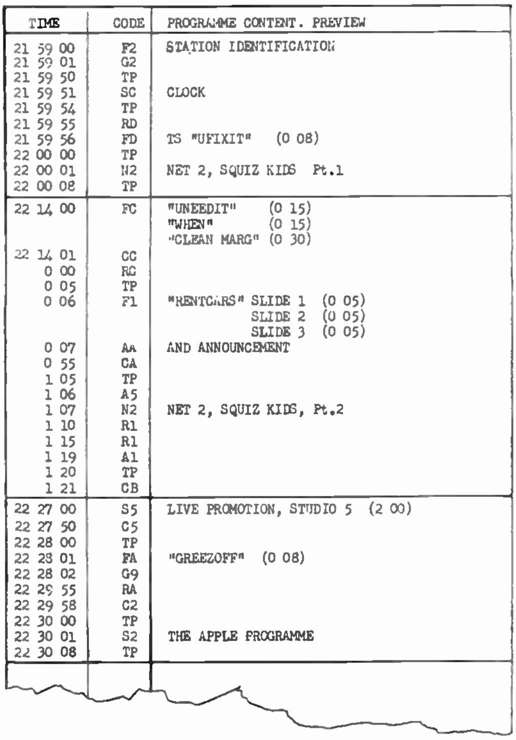
3.1. *1st Character of Operate Codes*

S	STUDIO	Put studio on preview and prelisten
F	FILM (room)	Each film *projector* is given an identifying letter and each slide or caption *projector* a number. The code F followed by the designate letter or number will switch on the projector lamps, operate any multiplex arrangements. and

		put the associated channel on Preview and Prelisten, i.e. Show on Preview.
R	RUN	The R code, followed by the projector identifying letter or number, will start the film projector, or change the slide or caption projector.
N	NETWORK (and Remote)	Puts incoming Network or Remote on Preview, and Prelisten.
A	AUDIO	Mix announcer sound, or grams, tape, etc. with outgoing programme sound. Each sound source of this type has an identifying *letter*. The code A and a *number* are used to set balance between this source and the sound of the selected vision channel.
T	TAKE	Or "Transmit" puts on air the source which is already on Preview and Prelisten.
C	CUE	Warning cues to studios, telecine, etc. On air cue is given by the vision switching equipment in the normal way.
G	GENLOCK	Operates a simple vision switcher which selects a specified remote signal and feeds it to automatic genlock equipment.
M	Miscellaneous	To switch on announcer's preview monitor for instance, or switch on lighting in announcer's booth.

CODES

S	Studio	G	Genlock
F	Film or Caption Projector	M	Miscellaneous
R	Run Film or Change Caption	TP	Take Preview
N	Network or Remote	SC	Station Clock
A	Audio	CC	Cue Clock
C	Cue	CB	Control Back



TIME	CODE	PROGRAMME CONTENT. PREVIEW
21 59 00	F2	STATION IDENTIFICATION
21 59 01	G2	
21 59 50	TP	
21 59 51	SC	CLOCK
21 59 54	TP	
21 59 55	RD	
21 59 56	FD	TS "UFIXIT" (0 08)
22 00 00	TP	
22 00 01	N2	NET 2, SQUIZ KIDS Pt.1
22 00 08	TP	
22 14 00	FC	"UNEEDIT" (0 15) "WHEN" (0 15) "CLEAN MARG" (0 30)
22 14 01	CC	
0 00	RC	
0 05	TP	
0 06	F1	"RENTCARS" SLIDE 1 (0 05) SLIDE 2 (0 05) SLIDE 3 (0 05)
0 07	AA	AND ANNOUNCEMENT
0 55	CA	
1 05	TP	
1 06	A5	
1 07	N2	NET 2, SQUIZ KIDS, Pt.2
1 10	R1	
1 15	R1	
1 19	A1	
1 20	TP	
1 21	CB	
22 27 00	S5	LIVE PROMOTION, STUDIO 5 (2 00)
22 27 50	C5	
22 28 00	TP	
22 28 01	FA	"GREEZOFF" (0 08)
22 28 02	G9	
22 29 55	RA	
22 29 58	C2	
22 30 00	TP	
22 30 01	S2	THE APPLE PROGRAMME
22 30 08	TP	

Fig. 2. Programmatic schedule.

3.2. *2nd Character of Operate Codes*

The second character can be either a letter or a figure but, as suggested above, the preferred choice is:

1st Character	*2nd Character*
S	1, 2, 3, etc. Studio Numbers.
F	A, B, C, etc. Film Projector letters.
	1, 2, 3, etc. Slide or Caption Projectors.
R	Same letter or figure as is used for F.
N	1, 2, 3, etc. Network and Remote sources.
A	A, B, C, etc. Audio Source letters.
	1, 2, 3, etc. for ratio of Announcer to Programme Sound levels.
T	Letter or Figure.
C	Same Figures as Studio or same Letter as Audio Source.
G	Same Figure as N.
M	Letter or Figure.

3.3. *Programmatic Schedule*

Based on this operate code system, the programme schedule of Fig. 1 can be written as in Fig. 2.

Referring to Fig. 2, the way in which these codes would operate would be:

21 59 00	F2	The Station Identification slide on Projector 2 is put on Preview.
21 59 01	G2	The station is genlocked to the incoming Network 2.
21 59 50	TP	The "Take Preview" code switches the source which is on preview (S.I. slide) on air.
21 59 51	SC	Station Clock put up on preview.
21 59 54	TP	Clock put on air by TP.
21 59 55	RD	Film projector D started by RD code.
21 59 56	FD	Film projector D put up on preview/prelisten.
22 00 00	TP	Film projector D put on air. It has now had its 5 sec. run up time.
22 00 01	N2	Network 2 on preview/prelisten.
22 00 08	TP	Network 2 on air.

End of this break.

22 14 00	FC	This is a time chosen to allow a safe margin before the next break, the exact starting time of which depends upon the running of the programme. Film projector C is put on Preview/Prelisten.
22 14 01	CC	Code CC switches control from the standard time clock to a Cue Clock.
0 00	RC	At the end of the electronic cue dot, or whatever is used to initiate the break, Film Projector C is run. Timings during this break are taken from this time 0 00 and the Cue Clock started.
0 05	TP	Film projector C put on air.
0 06	F1	Slide projector 1 is put on preview.
0 07	AA	Audio input A (Announcer) is preselected on a subsidiary audio switcher.
0 55	CA	The Announcer is given a 10 sec warning cue.
1 05	TP	The first slide is put on air.
1 06	A5	The Announcer channel is put on air by code A5. (If the code had been A2, A3, etc. then the Announcer would have been superimposed on the outgoing sound at progressively increased levels. A5 is audio (announcer) full up and normal programme down.)
1 07	N2	Incoming Network 2 put up on preview and prelisten.
1 10	R1	Slide changed on projector 1.
1 15	R1	Slide changed on projector 1.
1 19	A1	Fades announcer down and normal sound up
1 20	TP	Network 2 put on air.
1 21	CB	Control Back to standard time clock.

End of second break.

If the slides had been on the same telecine channel as say, film projector A and this were a conventional type of vidicon channel, then it would not have been possible to preview them. Instead the code sequences below would have been used:

0 00	RC	1 05	F1	1 15	R1
0 05	TP	1 06	A5	1 19	A1
0 07	AA	1 07	N2	1 20	TP
0 55	CA	1 10	R1		

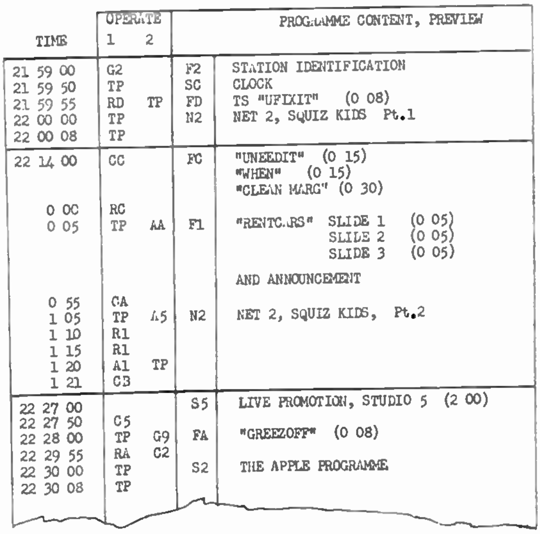
The code F1 at 1 05 would operate the multiplexer to show the first slide. It would incidentally put it up on preview until cancelled by N2 at 1 07.

22 27 00	S5	Studio 5 is put on preview and prelisten.
22 27 50	C5	Studio 5 is given a 10 sec warning cue.
22 28 00	TP	Studio 5 on air with live promotion.
22 28 01	FA	Film projector A on preview and prelisten.
22 28 02	G9	Genlock off (revert to mains or crystal lock).
22 29 55	RA	Roll film projector A
22 29 58	C2	10 sec warning cue to Studio 2.
22 30 00	TP	Film projector A on air.
22 30 01	S2	Studio 2 on preview and prelisten.
22 30 08	TP	Studio 2 on air.

End of third break.

The Programmatic Schedule shown in Fig. 2 has increased the number of time entries over those used conventionally by including all those normally deduced by the operating staff. But it will be seen that no further operations have been introduced.

The presentation of the schedule can be improved, and the number of lines reduced, by putting it in the form shown in Fig. 3. In this the codes are entered in one of three columns. The first two are general operate codes, whilst the third column is reserved for the codes which put the next programme segment on preview and prelisten. The improved layout reduces the number of time entries from 32 to 20, compared with 10 for the non-programmatic schedules.



TIME	OPERATE 1	2		PROGRAMME CONTENT, PREVIEW
21 59 00	G2		F2	STATION IDENTIFICATION
21 59 50	TP		SC	CLOCK
21 59 55	RD	TP	FD	TS "UFIXIT" (0 08)
22 00 00	TP		N2	NET 2, SQUIZ KIDS Pt.1
22 00 08	TP			
22 14 00	CC		FC	"UNEEDIT" (0 15) "WHEN" (0 15) "CLEAN MARG" (0 30)
0 00	RC			
0 05	TP	AA	F1	"RENTCARS" SLIDE 1 (0 05) SLIDE 2 (0 05) SLIDE 3 (0 05) AND ANNOUNCEMENT
0 55	CA			
1 05	TP	A5	N2	NET 2, SQUIZ KIDS, Pt.2
1 10	R1			
1 15	R1			
1 20	A1	TP		
1 21	CB			
22 27 00			S5	LIVE PROMOTION, STUDIO 5 (2 00)
22 27 50	C5			
22 28 00	TP	G9	FA	"GREEZOFF" (0 08)
22 29 55	RA	C2		
22 30 00	TP		S2	THE APPLE PROGRAMME
22 30 08	TP			

Fig. 3. Programmatic schedule of Fig. 2 with improved layout.

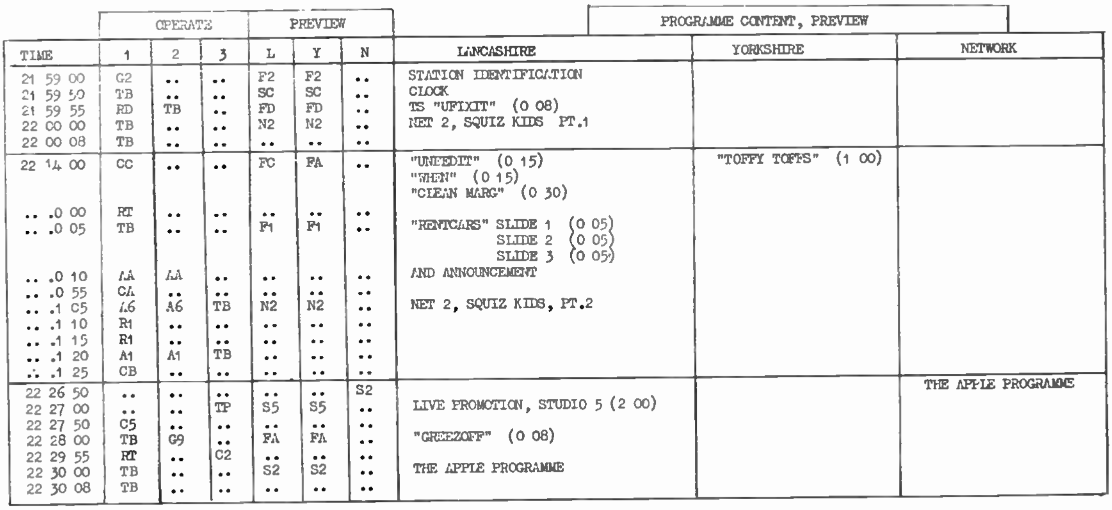
3.4. *Multiple Output Systems*

At many programme centres more than one programme is fed out. Apart from the feed to the transmitter, there are usually one or more feeds to outgoing networks, or (as in the case of the North of England programme contractors), two separate transmitters are fed, plus a network. Whilst these outputs are the same most of the time, they do vary occasionally, particularly during commercial breaks. There must therefore be three versions of the programme schedule shown in Fig. 3, usually combined on one sheet.

Figure 3 can be rewritten for three outputs, say Lancashire, Yorkshire and Network, as shown in Fig. 4.

CODES

S	Studio
F	Film or Caption Projector
R	Run Film or Change Caption
N	Networks or Remote
A	Audio
C	Cue
G	Genlock
M	Miscellaneous
TP	Take Preview
TA	Take All (L, Y & N)
TB	Take Both (L & Y)
SC	Station Clock
CC	Cue Clock
CB	Control Back
RT	Run Telecine



	OPERATE			PREVIEW			PROGRAMME CONTENT, PREVIEW		
TIME	1	2	3	L	Y	N	LANCASHIRE	YORKSHIRE	NETWORK
21 59 00	G2	..	..	F2	F2	..	STATION IDENTIFICATION		
21 59 50	TB	..	..	SC	SC	..	CLOCK		
21 59 55	RD	TB	..	FD	FD	..	TS "UFIXIT" (0 08)		
22 00 00	TB	..	..	N2	N2	..	NET 2, SQUIZ KIDS PT.1		
22 00 08	TB	..	..	..	..	..			
22 14 00	CC	..	..	FC	FA	..	"UNEEDIT" (0 15) "WHEN" (0 15) "CLEAN MARG" (0 30)	"TOFFY TOFFS" (1 00)	
.. .0 00	RT	..	..	..	..	..			
.. .0 05	TB	..	..	F1	F1	..	"RENTCARS" SLIDE 1 (0 05) SLIDE 2 (0 05) SLIDE 3 (0 05) AND ANNOUNCEMENT		
.. .0 10	AA	AA	..	..	..	..			
.. .0 55	CA	..	..	..	..	..			
.. .1 05	A6	A6	TB	N2	N2	..	NET 2, SQUIZ KIDS, PT.2		
.. .1 10	R1	..	..	..	..	..			
.. .1 15	R1	..	..	..	..	..			
.. .1 20	A1	A1	TB	..	..	..			
.. .1 25	CB	..	..	..	..	..			
22 26 50	..	..	..	..	..	S2			THE APPLE PROGRAMME
22 27 00	..	..	TP	S5	S5	..	LIVE PROMOTION, STUDIO 5 (2 00)		
22 27 50	C5	..	..	..	..	..			
22 28 00	TB	G9	..	FA	FA	..	"GREEZOFF" (0 08)		
22 29 55	RT	..	C2	..	..	..			
22 30 00	TB	..	..	S2	S2	..	THE APPLE PROGRAMME		
22 30 08	TB	..	..	..	..	..			

Fig. 4. Programmatic schedule for three outputs.

It should be noted that the position of certain codes in the schedule columns is now significant, but not that of others. For instance S2 will preview Studio 2 on the Lancashire, Yorkshire or Network switchers according to whether it is put in the L, Y or N columns, but RD will run film projector D irrespective of which column it is put in. The position-conscious codes are of course those that affect the three switchers feeding the L, Y and N outputs so that they are those having first characters S, F, N, A and possibly M.

Separate positions for the codes are provided under "Operate" and "Preview," mainly to segregate those of main interest to the Programme Controller which are put under "Preview" and they are the ones that identify the next programme. Other codes having a more engineering significance are put in the "Operate" columns but the code columns 1, 2 and 3 have the same significance for position conscious codes as L, Y and N. Thus, in Fig. 4, the code A6 entered under 1 and 2 at 1 05 will apply to the L and Y switchers.

In the Programme Content columns, the convention has been adopted of making an entry under Yorkshire only if it differs from Lancashire, and an entry under Network only when it is to be fed with programme.

The time that a programme actually goes on air can easily be seen by noting the time of the next T code, usually on the next line.

Three further codes have been introduced to give simultaneous operation on two or more outputs:

TA	TAKE ALL	Single code to switch all outputs to what is on their preview and prelisten buses.
TB	TAKE BOTH	Lancashire and Yorkshire only.
RT	RUN TELECINE	This code triggers a run bus on to which several projectors have their run circuits commoned. In Fig. 4, RT at 0 00 will run film projectors FC and FA simultaneously.

3.5. *Realization of Programmatic Schedule and Code Store*

In early thinking about the Programmation System, it was considered essential to have a common document, duplicated copies of which could be read by the Programme Controller, the Programmation Machine, Telecine, etc. etc. This would not only save time in preparation but, more important, would avoid errors inevitable when, say, someone punches a tape by reading a programme schedule. The ideal would be for the machine to read the actual programme schedule. It was envisaged that as the programme schedule master was typed, a copy would be made on a continuous roll of paper. This roll would be put in a display device before the Programme Controller and would unroll as the programme progressed, giving him the required information and at the same time the machine would read the operate instructions.

Although equipment is being developed in various countries which can read typescript and therefore could read the schedule directly, it is unlikely to be economic to use it for the present purpose.

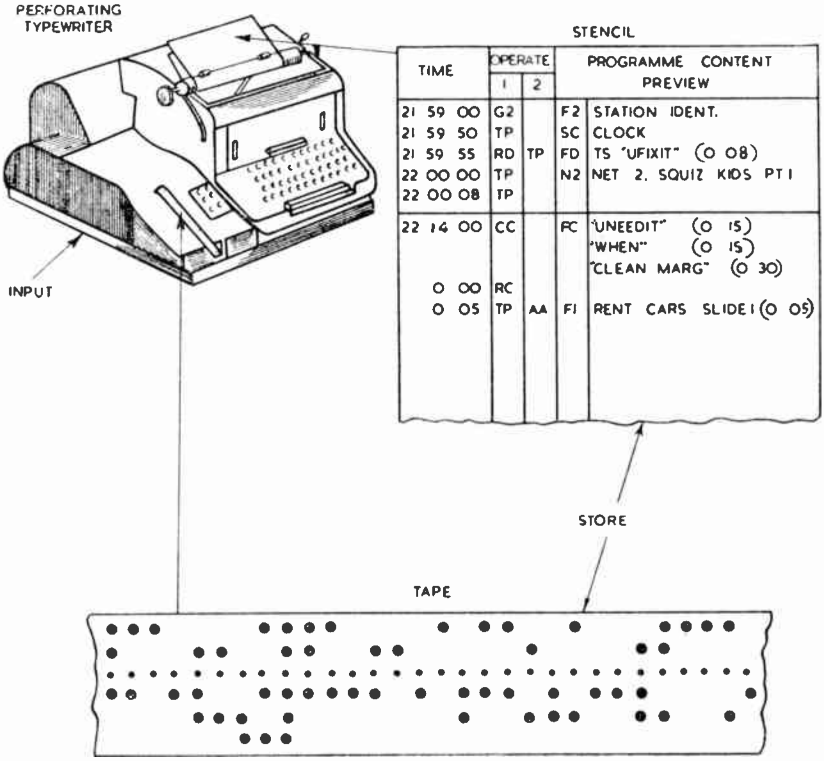
It would be more practicable to duplicate on the programme schedule the required information in the form of coded holes or opaque, conductive or magnetic dots which could more easily be read by a machine. Whilst such systems do exist, their application to the present problem looks like an expensive development. So one is forced to consider the use of a separate store of information, apart from the programme schedule, to be read by the machine.

Fortunately standard punched tape equipment is available which will automatically produce the time and code information on a tape, as a by-product of typing the programme schedule.

The programme schedule master is prepared on a typewriter which also has a tape punch attached so that the information as to time and the operate codes is entered on the paper tape as columns of coded holes and spaces, one column per character. Figure 5 shows the method.

The idea of the programme schedule unrolling before the Programme Controller and the machine reading the information can still be realized by coupling together the display device and tape reader.

Information capacity and speed of access is easily met with the advantage of cheap, well-tried easy to use equipment.



TIME	OPERATE		PROGRAMME CONTENT PREVIEW	
	1	2		
21 59 00	G2		F2	STATION IDENT.
21 59 50	TP		SC	CLOCK
21 59 55	RD	TP	FD	TS "UFIXIT" (0 08)
22 00 00	TP		N2	NET 2. SQUIZ KIDS PT I
22 00 08	TP			
22 14 00	CC		FC	"UNEEDIT" (0 15) "WHEN" (0 15) "CLEAN MARG" (0 30)
0 00	RC			
0 05	TP	AA	FI	RENT CARS SLIDE I (0 05)

Fig. 5. Preparation of programmatic stencil and tape.

As is current practice, a schedule is typed out showing:—Time. Operation. Explanatory Notes. This is expanded to show such items as Cue Studios, etc. Run Telecine, Gen. Lock.

As the time and code columns are typed the tape is simultaneously punched with the information entered there. There are six tape columns for time, and six for the three codes.

Punched cards do not seem to offer any advantage unless the broadcaster uses them for automatic log keeping or the billing of clients; although then it might be best to confine them to the Accounting Department and put the information on them from a tape/card translator.

Some of the facilities of punched cards can be had, without the cost and complexity of regular punched card systems, by using cards to carry the standard tape perforations along one side. A typical card is 7 in. × 3 in. and they are provided in continuous form so that several cards can be used and stored folded together. This would be a convenient store for a system operating on an individual break basis using a separate card or cards for each break.

3.6. *Choice of Tape and Code*

Punched tape equipment is manufactured at the moment for the two broad fields of teleprinter applications and "off line" or business machine use. The former normally uses a 5-unit tape (possible holes per column), and the latter a 7- or 8-unit tape, although either may use any of these. Due to its very wide use, teleprinter equipment is much cheaper and so to allow its use the 5-unit tape has been adopted in present Programmation Systems. By binary coding it gives $2^5 = 32$ different characters. This is not enough to accommodate 26 letters and 10 figures, so in teleprinter practice, the artifice of letter and figure cases is employed with two combinations reserved to shift between them. Programmation requirements of even large installations do not require all letters and figures, so that it is not necessary to use case shift on the tape. The five-unit C.C.I.T. International Code No. 2 is used so that the first 26 combinations have the meaning shown in Table 1.

The letter I, which is normal for combination 9, is not used to avoid confusion with 1, nor is the letter O for combination 15, or the figure 0 for combination 16.

This simply means that in choosing the two-character codes, if we wish to use R as one of the first characters, for instance, then we must never use 4. Or if we wish to use all the figures in the second character, then we can only use A, B, C, D, F, G, H, etc. as second character letters, and not E, Q, R, etc. In the schedule of Fig. 4 the code RT has been used for Run Telecine. This means that we cannot have R5 for a slide projector; 5 will have to be omitted from the series. Shift is used in cutting the master if necessary so that for instance, R or 4 will be typed as required, but the code combination 18 will be punched for both. Even with these restrictions, several hundred different two character codes are available. A further possible advantage of the 5-unit tape is the ease with which it can be transmitted over standard teleprinter circuits.

Equipment is available with quite sophisticated tape punch programme facilities, that is, the determination of what of the typed information is entered on the tape. However, the code punching programme required for Programmation is simple and fixed for a given system and can be easily obtained.

The first line of Fig. 4 enters on the tape:

215900G2 . . . . F2F2 . .

This can be done by switching on the punch at the start of the line and off after the last character position in the last code columns, either automatically or manually. Then the space bar is arranged to space the typewriter but not to punch. The full stop is made to print a full stop, but to punch, say, the space code, combination 31. It is used where no code entry is made. The regular combination for full stop is the same as M, so if M is required, an alternative combination is necessary. The combinations for Carriage Return and Line Feed are not punched because they do not occur in the time/code area. Letter and Figure Shift keys have to be prevented from punching and the Letter Shift code, all holes, is used as the error code so that all holes of a wrongly punched combination can be overpunched and will be skipped. The no-hole combination is used for tape feed between, say, breaks, and can be written on to help editing if required.

Punched tape usues 0·1 in. per character so that a line of the multiple output schedule of Fig. 4 will require 0·6 in. for the time and 1·2 in.

Table 1

Characters for C.C.I.T. No. 2 Code Combinations

Combination	*Character*	*Combination*	*Character*	*Combination*	*Character*
1	A	10	J	19	S
2	B	11	K	20	T or 5
3	C	12	L	21	U or 7
4	D	13	M	22	V
5	E or 3	14	N	23	W or 2
6	F	15	9	24	X
7	G	16	P	25	Y or 6
8	H	17	Q or 1	26	Z
9	8	18	R or 4		

for the codes, 1·8 in. per line, a total of say, 19 in. per break and 4 ft. per hour. Thus a day's programme is not likely to occupy more than 50 ft. of tape. Tape is supplied in 1,020 ft. rolls.

Five-unit tape is usually 11/16 in. wide, but there is a $\frac{7}{8}$ in. version on the edge of which can be printed, by the perforator, what is punched, but the printing lags the perforations by eight characters. Even so, it offers considerable advantages when the tape has to be edited.

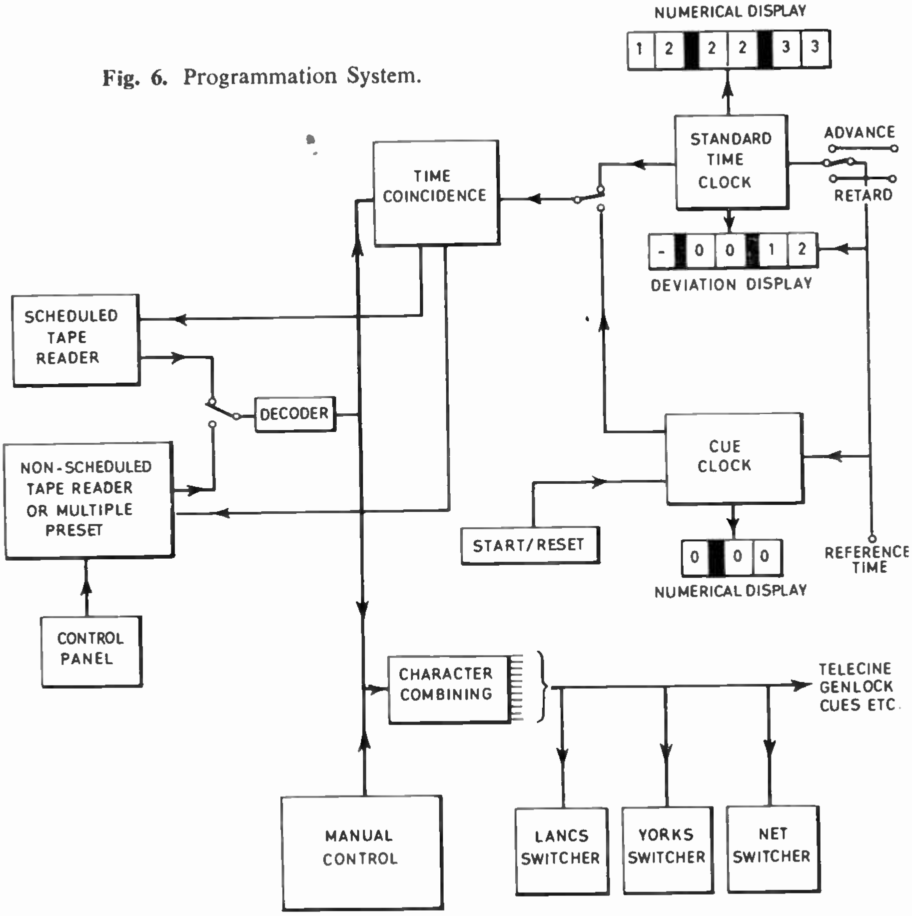


Fig. 6. Programmation System.

4. A Programmation System

The complete Programmation System requires that operations be initiated by:

(1) The scheduled tape produced as a by-product of typing the day's programme schedule, but occasionally modified as to timing.

(2) A short store to provide for late programme modifications. Its capacity is sufficient to cover up to a complete programme break.

(3) Manual control, particularly to give roving preview/prelisten facilities and apology service during emergencies.

A general equipment arrangement is shown in Fig. 6.

4.1. *Readers and Decoder*

A Decoder is fed from either a tape reader running the scheduled tape or from the short store required for late programme changes. One of the most important aspects of Programmation is to make it possible for one person, the Programme Controller, to exercise the control functions at present involving several people. To achieve this, the work load must be distributed over as much time as possible rather than let it build up to a number of peaks.

The short store provides for this by allowing the Controller to preset up to a complete non-scheduled programme break. It can be in the form of a multiple preset system or an auxiliary tape punch/reader. The former can be provided by rows of rotary switches requiring one switch per possible character entry, say 150 switches to set up 10 lines of Fig. 4 with cue clock time. Alternatively binary storage can be provided on uniselectors, relays, etc. preset sequentially from a simplified control panel.

Multiple preset systems are all relatively complicated compared with storage on a paper tape, or possibly on a simple magnetic drum or loop which, however, has to be complicated to provide ready means for checking what has been preset on it. Accordingly in current systems, the short store is provided by a typewriter giving control, display and record of what is preset. This operates a tape punch, the tape from which goes straight into the non-scheduled reader. A variable tape store between the punch and reader makes it possible to punch a complete break and hold it until required, or only one or more lines. If time is short, the first part of the break can be in the reader whilst the rest of it is being punched.

Where a typewriter keyboard is not favoured, the tape punch can be operated from a control panel such as is discussed in Section 4.3.

4.2. *Time Coincidence and Clocks*

One input to the Time Coincidence circuit is from either a standard time clock or a cue clock. These are driven from whatever is the station time reference, either a controlled 50 or 60 c/s or 1 sec pulses. The standard clock has means for advancing or retarding it with the number of seconds deviation shown on a numerical display along with the clock reading, also in numerical form, to compare with the programme schedule. The advance/retard feature is to allow for over or under running when breaks are not scheduled for cue clock use.

The cue clock is started 5 sec (telecine run-up time) before the start of a break whose start cannot be accurately foretold and runs to, say, 9 59 to provide time control in the break.

The other side of the Time Coincidence Circuit is from the Decoder. A comparison is made between the first time character on the tape, say tens of hours, and the tens of hours from the clock system. When these coincide the tape reader moves on to the next character and this is compared with the hours from the clock. Thus the tape is moved figure by figure as the clock reaches the entered time, until complete coincidence is obtained at the appropriate second.

Then the tape runs and is decoded character by character to feed the Character Combining Unit. This produces for each pair of characters a brief earth pulse on the output wire corresponding to that code. The earth pulses are distributed to the switchers, telecine, etc. To minimize the number of codes required and the wiring, those affecting the switchers are made position conscious (See Sect. 3.4.) For example, FC entered under L or 1 in Fig. 4 would put film projector C on preview for Lancashire only. For Yorkshire, it would be put under Y or 2. This is achieved by feeding the earth pulse corresponding to FC to all the switchers and also a battery pulse to the Lancashire switcher when code columns 1 and L are being decoded and to the Yorkshire switcher when 2 and Y. Then the switchers only operate when they receive coincident battery and earth pulses.

4.3. *Manual Control*

This can take many forms according to the system needs. Figure 7 shows a comprehensive panel suitable for the three output systems. It consists mainly of momentary contact keys operating the Character Combining equipment and allows any code to be punched out to take immediate action.

If the code is not position-conscious, then the first character is punched in the first CODE column and the second is one of the other three CODE columns. With positional codes, it is first determined which switchers will be affected by punching in the SELECT column, L, Y, N, ALL, BOTH (L and Y), P/V1 or P/V2 (Roving Preview/Prelisten monitor systems), followed by the two characters of the code.

For ease of operation, separate TAKE keys are provided to put on air what is on preview/prelisten on the various switchers and there is also a separate RT key. A switch to SEQUENCE replaces tape control by the clocks with a SEQU key which at each operation starts the read-out of the next line of codes. This is a useful

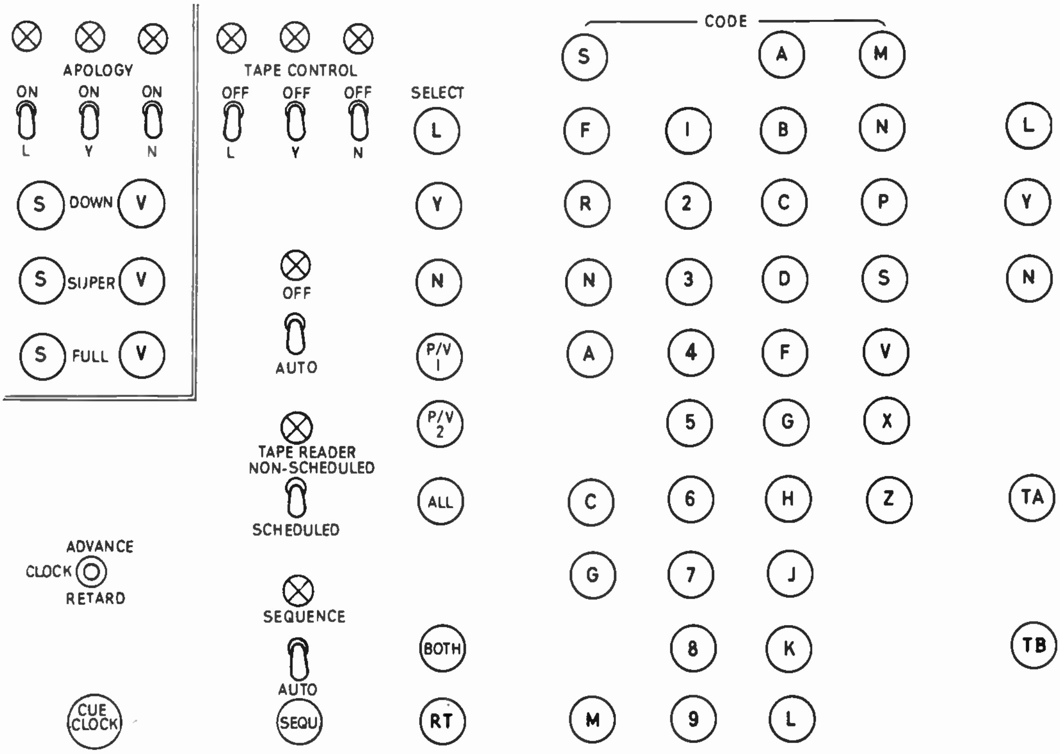


Fig. 7. Programmatic control panel.

method of operation giving the Controller variable time control. Three TAPE CONTROL switches allow taped instructions to the switchers to be switched off individually and an AUTO switch stops all taped codes, although the tape will continue to run against time. The TAPE READER switch selects either the scheduled or non-scheduled tape. A CLOCK switch, spring loaded to centre, controls the advance/retard of the standard clock and a CUE CLOCK button starts it or resets it if it is already running.

To facilitate emergency procedure, separate APOLOGY facilities are provided. The outputs to receive apology are first selected on the switches L, Y and N. Separate keys are provided for Sound and Vision apologies and are used in the sense:

DOWN	Programme down; no sound or black screen.
SUPER	Sound or Vision apology superimposed on programme.
FULL	Sound or Vision apology with no programme.

The vision apology is normally a caption and the sound apology either the announcer or a recorded apology and music. The keys can be punched as required to go from one state to another and return to normal is by the switches. Each change takes place at a medium rate, not as a cut, and sync. interlock is provided.

Roving preview/prelisten facilities are provided by punching the P/V1 or P/V2 button in the select column, followed by the code for the required programme source. If this is a telecine source, then the projector concerned will be brought into the show condition, but only for so long as the second character button is held down and provided that the projector is not multiplexed on a channel which is on air, or waiting to go on air.

In a system of more limited facilities, there is no need for code punching, and a more conventional control panel such as that shown in Fig. 8 can be used. A key per code is provided to cover:

	Facility	*Codes*
2	Studios	S1 S2 C1 C2
4	Film Projectors	FA FB FC FD RT
2	Slide Projectors	F1 F2 RS (Change slide projector that is on air).
2	Incoming Network and Remote	N1 N2 G1 G2 G9
3	Separate Audio	AA AB AC CA A1 to A6
	Single Output	TP

A cross fader is used in manual control between the separate sound and programme sound rather than buttons for A1, A2, etc.

4.4. *Speed and Accuracy of Operation*

To achieve the maximum timing accuracy, it would be necessary to read a line of codes either simultaneously or sequentially with storage and then produce all the operate pulses simultaneously at the exact specified time. With sequential read-out and code pulse production, there will be a variation from specified time according to how far along the line the code is entered, but this error reduces as the read-out speed increases. This approach is preferred as equipment is reduced in sequential operation. In any case, for maximum flexibility, it is desirable to have code lines at consecutive second intervals which automatically reduces timing variations to less than a second.

The present Programmation equipment is designed to read through six time figures and up to nine two character codes per line or 24 characters. To do this in less than a second, with a margin for the operation of subsidiary circuits, requires a reader speed of 30-40 characters per second. Unfortunately, available readers are either simple with an upper limit of 20 characters per second, or not so simple photoelectric devices for many hundreds of characters per second. Whilst the equipment is designed to operate fast enough to allow code lines at consecutive seconds with fast readers, when used with the simpler readers, a minimum of two sec between lines is required.

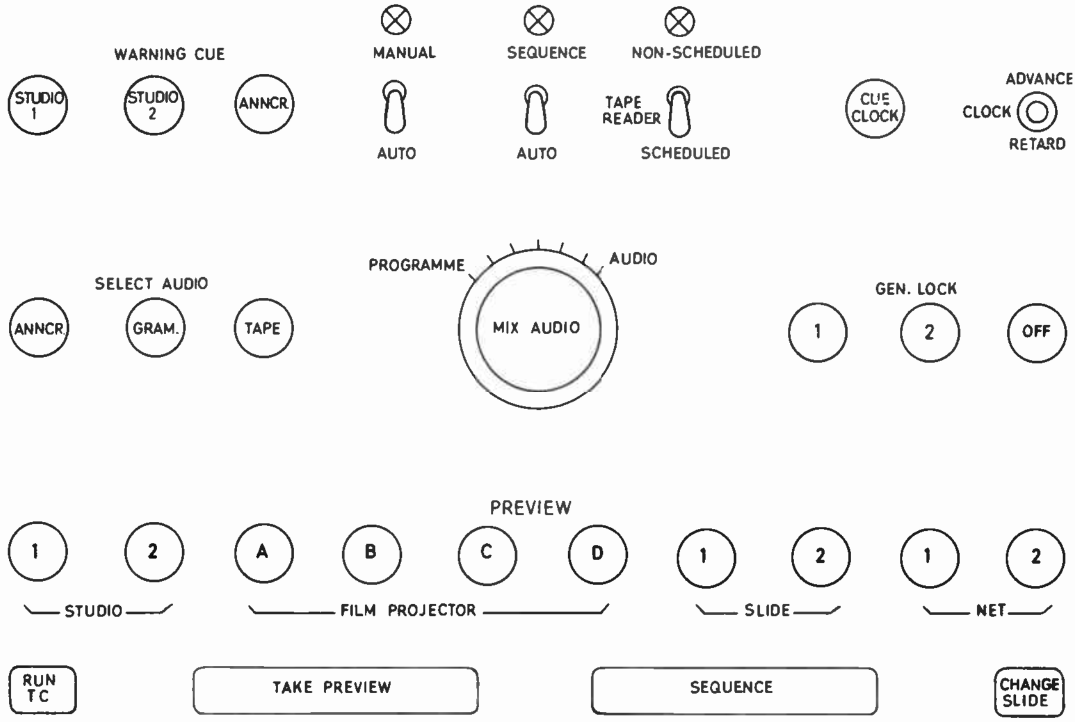


Fig. 8. Manual control panel for smaller station.

Reading at 20 per second is 50 millisec per character. The timing error is made up of two components, the first coming from the time coincidence method. If the scheduled time is, say, 12 59 25, then when the clock shows this time, it only has to move one column to the first character of the first code. But if the time was 10 00 00, then the tape would wait at the first figure until the clock reached this time; because the clock would be giving a time such as 09 23 27, so the first figures do not coincide until the actual time is reached and then the reader has to run through five extra columns before reaching the first character of the first code. Nominally this would be 250 millisec. The second error comes from the position of an operate code along a line and is nominally 100 millisec for each code position to the right. Examination of Fig. 4 shows that the position of time-sensitive codes such as the T, R and A-plus-figure codes do not vary more than two positions or 200 millisec.

Thus, even with the slow tape reader, the variation in timing is only say 0·5 sec and generally very much less than this.

4.5. *Equipment*

Space does not allow any detailed discussion of the equipment design, but a brief description will be given.

The Decoder is a conventional relay tree, manipulated to equalize contacts per relay. It employs seven high-speed plug-in relays which allows at least two contacts in parallel for each branch to increase reliability. Sequentially operating relays form a "column selector" which distributes the Decoder output to either the clocks or character combining as required, and also controls the generation of battery pulses for the position-conscious codes.

When the combinations for error, all holes and tape feed (no holes) are decoded, they make the tape reader move to the next column to skip these and the rest of the equipment is unaffected. The space code used for no column entry moves both the tape reader and column selector but produces no output pulses.

The clocks are simply small plug-in uniselectors with a few control relays. The standard clock can be set to any time for starting by dialling the time. For the time displays, a variety of devices are available among which the most popular are, respectively, a unit containing 12 miniature character projectors with a common screen, a neon tube display having 10 characters, and a multiple stack of edge illuminated characters on perspex sheets. The main requirement is that the displays should be large enough to be placed in front of the Controller with the Preview and On Air monitors. An alpha-numeric display is also desirable so that similar units can be used for code display when required.

The Manual Control Panel uses only some switches, cue lights and momentary contact buttons, and the Character Combining panel high-speed plug-in relays.

The switchers use a pair of uniselectors which alternate as preview/on air selectors with a transfer system between them. Means have been devised to make them home to a position briefly marked by the operate pulses. Uniselectors were chosen because, particularly in large systems, they are so much more economical than a relay matrix and are very suitable for colour signals. They allow up to 25 programme inputs of sound and vision. By resistive pads each vision input is split twelve ways to feed up to six selector pairs, i.e. six outputs. A five-input separate sound input selector for Announcer/grams/tape and means for cross-mixing this in any ratio with the normal programme sound are also included in the switchers.

Programme changes are made by fading down sound and vision and then fading up the new programme. The fade time is adjustable from a cut to a quite slow fade and, when required, a black screen can be held for a few seconds.

The organization of telecine in the Programmation system is not difficult and follows the usual Show, Run or Change and Off practice, but as already discussed, each projector is treated as a programme source and the system sorts out what channel this is on in the case of multiplexed equipment. No code is required to put a projector off, since this is arranged to take place automatically when it is no longer required.

5. Other Systems of Programmation

Programmation system thinking started early in 1957 and since then several other organizations have produced systems.

An ambitious automatic sound radio switching system was installed by the B.B.C. nearly ten years ago at their Skelton overseas transmitting centre.[1] This is a multiple preset system with clock control, using a plug board for presetting and uniselector switching. Since then, automation of sound radio programming has been well established in America, particularly through the work of Ampex and Gates.

In the television field, General Electric were early with a punched tape system[2] of rather limited application and accounts have now been published on four manual multiple preset systems. That at KRON-TV uses a cue clock and the paper[3] also outlines a punched card system under development. The KDKA-TV[4] system is nine preset with sequence operation only, and that at KETV[5] five preset with cue clock and sequence operation. An R.C.A. system[6] allows presetting of up to 25 events and read-out is on a count-down basis.

The N.B.C. have so far made the maximum use of automation. At their Washington station, not only is the programme switching handled by tape, but studio shows can have their switching recorded on tape during rehearsal for later use on transmission. In California, they have also installed a large automatic video tape control for time delay of programmes to other parts of the country.[7]

6. Acknowledgments

The author wishes to express his thanks to the Engineer-in-Chief of the Marconi Company for permission to publish this paper. He is also indebted to Mr. R. H. Hammans and his colleagues at Granada Television Network for their clear elucidation of many operational problems. Thanks are also due to the author's own colleagues, particularly Messrs. A. N. Heightman and R. G. Moore who have made many contributions in both system philosophy and equipment development.

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DISCUSSION

R. Barrass (Associate Member): Would Mr. Partington tell us how the return to normal procedure is effected and how the punched tape is checked against the schedule.

G. E. Partington (*in reply*): The return to normal procedure is simply by return of the apology select switches. If the programme going out is found to be the wrong one, you would simply push the two buttons in the apology section which would fade down to black. In other words, you have to treat it as a break-down, there is no alternative. This, of course, should not happen if the film and programme make-up is correct, and the routine sheet and tape are made up correctly. It is possible to go over to manual operation at any time, and when you know that the proper programme is available this would be punched up manually and, in the meantime, by manual operation, gramophone records and visual apologies, etc., can be transmitted, dependent upon the station practice.

The aim of programmation is not necessarily to take over every single operation—it can take over as much as the operating authority considers desirable.

Dealing with the question about checking the tape to make sure it is the same as the schedule, this is inherent in the system. A tape is not prepared by an operator reading the schedule and punching it, but is produced entirely automatically as a by-product of typing the stencil, so that it is only necessary to check the stencil visually by reading it. To check tapes produced separately, two are made separately and are then run together in a machine which stops when there is a difference between them, and then you determine which tape is wrong.

N. Hughes (Associate Member): What do you think is the weakest link in this automation system? Is it the tape itself, the relays, the uniselectors, or the mechanical assemblies?

G. E. Partington (*in reply*)*:* If we knew which was the weakest link we would be able to get rid of it. I don't think we are far enough ahead, but, obviously, we are taking every precaution to make everything as reliable as possible.

G. R. F. Metcalfe (Associate): You have explained in some detail how the preview system works in vision, but what about sound? Obviously, one of the prime factors with this system is that it can reduce the operational staff. If it does in fact reduce it to one man he is going to be so busy previewing and pressing buttons, that he is not going to be able to pre-listen to sound sources.

G. E. Partington (*in reply*)*:* In the Control Room for each output there are two monitors, one showing the programe on the air and the other the preview of the next programme. The switch for vision switching has in parallel a sound switch, thus providing pre-listen facilities. Most of the time, of course, the operator hasn't any buttons to press—the machine is, in fact, doing all that. When you go into it, however, you find that there are not usually more than two sounds to listen to. It is helpful to have discrete loudspeakers, since it is much easier to listen to two or three different sounds if they are coming from different positions than if they are all coming out of one loudspeaker.

H. J. C. Gower: In television programme switching operations there are two philosophies: the first states that the operation should be confined to source and destination switching, and the second includes also presentation switching such as combining "sound only" announcer with a caption source. Perhaps it is not entirely clear to us all here that the proposed equipment is of the second type and does perform certain presentation functions, although one would assume that for a more sophisticated type of presentation work one would employ a presentation suite separately from the automated programme switching equipment.

Clearly, although it has been dealt with at length already, there is, of course, the fact that the changed programme schedule will necessitate the preparation of a subsidiary tape before the transmission. In the case of programme breakdowns, there will often be no time to prepare a tape to accommodate the changed schedule, and manual operation must be resorted to.

G. E. Partington (*in reply*)*:* I can only say that experience has shown that it is surprising how quickly a schedule can be produced. In the programmation system we have tried to provide a code system which is easy to remember, and as it is used throughout one begins to think in terms of it. Operators can deal with these things more much quickly than one would imagine from first consideration.

Recommended Method of Expressing Electronic Measuring Instrument Characteristics

3. LOW FREQUENCY GENERATORS †

Prepared by the Technical Committee of the Institution and based on a report compiled by M. B. Martin (Associate Member)

Introduction

This is the third set of recommendations in a series‡ which has the objective of influencing uniformity in the presentation of information on the features, characteristics and performance of electronic measuring instruments and thus assisting in their comparative assessment and selection by potential users. The establishment of standards of performance is not an objective of these recommendations.

For the present purpose low-frequency signal generators are defined as laboratory instruments which produce unmodulated frequencies in the range 0 to 500 kc/s. The basic instrument is generally a sine-wave generator but the variants have to some extent been covered in these recommendations.

In the case of many of the features the method of expression is very similar to the recommendations for amplitude-modulated or frequency-modulated signal generators which have already been published‡.

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† Approved by the Council for publication on the 2nd December 1959. (Report No. 17.)

‡ "1. Amplitude-modulated or frequency-modulated signal generators," *J. Brit.I.R.E.*, **18**, pp. 7-16, January 1958; '2. Cathode-ray oscilloscopes," *J. Brit.I.R.E.*, **19**, pp. 29-36, January 1959; "4. Valve voltmeters," *J. Brit.I.R.E.*, **20**, April 1960. (To be published.)

U.D.C. No. 621.373.4.029.3

	FEATURE	METHOD OF EXPRESSION	REMARKS
		Part 1—GENERAL DATA	
1.1	**Power supply requirements**	.. volts d.c./a.c. .. c/s and/or battery .. watts (Voltage change ± .. %)	Maximum supply voltage variation for which the stated accuracies hold good must be given.
1.2	**Temperature range**	.. °C to .. °C	Maximum ambient temperature range for which the stated accuracies hold good with nominal power supplies.
1.3	**Accessories**		Details of any connectors and adaptors included with the instrument should be given.
1.4	**Waveforms**	Sine, square wave, etc.	
1.5	**Type**	B.f.o., r-c., etc.	Basic method of operation. Amplify as necessary.
1.6	**Construction and finish**		Where the construction conforms to a particular specification, the latter should be named.
1.7	**Valve and/or transistor complement**	Type numbers	
1.8	**Dimensions**	Height .. in. (.. cm) Width .. in. (.. cm) Depth .. in. (.. cm)	
1.9	**Weight**	.. lb (.. kg)	
		Part 2—FREQUENCY CHARACTERISTICS	
2.1	**Range**	From .. c/s to .. c/s in. .. bands	Frequency range and law of each band should be stated.
2.2	**Calibration accuracy**	.. % ± .. c/s	This is the maximum error at any value of the output frequency in relation to the calibration of the main frequency control. The type and effective scale length of the main frequency control should be given. If a built-in calibration check is fitted, state method, e.g. by tuning fork or by crystal, and effective range.
2.3	**Re-setting accuracy**	.. %	This is the re-setting accuracy of the main frequency control.

FEATURE	METHOD OF EXPRESSION	REMARKS
2.4 Incremental frequency	YES/NO	
2.4.1 Range	± .. % at .. c/s	This is the frequency range of the incremental control expressed as a percentage of the main dial calibration. The method used to provide incremental tuning should be stated.
2.4.2 Setting accuracy	.. % at .. c/s	This is the maximum error in any value of Δf expressed as a percentage of the output frequency.
2.5 Load reaction	.. % at .. c/s	This is the maximum change in frequency between open-circuit condition of the outlet and when loaded with a resistance equal to the nominal load impedance, with the attenuator at the reference setting.
2.6 Distortion		
2.6.1 Sine wave distortion	.. % of harmonics present at maximum rated output.	Preferably given in the form of curves: distortion / frequency, distortion / harmonics, distortion / output. Effect of mains hum must be included.
2.6.2 Square waveform	Rise time .. microsec Sag within .. %	
2.7 Drift		
2.7.1 Short term	.. % at .. c/s	This is the maximum change in frequency over any period of 10 min within a 7-hr period commencing 60 min after switching on. During the 10-min period the supply voltage and the temperature are assumed to be sensibly constant.
2.7.2 Long term	.. % at .. c/s	This is the maximum change in frequency over a period of 7 hr commencing 60 min after switching on. During this 7-hr period the supply voltage and the temperature are assumed to be sensibly constant.
2.8 Sweep facilities	YES/NO	State whether logarithmic or linear, whether with internal or external drive, and whether electrical or mechanical.
2.8.1 Sweep band	.. c/s to .. c/s	
2.8.2 Sweep speed	.. sec per band; if log, .. octaves/sec.	
2.8.3 Output constancy	± .. db over band	
2.8.4 External drive torque	.. oz. in. at input shaft.	If the drive shaft can be coupled to a pen or other recorder this should be stated.

Part 3 — OUTPUT LEVEL CHARACTERISTICS

	FEATURE	METHOD OF EXPRESSION	REMARKS
3.1	**Output level variation with frequency**	± .. db over full range *or* ± .. db from .. c/s to .. c/s and ± .. db from .. c/s to .. c/s and ± .. db from .. c/s to .. c/s	If the second manner of expression is used, the first figures quoted should be for the more constant portion of the range, i.e. the mid-section.
3.2	**Drift of level with time**	± .. db	This is the maximum change in the reference level over any period of 10 min in 7 hr commencing 60 min after switching on, without resetting the level monitor. A constant supply voltage is assumed.
3.3	**Output load impedance**	.. Ω	State whether balanced, unbalanced or floating. State whether switchable internal load is provided.
3.4	**Source impedance**	.. Ω	
3.5	**Internal attenuator**	YES/NO	
3.5.1	Loss range	0 to .. db in .. db steps.	
3.5.2	Accuracy	Within .. db over frequency range of the oscillator.	
3.5.3	Attenuator characteristic impedance	.. Ω	
3.6	**Maximum power output**	.. W	
3.7	**Hum and noise**	.. db down on max. output	
3.8	**Output level meter**		State principle of calibration.
3.9	**D.c. content**	.. % of max. output	
3.10	**Multi-phase output facilities**	YES/NO	
3.10.1	Angular relationship and accuracy	.. ° and .. ° lead or lag ± .. °	If the phase relationships are variable state the setting and resetting accuracies.
3.10.2	Output levels	.. V across .. Ω per phase	

Waveform Distortion in Television Links †

by

I. F. MACDIARMID ‡

A paper read on 4th July 1959 during the Institution's Convention in Cambridge.

Summary: The linear transmission performance of television links is now measured and specified in terms of their response to certain standardized test waveforms. The aim of the paper is to provide a simple non-mathematical introduction to the basic ideas connected with the measurement of waveform distortion. A number of examples of simple waveform distortions are given to illustrate the advantages of waveform measurements and their connection with the more familiar steady-state responses. The application of tolerance limits to waveform responses is then considered and an outline is given of the routine - and acceptance-test methods of determining the rating factor of a link. Finally a brief introduction is given to the basic ideas of the correction of waveform distortion without reference to the conventional steady-state measurement and equalization techniques.

1. Introduction

The concepts of sine-wave transmission and the methods of sine-wave circuit analysis are so firmly fixed in the minds of some engineers that they find the greatest difficulty in thinking in any other terms. In the case of speech or music transmission the exact reproduction of the original waveform is not important (subject to certain rather wide restrictions) provided that the magnitudes of its spectral components are reproduced accurately. The sine-wave concepts then yield enormous advantages in respect of simplicity of thinking and analysis. In the case of television transmission, however, the exact reproduction of waveform is an essential for distortionless transmission and in what may be termed "sine-wave thinking" this means that the phases of the spectral components of the waveform must be considered in addition to the magnitudes. This requirement, together with another difficulty concerning tolerances which will be mentioned later, adds so much complication to the methods of sine-wave thinking that, for many purposes concerned with television transmission, it is worth while to abandon the familiar sine-wave ideas and think directly in terms of some more relevant waveform.

The purpose of this paper is to give in simple terms some methods of thinking of waveform distortions which have proved useful in studying and designing links for the transmission of television signals and, as examples of these methods of thinking, to describe means of measuring and correcting waveform distortions in practical systems.

The following remarks apply to all that follows and are given now to avoid making the paper difficult to follow by virtue of frequent restrictions and provisos.

(*a*) The distortions which are referred to are all linear distortions, i.e. the distortion is independent of the magnitude of the applied signal.

(*b*) Examples and comments with respect to television systems all apply directly to the British 405-line 3-Mc/s system but with appropriate modifications would also apply to systems working on other standards.

(*c*) It is the author's aim to present an introduction to and way of thinking of the problems of waveform distortion in as simple and non-mathematical a manner as possible; consequently a number of statements will be made which are only approximately true or are subject to certain restrictions. These restrictions will be pointed out only if they are likely to be important in practice. Various text-books and specialized papers are available to those who wish to study the subject more fully.

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‡ Post Office Research Station, London, N.W.2.

U.D.C. No. 621.397.743:621.3.018.78

2. Waveform Distortion

2.1. *Choice of Test Waveform*

Before one can start thinking in terms of waveform response it is necessary to have in mind a suitable test waveform or waveforms.

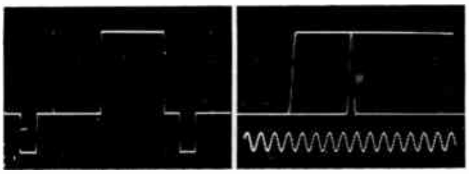

(*a*) (*b*)

Fig. 1. Pulse and bar waveform. (a) Complete waveform (2*T*). (b) 2*T* sine-squared pulse and bar edge on expanded time scale. The timing wave is 1 Mc/s.

Much has been written on this subject[1–5] and it is not proposed to elaborate on it here. The waveforms now used for the British 405-line system are the pulse-and-bar waveform illustrated in Fig. 1 and the 50-c/s square-wave which is mentioned later. Fig. 1(a) shows a complete cycle of the pulse-and-bar waveform and Fig. 1(b) shows the detail of both the pulse and one edge of the bar on an expanded time scale, this display being obtained by arranging the oscilloscope time-base to trigger twice in the 100-microsecond repetition period.

Two alternative widths of sine-squared pulse are used, the narrower one having a half-amplitude duration *T*, where *T* is the reciprocal of twice the nominal upper frequency limit of the television system ($T = 1/6$ microsec for the British 3-Mc/s system), and the wider one a half-amplitude duration 2*T*.

The frequency spectrum of the 2*T*-pulse is effectively confined to the 3-Mc/s bandwidth and consequently this pulse should be transmitted

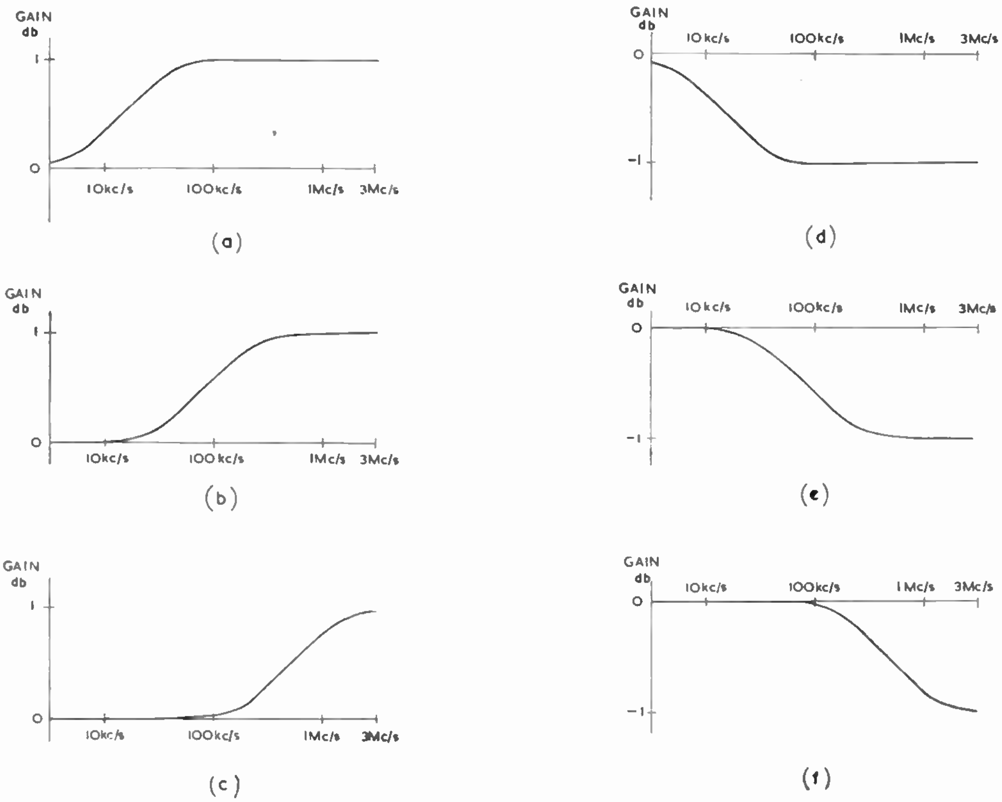


Fig. 2. Gain/frequency responses of exponential overshoot and undershoot distortions. (a), (b) and (c) are overshoot distortions of time-constant 12, 2 and ¼ microsec. (d), (e) and (f) are undershoot distortions of time-constant 12, 2, and ¼ microsec.

without any change of shape. On the other hand the spectrum of the T-pulse extends to 6 Mc/s and a cut-off near 3 Mc/s will therefore cause a change of shape, as will be seen later.

2.2. *Examples of Waveform Distortion*

As an introduction to thinking in terms of waveform responses it is instructive to consider some simple examples of waveform distortion. The examples considered first will all relate to minimum-phase-shift networks.[6] In this class of network, which includes most commonly used networks other than phase equalizers, the phase/frequency characteristic is uniquely related to the amplitude/frequency characteristic, taken over the whole frequency range from zero to infinity, and in most cases it is only necessary to consider the latter.

2.2.1. Exponential overshoots and undershoots

A simple class of waveform distortion which can be produced by various combinations of resistance and capacitance, or resistance and inductance, is illustrated in Figs. 2 and 3. Figure 2 shows the gain/frequency characteristics of the distortions, normalized to zero gain at low frequencies. The corresponding waveform distortions are shown in Fig. 3 which shows the response to the $2T$ pulse-and-bar waveform. In the cases where the high-frequency gain exceeds that at low frequencies the step response overshoots its final amplitude and returns to it on an exponential whose time-constant is related inversely to the frequency at which the distortion occurs. Similarly where the high-frequency gain is reduced the step response undershoots its final value and rises more slowly on an exponential similarly related to the frequency of the distortion. The magnitude of the overshoot or undershoot is related to the magnitude of the gain change. For small values of distortion where the time-constant of the exponential is long compared with the rise time of the step, the overshoot or undershoot expressed as a percentage of the final value of the step response is numerically equal to the percentage change in gain expressed as a voltage ratio. Figures 2 and 3 also show that distortions at low frequencies produce a waveform distortion with a long time-constant while distortions at higher frequencies produce waveform distortions with shorter time-constants. In addition they show that the bar is much more sensitive to low-frequency distortion than the pulse, but with the highest frequency illustrated the effect on the $2T$ pulse is more easily identified than that on the bar.

2.2.2. Resonant networks

A greater variety of responses is possible with resonant networks than with the non-resonant ones considered above. However only two have been selected for illustration. The gain/frequency characteristics are shown in Fig. 4 and the wave-

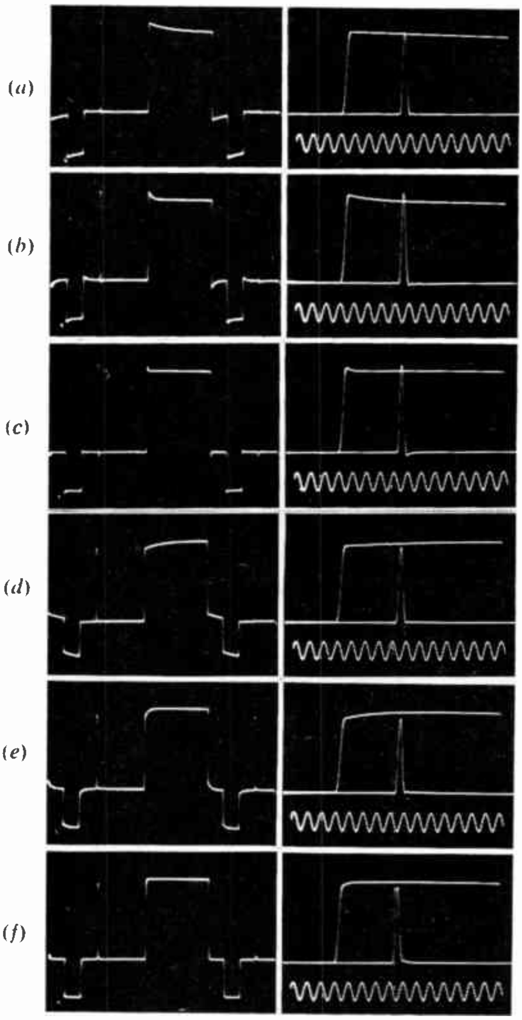


Fig. 3. Waveform responses of exponential overshoot and undershoot distortions. (a), (b) and (c) are overshoot distortions of time-constant 12, 2 and ⅓ microsec. (d) (e) and (f) are undershoot distortions of time-constant 12, 2 and ⅓ microsec.

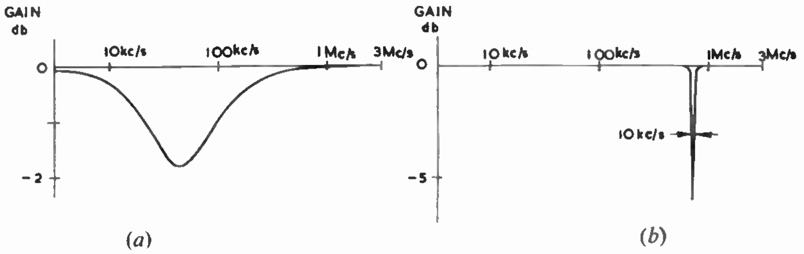


Fig. 4. Gain/frequency responses of resonant networks. (a) Flatly tuned 44-kc/s resonant network. (b) Sharply tuned 710-kc/s resonant network.

form responses in Fig. 5. The first network, Fig. 4(a) and 5(a), is very flatly tuned to 44 kc/s causing a dip of less than 2 db at this frequency. The effect on the bar response is very large. The network in Fig. 4(b) and 5(b) is sharply tuned to 710 kc/s causing the gain to dip by 6 db at this frequency. The effect on the waveform is to produce a lightly-damped oscillation following the pulse and the bar edge. The frequency of the oscillation, or "ringing" as it is often called, is the same as the frequency at which the gain dip occurs and the initial amplitude and the damping factor are determined mainly by the width of the dip and only to a minor extent by its magnitude provided this is large.

These distortions illustrate the difficulty of setting limits on the steady-state response when limits on the waveform response are really required. The case with the largest departure from a flat gain/frequency response gives a comparatively trivial waveform distortion while the case with the small departure from flatness gives a large waveform distortion. The latter is interesting because the gain/frequency and phase/frequency responses fit just inside an early (now superseded) specification for television links. The resulting serious waveform distortion produces streaking on a television picture of a magnitude which would be regarded as intolerable by most viewers.

2.2.3. Echoes

Echoes are produced by a signal arriving at its destination over two different paths having different time delays. In the case of radiated signals the receiver may pick up a direct signal plus an indirect one reflected from some large building. When the signals are confined to cables, echoes can be produced by reflections from impedance mismatches.

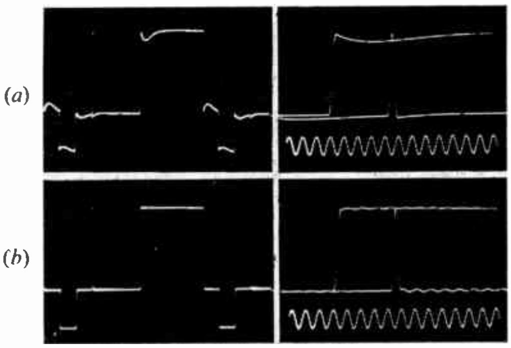
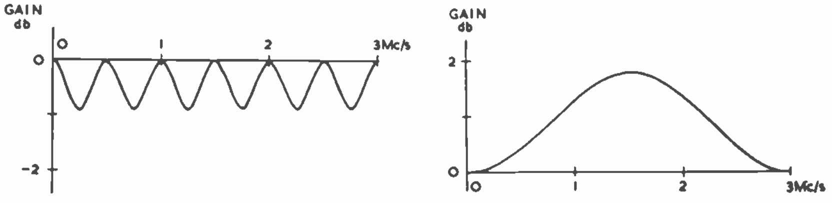


Fig. 5. Waveform responses of resonant networks. (a) Flatly tuned 44-kc/s resonant network. (b) Sharply tuned 710-kc/s resonant network.

Figures 6 and 7 show the gain/frequency and waveform responses corresponding to two echoes with different time delays. The echo with the longer delay can be seen in Fig. 7(a) to be a small replica of the pulse, following it by 2 microseconds, while a replica of the bar edge also follows the bar edge by 2 microseconds. In the cases illustrated the echoes are undistorted but in practice an echo signal, having travelled a greater distance, may itself have suffered waveform distortion.

The echo shown in Fig. 7(b) is inverted and delayed by $\frac{1}{3}$ microsecond. At this short delay the echo is not separated from the $2T$ pulse and looks rather similar to the exponential overshoot shown in Fig. 2(c). The similarity is not so surprising when the gain/frequency responses are compared, when they will be seen to have the same general character within the range explored by the $2T$ pulse.

A result which can be inferred from Figs. 6 and 7 is that a distortion spread over a large part of the frequency spectrum tends to produce a waveform distortion which is localized in time. The converse is also true as is illustrated in Figs. 4(b) and 5(b).



(a) (b)

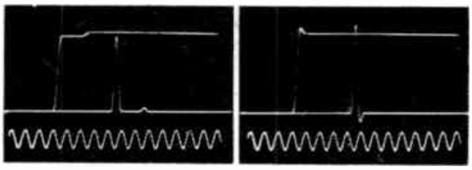
Fig. 6. Gain/frequency responses of echo distortions. (a) 5% erect echo at 2 microsec. (b) 10% inverted echo at $\frac{1}{3}$ microsec.

The sinusoidal ripple in Fig. 6(a) is not unlike the result which may be obtained in equalizing a long cable link by conventional means. In fact quasi-echoes are often produced by equalization tolerances. It can be seen that if the effect of more enthusiastic equalization is merely to reduce the pitch of the ripple without changing its amplitude the effect on the waveform response is to produce an echo of the same size but with a greater delay where it will be more difficult to deal with.

In addition to being a form of distortion met in practice, the echo is also of theoretical importance. By extending the concept of the echo to include echoes arriving before the main signal as well as after it, Wheeler[7] has shown that in a finite bandwidth any distortion of the gain/frequency or phase/frequency characteristics or of both can be represented by a pattern of echoes. This can be done by making a Fourier analysis of, say, the gain/frequency characteristic to express it as a series of sinusoidal terms of different pitch (Fig. 6 could represent two such terms) each of which terms is then identified with a pair of symmetrically placed echoes. A similar process is then used on the phase/frequency characteristic. It is not proposed to go further into Wheeler's method here, but the idea of expressing distortions in terms of echoes is important and will be referred to later.

2.2.4. Bandwidth restriction

Bandwidth restriction is not strictly speaking a waveform distortion and it is a fundamental feature of any practical television system. Bandwidth costs money and no more bandwidth can usually be allocated to a television circuit than is absolutely essential. It is therefore important to see what happens to the waveform response when the bandwidth is restricted.



(*a*) (*b*)

Fig. 7. Waveform responses of echo distortions. (a) 5% erect echo at 2 microsec. (b) 10% inverted echo at $\frac{1}{3}$ microsec.

Figures 8 and 9 show the gain/frequency characteristics and waveform responses corresponding to two different methods of bandwidth restriction, the upper frequency limit being 3 Mc/s. A slow cut-off, produced in this example by a 2*T* sine-squared shaping network, is shown in Figs. 8(a) and 9(a). The shapes of the *T* and 2*T* pulses in Fig. 9(a) are not greatly altered except that they are widened and their amplitudes are reduced.

It is appropriate to point out at this stage that in a low-pass system the area under a pulse is a constant, because the area represents the d.c. component of the pulse. This means that any distortion which widens a pulse, or adds positive skirts to it, must reduce its height relative to the bar, while any distortion causing overshoot adds negative area and thus causes the height of the pulse to increase.

The other type of bandwidth restriction, shown in Figs. 8(b) and 9(b), is the sharp cut-off, produced in this example by a filter which has virtually no attenuation distortion below 3 Mc/s but which cuts off sharply above this frequency. It will be seen that the filter has little effect on the 2*T* response but reduces the height of the *T* pulse and causes a damped oscillation or ringing to follow both the pulse and the bar edge. The reduction in *T* pulse height is however not nearly as great as that produced by the slow cut-off. These two

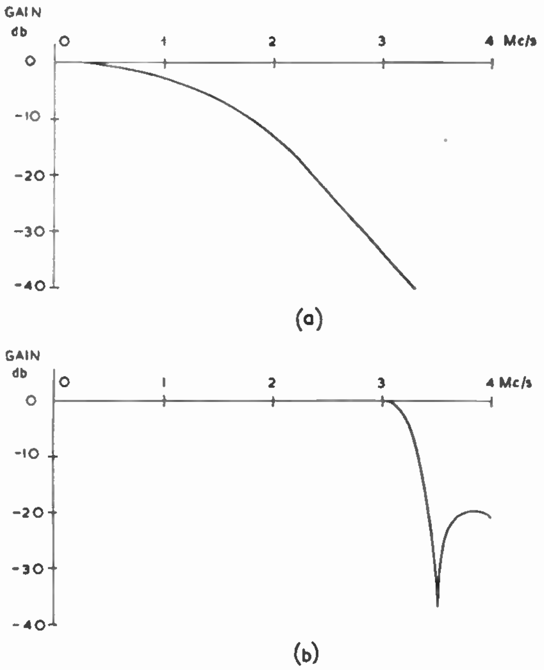


Fig. 8. Gain/frequency responses of bandwidth restricting networks. (a) Slow cut-off produced by $\frac{1}{3}$-microsec sine-squared pulse-shaping network. (b) Rapid cut-off produced by 3·2-Mc/s low pass filter.

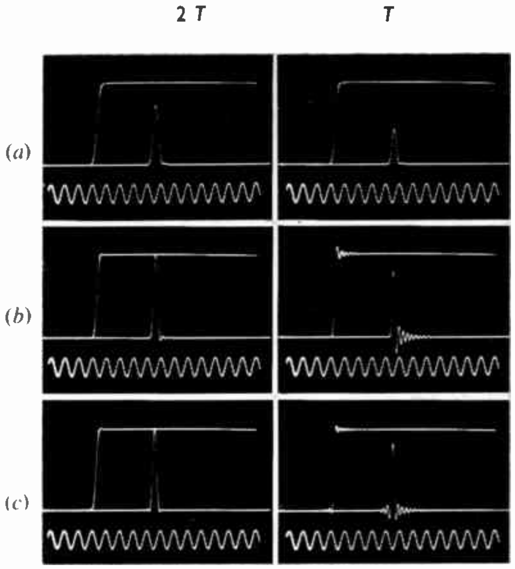


Fig. 9. Waveform responses of bandwidth restricting networks. (a) $\frac{1}{3}$-microsec sine-squared pulse-shaping network. (b) 3·2-Mc/s low pass filter. (c) Phase equalized 3·2-Mc/s low pass filter.

examples represent extremes of cut-off characteristic. Intermediate shapes of cut-off characteristic are possible and will have intermediate waveform responses; for example an intermediate shape, still developing a large loss at frequencies above 3 Mc/s, will give $2T$ and T pulse heights greater than in Fig. 9(a) but less than in Fig. 9(b) and the ringing which follows the T pulse will also be less than in Fig. 9(b). Because the heights of the $2T$ and T pulses are important in a television picture as they represent the brightness with which fine details are reproduced, the cut-off characteristic of Fig. 8(b) seems to be the most desirable provided that the ringing is not a limiting factor.

The filter whose response is shown in Fig. 9(b) has a negligible variation of gain up to 3 Mc/s but has a substantial phase distortion in the pass band. If this phase distortion is reduced by adding a suitable phase-equalizer the waveform response becomes as shown in Fig. 9(c). It can be seen that the principal effect of phase equalization is to reduce the amplitude of the ring on the right-hand side of the T pulse response and introduce a ring of almost equal size on the left hand side. Less noticeable effects are the slight improvement of the $2T$ response and a slight increase in the height of the T pulse. These latter effects are more important when the phase distortion is greater than that of the filter used for the illustrations.

The phase-equalized sharp cut-off filter is therefore the type of network which gives the largest heights to the T and $2T$ pulse responses consistent with negligible distortion of the $2T$ pulse shape and minimum ringing on the T pulse. The filter used is a practical approximation to the physically unrealizable "ideal low-pass filter". This has zero attenuation distortion and zero phase distortion in its pass band, an infinitely steep cut-off, and infinite attenuation in the stop band. The waveform response of the ideal filter can be calculated, e.g. the response of a 3-Mc/s filter to the T pulse has a pulse height of 82 per cent of the bar, a half-amplitude duration of 0·223 microsec, a first overshoot of 13 per cent of the pulse height and completely symmetrical ringing on the two sides of the pulse, the ringing frequency being 3Mc/s. The ideal low-pass filter represents the performance target for long television links on cable where the transmission band must be terminated sharply for economic reasons. If individual links can be made to approximate sufficiently closely to the ideal filter characteristics, the waveform response at the end of a number of links in tandem will be the same as that of one link.

2.2.5. Attenuation and phase distortions

With the exception of the phase-equalized filter all the distortions so far discussed have been of the minimum-phase-shift type in which the phase distortion is uniquely related to the attenuation distortion over the whole frequency range from zero to infinity and need not be considered separately. It is, however, of interest to know how the attenuation and phase distortions taken separately affect the waveform response. As it is not proposed to occupy space in a paper on waveform distortion with discussion of the difficulties of measuring phase distortion and of expressing the results in a useful manner, an example is given entirely in terms of waveform response without reference to the actual values of steady-state distortion. The example selected is of a distortion which is entirely confined to the frequency band explored by a $2T$ pulse and is not complicated by effects caused by a cut-off.

Figure 10(a) shows the waveform distortion of the minimum-phase-shift type which is not unlike the exponential undershoot shown in Fig. 3. The waveform response of the attenuation distortion only is shown in Fig. 10(b) while that of the phase distortion only is shown in Fig. 10(c). It can be seen that the attenuation distortion gives a sine-squared pulse response which is completely symmetrical about the centre line through the pulse. This is the feature of a sine-squared pulse response which enables the absence of phase distortion to be verified. Referring back to Figs. 9(b) and 9(c) it can be seen that the addition of the phase equalizer to the filter makes the ringing, caused by the filter cut-off (attenuation distortion), very nearly symmetrical and the lack of complete symmetry is a measure of the imperfection of the correction of the phase distortion.

The effect of phase distortion only is to produce a pulse response which is skew-symmetrical about the centre line in the manner shown in Fig. 10(c). The height of the pulse is not materially affected in this case as equal positive and negative areas are added to it. This is an approximation which applies only when the amount of phase distortion is modest as in the example chosen.

Comparison of Figs. 10(b) and (c) with Fig. 10(a) shows that on the right-hand side of the pulse the distortion is of the same size and shape in (b) and (c) and each is about one-half the size of the distortion in (a). On the left-hand side of the pulse the distortions in (b) and (c) are also of about the same size and shape but of opposite sign while in (a) there is no distortion on the left-hand side. It can be seen from this that when the attenuation and phase distortions are combined to give the minimum-phase-shift case, the distortions on the left-hand side of the pulse cancel while those on the right-hand side add. The attenuation and phase distortions in a minimum-phase-shift network of the type used in the example therefore contribute equally to the waveform distortion which normally always appears on the right-hand side of the pulse. The appearance of distortions on the left-hand side as in Figs. 9(c), 10(b) and 10(c) is at first sight rather mysterious as it suggests that the network being tested is giving an output in anticipation of the input signal being applied. This is clearly not possible and any network having a distortion on the left-hand side of the pulse reponse must contain a delay, equal at least to the time between

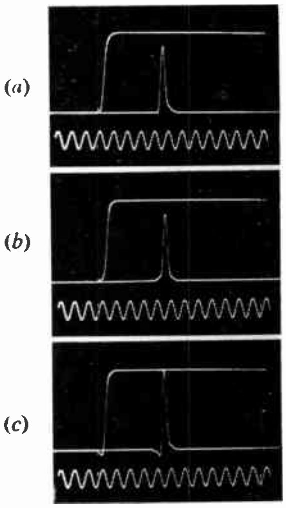


Fig. 10. Waveform responses of attenuation and phase distortions. (a) Both attenuation and phase distortion. (b) Attenuation distortion only. (c) Phase distortion only.

the beginning of the distortion and the beginning of the pulse.

The statement made above that the attenuation and phase distortions contribute equally to the waveform distortion is an approximation which applies only to distortions of the type considered. Another case of practical importance is where the attenuation distortion occurs outside the frequency band of interest. Consider, for example, a low-pass filter with no attenuation distortion in its pass-band up to say 3 Mc/s, and then a rapid cut-off to a stop-band attenuation of say 40 db, which is constant at all frequencies up to infinity. The waveform response of such a filter would be not unlike that shown in Fig. 9(b). If now the stop-band attenuation were increased to say 120 db, for example by connecting three similar filters in cascade, the effect of the increased attenuation on the waveform would be negligible because one 40-db filter will already reduce all the spectral components of the pulse above 3 Mc/s to negligible proportions. However, in a minimum-phase-shift network, the phase-shift at any frequency depends on the attenuation over the whole frequency range from zero to infinity.[6] The increase in attenuation above 3 Mc/s will therefore cause increased phase distortion below 3 Mc/s and this can have a considerable effect on the waveform response. In transmission systems having a sharp cut-off, the phase distortion in the pass-band can have a very much greater effect on the waveform response than any small attenuation distortion which exists in the pass-band. This case is of practical importance when considering long cable links where enormous attenuations exist outside the pass-band. The waveform distortion in such cases may be caused entirely by the phase distortion and will take the form of a reduction in *T*-pulse height, an increase in half-amplitude duration and a very large-amplitude ring on the right-hand side of the pulse. The benefits of phase equalization in such a case are much more striking than in the example shown in Figs. 9(b) and (c).

2.3. *Summary of Section* 2

The waveform distortions which have been shown are, with the exception of Figs. 10(b) and 10(c), typical of distortions which may occur in television links and equipment, although in practice they do not often occur singly and may therefore be more difficult to identify. The examples illustrate some of the advantages of the pulse-and-bar waveform as a sensitive test signal for showing distortions and indicate how different types of distortion occurring in different parts of the frequency spectrum are shown up by the pulse-and-bar waveform. They also illustrate some of the difficulties in putting limits on steady-state characteristics when limits on waveform distortion are the primary requirement. In most of the examples, phase distortion contributes equally with attenuation distortion to produce the total waveform distortion, but in some practical cases the effect of the phase distortion may predominate. Attenuation distortion without phase distortion is rare in television links but in picture generating and reproducing equipment, aperture distortion, caused by the finite size of a scanning spot, is of this type.

3. The Measurement and Specification of Waveform Distortion

3.1. *The Rating Factor*

The desirability of measuring waveform distortions in a manner which is quantitatively related to the subjective impairment of television pictures should be obvious. A method of doing this was proposed by Dr. N. W. Lewis[3] in 1954 and has been used successfully by the Post Office and other organizations since that date. There is little to be added to the 1954 paper but it seems desirable to include a brief description of the method together with some explanatory comment based mainly on questions which have been posed verbally to Dr. Lewis and the author from time to time.

The basic aim is to find a method of placing tolerance limits on waveform responses such that for a tolerance of given size the picture impairment would be the same irrespective of how the waveform reached the limits. To meet the need to have limits of various degrees of stringency to suit the different requirements for individual items of equipment or complex chains of links, the limits are expressed numerically in terms of a rating factor, *K*, whose value can be chosen to suit the individual requirements. For example, it is recommended that, for the 405-line system, an international "hypothetical reference circuit" (a 2500-km circuit with two intermediate video interconnexion points) should have a rating factor not exceeding 5 per cent, while a short video link on coaxial cable (up to 6 miles) can have a rating factor of less than 0·5 per cent and a single video amplifier, less than 0·25 per cent.

The standard of comparison, used in comparing subjectively the effects of different types of distortion, is a single undistorted echo with a time delay greater than 4/3 microsec. The relative amplitude of this echo is numerically equal to the rating factor, i.e. a 5 per cent. echo at 2 microsec has a rating factor of 5 per cent. Any other type of distortion with a rating factor of 5 per cent should give approximately the same degree of picture impairment when judged subjectively. It should be pointed out that in comparisons of this sort there is always a very large spread of opinion—two distortions, judged to be equal by one viewer, may give an entirely different impression to another. The waveform limits used in determining the rating factor have been arrived at partly from theoretical considerations, partly from the measurement of distortions on a large number of links, and partly from subjective observations of a large variety of distortions by a small number of experienced observers, viewing under very critical conditions. The rating system is therefore essentially empirical but experience has not yet shown the need for any change in the limits since they were first introduced.

The rating system can be used in two different ways. It can be used either as a GO/NO-GO gauge to determine whether or not a link is meeting some prescribed standard of performance, or as a means of expressing the results of measurements on a link. In the latter case several different values of K are obtained corresponding to different features of the waveform response. When it is desired to express the performance of the link by a single figure the largest of the measured values of K is taken.

Two different methods of measuring the rating factor are available which are known as the "Routine-Test Method" and the "Acceptance-Test Method". In the former, the rating factor is obtained directly from measurements on the oscilloscope using graticules and, as the name implies, the method is suitable for routine tests and many similar purposes where a quick answer is required and where simplicity is important. The acceptance-test method is more complicated and involves making microscope measurements from photographs of the waveform and calculating the rating factor from these measurements. This method gives greater accuracy than the routine-test method at the cost of speed and complication.

3.2.1. Routine-test method

The response to the $2T$ pulse-and-bar test waveform is measured with the aid of graticules of the type shown in Figs. 11(a) and (b). The actual graticules must of course be engraved for some specific value or values of K. For example the limits shown for the top of the bar in Fig. 11(a) would be at 1·04 and 0·96 for $K = 4\%$.

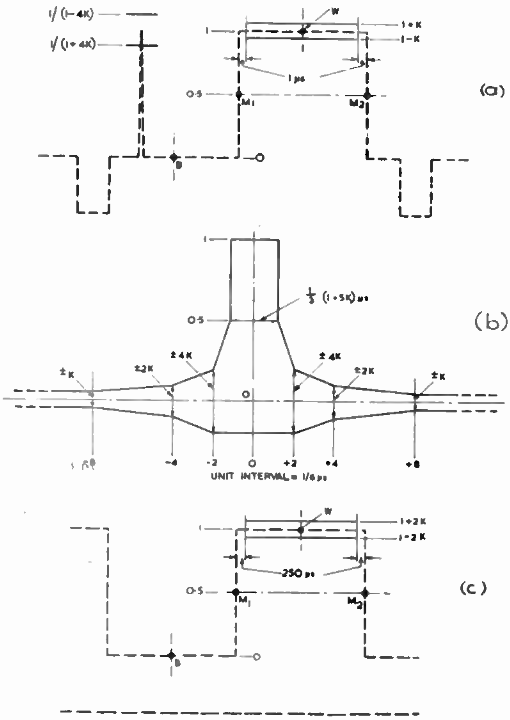


Fig. 11. Waveform-response limits. (a) Response to $2T$ pulse-and-bar test signal. (b) Response to $2T$-pulse test signal. (c) Response to 50-c/s square-wave test signal.

It is convenient to have limits for two values of K on a single graticule, e.g. 2% and 4%, other values being obtained by interpolation. Where the range of values of K encountered is very large it may be necessary to have more than one graticule of each type to cover the range.

Using the graticule in Fig. 11(a), the oscilloscope controls are adjusted so that the trace coincides with the reference points B, W, M1 and M2. The top of the bar is inspected to see whether or not the response is within the appropriate limits or, alternatively, the value of K for the top of the bar can be estimated by interpolation. The first microsecond of the response on either side of the transitions is excluded from this measurement, as distortion in this range is indicated more sensitively by the response to the sine-squared pulse. The same graticule shows limits for the height of the $2T$ pulse with respect to the bar; this is another feature of the waveform response used in determining the rating factor.

The shape of the $2T$ sine-squared pulse is next inspected using the graticule in Fig. 11(b). The oscilloscope controls are adjusted so that the trace has the same amplitude as the graticule and is placed centrally in it with the correct time scale. The time scale can be set most conveniently by adjusting the time-base controls to make a timing-wave, temporarily replacing the incoming signal, coincide with suitable reference marks on the graticule. As before, the graticule can be used to determine whether or not the $2T$ pulse response is within limits or, alternatively, the rating factor of the worst feature of the response. The shape of the limits on this graticule takes account of the fact that distortions such as echoes having short time delays are less visible on a picture than the same distortions with longer time delays.

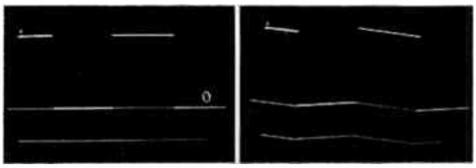
The spectrum of the $2T$ pulse-and-bar waveform is confined to a 3-Mc/s bandwith and consequently there is no difficulty in placing limits on its waveform response. The T-pulse, however, has a spectrum extending to about 6 Mc/s and the response of a link to a T-pulse therefore depends not only on its performance up to 3 Mc/s but also on its performance between 3 and 6 Mc/s which is largely irrelevant to its suitability for passing 405-line pictures. It is therefore not possible to place hard-and-fast T-pulse limits on the response of a link using the routine-test method. However a few features of the T-pulse response are measured and compared with measurements made when the link was first lined up so that any deterioration may be detected. The features to be measured together with some very tentative figures corresponding to various rating factors are shown in Table 1. The figures in Table 1 refer only to links having a relatively sharp cut-off just above 3 Mc/s and even in this case can only be used as an empirical guide. It may be convenient to measure the bar/T-pulse amplitude ratio in addition to the features shown in Table 1. Distortions affecting the half-amplitude duration of the T-pulse will in most cases also affect the bar/T-pulse amplitude ratio and it is easier to detect small changes in this quantity than in the half-amplitude duration.

The pulse-and-bar test signal is only useful in measuring distortions at frequencies above the line-repetition frequency (10 kc/s) although phase distortion above this frequency, associated with attenuation distortion below this frequency, may affect the flatness of the bar top. The distortion at lower frequencies is measured by the response to a 50-c/s square-wave with added line-synchronizing pulses. The limits for this signal are shown in Fig. 11(c) but the graticule intended for the bar (Fig. 11(a)) may be used if the tolerance is made twice as great, i.e. limits giving $K = 4\%$ for the bar correspond to $K = 2\%$ for the 50-c/s square-wave. The test signal and an example of distortion are shown in Fig. 12. Distortion of this type will normally be removed completely

Table 1

Features	Rating factors					
	1%	2%	3%	4%	5%	6%
Half-amplitude duration, maximum, μsec	0·245	0·250	0·255	0·260	0·265	0·270
Ringing frequency, minimum, Mc/s	3	3	3	3	3	3
First lobe (negative), leading or trailing, maximum, %	10	12	14	16	18	20
Second lobe (positive), leading or trailing, maximum, %	6	8	9	10	11	12

by a black-level clamp at the television transmitter and so it is in a rather different category from the other types of waveform distortion. For this reason the rating factor for the 50-c/s square-wave is often quoted separately from that for other waveform distortions.



(*a*) (*b*)

Fig. 12. 50-c/s square-wave test signal. (a) Test signal. (b) Example of distortion.

The waveform responses of a number of television links together with their rating factors have been published.[3] It may be of interest to give the rating factors of the various illustrative distortions used in this paper. Table 2 shows the figures obtained by the routine-test method for the different features measured and the overall rating factors. Comparison of these figures with the gain/frequency responses given earlier confirms that, even for distortions of a similar type (e.g. Figs. 3(a) and 3(c) or Figs. 7(a) and 7(b)), the steady-state tolerances have no direct connection with the rating factor.

3.2.2. Acceptance-test method

A detailed description of the procedures used in the acceptance-test method of determining the rating factor would be out of place in this introductory account of waveform measuring methods. Two papers by Lewis[3, 8] give full details of the processes used and should be consulted by anyone intending to use the method. A brief outline of the principles will, however, be given here as they contribute to a better understanding of waveform distortion.

The limits on the response to the bar and 50-c/s square-wave test signals are the same as in the routine-test method and so will not be considered further. The 2*T* sine-squared pulse is not used in the acceptance-test method. The response to the *T*-pulse is photographed with a suitable timing wave on the same negative. A photograph showing the *T*-pulse response of the test equipment alone is also required. The photograph of the link response is adjusted in the measuring microscope so that the axes of

Table 2

Rating Factors by the Routine-Test Method.

Waveform shown in Fig. No.	Bar response %	2*T* bar/pulse ratio %	2*T* pulse shape %	*T*-pulse %	50-c/s square-wave %	Overall rating factor *K*%
3(a)	6	−2·5	<0·5	—	—	6
3(b)	6	−2·5	1	—	—	6
3(c)	<0·5	−1·5	1	—	—	1·5
3(d)	6	+2·5	<0·5	—	—	6
3(e)	6	+2·5	1	—	—	6
3(f)	<0·5	+1·5	1	—	—	1·5
5(a)	13	0·5	2	—	—	13
5(b)	0·5	0	1·5	—	—	1·5
7(a)	5	+1·2	5	—	—	5
7(b)	0	−2·5	2·5	—	—	2·5
9(a)	0	10	6	17†	—	17
9(b)	0	0	1	2·4†	—	2·4
9(c)	<0·5	<0·5	<0·5	<0·5	—	<0·5
10(a)	0	6	4·5	—	—	6
10(b)	0	6	2	—	—	6
10(c)	0	<0·5	2	—	—	2
12(b)	—	—	—	—	2	2

† These figures are calculated by the acceptance-test method.

the pulse response are aligned with the microscope co-ordinates. The point mid-way between the half-amplitude points on the pulse is located and this position is used as the time reference point. The timing wave is used to determine a series of points spaced at 1/12-microsec intervals on both sides of the time reference point and the amplitude of the waveform measured at each of these times. This is equivalent to the sampling of a waveform in a time-division multiplex system and the series of samples so obtained (called a "time series" in this case) completely describes the waveform provided that its spectrum contains no components above 6 Mc/s. The use of a sine-squared pulse ensures that this condition is met for all practical purposes.

The advantage of expressing the waveform response in terms of a time series lies in the fact that this form of expression is particularly convenient for arithmetical manipulation. We are interested in the response of a link only up to 3 Mc/s but cannot make an ideal low-pass filter to restrict the band to this frequency. We can however multiply the time series of the link by the time series of an ideal 3-Mc/s low-pass filter and obtain a resultant time series, with ordinates spaced at $\frac{1}{6}$-microsec, representing the tandem connection of the link and ideal filter.

The measurement and filtration processes are carried out both for the link response and that of the test equipment. By dividing the link time series by that of the test equipment a resultant series is obtained which is free from any imperfections of the test equipment (except non-linearity). This series represents the "filtered impulse response" of the link or in other words the response of the link to a pulse defined by $\sin(\pi t/T)/(\pi t/T)$. The waveform of this pulse is shown in Fig. 13. Its spectrum is uniform in amplitude up to a frequency $1/2T$ and zero at higher frequencies.

The time series representing the filtered impulse response of the link contains all the required information about the distortion introduced by the link up to the highest frequency of interest. If the link were distortionless the filtered impulse response would be $\sin(\pi t/T)/(\pi t/T)$ and the time series representing it would contain only one term—the one representing distortionless transmission. This is because, at each sampling interval in the final time series with $\frac{1}{6}$-microsec spacing, the ringing associated with the ideal low-pass filter response is passing through zero as illustrated in Fig. 13 and the only non-zero sample is the one at the time reference point which, in this case, coincides with the peak of the pulse. When distortion is present additional terms appear in the time series and in the same way each distortion term represents the magnitude of a $\sin(\pi t/T)/(\pi t/T)$ pulse whose peak occurs at the time appropriate for that distortion term. The time series therefore contains a central or main term representing the undistorted transmission, plus a number of distortion terms at intervals of $\frac{1}{6}$ microsec on either side of the main term, the magnitude of each distortion term being the amplitude of an echo of the main term occurring at the appropriate time. The idea of expressing distortions in terms of echoes thus appears again. In this case the echoes do not need to appear in symmetrically placed pairs because they do not represent attenuation or phase distortion considered separately.

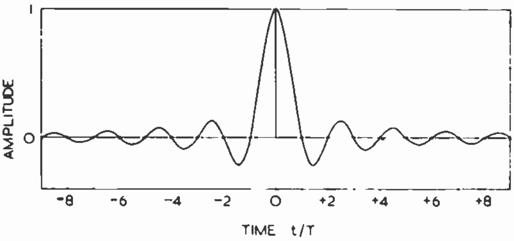


Fig. 13. Impulse response of ideal low-pass filter (cut-off frequency $1/2T$). The sampling points for the time series with interval T are marked.

Before finding the acceptance-test rating factor one more time series must be formed. This is obtained by multiplying the filtered impulse response series by a series $[\frac{1}{2}\ 1\ \frac{1}{2}]$ which is a simple approximation to a $2T$ sine-squared pulse. The resultant series therefore represents approximately the $2T$-pulse response of the link, calculated from its response to a T-pulse.

Four different types of restrictions are placed on these series, each representing a limit on a different property of the waveform response and yielding a different rating factor. Details of the arithmetical operations will not be given here but the approximate significance of the operations is useful as it permits comparison with the limits used in the routine-test method. The limits used in the acceptance-test method are as follows:

- K_1 This limit is closely equivalent to the limit placed on the shape of the $2T$-response by the graticule shown in Fig. 11(b).
- K_2 This limit is closely equivalent to the limit placed on the $2T$ bar/pulse amplitude ratio used in the routine-test method.
- K_3 This limit is equivalent to a restriction on a bar/pulse amplitude ratio where the test signal is a hypothetical pulse-and-bar waveform in which the pulse is an ideal filtered impulse.
- K_4 This is an upper limit on the average amplitude, ignoring signs, of the 16 central echo terms of the filtered impulse response time series.

While K_1 and K_2 have close equivalents in the routine-test method, K_3 and K_4 have not. K_3 takes account of distortions near the upper frequency limit of the link in one way. In the routine-test method these distortions will usually affect the half-amplitude duration of the T-pulse response and/or the initial amplitude of the ringing. K_4 takes account of excessive ringing, too low a cut-off frequency in the link and/or a long train of echoes whose magnitudes are not individually great enough to reach one of the other limits.

As in the routine-test method, when a single overall rating factor is required for a link, the largest value of K obtained for K_1, K_2, K_3, K_4, the bar response or the 50-c/s square-wave response is taken.

3.3. *The Tandem Connexion of Links*

One of the difficulties which arises from expressing the performance of links in terms of their waveform response is that of obtaining the waveform response of a tandem connexion of two or more links when the waveform responses of the links taken separately are known. For some simple or idealized distortions the solution can be obtained explicitly by means of the convolution integral (or Duhamel integral), details of which will not be given here. For most distortions experienced in practice numerical integration is required and the most convenient way of doing this is by the multiplication of time series referred to above. However, when the waveform distortions are small, the approximate result of tandem combination of two links, whose waveform responses are known separately, can be obtained simply by adding the two distortions. The justification for this can be seen by considering a simple example.

Since it is possible to express waveform distortion in terms of echoes, it will be sufficient to consider an example where the distortion in each link consists of a single echo. Let us consider a link with a single erect echo of 10 per cent amplitude at 1 microsec connected in tandem with a link which has a single erect echo of 5 per cent amplitude at 1 microsec. If a $2T$-pulse is applied to the first link the output will consist of the pulse followed at 1 microsec by a 10 per cent echo. The pulse will come through the second link unchanged and so will the echo. The second link will however introduce an echo of the pulse at 1 microsec and of 5 per cent amplitude. This will coincide with the echo from the first link and add to it giving an echo of 15 per cent, 1 microsec after the pulse. The echo from the first link will, however, also cause an echo to be produced by the second link which will have an amplitude of 5 per cent of 10 per cent, i.e. 0·5 per cent, and will occur 2 microsec after the pulse. For many purposes this subsidiary echo can be considered to be negligible. Thus we see that there is a "tendency of corresponding echoes to add",[8] which is a most useful result when considering the addition of small waveform distortions.

A further question of practical importance is how the rating factors add up when a number of links are connected in tandem. This problem has no complete solution except where the time series of the individual links are available. Then, by multiplying the individual time series, that of the tandem combination can be obtained and the overall rating factor calculated.

Where only the rating factors are known the situation is more difficult. For reasonably small distortions the K_2 and K_3 rating factors or the corresponding $2T$ bar/pulse figure in the routine-test method, all add algebraically. Where links are of a similar type and the distortions are systematic rather than random, the rating factors tend to add linearly. Where the distortions are random, as for example where they are due to component tolerances, or where individual correction to obtain the best possible rating factor has been used, or where a large number of links with dissimilar equipment are involved, the rating factors tend to add on a root-sum-square basis.

In practice, when a reasonably large number of links is involved, the rating factor of the tendem combination usually lies somewhere between that obtained by linear and root-sum-square addition of the individual rating factors.

4. The Correction of Waveform Distortion

Having obtained a suitable method of measuring waveform distortion and methods of placing limits on it, the next question is what to do if the response of a link or piece of equipment falls outside the desired limits. Continuing with the approach which has been developed in this paper it is obviously desirable to deal with the distortion on a waveform basis rather than to refer back to steady-state measurements. Although in the present state of the art this is not always possible, a good deal of progress has been made in the correction of waveform distortions on a video-to-video basis. The subject is however a large one and only an introduction to it will be attempted here.

The presence of waveform distortion in a linear transmission system is synonymous with imperfection of equalization. Consequently, to reduce the waveform distortion to tolerable limits, the equalization must be improved. Equalization, in the steady-state sense, is a highly developed art. It involves three main steps prior to the construction of the equalizer network. The first of these is the measurement of the distortion in steady-state terms. Secondly, the desired equalization characteristic must be approximated with the desired tolerance by a network function which can be realized physically. Thirdly, the network itself must be synthesized from the function. In practice the second and third steps are sometimes combined. Three sources of error exist in the process, namely errors in measurement, approximation tolerances, and tolerances in the construction of the final network. It should be pointed out that tolerances in steady-state response cannot easily be transformed into tolerances in waveform response and vice versa, with the result that improving the equalization of a television link by normal steady-state means is often a very disappointing process.

To ensure that the design tolerances in an equalizer are such that they have the minimum undesirable effect on the waveform distortion it is essential that the measurement and the approximation process are carried out on a waveform basis. Fortunately this is quite easy to do in many cases—easier in fact than by the normal steady-state methods. The measurement of the distortion with a suitable test waveform and oscilloscope has already been described. The approximation problem can be solved by introducing into the circuit a suitable adjustable network and operating its controls until the waveform response lies within the desired limits. The settings on the adjustable network can then be used to obtain a fixed network for permanent installation, or in some cases, such as the reduction of distortion on a long link whose characteristics may be expected to vary with time, it is often more convenient to leave the adjustable network permanently in circuit. The use of an adjustable network with a display of the waveform response is equivalent to the use of an analogue computer to solve the problems of approximation to the desired equalization characteristic by a realizable network function and the transformation of tolerances of gain and phase to tolerances of waveform distortion. In this case, however, no analogue is required as the quantities of interest can be measured directly.

Networks designed in this way are known as "waveform correctors" to distinguish them from equalizers whose purpose is to "make equal" gain/frequency and group-delay/frequency characteristics. The circuit arrangements used for waveform correctors and equalizers may in fact be identical—it is only the basis of the design that is different. The first use of waveform correctors was almost certainly for the correction of telephone cable pairs for television outside broadcasts.[9, 10] In this instance the replacement of the adjustable networks by fixed networks was not considered, due to the temporary nature of the links.

Almost any form of adjustable equalizer can be used as a variable waveform corrector provided that the components can be chosen to give a waveform distortion in the opposite sense to that which must be corrected. It is desirable that the various controls should be free from interaction and should produce easily distinguishable effects on the waveform. Experience has shown, however, that these features are by no means as important as was first imagined. A variety of circuits have been used successfully as waveform correctors and there is still scope for development on these lines. Examples of some arrangements commonly used on television links are given in Reference 5.

5. Conclusion

Some of the advantages of specifying, measuring and correcting the linear transmission performance of television links in a consistent manner using their response to standardized test waveforms have been demonstrated. These methods have led not only to a reduction in the time (and therefore cost) spent in setting up and maintaining links but also to an improvement in their performance. While the methods have been described in relation to television links, for which they were devised, they are also finding application in other items of television equipment as for example studio equipment, transmitters and even receivers.

It is perhaps worth stressing once more that only linear distortions have been discussed in this paper. The measurement of non-linearity is a separate subject and requires special waveforms. There is a certain amount of non-linearity distortion present on most long television links, but it is generally not sufficient to affect seriously what has been said about the measurement, specification and correction of linear waveform distortion. The acceptance-test method of determining the rating factor is affected to the greatest extent by non-linearity because it depends on the calculation of the step response and the 2*T*-pulse response from measurements on the *T*-pulse. These calculations are only valid in a linear system. However, the routine-test method is still a most valuable test method even in the presence of substantial amounts of non-linearity because it measures the actual response of a link to typical elements of a television picture. The interpretation of the measurements may, of course, be different in the presence of substantial non-linearity—further work is required on this subject.

It can be seen that the ideas about waveform response, which have been set out in this paper, have gone some of the way towards obtaining distortionless transmission of television signals. They have also brought to light new problems. As further developments on these lines and an increase in the use of waveform methods can be expected, the author hopes that this introductory paper will be helpful in providing a better understanding of the subject.

6. Acknowledgments

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7. H. A. Wheeler, "The interpretation of amplitude and phase distortion in terms of paired echoes", *Proc. Inst. Radio Engrs*, **27**, p. 359, 1939.
8. N. W. Lewis, "Waveform computations by the time-series method", *Proc. Instn Elect. Engrs*, Paper No. 1382R, 1952 (**99**, Part III p. 294).
9. T. Kilvington, "A new television repeater for telephone cable circuits", *P.O. Elect. Engrs J.*, **42**, p. 76, July, 1949.
10. M. B. Williams and J. B. Sewter, "The provision of circuits for television outside broadcasts", *P.O. Elect. Engrs J.*, **48**, p. 166, October, 1955.

DISCUSSION

B. W. Osborne (Associate Member): Would Mr. Macdiarmid elaborate on the possibility of pulse and bar measurements in the case of a vestigial side-band receiver receiving 100 per cent. modulated signals and on how to interpret the response of a normal domestic receiver?

I. F. Macdiarmid (*in reply*): The method of rating which has been described is strictly applicable only to linear systems. Where you have a small amount of non-linearity distortion as is common on line links, there is not much difference from the linear case and the methods developed for linear circuits still apply to a reasonable degree of accuracy. In the case of a television receiver this is no longer so; however, the part of the rating factor that is affected principally is the half-amplitude duration of the T and $2T$ pulses. With a television receiver it would therefore be as well to discount the half-amplitude duration limit from the rating factor and quote it as a separate measurement for information. The significance of this half-amplitude duration measurement will no doubt be better understood when experience has been gained of these measurements.

W. N. Anderson: In our experience the acceptance test method is an extremely difficult and time consuming process. Unless you have laboratory facilities and skilled personnel, few organizations could spare the time needed to evaluate the performance of a system to a T pulse.

I. F. Macdiarmid (*in reply*): The time spent is I think mainly in measurement of the photographs. It would certainly be fairly simple to arrange for the arithmetic to be programmed for an automatic computer, although we have not in fact done so, our results so far having been obtained by computation on hand machines. The time spent obviously makes it rather unattractive to busy engineers and it is essentially a laboratory method. However, it is a method which provides the most precise type of measurement and it enables very small distortions to be measured accurately. Precise methods of measurement always take much longer and are more difficult than routine methods which can be used easily on a day to day basis.

W. N. Anderson: It must not be thought that the method of using $2T$ pulses is in any way a substitute for the acceptance-test method. Apart from difficulties over the acceptance test method, I would like to add that we have been using waveform testing, as described by Mr. Macdiarmid, with good success for the past four years. Consideration is now being given to the setting-up of high power transmitters by this method.

I. F. Macdiarmid (*in reply*): The difficulty is that of interpreting the response to a T pulse directly from measurements on an oscilloscope. It arises mainly because the bandwidth and the shape of the upper cut-off is not the same on all links. It may be possible to extend the usefulness of the routine-test method by including certain features of the T-pulse response if the bandwidth of the link is defined by the temporary insertion of a suitable low-pass filter. Preliminary tests show that this approach is promising but sufficient experience is not yet available to permit definite proposals for limits.

D. G. Preston: The line links used in this country introduce negligible linear distortion but do cause appreciable non-linear distortion. The important thing is that the non-linear distortion appears on positive modulation links as overshoots occurring in the first and last microseconds of the 40-microsecond bar where it is ignored in assessing the K-rating factor. As a result you can have a good rating factor and unsatisfactory distortion. It should be fairly simple to amend all the rating factors to take account of this non-linear distortion.

I. F. Macdiarmid (*in reply*): This is again a quadrature effect which also shows up in positive modulation systems as a widening of the T and $2T$ pulses. I am not so sure that it would be be a simple matter to include non-linear distortion of this type in the rating factor, but I would like to hear any detailed suggestions that Mr. Preston can make.

APPLICANTS FOR ELECTION AND TRANSFER

As a result of its February meeting the Membership Committee recommended to the Council the following elections and transfers.

In accordance with a resolution of Council, and in the absence of any objections, the election and transfer of the candidates to the class indicated will be confirmed fourteen days after the date of circulation of this list. Any objections or communications concerning these elections should be addressed to the General Secretary for submission to the Council.

Direct Election to Member

ST. JOHNSTON, Andrew, B.Sc. (Hons.). *Hertford.*

Transfer from Associate Member to Member

COLLINGS, John Ivor. *Lagos.*
FALKNER, Robert Ian T. *London, S.W.7.*

Direct Election to Associate Member

CRAIG, Joseph A. C., B.Sc. *Larne, Co. Antrim.*
KITCHINGMAN, Captain James Victor, R.N. *Portsmouth.*
NIELD, Philip Newton, B.Sc. *Wythall, Worcs.*
PURDUE, Geoffrey John. *Pinner, Middlesex.*
SAXENA, M. C., M.Sc., B.Sc. *Lucknow, India.*
STUNT, Charles Peter Albert. *Chelmsford, Essex.*
TUPPER, George Ivor Frederick. *Harrow, Middlesex.*

Transfer from Associate to Associate Member

BILSBOROUGH, Gordon. *St. Albans, Herts.*

Transfer from Graduate to Associate Member

AKINDELE, Theophilus Olowole. *London, W.8.*
HEAD, Reginald Edward Albert. *Wolverhampton, Staffs.*
MEIJ, Gerrit Verster, B.Sc.(Eng.). *Pretoria, S. Africa.*
REED, Christopher. *Wells, Somerset.*
REID, William Lawrence. *Southall, Middlesex.*

Transfer from Student to Associate Member

NICHOLS, Basil Hopes. *Cramlington, Northumberland.*

Direct Election to Associate

ANAND, Capt. Jagdish C., B.Sc.(Hons.), Ind. Sigs. *Bangalore.*
BARLOW, Donald Austin, M.Sc. *Uxbridge, Middlesex.*
CHITTY, Arthur Richard. *Preston, Lancs.*
DAVIES, John David. *Liverpool.*
GEI, Cdr. Jogindar Singh, Indian Navy. *Cochin, India.*
GRAY, David Johnston. *Christchurch, New Zealand.*
MAGUIRE, Donald Walter. *Enfield, Middlesex.*
NASH, Leonard Cyril. *Rickmansworth, Herts.*
TAYLOR, William Albert. *Welling, Kent.*

Transfer from Student to Associate

GILBERT, Plt. Off. Garvin Robert, R.N.Z.A.F. *Wigan, New Zealand.*
WHITE, Raymond William. *High Wycombe, Bucks.*

Direct Election to Graduate

ABROOK, George Edward. *Iver Heath, Bucks.*
ANDERSON, David George Andrew. *London, S.W.9.*
ANSDELL, Arthur Anthony. *London, W.5.*
CHERRY, Clive John. *Lancing, Sussex.*
CROSS, Geoffrey. *Wendover, Bucks.*
FORREST, Eric Graham. *Wirral, Cheshire.*
GLANVILLE, Rodney Francis. *Plymouth, Devon.*
HORROCKS, David Heaton. *Bolton, Lancs.*
JACKSON, David Arfor. *Hampton, Middlesex.*
JOHNSTON, Tom. *Dalkeith, Midlothian.*
MORRIS, John Henry. *Hayes, Middlesex.*
NEWMAN, Ronald Victor. *Cowes, Isle of Wight.*
PUDDEFOOT, Dennis John. *Dunstable, Beds.*
SEDGWICK, Anthony. *Bromley, Kent.*
STRAND, Roy Charlesworth. *Chislehurst, Kent.*
TOTTMAN, Leslie, B.Sc. *Letchworth, Herts.*
WALLBANK, Mark Buckland. *Warlingham, Surrey.*
WELLS, Andrew Hammond. *London, N.W.2.*
WICKEN, Clifford. *Woodford Wells, Essex.*
WINTER, William Frederick. *Bath, Somerset.*

Transfer from Student to Graduate

AKINYEMI, Issac Olaonipekun. *London, N.7.*
BROOKS, Peter John. *Hamilton, Canada.*
BUNTING, Derek Henry Stanley. *Seven Kings, Essex.*
DOGRA, Yash Pal. *Bangalore.*
EWART, Flg. Off. James Lorne, R.N.A.F. *Christchurch, New Zealand.*
EXTON, Harold. *Bird, Canada.*
MASSINGHAM, Richard Peter. *Bury St. Edmunds, Suffolk.*
PALMER, Leonard Sidney. *West Wimbledon, S.W.20.*
SPARKES, Joseph Thomas. *Liverpool.*
SOOD, Baldev Krishen. *Poona.*
SUJAN, Chander Sobhraj. *Bombay.*
TAYLOR, Thomas George. *Newport, Mon.*

STUDENTSHIP REGISTRATIONS

The following 65 students were registered at the December and January meetings of the Committee. The names of a further 33 students registered at the February meeting will be published later.

PATET, Niranjan Kumar, B.Sc. *Dehra Dun.*
PATIL, Manohar H., M.Sc. *Bombay.*
PENDRY, Brian. *Belfast.*
PREEDY, Anthony R. *Wellington, Salop.*
PRESCOTT, Edward Horace Albert. *Lowestoft, Suffolk.*
PRESTON, George Cyril, B.Sc. *Carshalton.*
RAMAMOORTHY, Obla R. *London, W.14.*
RASHID, Akhtar. *London, W.5.*
RIDLEY, Peter. *Brampton, Cumberland.*
*ROWLANDSON, Gerard Anthony Gillan. *Bracknell, Berks.*
SAGE, Maurice George. *London, S.W.13.*
*SASTRY, Nukala V., B.A. *Nizamarabad.*
SHARMA, Des Raj. *Bombay, India.*
SPARKE JONES, David A. *Johannesburg.*
*STANLEY, Anthony R. *Cheam, Surrey.*
*TALMACIU, Josef. *London, S.W.7.*
TAYLOR, Ronald J. I. *London, N.W.10.*
TOKEKAR, Shrikrishn Chintaman, B.Sc. *Lashkar, India.*
WASHINGTON, Derek. *Reigate, Surrey.*
WELLS, Wilfred Stanley. *Wirral, Cheshire.*
WILLIAMS, Robert Hywel. *Lausanne.*
YOHANNAN, Kudili A. *Ernakulam, India.*
ZEPLER, Matthew Martin, B.A. *Southampton.*

AGHANYA, Ebenezer O. *Southampton.*
ASPRAS, Anthony. *Manchester.*
BAILEY, Kenneth Alan. *Bletchley, Bucks.*
BINENSTOK, Joseph. *Bnei Braa, Israel.*
CALEY, Eric Herbert. *London, S.W.9.*
COWLE, Bernard Stanley. *Southampton.*
DENYER, Derek Herbert Cecil. *London, N.W.10.*
DESAI, Shrihari Baburao. *Bombay.*
ECCLES, Martin David. *Welwyn Garden City, Herts.*
EDWARDS, Major Neville Arthur Frank, R.E. *B.F.P.O. 29.*
ELLIS, Roy Heron. *Bournemouth, Hants.*
*FARUQI, Muzaffar Hussain Shah. *Karachi.*
FERBRACHE, Rex Reginald. *St. Peter Port, Guernsey, C.I.*
GARTHWAITE, Frank George Leslie. *Earlswood, Surrey.*
INKPIN, Jack Dennis. *Brighton, Sussex.*
JONAS, Malkiel. *Jerusalem, Israel.*
KHAN, Khansahib. *London, W.2.*
KUMAR, Narendra. *Lucknow, India.*
LESS, William Victor. *London, N.16.*
LEUNG, Frederick. *Hong Kong.*

LIGHTBOURNE, John V. W. *Birmingham.*
LYFORD, Dennis R. *Airdrie, Lanarkshire.*
McKISSOCK, James Barr. *Greenock, Renfrewshire.*
McLEAN, Plt. Off. Donald, R.A.F. *Saffron Walden, Essex.*
MALONE, Colin T. *Hayes, Middlesex.*
OBEYESEKERA, Piyasena. *London, S.E.27.*
OLOMU, Solomon Ovenseri. *Lagos, Nigeria.*
RAMAN, Ganapathy, B.Sc. *Madras.*
RICE, William Barry. *Slough, Bucks.*
ROWE, John Albert. *Malmesbury, Wilts.*
SANDRASEGARAM, Sampanther, B.Sc. *London, W.2.*
SCHOFIELD, Paul Whitworth. *Leed.*
SHILLONG, Leo Andrew. *Toronto.*
SMEETH, Boris. *Nairobi, Kenya.*
SMITH, Alan. *Downpatrick, Co. Down.*
SOKOLOWSKI, Ignacy. *London, N.W.3.*
SWIFT, Colin William. *Crumlin, N. Ireland.*
THANH, Nguyen Ngoc. *London, N.W.6.*
WADDINGTON, John B. *East Molesey.*
WALTER, Robert William. *Leicester.*
WAY, Stephen John Francis. *Carshalton.*
WILLIAMS, Paul David. *Carlingford, Australia.*

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* Reinstatement.

STEREOPHONIC BROADCASTING

A system for stereophonic broadcasting which utilizes time-multiplex communication techniques has been proposed by Mullard Ltd. The system is applicable to normal f.m. (e.g. Band II) transmissions and meets all the usual performance requirements. At a recent demonstration it produced acceptable stereophony under conditions approximating to normal home reception and it was shown to be suitable also for bilingual transmissions.

The system is a twin-channel application of the principles of pulse-amplitude time-multiplexing under conditions in which the bandwidth, after multiplexing but before modulation of the transmitter, is restricted to a logical minimum. The system is essentially symmetrical in character as regards its treatment of the two stereophonic signals and leads to a simple and therefore economic receiver design.

At the transmitter a sampling generator operating at the multiplexing frequency, 32·5 kc/s, produces two sinusoids in anti-phase. These are fed into two mixing or multiplying devices to which are also applied respectively the two stereophonic signals A and B, suitably pre-emphasized. The sampling sinusoids are half-wave rectified to produce two time-interlaced pulse trains, one amplitude modulated by A, the other by B.

The complex output signal from the encoding mixers alone does not contain any information to resolve the A, B ambiguity in a subsequent receiver. In order to provide for correct synchronization, a small amplitude component at the sampling or multiplexing frequency in phase quadrature with both sampling pulse trains is therefore introduced. The complex signal is passed through a low-pass filter before entry into the frequency modulator of the transmitter. Thereafter a normal transmitter is used.

The filtered complex wave fed to the frequency modulator of the transmitter has a frequency spectrum consisting of (A + B) at audio frequency, (A – B) d.s.b. a.m. on a suppressed subcarrier at the sampling frequency, and (A + B) d.s.b. a.m. on a subcarrier at the second harmonic of the sampling frequency. Audio bandwidth is usually 15 kc/s and the sampling frequency 32·5 kc/s. The total bandwidth of the spectrum therefore is 80 kc/s.

Such a modulating spectrum is acceptable in f.m. transmitters without exceeding normal r.f. signal bandwidths; by retaining a complex signal bandwidth of 80 kc/s, ease of receiver synchronization is achieved without either radiating a special high power synchronization signal from the transmitter, or complicating the receiver by the inclusion of high quality synchronizing filters.

A normal receiver is used up to the output circuit of the frequency discriminator and the negative synchronizing pulses are separated in a synchronizing separation circuit and are used to phase-lock an oscillator at the multiplexing frequency. The output from this oscillator is rephased by ±90 deg, to obtain the correct in-phase, anti-phase relationship for operating the decoding mixers. These are thereby synchronized with the encoding mixers in the transmitter, and thus reproduce the signals A and B respectively. After de-emphasis these signals are then directed into the two output amplifiers.

In the case where the stereo receiver is receiving a monophonic transmission, no synchronizing pulses are available, and the monophonic signal appears in both audio output circuits, irrespective of whether the synchronizing oscillator free runs or stops under these conditions. An advantage in output signal/noise ratio is obtained in the latter case. The listener with a monophonic receiver will continue to hear an acceptable monophonic signal when receiving a stereophonic transmission on account of the high sampling frequency.

The theoretical limit of cross-talk of the A input into the B output and vice-versa is –45 db. Preliminary adjacent channel interference tests (at approximately 220 kc/s separation) appear to yield extremely acceptable results.

The normal f.m. receiver required has to be followed by a synchronizing separator, decoder and two audio output circuits. The synchronizing separator circuit requires the use of either a transistor or a triode in the oscillator. In some existing normal receiver designs such a triode is already available for use in this way. The two encoding mixers at their simplest may each embody only one semiconductor diode, or one transistor. In a valve receiver a double triode or other double valve may be used.

Measurement of Complex Permeability by Discriminator [†]

by

J. C. ANDERSON, M.SC., PH.D., ASSOCIATE MEMBER[‡]

Summary: A modified Foster-Seeley discriminator can be used to measure the real and imaginary parts of v.h.f. permeability in a ferromagnetic sample. The circuit is described and the theory and design criteria given. The results of measurements on colloidal nickel in liquid suspension are quoted.

1. Introduction

Since permeability is a complex quantity at v.h.f. it is necessary that apparatus designed for its measurement should be capable of resolving the real and imaginary parts μ_1 and μ_2, where relative permeability is given by $\mu_r = \mu_1 - j\mu_2$. When the specimen is inserted in a coil carrying an r.f. current the magnitude of the current is modified proportionally to $|\mu_r| = (\mu_1^2 + \mu_2^2)^{\frac{1}{2}}$, and its phase angle is changed by an amount proportional to $\tan^{-1}(\mu_2/\mu_1)$. It follows that both a magnitude and a phase measurement must be made. A Foster-Seeley discriminator circuit is suitable, with slight modification. By extremely careful attention to layout and screening it is possible to operate the circuit up to over 200 Mc/s. The advantageous feature of the balanced-type circuit, such as the discriminator, for operation at such high frequencies, is that it is possible to arrange the layout so that capacitive pick-up is the same for each half of the circuit, and is thereby effectively eliminated.

2. The Circuit

A sketch of the layout employed together with the physical layout of the coil connections is given in Fig. 1. It will be noted that it is not possible to get an entirely symmetrical layout for the coil connections.

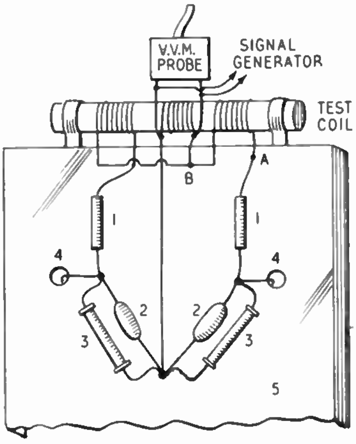

Fig. 1. Schematic layout of discriminator circuit. Key: 1. 5 pF capacitor; 2. diode; 3. resistor; 4. hole in chassis to r.f. filter; 5. chassis.

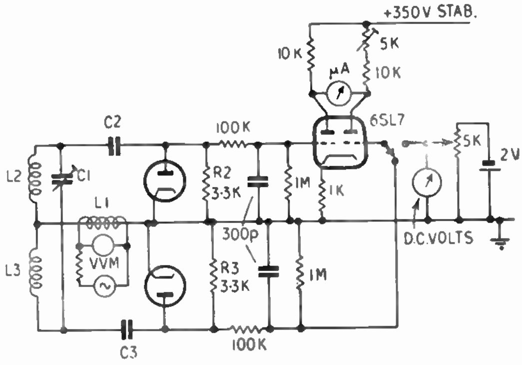

Fig. 2. Modified discriminator circuit for v.h.f. permeability measurement.

Referring to Fig. 2, the coils L1, L2 and L3 are wound on the same former with the primary coil L1 between the other two, which form two identical halves of the secondary and are wound in opposite directions. The capacitor C1 across the whole of the secondary is used to adjust the total secondary impedance such that the e.m.f.

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[‡] Royal Holloway College, University of London, Englefield Green, Surrey.

U.D.C. No. 621.317.41:621.376.432

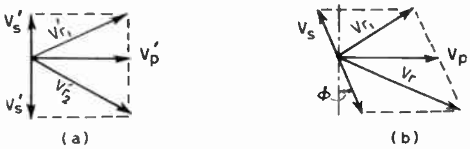
induced in it is 90 deg out of phase with the primary voltage. The r.f. voltages across L2 and L3 are peak-rectified, producing d.c. voltages, negative with respect to ground, across R2 and R3 respectively. The shunt diode circuit is chosen because it requires one less capacitor than the series arrangement and also presents less difficulty at v.h.f. due to the cathodes being grounded direct. The time constants C_2R_2 and C_3R_3 must be chosen to be longer than the period of the signal frequency at the highest frequency to be handled.

The signal generator across L1 must have a high internal impedance to ensure constant-current operation, and the valve voltmeter used to measure signal voltage should have a low input capacitance, preferably not greater than 1 pF. Miniature germanium diodes are the most suitable type of detector. The d.c. voltages developed across R2 and R3 are applied, after filtering, to the grids of a cathode-coupled amplifier having a microammeter connected between the anodes.

Calculation of results is much simplified if it is possible to measure the voltage across one half of the secondary coil. To avoid the asymmetry which would be introduced by the connection of a valve voltmeter across only one half of the secondary it is arranged to switch one of the grids of the amplifier to a d.c. source which is measured. By adjusting this supply, until the microammeter reads the same as it did with the signal connected to both grids, the required voltage is measured indirectly. Pre-calibration allows absolute determination of the voltage.

3. Theory

After initial setting of C1 the vector relations between primary and secondary voltages fulfil the well-known Foster-Seeley condition shown in Fig. 3(a), in which the voltages across the diodes are equal to the vector sum of V'_p and V'_s and will be the same across each diode. The potentials across R2 and R3 will be equal and the two halves of V3 will pass approximately equal currents. The preset anode load resistor in one half of V3 is adjusted, under these conditions, to give zero current in the microammeter.



(a) (b)

Fig. 3. Vector diagrams for the discriminator.

When a specimen is inserted into the coils a small phase shift φ occurs as shown in Fig. 3(b). We now have resultant voltages V_{r1} and V_{r2}, across diodes 1 and 2 respectively, given by

$$|V_{r1}|^2 = |V_p|^2 + |V_s|^2 + 2|V_pV_s| \sin\varphi$$

and

$$|V_{r2}|^2 = |V_p|^2 + |V_s|^2 - 2|V_pV_s| \sin\varphi$$

It follows that

$$|V_{r1}|^2 - |V_{r2}|^2 = 4|V_pV_s| \sin\varphi \quad \ldots\ldots\ldots(1)$$

The phase shift introduced by the specimen is due to the resistance it reflects into the coils and to the alteration of permeability of the medium inside the coil. In the present method it is only the permeability effect which is of interest. This is met by using a blank specimen, identical in all respects to the ferromagnetic one, which does not contain the ferromagnetic material. The initial setting up is done with the blank specimen present so that the phase shift introduced by the specimen under examination is due to the ferromagnetic content only.

With small signals the diodes may be taken, to a close approximation, as square-law detectors, so that the d.c. voltages developed across R2 and R3 are proportional to the squares of the applied signal voltages. Thus the microammeter will register a reading proportional to sin φ and to the product $|V_pV_s|$.

Considering now the insertion of a ferromagnetic specimen, characterized by a permeability $\mu = \mu_0(\mu_1 - j\mu_2)$, the secondary voltage will be given, neglecting the effects of reflected resistance, by

$$\begin{aligned} V_s &= j\omega\,(\mu_1 - j\mu_2) \,.\, Mi_p \\ &= V'_s\,(\mu_1 - j\mu_2) \end{aligned}$$

where V'_s is the secondary induced e.m.f. with the blank present, M is the mutual inductance between the primary and one half of the secondary coil and i_p is the primary current.

Thus

$$|V_s| - |V'_s| = |V'_s|(|\mu_r| - 1)$$

i.e. $$|\mu_r| = 1 + \frac{|V_s| - |V'_s|}{|V'_s|} \qquad \text{.........(2)}$$

If we now include the square-law characteristic of the detector by means of $E_s = k\,|V_s|^2$ and $E'_s = k\,|V'_s|^2$, where E_s and E'_s are the d.c. voltages measured at the grid of one half of the amplifier valve, eqn. (2) becomes

$$|\mu_r| = 1 + A/(E'_s)^{\frac{1}{2}} \qquad \text{.........(3)}$$

where $A = (E_s)^{\frac{1}{2}} - (E'_s)^{\frac{1}{2}}$.

Referring back to eqn. (1), making use of the square-law relation, and again denoting d.c. voltages at the valve grids by E where the a.c. voltage is V, we have

$$E_{r1} - E_{r2} = 4\,(E_pE_s)^{\frac{1}{2}}\,\varphi \qquad \text{.........(4)}$$

where φ is assumed small.

The induced secondary e.m.f. with the specimen present may be written as

$$V_s = |V'_s|\;\overline{|\tan^{-1}(\mu_2/\mu_1)} = |V'_s|\;\overline{|\varphi}$$

Thus, for small angles, $\varphi = \mu_2/\mu_1$.

Substituting in eqn. (4) leads to

$$\mu_2/\mu_1 = B/4\,(E_pE_s)^{\frac{1}{2}} \qquad \text{.........(5)}$$

where $B = E_{r1} - E_{r2}$

Combining eqns. (3) and (5) yields explicit expressions for μ_1 and μ_2 as follows:

$$\mu_1 = \frac{(1 + A/(E'_s)^{\frac{1}{2}})}{(1 + B^2/16E_pE_s)^{\frac{1}{2}}}$$

$$\mu_2 = \frac{B}{4\,(E_pE_s)^{\frac{1}{2}}}$$

The assumptions implicit in the above treatment are that the primary current remains constant on insertion of the specimen and that the dectector exerts negligible loading effect on the coil. Both these conditions can be met by suitable choice of components.

It may be remarked that if a square-law detector is not used the necessary corrections to the theory are easily applied; they do not involve the measurement of any additional parameters.

4. Experimental Method

The experiments reported here were conducted on a colloidal nickel solution. This consisted of spherical particles of approximately 50 angstroms diameter, suspended in a solution of diethyl phthalate. The specimen was contained in a small test-tube which fitted inside the coil former. An identical tube containing the phthalate, but no nickel, was used as a blank.

The blank was inserted in the coil and C1 adjusted until removal of the signal caused no change in the microammeter reading; the reading was noted, together with the primary voltage recorded on the valve voltmeter connected across L1. The grid of the amplifier was then switched to the d.c. supply which was adjusted to bring the microammeter back to the noted reading. The measured value of the d.c. voltage was noted, this being E'_s. The blank was next replaced by the specimen and the change in microammeter reading gave the value for A. Switching the grid back to the signal circuit then gave a new microammeter reading which, subtracted from the first one noted, gave the value for B. The value of V_p, as indicated on the valve voltmeter when the specimen is in the coil, was found not to differ from that obtained with the blank present.

In order to refer all quantities to the amplifier grid initial calibration must be carried out. The cathode-coupled amplifier sensitivity is measured by plotting microammeter reading against d.c. voltage on one of the grids. The mean slope of this graph gives a conversion factor for microammeter reading to equivalent grid volts. In the case of the apparatus used in these experiments the factor was 0·427 mA per volt. Much higher figures are, of course, easily attainable, but the gain was deliberately kept as low as possible to achieve absolute steadiness in the microammeter reading.

The other necessary calibration is to obtain an overall detector efficiency figure. The amplifier grid is switched to d.c. and the secondary coil providing the signal for the other grid is shorted by breaking the connection at A (Fig. 1) and transferring it to B. Variation of the primary voltage by means of the signal generator provides variation of the microammeter reading, and this is offset by varying the d.c. grid supply. The d.c. voltage corresponding to a given V'_p is the voltage E'_p required. This conversion factor varies with frequency, and is plotted over the frequency range required for the values of V'_p actually encountered in the experiment. A typical calibration curve is shown in Fig. 4.

From the readings taken the permeabilities may be calculated. The voltage E_s across the secondary with the specimen inserted is not measured explicitly, but may be obtained from $E_s = (A + (E'_s)^{\frac{1}{2}})^2$.

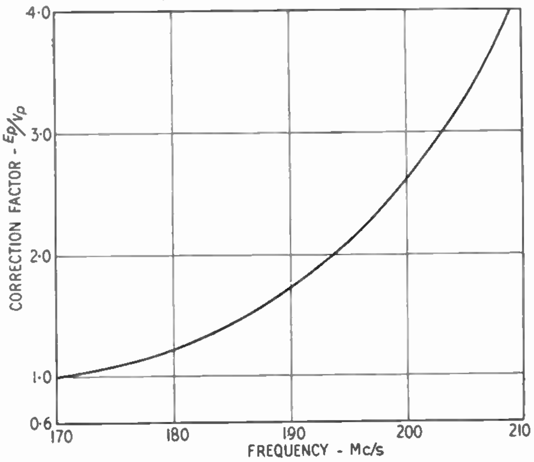


Fig. 4. Calibration curve for coil 2.

The winding of the test coils is of some importance, and Table 1 gives the number of turns of 22 S.W.G. copper wire, wound on a $\frac{3}{8}$-in. former, used over the frequency range 50 to 250 Mc/s.

Table 1

Frequency range (Mc/s)	Primary turns	Secondary turns (each half)	C1 value (pF)
250—210	1	2	0·5—5
210—170	2	3	0·5—5
170—100	3	4	0·5—25
100—50	4	5	5—30

It will be realized that no allowance is made for the resistive effect of the ferromagnetic particles themselves. Due to the small size of the particles and their extremely low (0·05%) concentration in the solution, this error is considered negligible. Nevertheless, as a precaution, the Q-factor of the test coil is kept fairly low (of the order of 30 to 50) by the use of a suitable L to C ratio. This ensures that small changes in resistance reflected into the test coil do not affect the voltage developed very much. A further point of similar importance is that the blank and the specimen introduce changes in the self-capacitance of the test coil, and if the dielectric constant is changed by the presence of the ferromagnetic particles a false change in voltage will be recorded due to the detuning of the coil. Again, this did not prove a problem with the type of specimen used but could cause trouble with other specimens.

5. Results

Figure 5 shows the results of measurements made on colloidal nickel; real and imaginary parts of permeability are plotted against frequency. As may be expected, the total relative permeability is in the region of unity for the small particles (which behave as single domains) in such low concentration.

The deviations in the region of 140 Mc/s are of interest. These have been ascribed to electronic spin resonance in the magneto-crystalline anisotropy field, and have been discussed else-

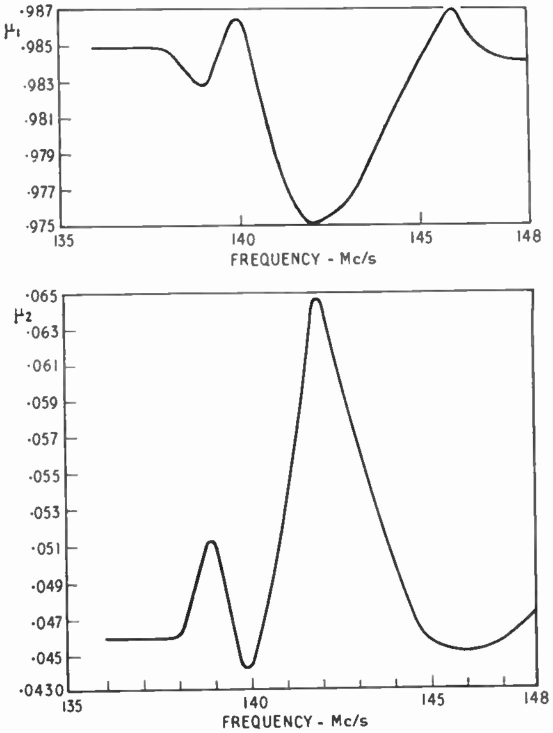


Fig. 5. Real and imaginary parts of complex permeability of nickel colloid at 55° C as a function of frequency.

where†. It is of importance to establish that this resonance is not an artifact of the circuit but is, in fact, a genuine effect. This has been done by observing the variation of the frequency at which the resonance occurs as the specimen temperature varies. It was found to correlate with the temperature variation of resonant frequency observed in a polycrystalline specimen using a transmission line technique. In addition quantitative calculation of the expected resonance frequency, from the known magnetocrystalline anisotropy constants of nickel, gives a value close to that at which the deviation in the permeability curves occurs.

Similar measurements have been successfully made in this apparatus on magnetite in colloidal form, nickel-iron alloy small particles suspended in wax and on cobalt precipitated in a copper matrix.

6. Conclusion

The method described has proved to be of high sensitivity, enabling measurement of permeability at v.h.f. to one part in 10^4. Apart from the interest in permeability as such, application of Maxwell's equations will yield the real and imaginary parts of surface impedance. By suitable recasting of the theory it will also be possible to measure complex dielectric constant over the same frequency range.

7. Acknowledgments

This work was carried out in the Department of Physics, University of the Witwatersrand, Johannesburg, whose Research Committee provided a grant.

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† J. C. Anderson and B. Donovan, Internal ferromagnetic resonance in nickel," *Proc. Phys. Soc.*, 73, Part 4, pp. 593-599, April 1959.

# of current interest . . .

Commonwealth Technical Training Week

In the September 1959 *Journal*, a preliminary announcement was made concerning the holding of a Commonwealth Technical Training Week in 1961. It is now possible to announce that His Royal Highness, The Prince Philip, Duke of Edinburgh, in his capacity as President of the City & Guilds of London Institute, has approved the decision that in the United Kingdom the Week will be from Monday, 29th May, 1961, to Sunday, 4th June, 1961, inclusive. It is hoped that it will be possible to hold the Week in other parts of the Commonwealth and that, as far as possible, the same dates will be chosen.

The object of the Week is to stimulate awareness of the responsibility of the community towards young people entering employment, and to stress the importance of schemes of induction and training. In this country the direct organization will, under the general supervision of a United Kingdom Committee, be in the hands of local authorities who have been informed of the dates selected. The success of the Week will thus depend directly on local initiative and it is hoped that there will be participation not only by the appropriate civic heads, but also by all important interests such as, for example, civic, educational, youth service, youth employment, religious, industrial, commercial and agricultural.

Trans-Pacific Telephone Cable

The Pacific Cable Conference was held in Sydney last year to consider the possibility of constructing a large-capacity telephone cable across the Pacific from Vancouver to New Zealand and Australia. The Conference concluded that such a cable was a perfectly practical proposition and recommended that it should go ahead. The Governments of the United Kingdom, Canada, Australia and New Zealand have now accepted these recommendations and are ready to proceed with the construction of the cable. The total estimated cost is £26·3 million, of which the U.K. share is £8·3 million.

The new cable, which it is hoped to complete in 1964, will form a further link in the "round-the-world" telephone cable system which was proposed by the Commonwealth Telecommunications Conference which met in London in 1958. The first part of the system will be the new cable to Canada (generally known as CANTAT) which is due for completion next year. CANTAT will be linked to the Trans-Pacific cable by lines across Canada, the complete system providing first class telephone and telegraph communications half-way round the world, a route distance of about 14,000 miles.

A trans-Pacific cable is one of the biggest telecommunications projects ever undertaken. It will be over 8,000 nautical miles long and will include more than 300 under-sea amplifiers. In places, cable and amplifiers will be laid at depths of almost four miles. The design of the cable will be British throughout and it will use the lightweight cable and rigid repeaters developed in the United Kingdom and being used in CANTAT; it will have a capacity of at least 80 telephone channels.

Technical Education in New South Wales

The Associateship of the Sydney Technical College (A.S.T.C.), a qualification issued as the result of completion of a diploma course run by the University of New South Wales for the Department of Technical Education, is to disappear. These courses are to be replaced by University courses which will be available to students studying part-time. They will lead to the Degree of Bachelor of Science (Technology) and the first courses will be introduced in 1961.

Radio and electronic engineering will be provided for in a separate university degree course leading to B.Sc.Tech. and courses will start next year.

The I.T.A.'s Dover Station

The Dover station of the Independent Television Authority which began transmitting programmes on 31st January has a service area which stretches as far west as a line from Chatham through Tunbridge Wells to Eastbourne and has a population of about 1 million. Transmissions are on Channel 10 (vision 199·7135 Mc/s, sound 196·1985 Mc/s), vertically polarized, and the station will have a maximum directional effective radiated power of 100 kW. The aerial is an array of full-wave vertical dipoles with a screening frame to ensure that radiation towards France is negligible.

The Application of Closed-circuit Television in the Nuclear Industry[†]

by

P. BARRATT, M.A., PH.D.[‡] and I. M. WATERS[‡]

A paper read on 4th July 1959 during the Institution's Convention in Cambridge.

Summary: This paper reviews briefly the historical development of industrial television systems, and the applications of conventional equipment in the many branches of industry which depend upon nuclear processes. Special systems must be designed for use in the intense radiation fields and high ambient temperatures and pressures which occur in a nuclear reactor. The possible ambient conditions and their influences upon television camera design are discussed, with indications of the ways in which specific problems may be solved. An assessment of future trends suggests that television equipment will be called upon to operate in increasingly unfavourable environments; simultaneously, standard television systems will be used extensively for remote observation and display.

1. Introduction

It is only six years since television equipment designed for solely utilitarian purposes made its appearance in this country. During this time, it has been accepted as a separate class of design, termed industrial or closed-circuit television, within the general field of television transmission equipment.

The first full-scale commercial exploitation of nuclear energy took place within this period and was marked by the construction of the nuclear power-station at Calder Hall, which has been supplying electrical power to the National Grid for the past three years.

Television techniques were therefore available from the start of the large-scale expansion in the nuclear industry which has taken place. It is obvious that the major demands have been made in established fields such as metallurgy, the design and fabrication of large and complex pressure vessels, heat transfer equipment, the remote handling of radioactive materials, and so on. These topics are beyond the scope of this paper.

The significant factor is the emission of high energy radiation, inevitably accompanying any release of atomic energy, which prevents human observers and operators approaching the regions in which the processes are taking place. Exposure of the human body to high-level radiation fields results in temporary or permanent damage and, in extreme cases, death.[1]

The demands which have been made upon television may therefore be attributed to a single requirement, the need to observe events and investigate processes occurring under conditions in which the direct use of the human eye is impossible.

2. The Evolution of Closed-Circuit Television

The development of television, prior to the introduction of closed-circuit systems for industrial purposes, was directed almost completely towards television broadcasting. The two applications are very dissimilar in their requirements, and broadcasting equipment is, in general, too large, complex and expensive for use in the control and observation of scientific and industrial processes.

It is pertinent to examine briefly the way in which industrial television originated since the initial atomic applications would not have been possible in the absence of the established industrial television techniques.

Many of the atomic applications are similar to those found in other industries. For instance, a large amount of auxiliary equipment that must

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[‡] Pye Limited, Cambridge.

U.D.C. No. 621.397:621.039

be used in a nuclear power station will be found in a chemical plant or a conventional power station. Thus the need for remote control is not peculiar to the nuclear industry. To take a specific example, a television camera which is remotely-controlled and completely sealed, for protection from dust and unfavourable atmospheres, will find applications throughout industry. The additional advantage is found in atomic applications that the sealed housing permits the camera assembly to be decontaminated by washing-off active dust after removal from the radioactive area.

Hence, industrial television has tended to develop so that it is suitable for atomic applications, although the influence of this particular field upon design should not be underestimated.

The initial impetus to the development of industrial equipment was given by the perfection of small, photo-conductive, camera tubes known variously as the "Vidicon", "Staticon" or "Resistron", depending upon their country of origin. Using these tubes, cameras could be constructed which were much smaller and compact than broadcast cameras. The tube employed in the majority of modern broadcast cameras (and in certain special industrial equipments) is the 3″ Image Orthicon. Compared with the Orthicon dimensions of 3″ dia. by 16″ long, the Staticon of 1″ dia. by 6″ long permits a significant reduction in camera volume to be made. The format size of the industrial tube is approximately that of a 16 mm film frame and therefore allows the wide range of 16 mm cine lenses to be employed. Broadcast-tube formats correspond to film sizes of 35 mm or greater. Furthermore, the Staticon type of tube has a low velocity electron beam and hence requires considerably lower operating voltages and less scanning power. The reduction in scanning power makes it possible to locate scan-generating circuits in the control equipment at the remote end of the camera cable, thereby reducing appreciably the numbers of components within the camera itself.

With these advantages, and without the necessity for providing facilities such as viewfinders, talkback, etc., television cameras have been produced which are particularly suited for industrial applications. The various disadvantages which the small photo-conductive tubes have are far more important in broadcast than in industrial work. Their light-sensitivity under typical average conditions is an order of magnitude less than that of an Image-Orthicon but this is rarely important since many industrial cameras are used within buildings and the optimum light level of 50 to 100 foot-candles can be easily achieved. Again, the depth of the field of focus desirable in industrial use is often small compared with that needed in a broadcast camera, and the wider aperture lenses which can be used compensate to some extent for the lower light-sensitivity.

A more important effect is that of "lag"; the image registered in any one picture frame is not completely erased by the time a new image is formed. As a result of this, moving objects have "trails" behind them when they are reproduced on the monitor. The effect is barely perceptible when adequate levels of illumination are used, but worsens with decrease in light level.

The lower limit of light level for satisfactory tube performance is influenced by the magnitude of the lag. An adequate picture may be obtained of a stationary or slowly-moving object with a highlight brightness of 5 foot-lamberts, and a lens aperture of $f/1{\cdot}4$, but higher light levels are required if the movement is greater.

The low level of the output signal from a photo-conductive tube compared with an Image-Orthicon, implies the provision of more elaborate pre-amplification circuits, in order to raise the video signal to a level suitable for transmission by the camera cable to the control and display equipment.

The simplifications in camera design which resulted from the use of photo-conductive tubes were paralleled in the control equipment. The number of components in a camera should be as small as possible to minimize the effects of radiation (see Sections 4.2 and 4.3); but this does not apply to control equipment, which is normally outside the hazardous area. Nevertheless, a decrease in the size of control equipment increases its portability and enhances its general usefulness.

The normal broadcasting practice for the control of television cameras is cumbersome for industrial application. Three separate units are employed: the Camera Control Unit; the Camera Power Supply Unit; the Synchronizing Pulse Generator which produces the driving-pulses, with strictly controlled time relationships, controlling the operation of the entire system. In industrial equipment, all these functions are combined in a single, portable unit. This is facilitated by the independent mode of operation of closed-circuit installations; since there is usually no necessity for the synchronous operation of a number of cameras, their outputs can be combined for final presentation. A simplification in the form of the vertical synchronizing-waveform is also possible, by replacing the broad serrated vertical sync. waveform (and equalizing pulses) of the broadcast system by a single pulse with a width of approximately 1½ lines. This has been found completely satisfactory in practice, and has resulted in an appreciable reduction in the complexity of the control unit circuits.

It now appears that the limit has been reached for simplification, using existing components. Further attempts would lead to degradation of the picture quality and, probably more serious, reduced reliability.

Comparison of broadcast and industrial equipment must take into account the differing requirements and conditions of operation if valid conclusions are to be drawn. It is, for instance, fallacious to regard industrial systems as a cheap form of broadcast equipment. The quality of the reproduced image is not degraded in the interests of economy; the economies are the results of circuit simplifications permitted by the operational requirements. A television image used for industrial purposes must often convey a great deal more information than is necessary in broadcasting.

Again, in broadcasting, the aim is a true-to-life reproduction of the original scene, with an aesthetically acceptable balance of light and shade. This is not required in many closed-circuit applications, where the maximum visual information is to be transmitted and presented in the most convenient way. For instance, the grey-scale reproduction of an image may be grossly distorted to enhance some particular point of detail in an industrial installation; deliberately-induced distortions such as this would be unacceptable in broadcast systems.

2.1. *Specification of Performance*

The design of industrial equipment has not yet reached a stage at which an agreed specification of performance and quality can be formulated, but general agreement is being reached on certain desirable characteristics.

For instance, the preferred scanning standard for the majority of equipment is 625 lines, 50 fields, 2 : 1 interlaced, for operation with a 50 c/s a.c. supply. (When the a.c. supply frequency is 60 c/s, the U.S.A. standard of 525 lines is employed.)

The resolution at the centre of the image is normally expected to be of the order of 600 lines or greater; this is usually adequate. This resolution determines the quality of the electronic and optical components of the camera, and the bandwidth of the video amplifier.

Figure 1 shows in diagrammatic form the layout of a typical up-to-date industrial television camera chain.

It will be seen that the camera itself contains the minimum circuitry, only two valve stages; this is desirable in atomic applications, where the minimum number of components should be exposed to radiation.

The Control Unit will be seen to split broadly into

(*a*) The video processing amplifier, producing an output waveform of standard level for display on normal television monitors, by amplifying and frequency correcting the camera signal, and adding to it blanking and synchronizing waveforms.

(*b*) Circuits producing the scanning currents required by the camera tube, and the blanking waveforms used by the camera, are mixed into the video signal in the processing amplifier.

(*c*) The synchronizing pulse generator, providing two trains of pulses at vertical and horizontal frequencies correctly time related so as to produce the desired interlaced scanning.

(*d*) A circuit which permits the camera to adjust itself automatically to the mean level of lighting on the scene televised, and to maintain a nearly constant level of output signal.

(*e*) All necessary high and low voltage power supplies.

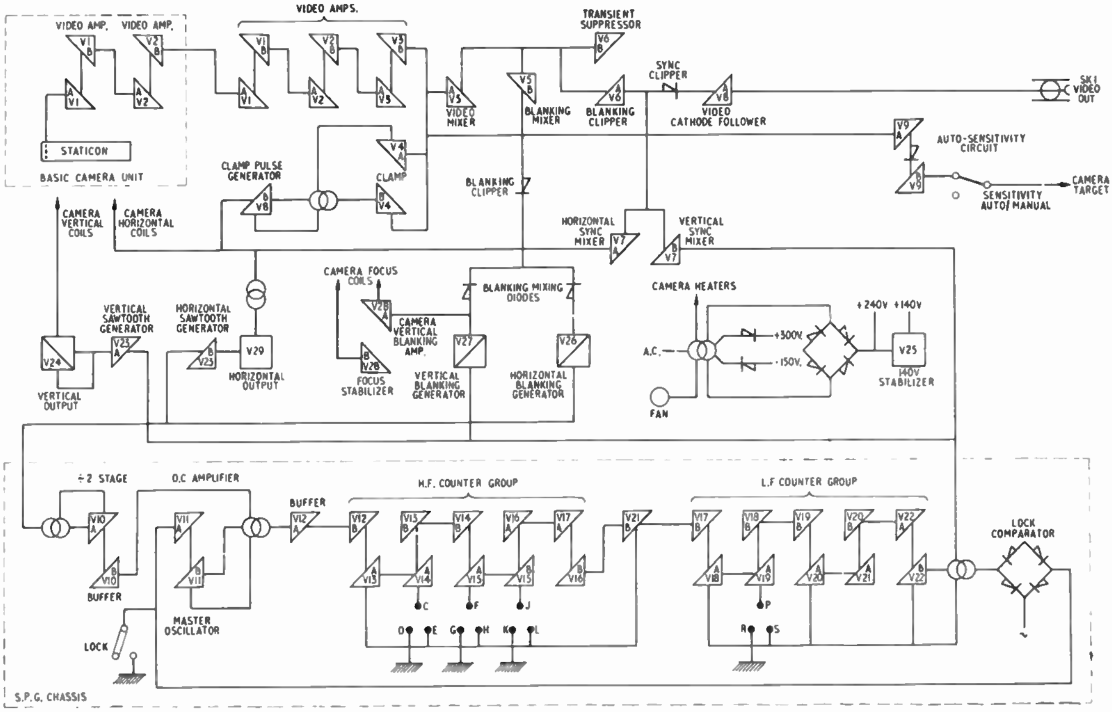

Fig. 1. Block schematic of a typical industrial camera chain.

2.2. *Specific Nuclear Applications*

The applications of television in the nuclear field fall into two categories:

(*a*) Applications in which essentially conventional closed-circuit equipment is employed for remote inspection and control in radioactive, or otherwise hazardous, areas.

(*b*) The need for specially designed cameras which can withstand the high temperature and/or radiation levels existing within a reactor core, or in close proximity to large radioactive sources. These cameras may be for remote observations only, or act as a combination of manipulating tool and means of observation.

The two classes differ sufficiently widely in operating conditions and the types of equipment required to merit separate discussion.

3. Applications of Conventional Industrial Equipment

3.1. *Surveillance*

This is perhaps the most obvious use—maintaining supervisory observations of a potentially hazardous area so that personnel and equipment may be safeguarded.

Typical examples are to be found in the installations at various research reactors. These reactors are contained within a cylindrical pressure vessel which could contain any escape of active material resulting from a reactor fault. When the reactor is operating normally, personnel may operate equipment located within this shell for extended periods of time without hazard. An escape of active material from the reactor, would lead to the sealing of the shell; subsequent control of the reactor and the means of decontaminating the interior of the shell, would be transferred to an external control room.

Sealed television cameras are installed within the shell so that operators in the external control room can assess the magnitude of the accident and direct the necessary damage-control operations. Sealed cameras are used so that moisture, for instance, cannot enter the camera, and the assembly may be decontaminated by washing. (Fig. 2.)

The television equipment can therefore familiarize personnel with the tasks to be carried out, without subjecting them to radiation. This considerably reduces the time for which they must be exposed to radiation when they enter the active area. While the task is being performed, all their actions can be observed remotely and directed by two-way audio communications with the emergency control room.

Fig. 2. General purpose industrial camera, contained in a sealed enclosure, and fitted with a remote controlled pan-and-tilt head.

The permissible duration of exposure to radiation is determined by the type of radiation and the flux. In serious accidents the permitted exposure period may be very short and some tasks would require the exposure of several persons before completion if television did not remove the necessity for direct preliminary inspection.

The cameras may include lens-change and pan-and-tilt facilities, all remotely controlled, so that any part of the region may be examined with various magnifications.

3.2. *Instrumental Applications*

Inaccessibility is an abnormal condition of the locations discussed in the previous section. In "hot" laboratories, and in close proximity to research machines, high radiation levels may be characteristic of normal operation.

It is normal practice to handle highly active materials, e.g. irradiated reactor-fuel elements or the radio-isotope sources used in various industrial and medical techniques, in completely enclosed "caves". The cave walls are frequently several feet thick and constructed of shielding materials such as high-density concrete or lead.

In each of these cases, instruments which must be located in the working region can be read remotely using closed-circuit television.

Typical instances of research machines are particle-accelerating devices such as cyclotrons and high voltage sources, e.g. van de Graaf machines. In addition to relaying instrument readings, the appearance of a bombarded target can be examined remotely.

Electromagnetic isotope separators can be more easily controlled using television; remote observations provide the data necessary for the accurate focusing of the ion beam essential in obtaining a high degree of purity in the separated products. This machine is not, in itself, a source of danger but the materials processed may be both radio-active and toxic, e.g. plutonium. Cameras used in this application are sealed to permit subsequent decontamination, and shielded by mu-metal to overcome the effects of the large magnetic field existing close to the machine.

"Hot" laboratory uses of television are various, and supplement the zinc bromide windows which are, at present, provided in the cave walls. Operations in the cave are carried out by mechanical manipulators operating within the field of the windows, which have thicknesses comparable with those of the cave walls and attenuate the radiation fluxes to a safe level.

The initial costs of a zinc bromide window and a closed-circuit television system are similar and, taking reliability into account, there would probably be no advantage in replacing a window by a television system in the simple case where direct-acting mechanical manipulators are used.

This cannot be said of the future; the development of electrical servo-controlled manipulators which can function when separated from the operator by greater thicknesses of shielding than at present used, will render television observation essential. Stereoscopic television, providing a three-dimensional presentation by the simultaneous transmission of left and right eye images, has already proved valuable in manipulator operation and will be vital under the conditions discussed. Even under existing conditions, a stereoscopic camera placed within the cave can give an operator a more realistic view of the manipulator grab movements than he can obtain through, say, a four-foot thick zinc bromide window. (Fig. 3)

The use of instruments within a cave is greatly facilitated if they form part of a television system, particularly if close viewing is required. Typical examples are metallurgical microscopes, test machines such as Hardometers and Tensometers, and combined X-ray and image-intensifier units. Television can display the images which would normally be seen in the eyepieces of these instruments upon monitors outside the cave.

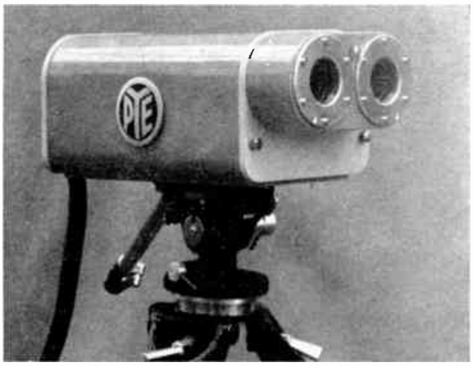

Fig. 3. A sealed stereoscopic camera for use in connection with master/slave manipulator.

A medical application which deserves mention is associated with the radiation treatment of certain diseases. A beam of radiation is directed upon the patient, but it is undesirable that the medical staff should receive any more radiation than is necessary since the cumulative doses may be significantly large. Television can be used for close scrutiny of the patient and equipment during treatment while reducing the exposure of the other persons involved.

If we assume that conventional television equipment is used in these applications, the operating life terminates when a radiation dose of between 10^7 and 10^8 rads has been received. The optical components of the camera are then unusable, but their replacement is sufficient to restore the camera to a normal operating state. Radiation effects are discussed in greater detail in Sections 4.2 and 4.3.

3.3. *Routine Process Supervision and Control*

Television is eminently suitable for aiding the control of industrial processes, particularly when they are on a large scale. The nuclear power stations which are under construction for the Central Electricity Generating Board present a further wide field of application and television will play a vital part in their routine operation, in addition to the more specific functions already discussed above.

Television is notably valuable in two respects: as stressed above, it can function in regions inaccessible to human beings, and observations of processes taking part in widely-spaced parts of the plant can be co-ordinated at a central point using television monitors, considerably aiding control. As an example, the complete routine of fuel-changing can be observed and controlled from one point.

Discharged fuel-elements are thermally hot and highly radio-active; they must be loaded under water into coffins which are transferred automatically to cooling ponds for underwater storage, remaining there until their activity has fallen to a sufficiently low level for safe despatch to a fuel-reprocessing plant.

The coffin-loading operation must be observed and, since it takes place in a working-space below the reactor which has an atmosphere with a high moisture-content, a special camera housing is required incorporating a windscreen-wiper and a demister.

3.4. *Inspection*

Several aspects of inspection have already been discussed, but one specific use of television deserves individual treatment. Reactor pressure-vessels, in common with any other form of pressure vessel or boiler, must, by law, be insured against third-party risks. Internal and external examination of conventional pressure vessels, to the satisfaction of the underwriters, can be carried out at any time by taking the vessel out of operation. The more evidence the user is able to supply of the continued adequacy of the structure and welds during use, the more favourable will the premium become.

Reactor pressure-vessels may only be inspected directly before the reactor becomes operational. The problem can be partly overcome by using a special camera, with incorporated lighting, which can be lowered into the reactor before the initial start-up. Photographs of the monitor displays of the various parts of the structure can be used as references, with which subsequent television pictures may be compared. The correct use of lighting and lenses can reveal a great deal of the fine detail of welds and scale on steelwork. In practice, it must be remembered that large magnifications can be used with television systems and small cracks, for instance, may appear disproportionately large on a television monitor.

4. Specially-designed Reactor Inspection Cameras

We have so far outlined the evolution of closed-circuit television as a tool for the atomic industry and have detailed some of the uses to which it has been directly applied without undue modification or adaption.

We will now proceed to consider the rather more severe conditions imposed by the operation of cameras within the reactors themselves.

4.1. *Reactor Camera Ambient Conditions*

Despite the large sizes of many reactors, they are very delicate installations. Successful operation depends upon the fine control of both the necessary and the unwanted, but unavoidable, physical and chemical processes. Furthermore, the large quantities of electricity which a reactor can produce through its associated generators, and the comparatively long durations of shut-down and start-up operations, make it essential for inspection to be carried out under conditions which are as close to those of normal reactor operation as possible. Ignoring the effects of radiation for the present, this implies high ambient temperatures and pressures. The operating pressure of the Advanced Gas-cooled Reactor at Windscale will be 275 lb/in^2, and the highest gas temperature approximately 575°C. Even with special components, temperatures of this order are prohibitive and a cooling system for the camera is essential. (Fig. 4.) This conclusion introduces further characteristics of the reactor; inspection of a fuel-element channel means that the camera will be located in a cylindrical hole, only a few inches in diameter, through which gas may be flowing with a mass-flow rate of several pounds per second. The restricted flow area, coupled with the high flow rate, implies that turbulence in the gas, and hence heat-transfer, will be a prominent phenomena. The cooling of the camera is therefore a major problem, further complicated by the considerable distances which the camera-coolant must travel before reaching the camera, usually through regions with undesirably high ambient temperatures. The high ambient pressure then becomes important since, after cooling the camera, the gas must be removed, and this is not a simple problem when an external pressure of several hundred pounds per square inch must be overcome.

The extreme inaccessibility of positions within a reactor has already been implied above, and brings with it the difficulty of inserting the camera into the reactor and subsequently controlling movement to required positions.

An indirect, but relevant, consequence of the containment of nuclear processes is the frequent absence of light in the regions to be inspected. The humidity of the surrounding atmosphere is also important; cooling of the camera may result in condensation in the optical system.

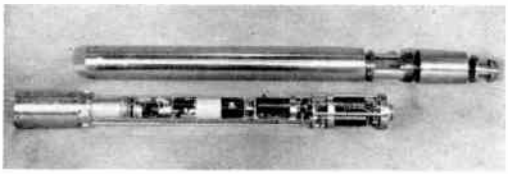

Fig. 4. Reactor inspection camera, for use in a graphite moderated, carbon-dioxide cooled reactor; as at Calder Hall or Chaplecross.

The high operating temperatures of reactors and the forced use of materials with suitable nuclear properties, but less desirable chemical properties, introduces chemical and metallurgical problems. Apart from the need for "clean" components, the television camera and its ancillary equipment must not introduce any element or compound which, by chemical reaction, e.g. corrosion to use a general term, will affect the reactor-components' structural strength. Nuclear processes must not be affected by, for instance, introducing materials which will reduce the local neutron flux significantly.

The possible functions of the camera must also be examined here since they are dictated by characteristics of the reactor. Visual inspection is an obvious application and, for greatest efficiency, requires as large a field of view as possible. A camera may be required to view the walls of a fuel-element channel, or the top of a fuel-element itself; the first case implies viewing at right-angles to the camera axis, the second straight-ahead observation. The camera may be associated with other equipment which is also performing some function under remote control; for example, grab systems can be used to retrieve broken pieces of fuel-elements, or to lift out elements themselves. Each of these operations would be virtually impossible without the simultaneous use of television.

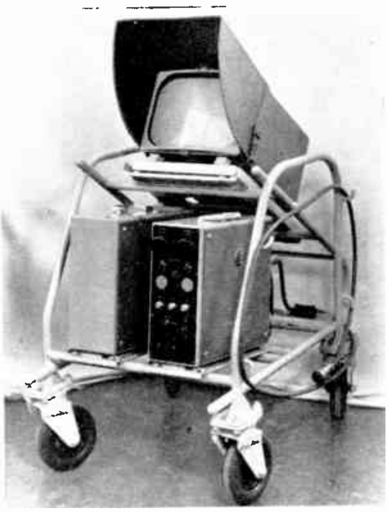

Fig. 5 The control and viewing equipment employed with a reactor camera.

The second part of this discussion is rather lengthy and it is useful to summarize the points covered above before embarking on the radiation characteristics of a reactor. So far, we have shown that the chemical and nuclear features of a reactor can be affected by the television equipment, high ambient temperatures and pressures are present, possible camera locations are restricted in volume, external lighting is frequently absent, and a variety of functions may be required of the camera and its associated equipment.

In general, only two types of radiation need be considered, neutrons and gamma-rays. This must not be interpreted as implying that only these radiations occur; the ranges of other particles are usually too small for them to reach the television camera.

In a working reactor, large atoms such as those of uranium are being broken by fission into two atoms of similar sizes. These disruptions are due to the interactions between neutrons and the heavy atoms. The disintegrations are accompanied by the emission of gamma-rays, and neutrons, while the "fission-fragments"—the new, smaller, atoms—move initially with high velocities. Many of the fission-product atoms are unstable and decay by emitting gamma-rays, beta rays (i.e. electrons), and, in a few cases, neutrons and positrons. Many of these active fission-products decay slowly and are still present in a shut-down reactor; they continue to emit gamma and beta rays but the neutron flux associated with fission is virtually absent, as are the ejected fission fragments. Some orders of magnitude will help to fill in the picture. For every watt of energy produced by fission, $3{\cdot}1 \times 10^{10}$ large atoms are broken-up per second. In a working reactor, the number of neutrons crossing an area of one cm^2 per second may be greater than 10^{13}; the corresponding figure for a shut-down reactor is approximately 10^3. The fluxes of gamma radiation are usually expressed in terms of the number of gamma photons crossing one cm^2 per second. This may be as high as 10^{15} for a working reactor and 10^{11} for a shut-down reactor. Beta fluxes are approximately one-half those of the gamma radiation.

The properties of these radiations are summarized in Table 1.

4.2. *Radiation Effects*

The ranges of neutrons and gamma rays in matter are in general very much greater than those of beta particles (Table 1); this is a consequence of their lack of charge. Beta particles, though much smaller than neutrons, are readily deflected in the proximity of any charge centre, whereas interactions between neutrons or gamma rays and atoms require the uncharged particles to pass very close to the atoms. When neutrons and gamma rays collide with other atoms, relatively large amount of energy can be transferred, other particles are set in motion, and the effect spreads until the energies of the particles involved become too small to produce significant effects.

The mechanisms of radiation damage are complex, and many effects occur.[3] It will be adequate for the present purpose to indicate briefly the possible types of effect and their relevance; Section 4.3 will consider specific materials used in television equipment.

Radiation damage can be considered as occurring on two general scales: the electronic, and the atomic or molecular.

Disturbance of electrons results in changes in properties such as electrical conductivity, i.e. properties which depend upon electronic states. Devices which depend upon maintaining well-defined free-electron concentrations, transistors for example, are particularly sensitive to radiation.

Effects on the atomic and molecular scale are often mechanical in nature. Radiation damage then implies the displacement of atoms from crystal lattice positions, and many mechanical properties are sensitive to disruption of the basic structure of the material. Density, elastic properties, yield strength, etc., are all affected to varying degrees by radiation. With compounds, chemical changes occur as the atoms making up molecules are displaced and the molecules broken-up. Materials containing complex molecules suffer drastic changes in physical properties for comparatively small radiation doses; as examples, natural rubber hardens while butyl rubber softens. The chemical changes caused by radiation may also have undesirable products: some plastics evolve considerable quantities of gas; fluorine is liberated from polytetrafluoroethylene and attacks surrounding materials very rapidly.

Table 1

Some Properties of Radiation Fields

PROPERTY	GAMMA-RAYS	NEUTRON	BETA-RAYS
Nature	Primarily wavelike	Primarily particle	Primarily particle
Particle mass (Hydrogen atom = 1)	—	1	1/1843
Charge	0	0	-1
Range in air (sea-level)	Approx. 300 m (approx. 1 MeV.)	Approx. 200 m (thermal)	4·2 m (1·2 MeV.) 1·1 m (0·45 MeV.)
Effects upon organic materials	Collide with, and excite, electrons. The ionization produced disrupts the complex molecules and radiation damage is LARGE.	*Slow neutrons* are captured by light atoms. Gamma rays are emitted and cause LARGE radiation damage. *Fast neutrons* collide with light atoms, which recoil and cause ionization by exciting electrons. Radiation damage is VERY LARGE.	Produce excited electrons which cause ionization and disrupt complex molecules. Radiation damage MODERATE.
Effect upon inorganic materials and metals	Collide with electrons; ionization produced causes NEGLIGIBLE radiation damage.	*Slow neutrons* are captured by atomic nuclei; gamma rays emitted cause ionization and VERY SLIGHT radiation damage.	Cause some ionization, and NEGLIGIBLE radiation damage.
Typical fluxes	Working reactor: up to 10^{15} photons cm^{-2}sec^{-1}. Shut-down reactor or intense source: 10^{11} photons cm^{-2}sec^{-1}.	Working reactor: 10^{13}n.cm^{2}sec^{-1}.	Comparable with gamma, but greatly reduced by distance from source.
Typical radiation energies	Mean energy in working reactor approx. 0·7 MeV. Cobalt 60 source, 1·7 and 1·33 MeV.	Working reactor: most 1 to 2 MeV, some up to 15 MeV.	Mean energy in working reactor approx. 0·4 MeV but may be up to 10 MeV. Cobalt 60 source, 0·31 MeV.

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Not all the molecular effects are mechanical, however, and optical behaviour can also be affected. Displacement of atoms alters the resonant frequencies of the complicated systems of atoms making up materials, and strong absorption may occur in important regions of the spectrum. Normal optical glass is susceptible to such damage; its transmission coefficient decreases in magnitude and a brown colouration appears.

Another irradiation effect which must be taken into account is the heating of material as energy is given up by the radiation. This can be a very large effect since a radiation dose of 10^8 rad (see below) implies the absorption of 240 calories gm^{-1} or 430 B.T.U. lb^{-1}.

Neutron fluxes passing through matter have a further unfortunate effect in that they produce artificially radioactive atoms from the stable atoms present. A typical reaction is

$$\text{Al}^{27} + n \rightarrow \text{Al}^{28} + \gamma$$

The aluminium atoms of mass number 28 are unstable and decay with a half-life of 2·3 minutes. The magnitude of the induced activity and the rate at which it decays varies from element to element. Table 2 shows some typical induced activities and the energies of the emissions occurring with the decays.

This production of radioactivity in originally stable material is, for our purposes, limited to neutron fluxes. Gamma-ray energies must be considerably higher than those which usually occur before they can initiate nuclear reactions.

4.3. *Radiation Dose Units*

In the next section we will examine the influence of the installation characteristics upon television equipment design; prior to this it is necessary to define the units of radiation dose which are commonly employed.†

The simplest method is to state the integrated flux received by the specimen, i.e. neutrons per cm^2 and gamma photons per cm^2, together with the energies of the particles or photons. This

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† For more detailed information on radiation units see *J. Brit.I.R.E.*, **14**, pp. 648-50, December 1957 (Appendix 2).

Table 2

Approximate Activities Induced in Various Elements by Neutron Irradiation

(Assuming equilibrium is reached in a flux of 10^{12} thermal neutrons $\text{cm}^{-2}\text{sec}^{-1}$ and based on data given by Frisch[2])

Element.	No. of disintegrations per second per gram of naturally-occurring element, 100 seconds after removal from flux.	Time for activity to fall to 1 / 10th of original value.	Energies of gamma rays emitted (MeV).	Energies of beta particles emitted (MeV).
Cobalt	$3{\cdot}1 \times 10^{11}$	17·3 years	1·77, 1·33	1·48, 0·31
Manganese	$1{\cdot}4 \times 10^{11}$	8·7 hours	3·0, 2·6, 1·75, 0·85	2·86, 1·05 0·7
Vanadium	$4{\cdot}1 \times 10^{10}$	12·3 minutes	1·46	2·73
Silver	$4{\cdot}1 \times 10^{9}$	2·5 years	2·0 to 0·93, 0·89, 0·66	2·86, 2·12 0·53, 0·087
Iron	$7{\cdot}8 \times 10^{7}$	150 days	1·3, 1·1, 0·19	1·56, 0·46, 0·27
Magnesium	$1{\cdot}3 \times 10^{7}$	32 minutes	1·015, 0·834, 0·18	1·75, 1·59
Aluminium	$3{\cdot}1 \times 10^{6}$	7·7 minutes	1·782	2·865

has some practical advantages but makes correlation of results for differing materials impossible because no information is given on the proportion of the radiation which is intercepted by the material.

The "roentgen" is, by definition, used for X- and gamma-ray doses, and is defined as that quantity of the radiation which results in the absorption of 83·8 ergs per gram of dry air at N.T.P. Unfortunately, this same quantity of radiation would produce an absorption of 93 ergs per gram of tissue, and so on.

The "rad" is becoming generally accepted as the unit of dose; it represents an energy absorption of 100 ergs gm^{-7}, and may be applied to any type of radiation.

In practice, the differences between roentgens and rads are rarely significant and they may be considered numerically identical.

The dose rate can only be predicted when the nature of the material and the properties of the incident radiation are known. The calculation is comparatively complex for neutron irradiation, but gamma doses can be readily estimated using

$$1 \text{ roentgen or rad} = \frac{1{\cdot}9 \times 10^9}{E} \text{ gamma photons cm}^{-2}$$

This is satisfactory, to about ± 15%, for gamma ray energies (E) from 0·07 to 2 Mev.

A further unit, which is employed primarily in defining radioactive sources, is the Curie, defined as that quantity of material in which there are $3{\cdot}7 \times 10^{10}$ disintegrations per second. It follows that the gamma dose rate, in roentgens per hour, at a distance of 1 m from a source of A curies is $0{\cdot}57\,A.E_t$, where E_t is the total gamma photon energy per disintegration.[3]

In the examples of the behaviour of electronic components given below, no consistent use of radiation-dose units will be found. This is inevitable because published data rarely contains sufficient information to permit conversion to a common unit.

It cannot be overemphasized that, when television is required for operation in radiation fields, all the relevant data should be specified, i.e. the types of radiation, the appropriate fluxes, and the energy spectra of each component of the radiation.

4.4. *High Temperature Design Considerations*

This is not a problem peculiar to either television or nuclear installations. Many other branches of technology require that equipment be kept at temperatures differing considerably from the ambient.

Two techniques are possible: the equipment is thermally isolated from its environment as completely as possible so that negligible heat flow occurs; the temperature of the equipment is maintained at the required level by the presence of a cooling fluid which removes the unwanted heat.

The temperature of the equipment must inevitably increase with time using the first method, but an equilibrium state is possible and desirable with the second. It must be remembered that electronic equipment generally dissipates significant quantities of heat, and this should be removed if equipment temperatures are not to rise with time.

There is no doubt that, ideally, the complete thermal isolation of the camera is preferable but many practical considerations complicate the situation. Thermal isolation is very difficult to achieve; typical insulants such as rock wool have conductivities of, say,

$$0{\cdot}2 \text{ B.T.U. in.}^{-1} \text{ ft}^{-2} \text{ hr}^{-1} \,{}^{\circ}\text{F}^{-1},$$

or approximately $10^{-4}\text{cal sec}^{-1}\text{cm}^{-3} \,{}^{\circ}\text{C}^{-1}$

and these are inadequate when large temperature differences are present. Furthermore, they are comparatively bulky. An additional factor is introduced at high ambient temperatures since thermal radiation, as well as conduction, must be considered. The use of "vacuum flask" techniques is possible but, again, separation of the inner and outer containers must be achieved without introducing significant conducting paths. With the additional factors of heat dissipation by the enclosed equipment, and the possible need for the complete unit to be as small as possible, thermal isolation is only practicable when small differences in temperature exist and the operational period required is short.

An approach which is occasionally used is that of enclosing the camera in a jacket through which water, or some other fluid, circulates. The method is flexible in that the effective ambient temperature may be maintained at a constant level over a range of actual ambient temperatures by suitable control of the coolant flow rate. This solution is probably the simplest course when there are no important size restrictions.

The small permissible diameters of reactor inspection cameras do not, in general, allow water jackets to be used, or elaborate thermal insulation. Under these conditions, and with an unpressurized gas-cooled reactor, the simplest solution is to carry gaseous coolant to the camera through a flexible hose, finally allowing it to exhaust into the reactor. This, incidentally, solves the difficulties associated with the camera cable; as long as the cable diameter is small relative to the bore of the camera supporting hose, the hose can contain the cable and the latter is protected from the ambient temperature.

The television camera design must allow the cooling gas to pass around the temperature-sensitive components, and special arrangements are required to allow cable and gas to enter the camera through the same connector assembly. In locations where (*a*) size is not restricted, or (*b*) where temperatures only slightly above the optimum temperature of the equipment (say 50°C higher or less) or ventilation poor, or (*c*) where sealing is not vital, then separate hoses may be used as inlet and outlet for cooling air supplied from a conventional air-line.

Camera operation within hot liquid, or in high pressure gases, requires a cooling circuit which is isolated from the reactor atmosphere. This can be achieved with a concentric hose system, the inner hose carrying the camera cable. These composite hoses provide a return path for the camera coolant, which may be recirculated if suitable heat-exchanging equipment is provided external to the reactor. The camera-coolant pressure is primarily determined by the gas flow characteristics of the hose. It is usually necessary to use a fairly high pressure, in excess of 100 lb/in^2, say; the possibility of active coolant leaking into the camera under shut-down reactor conditions can be overcome by operating the camera with an internal pressure greater than ambient. The insertion of a camera into a working reactor would result in an equilibrium value of activity being reached by the camera coolant, and leaks would therefore be less significant. It should be emphasized that leaks may only be detectable when moving parts pass through the camera container, e.g. drive-rods for grab attachments.

The choice of materials should be made with regard to the high temperature, but their compatibility with the reactor materials must also be considered.

4.5. *Designing for High Ambient Pressures*

Pressures which are high in this context are moderate compared with some applications, e.g. underwater television, and the latter techniques may be directly applicable in the atomic field.

The simplest case occurs when cable must be brought through pressure-vessel walls. The sealing must satisfy very stringent requirements since failure could, in some cases, mean loss of reactor pressure and the release of radioactive gases. A very effective method employs glass-to-metal seals; connecting wires pass through holes in a metal disc and are sealed in with glass beads. The coefficient of thermal expansion of the glass matches those of the metal disc and the wire connector, hence the seal remains effective despite temperature variations. This type of seal can be directly welded to, for instance, pressure vessel walls.

The need for maintenance of the equipment and the common necessity of a coolant-gas hose imply the use of seals in the camera. The use of O-rings at the junctions is usually satisfactory but the number of such seals must be kept to a minimum since they represent possible failure points.

The choice of sealing material is considerably restricted by three factors: the ambient temperature; the possibility of radiation damage to the seal material; and chemical implications of inserting the material into the reactor.

Other sealing problems arise but they are usually peculiar to a particular application and have little general significance.

4.6. *Mechanical Design of Reactor Cameras*

This is an aspect which, to some extent, has been touched upon in the two preceding sections. The cameras themselves have frequently to be designed with undesirably small dimensions, and the choice of container metal may be limited to steel, aluminium, or, in the near future for inspection in hot environments, one of the less well-known metals. At the present time, stainless steel is adequate for most applications, but this will not be so if reactor temperatures become significantly higher.

Apart from the ability to withstand considerable pressure differences, the camera container may also be called upon to support large loads if grab attachments are used.

Within the camera, ventilation must be adequate for all components, a large number of which have to be located in a small space, structural materials must not be used which are good absorbers of radiation or very susceptible to radiation damage (see below), and the possibility of remote maintenance may have to be borne in mind.

As explained above, a camera irradiated with neutrons may become too active for direct handling and maintenance must be carried out using a manipulator, working behind suitable shielding. This condition calls for considerable ingenuity in the design.

Many other mechanical problems must be solved and some indication of the scope is given by the following brief list: design of cooling hose, design of suitable hose-and-cable winding gear, remote control of mechanical motions of grabs, remote focusing of optical systems, etc. They will not be considered in detail since they are not characteristic only of nuclear installations.

4.7. *Electronic Design of Cameras for High Radiation Level Operation*

This is the field in which most remains to be done. Great progress has already been made in developing simple, non-critical circuits which can withstand considerable variations in working conditions, but problems such as cooling are created by the use of sensitive equipment, hence the working-part of the camera is the logical point to make the greatest effort.

The need for components which will operate with high ambient temperatures is not restricted to either television or nuclear installations and will not be dwelt upon beyond noting that many components satisfying radiation-resistance requirements are also correspondingly resistant to temperature effects.

Table 3 indicates some of the difficulties which are encountered in using electronic components in radiation fields. It illustrates well the wide variety of effects which can occur and the lack of uniformity in the doses at which they become significant.

The designer of electronic equipment which is to operate in radiation fields must follow a number of rules:

(i) The amount of equipment located in the most extreme conditions of a given situation should be an absolute minimum.

(ii) Components used should not contain elements with high absorption cross-sections for the incident radiation; e.g. boron and cadmium have high neutron absorption cross-sections. The heat developed is undesirable from the equipment point of view, and the possible release of boron into any neutron system would be very unpopular, apart from the resultant local depression of the neutron flux in normal operation.

(iii) Where structural strength is required, metals should be used, remembering that iron, cobalt, etc. become highly active, and aluminium is, in general, most suitable.

(iv) Undue confidence should not be placed in the insulating properties or mechanical strength of many plastics.

(v) The use of "air-gaps" for insulation should take into account the ionized state of the atmosphere in the equipment, which is the result of irradiation.

(vi) Materials should not be used which evolve corrosive substances under irradiation.

(vii) The dimensional changes of some irradiated materials must be allowed for by increasing tolerances.

(viii) The use of magnetic materials containing cobalt is undesirable because the induced activity has a long half-life. Solenoids may be used to produce magnetic fields, or electrostatic focus employed where applicable.

These are not exhaustive rules and, for a given application, it is desirable to examine every component which is to be used by preparing a statement of every element it contains. It is then relatively easy to predict qualitatively any unfortunate effects. The results of such analyses are often surprising; many components contain considerably more than ten elements in significant amounts.

In practice, this careful choice of components is probably the most important, and difficult, preliminary move in designing a camera for use under irradiation conditions.

In some cases it is necessary to allow for a characteristic of radiation damage which complicates the "integrated effect" already discussed

Table 3

Examples of Radiation Damage in Electronic Components and Materials.

COMPONENT OR MATERIAL	RADIATION DOSE OR FLUX†	RADIATION DAMAGE
CAPACITORS—		
Electrolytic (boron containing).	10^{17}n.cm^{-2} approx.	Failure due to gas evolution (4)
	10^{16} gamma cm^{-2} $+10^{17}$n.cm^{-2}.	Capacitance decrease approx. 10%; power factor decreases 3% to 30%.(5)
Oil-filled.	10^{18}n.cm^{-2} or $+5\times10^{15}$ gamma cm^{-2}.	Oil leakage; capacitance decreases approx. 10%. (4,5)
Paper and mica.	$+10^{17}$n.cm^{-2} or $+10^{16}$ gamma cm^{-2}.	Worst effect observed is capacitance change of a few %.(4,6)
Ceramic.	10^{14}n.cm^{-2}.	Capacitance decrease of approx. 1% and power factor decrease approx. $-0{\cdot}1$%.(6)
	10^{18}n.cm^{-2}	Negligible changes.(4)
	5×10^{16}n.cm^{-2} and 5×10^{15} gamma cm^{-2}.	No detectable integrated effect in capacitance; rate effect may be -5% capacitance change.(5)
RESISTORS—		
Wire-wound.	$+3{\cdot}6\times10^{16}$n.cm^{-2} and $+3{\cdot}6\times10^{15}$ gamma cm^{-2}	Resistance change less than $0{\cdot}5$%.(5)
Carbon.	10^{18}n.cm.$^{-2}$ and 10^{17} gamma cm^{-2}.	Resistance decrease of few % and rate effect negligible.(4,5)
VALVES.	$+10^{17}$n.cm^{-2}.	Some fail due to glass damage by 10^{17}n.cm^{-2} others show no apparent damage by 10^{18}n.cm^{-2}. (4)
TELEVISION TUBES.	Approx. 10^{11}n.cm^{-2} sec^{-1} and 10^{11} gamma cm^{-2} sec^{-1}.	Considerable increase in dark current (rate effect); integrated effect negligible apart from glass darkening.(5)
PLASTIC INSULANTS.	Approx. 10^{17}n.cm^{-2} or $+5{\cdot}10^{7}$ rad.	Considerable changes in mechanical properties of most plastics. Insulation resistance may decrease by a factor of 10^{3}.(7,8)
SEMI-CONDUCTOR DEVICES.	10^{13} to 10^{16}n.cm^{-2}.	Germanium diodes tend to become ohmic, and resistance and leakage currents may increase by several hundred %. Silicon diodes show high leakage currents and increases in back and forward resistances.(6,7) Loss of amplification in germanium transistors by 10^{14}n.cm^{-2}.(9)
GLASS.	10^{14}n.cm^{-2} or 10^{7} rad.	Discolouration.(9,10)

† Where only neutron flux or dose is specified it may be assumed that a comparable gamma flux or dose is implied.

by implication. Integrated effects are the changes in properties which are determined by total radiation dose only. "Rate effects" are changes defined by the magnitude of the incident flux and exist only while the radiation flux persists. Upon removal of the flux, the property magnitude reverts to a value given by the integrated-effect for the flux received. This implies that component properties measured before and after irradiation are not necessarily representative of actual values during irradiation. The magnitudes of rate-effects vary from component to component.

We have said above that shielding is, in general, not practicable. A simple calculation of the weight of lead needed for a shield several inches thick around a moderate-sized camera easily demonstrates this. A two-inch lead shield around a camera of diameter 3·5 in. and length 36 in. would weigh approximately one-quarter of a ton. The incident gamma flux would be reduced to 1/10 for 4 MeV photons and 1/100 for 0·7 MeV photons. Shielding materials with high boron contents have been developed but large amounts would be required to produce significant reductions in neutron fluxes, although weight would not necessarily be a prohibitive factor. Slow neutron fluxes can be reduced by a factor of 10^5 with a $\frac{1}{4}$ in. thickness of Boral, but 6 in. of polyethylene or 10 in. of water are required to attenuate fast neutron fluxes to 1/10 of their incident value. But as has already been pointed out, the introduction of such neutron absorbing shielding materials would, if for no other reason, be unacceptable on account of the effects that they would have on the operation of the reactor itself.

In practice, the optical system itself is most sensitive to radiation damage. Table 3 shows that optical glass becomes discoloured when it has received a certain amount of radiation and, at moderate radiation levels, the useful life of the camera is found to be limited by the behaviour of the lens system and the face-plate of the camera tube. The electronic equipment does not show significant damage at these doses, and replacement of the damaged glass is sufficient to restore the camera to normal operation. Fortunately, there are several possible substitutes for optical glass, although the lens-making techniques for these materials are less well-developed and less versatile lens-systems must be accepted.

When considering the foregoing physical effects on the choice of the actual circuits and components employed, the designer is forced to strive for some measure of compromise between the optimum television performance and what the overall operating conditions permit.

Although the circuitry must be a minimum, it is necessary to provide sufficient head amplifier gain to raise the camera tube output signal level sufficiently for it to be passed to the control equipment over several hundred feet of cable, without suffering from the pick-up of any spurious signals. Since the camera may be called to observe fine detail in the structure within the reactor, a satisfactory bandwidth of at least 5 Mc/s must be maintained thoughout the amplifier, and the output passed to the camera-control unit from a suitably low impedance source.

It is also desirable to achieve this performance with the minimum anode supply voltage, so that all capacitors employed have working voltages which give good safety factors, despite the temperature rise derating required, without the need to employ unduly large components.

In the interest of stability, it is essential to ensure that the heater supply to the camera tube and amplifier valve is maintained within satisfactory limits against variations of camera cable resistance caused when the camera is taken in and out of the hot areas of the reactor.

Finally, it is desirable to provide some form of "over temperature" alarm system so that the coolant flow may be increased, or the camera withdrawn from the reactor in the event of the safe operating temperature being exceeded.

5. Future Developments

There is no escaping the conclusion that the most stringent demands upon television equipment have been, and will be, determined by reactor characteristics. Although television techniques are of great importance in this field, it would be unrealistic to expect concessions in operating conditions so that television could be used; a great many other processes and techniques are involved in reactor operation and television must be kept in perspective.

Other applications of television, e.g. in "hot" laboratories, will usually involve more favourable conditions than those of in-pile operation, and the future outlook will probably be one of the increasing use of television for remote observation and display. The performance of equipment will be continually improved and the "building-block" approach applied to give the installations increased versatility and flexibility.

In the past, the television systems used have presented black-and-white, as distinct from colour, images. There are many tasks which can be performed without colour information and the complexity and comparatively high cost of available colour television equipment have not yet justified its use. There is, however, an increasing need for colour television in, for instance, hot laboratories for metallurgical study and processing, and less costly colour equipment to meet such industrial requirements is now being evolved.

These are typical evolutionary stages of any equipment; the impetus for revolutionary changes in conception and design will be dictated by changes in reactor design, for the reason given above. We must therefore consider possible developments of reactors.

One likely trend is to higher temperatures; the coolant itself is, at present, rarely at temperatures in excess of 400°C, with the fuel elements themselves a few hundred degrees higher. It would be desirable to operate with considerably higher coolant temperatures for more efficient operation of the turbine systems, but the metallurgical problems posed in reactor design are proving extremely difficult. As an instance, beryllium will probably supersede many other materials for fuel-element cladding, but the working of beryllium is hazardous since the dust is highly toxic. However, beryllium will withstand higher temperatures and this is sufficient incentive to overcome the associated problems.

Apart from the possibility of on-load reactor inspection, the desirability of immediate access after shut-down justifies the development of equipment which will withstand higher temperatures. Increases in pressure are less formidable in their implications, but, considering both pressure and temperature, it is apparent that television cameras must become even more insensitive to their environment. The development of components to withstand higher temperatures can only offer a partial solution, and cooling techniques must be studied further. No simple solution can be expected because large temperature differentials must inevitably be maintained and large amounts of heat must be removed by expending equivalent amounts of some other form of energy. The solution can only take the form of decreasing the effective heat transfer coefficient between the temperature-sensitive equipment and its environment, and reduction of the thermal capacity of vital equipment. The decrease in size required by temperature-control considerations will increase the manoeuvrability of the equipment.

The radiation problem cannot be approached in the same way. Side-effects, such as heating, can be reduced by decreasing the size of components but negligible useful isolation can be achieved by shielding under extreme radiation conditions. The size and mass of the material required for useful shielding would be prohibitive in many applications, and camera positioning would be a major problem. The answer will probably lie in following the courses already discussed, selection of components, reduction in the numbers of components by improved circuit design, and the design of new components. Any cameras intended to operate in a working reactor will almost certainly become highly radioactive and a great deal of work is yet to be done to facilitate remote servicing of the equipment.

As far as reactor types are concerned, most applications of television have been with gas-cooled reactor systems, if we restrict ourselves to in-pile operation. The sealing necessary when ambient pressure is high, and the associated requirements that no active reactor-coolant should escape via the camera system, renders cameras relatively insensitive to the nature of the surrounding medium. The increasing numbers of boiling water and pressurized water-reactors in the world will produce a demand for underwater television cameras, at least for in-pile inspection during shut-down conditions; on-load inspection is unlikely to come until techniques for fuel-element handling in this type of reactor reach a state comparable with those which are well-advanced for gas-cooled reactors. The problems raised by reactors which are liquid moderated and/or cooled are likely to be primarily mechanical and chemical.

A manufacturing problem which may be expected to grow in importance is that of cleanliness. Improved filtration and purification systems will make it essential for the amount of foreign matter introduced by television equipment to be kept to a minimum.

It is not possible to generalize on future size requirements for equipment. The diameters of a few inches which can be achieved with cylindrical cameras should be adequate for most applications in the immediate future and reduction of length is probably the next step. This should not be interpreted as minimizing the need for cameras, for all applications, to have volumes as small as possible, and improvements in component design will tend to be such as to permit reductions in equipment size.

Although not strictly a television problem, remote handling attachments are already fitted to cameras and are thus effectively part of the camera. These grabs are versatile in their present state but new requirements will inevitably arise, governed by, for instance, fuel-element design.

Optically, many improvements are possible and desirable. Existing optical-systems are adequate for the basic requirements of operation in restricted spaces, but techniques such as stereoscopy cannot be generally used, or multiple lens and "zoom" lens systems. Lighting arrangements also offer considerable scope for improvement, particularly with regard to improving the ratio of the energy appearing as useful radiation to that dissipated as heat.

These are some aspects of the future which face the mechanical and electronic designers of television equipment; many more problems could be added to the list. In brief, television equipment, and the cameras in particular, must operate with considerably higher ambient temperatures and pressures, in radiation fluxes comparable to or greater than those of existing reactors on full load, dimensions should be reduced, camera containers must be unaffected by hot gases, light and heavy water, and organic liquids, and the associated optical and mechanical facilities must be increased.

6. Conclusion

We have attempted to give a balanced account of the way in which television has played a part in the development of nuclear energy, the types of problem which must be overcome, and the future requirements. It will be apparent that television has already made a notable contribution and, now that its value is realized, will be increasingly regarded as a technique to be considered in the original design of installations rather a refinement added at a later stage.

It cannot be said that the imminent problems are simple, particularly those related to temperature and radiation, but there are numerous promising approaches which have yet to be fully investigated. Thus, as well as producing more sophisticated equipment for conditions which are not exacting, there is the possibility of increasing considerably the range of conditions under which operation is possible.

7. Acknowledgments

The authors wish to thank those of their colleagues whose work and experience have been drawn upon in the course of this discussion, and the Directors of Pye Ltd. for permission to publish this paper.

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News from the Sections . . .

West Midlands Section

"Problems of Medical Instrumentation" was the subject of the paper read on 13th January in Wolverhampton by Mr. Peter Styles of St. Thomas's Hospital Electronics Department. This paper had been sponsored by the Institution's Medical Electronics Group.

The speaker opened with a survey of the instrumentation problems involved in radiotherapy treatment of anaesthetized patients in an atmosphere of high pressure oxygen. These included measurement of oxygen tension, respiratory flow rates, temperature, heart rate, muscle potentials, etc. Some of the techniques described were conventional, others special to medical electronics, but all were complicated by the increased fire risk due to the pressurized oxygen atmosphere. In the category of special techniques, the development of probes for the measurement of oxygen tension in liquids and tissue was given detailed treatment. The linearization of inferential flow measuring transducers used for respiration monitoring was also considered.

Mr. Styles then referred to a problem common to many branches of medical electronics, that of resolving transient signals in the presence of a high random noise background. One method quoted for overcoming this difficulty was successive re-writing of the signal on a very long persistence c.r.o., in which trace brightness was an inverse function of writing speed. The low probability, high amplitude random noise components were then reproduced at low brightness. Drift in d.c. amplifiers was also considered and some automatic drift-cancelling systems which had been successfully employed were described.

An associated problem which Mr. Styles discussed was that of obtaining a record of transient phenomena with large random time intervals between signals. Continuous recording presented obvious economic difficulties, the eventual solution being a tape recorder in an f.m. system, necessary to give the required bandwidth of d.c. to 3,000 c/s. The recorder was operated with a short loop of tape, continuously recording, sampling by means of a separate playback head, and erasing. Wanted signals from the playback head were then transferred to a separate recording system.

In conclusion, Mr. Styles outlined a system of closed circuit television employed with specialized optical instruments. This had proved of great value in the teaching of eye surgery and the diagnosis of defects, since it permitted mass viewing of a patient's eye. F. D.

South Western Section

The South Western Section met on 27th January in Bristol to hear a paper entitled "An Equipment for Automatically Processing Time-Multiplexed Telemetry Data" which was presented jointly by Messrs. J. H. Russell, N. Purnell and T. T. Walters.

In his opening remarks Mr. Russell outlined the data processing problem (as distinct from data evaluation) which is set by a telemetry system capable of transmitting up to half a million measurements in under two minutes. The solution was found in the automatic data processing equipment, known as "Timtape", which was the subject of this paper. At this point a short technical film was shown to provide a background to the detailed description of the equipment which was to follow. This included a number of interesting shots of "Bloodhound" missiles in action.

Mr. Walters then took up the theme by explaining briefly how data was transmitted by the telemetry system and recorded on magnetic tape. This tape could be played back into "Timtape" at a speed suited to its requirements and so rendered the latter quite independent of the telemetry equipment. He gave a lucid and detailed description of this complex piece of equipment, tracing the information through the system to the two forms of output, namely digital information on punched cards and an analogue photographic record from a camera recorder.

At the conclusion Mr. Purnell joined his co-authors and together they handled the lively and informed discussion which followed. Considerable interest was shown in the analogue-to-digital converter which formed part of the data processing equipment. G. F. N. K.

Simple Standing Wave Measurements at Low Input Powers†

by

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Summary: The standing wave ratios of microwave components which contain or can be made to contain a crystal detector can be measured at low input power with a minimum of equipment. This method should prove useful where slotted lines and sensitive receivers are not readily available.

1. Introduction

Certain microwave components, particularly crystals, may have impedances which are dependent on the amount of power to which they are exposed[1]. Thus to obtain consistent results it is often necessary to measure the standing wave ratio at very low input powers. If the normal slotted line section is used to measure the standing wave the power available to the probe will be extremely low and a superheterodyne receiver or travelling wave tube amplifier will be required to give the desired sensitivity. If the component to be measured contains or can be made to contain a crystal detector a modified form of the method proposed by Liberman[2] may be employed.

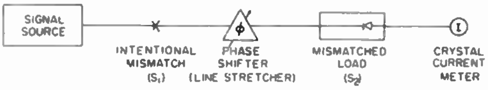

Fig. 1. Measurement of mismatched load with intentional mismatch and phase-shifter.

2. Theory

Liberman showed that if a mismatched load, which includes a crystal diode, is fed from an intentionally mismatched source through a line stretcher or phase shifter as shown in Fig. 1 the following conditions hold. With the line stretcher adjusted to give maximum crystal output the power into the load is[3]

$$P_{c\,(\max)} = P_0 \frac{4S_1S_2}{(S_1+S_2)^2}$$

when P_0 is the power available from the matched source to the matched load, S_1 and S_2 are the v.s.w.r.'s of the source and load respectively. If the line stretcher is now adjusted to give minimum output from the crystal mount the power into the crystal is

$$P_{c\,(\min)} = P_0 \frac{4S_1S_2}{(1+S_1S_2)^2}$$

The ratio of the two powers is

$$\frac{P_{c\,(\max)}}{P_{c\,(\min)}} = r = \left(\frac{1+S_1S_2}{S_1+S_2}\right)^2$$

and if the crystal is ideally square law

$$\frac{I_{\max}}{I_{\min}} = r = \left(\frac{1+S_1S_2}{S_1+S_2}\right)^2$$

where $I_{\max}$ and $I_{\min}$ are the crystal currents corresponding to $P_{c\,(\max)}$ and $P_{c\,(\min)}$.

If now S_1 is made very large with respect to S_2 we have that

$$\frac{I_{\max}}{I_{\min}} \cong S_2^2$$

and S_2 is approximately equal to the square root of the ratio of the crystal currents. The source v.s.w.r., S_1, may be made very large by the introduction of a suitable discontinuity in the waveguide or transmission line between the signal source and the phase shifter.

3. Experimental Arrangement

This method has the great advantage of simplicity, a minimum of components being required. Although the phase shifter should have a low v.s.w.r. it does not need to be calibrated. If S_1 is very much larger than S_2 the accuracy of measurements may be as good as those made with a slotted line. Even when S_1 is not much larger than S_2 but the value of S_1 is

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known, corrections may be applied as shown in Fig. 2.

However, this method is subject to two sources of error. For large values of S_2 the power incident on the crystal will vary over wide limits and this in turn will change the crystal input impedance and hence the v.s.w.r. The second source of error arises from the assumption that the response of the crystal is exactly square law—which may not strictly be the case[4].

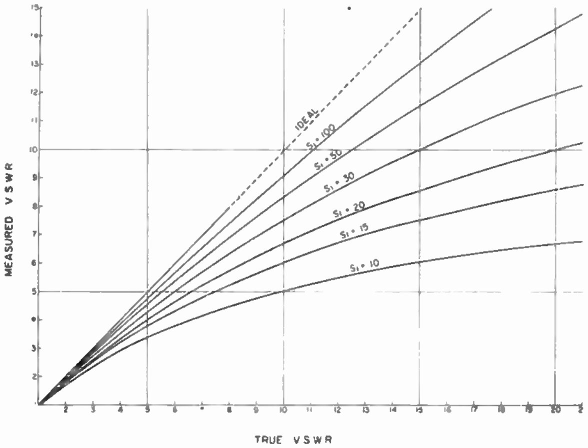

Fig. 2. Corrections to be applied to measured s.w.r.

An improved method calls for the introduction of a calibrated attenuator in the output of the signal source. The phase shifter is now adjusted to obtain the maximum and minimum power transfer to the crystal, while the attenuator is adjusted to give the same crystal output for both conditions. From considerations similar to those given by Liberman it can be shown that the ratio of maximum to minimum power is

$$\frac{P_{\text{in (max)}}}{P_{\text{in (min)}}} = \left(\frac{1+S_1S_2}{S_1+S_2}\right)^2 \cong S_2^2 \text{ for } S_1 \gg S_2$$

This ratio is determined directly from the attenuator readings for the two conditions. To preserve the accuracy of the calibrated attenuator it is necessary to insert an attenuating pad ahead of the mismatch discontinuity. Thus with a slight loss of simplicity the sources of error inherent in the previous method are avoided.

In order to confirm that measurements made with the method described were as accurate as calculated a number of configurations were built up. Most of the measurements were carried out at X-band so that waveguide components were employed. The line length between source and load was varied by one of three methods, phase shifter, sliding-fit line stretcher or a waveguide squeeze-section. The mismatch at the source was provided by either an iris or the 20-db

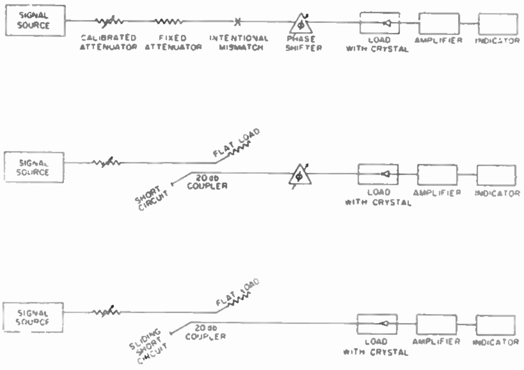

Fig. 3. Typical configurations of components for measurement of s.w.r. at low powers.

Table 1

Comparison of S.W.R. Measurements on Crystal Mount

Frequency	8·6 Gc/s	9·0 Gc/s	9·6 Gc/s
Directional Coupler and Sliding Short ...	8·5 db	1·5 db	6 db
Iris Discontinuity and Squeeze Section ...	8·5 db	1·5 db	6 db
Slotted Line with Superheterodyne Receiver	8·5 db	1·25 db	6 db

All measurements made with same power into crystal.

Table 2

Comparison of S.W.R. Measurements on Sliding Screw Tuner with Padded Crystal Mount

Frequency	8·6 Gc/s	9·0 Gc/s	9·6 Gc/s
Directional Coupler and Sliding Short ...	14·5 db	16·5 db	18·0 db
Iris Discontinuity and Squeeze Section ...	14·0 db	16·0 db	17·0 db
Directional Coupler, Short and Phase Shifter	14·0 db	16·5 db	18·0 db
Slotted Line with Superheterodyne Receiver	14·5 db	17·5 db	19·0 db

coupler and a short. With the second type of generator mismatch the variation of line length could also be carried out by moving the position of the short. A large number of combinations are possible as indicated in Fig. 3.

4. Results Obtained

The results of measurements made by different methods were compared and good agreement was found between the various readings. Typical comparisons are shown in Tables 1 and 2. A series of low s.w.r.'s, those of a crystal mount, are compared in Table 1 while Table 2 deals with a series of higher s.w.r.'s of a sliding screw tuner measured as a two-port component in front of a padded crystal mount.

5. Conclusions

The method described allows measurements of standing wave ratios to be made at relatively low power levels with a minimum of equipment. This is particularly useful when crystals and other power sensitive elements are part of the component being measured or when suitable slotted lines and superheterodyne receivers are not available.

6. References

1. H. N. Dawirs and E. K. Damon, "Measurement of crystal impedances at low levels," *Trans. Inst. Radio Engrs (Microwave Theory and Techniques)*, **MTT-4**, No. 2, pp. 94-6, April 1956.
2. L. S. Liberman, "A method of measuring v.s.w.r. of video detectors," *Radioteckhnika i electronika*, **2**, No. 7, pp. 941-942, 1957.
3. J. H. Craven, "The probability of specified losses at mismatched junctions," *J. Brit.I.R.E.*, **18**, pp. 293-6, May 1958.
4. A. Staniforth and J. H. Craven, "Improvement in square law operation of 1N23B crystals from 2 kmc to 11 kmc," *Trans. Inst. Radio Engrs (Microwave Theory and Techniques)*, **MTT-8**, No. 1, January 1960.

THE MANUFACTURE OF SEMI-CONDUCTOR DEVICES

Silicon as a semi-conductor material for diodes and transistors has not so far achieved the degree of use of germanium, in spite of its many advantages, largely due to difficulties in fabrication. The decision of Ferranti Ltd. to concentrate solely on silicon devices is therefore notable, especially as it is intended to follow the £500,000 spent since 1954 by an expenditure of £1,000,000 over the next five years. An Institution representative was recently shown some of the Company's activities which include diodes of many types, transistors and photocells.

Production of a new high frequency, double-diffused, mesa silicon transistor, has now commenced at the Gem Mill factory in Oldham. This device is intended for use in high frequency amplifiers and oscillators up to 100 Mc/s.

The essential problem in fabricating this transistor has been to develop a process which would enable transistor structures to be produced, in which all the major device dimensions are very small. Typically, collector diameters of 0·010 in. and base widths of 0·0001 in. are required. A further major problem, having produced a structure of this size, was to develop a process for making separate electrical contacts.

The technique introduced by Bell Telephone Laboratories known as "diffusion" has been adopted in which slices of single crystal silicon are heated at high temperatures in the presence of suitable chemical gas mixtures. The appropriate chemical impurities are thus introduced into the silicon to form the required *npn* transistor structure just beneath the surface. For this transistor a particularly complicated version of the basic technique called "mask diffusion" is employed which involves several carefully controlled successive diffusion processes. When completed these result in the junction geometry, illustrated in Fig. 1, being formed throughout the whole area of the slice.

An important production point about this diffusion process for fabrication of transistors, is that it permits the simultaneous formation of a large number of transistors.

The next stage in the processing of the diffused slices into individual transistors is conversion of the slices into "mesa dice" (Fig. 2). The critical regions of the transistor are all contained within the mesa, 0·002 in. high and 0·010 in. in diameter and this construction provides a direct contact to the base region of the transistor giving more reliable electrical contacts with lower base lead resistances. Gold wires, 0·001 in. in diameter, are then attached by pressure bonding to the emitter and base regions.

Further assembly operations, to convert the wire bonded tab assembly into an encapsulated transistor (Fig. 3) follow conventional practice.

A new automatic plant has been set up at Gem Mill for the production of a series of 500 mA double-ended diffusion diodes. This plant is estimated to be capable of producing 43,000 silicon diodes a week up to test stage.

Most of the operations have been specially designed for automatic assembly techniques and indeed all operations in the final assembly of the header such as flash welding the wire on the back of it and passing through a hydrogen furnace to remove oxidation and the final encapsidation are carried out by automatic transfer mechanisms. As the stages of copper and gold plating the header assembly and of pre-soldering the dice to the header lend themselves well to batch production, no automatic mechanism is used for these processes.

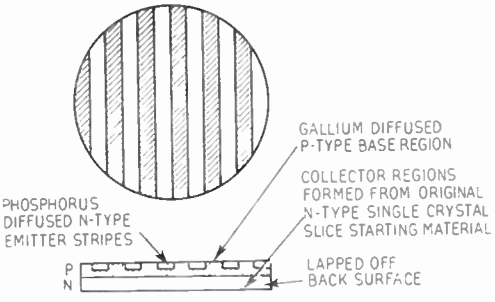

Fig. 1.

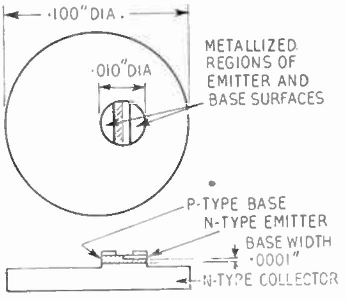

Fig. 2.

Fig. 3.

Radio Engineering Overseas . . .

The following abstracts are taken from European and Commonwealth journals received in the Library of the Institution. Members who wish to borrow any of these journals should apply to the Librarian, stating full bibliographical details, i.e. title, author, journal and date, of the paper required. All papers are in the language of the country of origin of the journal unless otherwise stated. The Institution regrets that translations cannot be supplied.

H.F. VOLTAGE MEASUREMENTS

In a recent paper, first presented at a conference in Ljubljana in 1958, a Yugoslav engineer has described a measuring amplifier by which—in connection with an appropriate auxiliary oscillator—measurements of high-frequency signals are rendered possible down to the level of − 100 dbm in the frequency range between 50 and several thousand Mc/s. The measuring device consists of a 35-Mc/s intermediate-frequency amplifier of 2 Mc/s bandwidth and an aperiodic crystal mixer stage. A large pointer instrument fitted with a logarithmic scale facilitates reading of variations of the measured signal of 0·5 db. Accurate frequency setting of the auxiliary oscillator is rendered possible by a built-in discriminator, and the operating point of the mixing diode may be set and checked accurately by a pointer instrument in the mixing circuit. The measuring device provides a means for recording characteristics of frequency dependent networks such as resonators, filters, etc., as well as an adequate zero indicator for bridge measurements for its high sensitivity.

"Measurement of high-frequency voltages at low levels." Zvonko Fazarine. *Elektrotehniski Vestnik*, **27**, pp. 17-20, No. 7-8, 1959.

RING MODULATORS

The performance of ring modulators using dry rectifiers fundamentally depends on the homogeneity of the electrical characteristics of the rectifiers used and on the balance of the various elements constituting such a modulator. Silicon diodes with high reverse incremental resistance and comparatively high direct current theshold voltage fulfil these conditions in quite a satisfactory way, and are particularly suitable for the building of excellent channel modulators. How this is made possible is explained in a recent French paper, which gives a comparison of their qualities in this respect with those of other types of dry rectifiers, and shows by the study of the characteristics of silicon rectifiers their special advantages for modulation purposes.

"Application of silicon diodes to ring modulators." R. Dallemagne. *Cables & Transmission*, **14**, pp. 12-29, January 1960.

DELAY LINES

Various types of delay lines with a three-dimensional grid structure have been investigated in a recent German paper. The suitability of such delay lines for use as frequency controlling elements in a backward wave oscillator for the millimetric wave region has been determined. The dispersion characteristics, as well as the data for the electric field strength in the direction of wave propagation have been measured. The method which has been developed for the purpose of measuring these quantities also permits the measurements of the space harmonics of the field. Measured and calculated values agree well with one another in most cases, and larger deviations have been explained.

"Investigations on nonhomogeneous periodic delay lines." H. Wehrig. *Nachrichtentechnische Zeitschrift*, **13**, pp. 71-81, February 1960.

PARAMETRIC AMPLIFICATION

German engineers have recently investigated the signal and noise behaviour of an amplifier cascade consisting of a reactance-type straight amplifier as pre-amplifier, followed by a conventional triode amplifier. The transducer gain and the bandwidth of the reactance-type straight amplifier as well as the overall noise figure of the cascade network are presented as a function of the parametric negative conductance. The minimum overall noise figure is calculated and the paper states for this purpose certain design rules for the negative conductance and the coupling of the following amplifier to the pre-amplifier. The minimum overall noise figure which can be attained for a prescribed bandwidth of the prestage or a power matching condition at the input of the amplifier is investigated. Measuring results are given which were determined on an experimental setup for a signal frequency of 510 Mc/s and a pump frequency of 1800 Mc/s, using as a following amplifier a conventional triode in a grounded-grid configuration. In satisfactory agreement with the analysis, the experimental results show that with a relative bandwidth of the reactance-type straight amplifier of 5 per cent. the overall noise figure of the amplifier cascade was reduced by a factor of four compared to the minimum noise figure of the following amplifier. For a power matching condition at the amplifier input and a relative bandwidth of 5 per cent. a reduction of the overall noise figure by a factor of two was attained with respect to the minimum noise figure of the following amplifier.

"The reactance type straight amplifier as a low noise preamplifier in the v.h.f. region." R. Maurer, K. H. Locherer and K. Bomhardt. *Archiv der Elektrischen Ubertragung*, **13**, pp. 509-512, December 1959.

MAGNETRON DESIGN

Four experimental magnetrons have been developed in Holland for wavelengths of 3·2 and 1·2 cm, 8 and 4 mm, and with peak outputs of 1100, 70, 80 and 40 kW, respectively. The four magnetrons have virtually the same geometrical proportions: considerations of similarity show that the wavelength is then proportional, and the magnetic field inversely proportional, to the linear dimensions, and that for the same anode voltage and current the same power is generated. Deviations from the theory are due to the limitations on the electrode conductance, magnetic field and thermionic emission. The tubes are made largely of copper components and contain an axially mounted L-type cathode. The 3·2 cm magnetron has a mean power of 900 W, to achieve which its cathode has been designed to have a high heat dissipation. The small dimensions of the 4 mm magnetron necessitate a special assembly technique. Life tests on a 3·2 cm, a 1·2 cm and an 8 mm magnetron were terminated after 238, 700 and 1488 hours respectively; the power outputs had dropped in that time by about 15 per cent.

"A range of pulsed magnetrons for centimetre and millimetre waves." J. Verweel and G. H. Plantinga. *Philips Technical Review*, **21**, No. 1, pp. 1-9, 1959/60.

RHOMBIC AERIALS

Rhombic aerials used so far have not yet reached the theoretical of optimum performance. This is partly attributable to their complexities in design. To overcome this the radiation impedance and the attenuation factor have been investigated by the German engineers and improved formulae for the statements of theoretical calculations are proposed. Aerial gain and efficiency as a function of input impedance are recorded in tabular and graphical form. Bandwidth and aerial gain are treated in terms of the taper angle. A rhombic aerial with a gradually changing taper angle (exponential rhombic aerial) is discussed. This is followed by some proposals for designs.

"Rhombic aerials with optimum performance." P. Miram and E. Palm. *Nachrichtentechnische Zeitschrift*, **13**, pp. 82-91, February 1960.

C.W. RADAR

A recent German paper discusses the effect of frequency fluctuations in systems employing a compensation method or the Doppler effect particularly with reference to the frequency stability required for navigation systems. Bridge type oscillators with two crystals are recommended for use as oscillators with a high frequency stability. The circuit of the frequency determining portion of the oscillator has the form of a bandpass or a phase shifter and measurements on a phase-shifter-oscillator and a crystal controlled transistor oscillator are reported. In case of the latter, the frequency fluctuations have been reduced to 3×10^{-9} per day.

"The importance of constant frequencies in c.w.-radar techniques and methods for achieving a high frequency stability. W. Herzog. *Nachrichtentechnische Zeitschrift*, **13**, pp. 29-33, January 1960.

COMPANDERS

For signal transmission paths or recordings which are affected by interference the use of companders is often recommended. An investigation of various companders by German engineers has shown that the best transmission quality is only achieved by means of a syllable compander operating at carrier frequency level when the transmission frequency band must not be much larger than the original frequency band. An experimental test with the compander described has revealed that it is possible to install carrier-frequency music links over 2,500 km with the quality recommended by C.C.I.T.T.

"A compander for broadcast programme links." W. von Guttenberg, and H. Hochrath. *Nachrichtentechnische Zeitschrift*, **13**, pp. 9-14, January 1960.

COLOUR TELEVISION

Colour television by the N.T.S.C. method leads to a vestigial-sideband transmission for the I-component of the colour signal, which is modulated onto a sub-carrier. A paper by a German engineer discusses first the related transmission errors and then shows how colour crosstalk into the Q-channel and the frequency-response error of the I-signal can be eliminated by suitable circuit arrangements in the colour receiver. Thereafter the paper deals with circuits which also allow a pre-equalization of the I-signal in the colour modulator. The crosstalk interference appearing in this case is discussed.

"Vestigial side-band transmission of colour signals on the NTSC system." H. Schonfelder. *Archiv der Elektrischen Ubertragung*, **14**, pp. 37-46, January 1960.