The Journal of the

BRITISH INSTITUTION OF RADIO ENGINEERS

FOUNDED 1925 INCORPORATED BY ROYAL CHARTER 1961

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

VOLUME 23 APRIL 1962 NUMBER 4

RESEARCH IN RADIO AND ELECTRONICS

RIGHT from its inception the Institution has always stressed the value of research in all branches of radio and electronics, and has taken an active part in disseminating information, by means of its meetings, Conventions and the *Journal*, on the results of current research projects.

By the announcement elsewhere in this issue of the establishment of research studentships the Institution reaffirms its faith in the value of, and need for, additional fundamental research. While it is admitted that these studentships make only a very small contribution in relation to the total effort of Great Britain, they do express the faith of the Institution in a tangible form.

It is well known to members that our Charter President is greatly concerned with the co-ordination and development of research in electronics and that he has appointed a permanent Research Committee of the Institution which has now started work on a report reviewing and assessing the pattern of future research in radio and electronics.

In order to mark the Charter Presidency of Admiral of the Fleet the Earl Mountbatten of Burma, and to indicate his particular interest in research matters, it is appropriate that, with his permission, the Institution's new studentships will be named Mountbatten Research Studentships.

The Council of the Institution has recently authorized the establishment of an Institution Research Fund. If this attracts reasonable support from industry and members it is the Council's intention to use the funds to set up more Research Studentships, and later, possibly, Research Fellowships and even a Chair in Electronics.

It cannot be too strongly emphasized that the future success and competitiveness of the British radio and electronics industry depends in a very large measure on the strengthening of research of both fundamental and applied kinds. This research must be forward-looking, solving not so much the problems of the present, but anticipating—as far as is humanly possible—the problems of the future. Increased efficiency and co-ordination of existing research programs—which at present cost perhaps £30,000,000 per annum in British radio and electronics—must go hand-in-hand with new independent research, for which money must be found by Government and industry together.

By its Charter the Institution is charged to do all it can to promote advancement of knowledge in radio and electronic science. Every member is committed to that task and the establishment of the Mountbatten Research Studentships is a first step by which the Institution may collaborate with industry and Government in encouraging and securing increased research facilities.

W. E. M.

INSTITUTION NOTICES

The Research Committee

As announced in the report of the Proceedings of Council in the March *Journal*, a Research Committee has been set up having the following membership:

L. H. Bedford, C.B.E., M.A., B.Sc., F.C.G.I. (Member) —*Chairman*
Professor M. R. Gavin, M.B.E., D.Sc. (Member)
I. Maddock, O.B.E., B.Sc.(Hons.) (Member)
W. E. Miller, M.A. (Member)
P. E. Trier, M.A. (Member)
Professor D. G. Tucker, D.Sc. (Member)
Professor E. E. Zepler, Ph.D. (Member)

The terms of reference of the Committee are:

"To consider the research needs of the United Kingdom and the Commonwealth in developing radio and electronic science and engineering, to consider all possible means by which research may be fostered in radio and electronics and to advise the Council of the Institution on schemes of Research Studentships and Fellowships and other endowments which may be sponsored by the Institution and to act as a selection committee if and when appointments are made to such posts."

Reference is made in the editorial to this *Journal* to the establishment of Research Studentships.

Symposium on Tunnel Diodes

Publication of the papers presented at the joint meeting on Tunnel Diodes which was arranged by the Institution and the Electronics Group of the Institute of Physics and the Physical Society in February 1961 has now been completed.

The December issue of the *British Journal of Applied Physics* contains a survey article by I. G. Cressell on the papers given at the meeting, and two papers:

"The Tunnel Diode" by A. K. Jonscher.

"Indium Antimonide Tunnel Diodes" by K. F. Hulme.

Copies of the complete issue of *B.J.A.P.* may be obtained price 12s. 6d. from the Institute at 47 Belgrave Square, London, S.W.1 (*not* from the Brit.I.R.E.).

Four of the papers sponsored by the Brit.I.R.E. at this meeting have now appeared in the *Journal* as follows:

"The Design and Construction of Tunnel Diodes" by J. Przybylski and G. N. Roberts (*December*); "The Tunnel Diode as a 'Solid-state Circuit' Element" by A. E. Brewster (*December*); "Theory and Experimental Characteristics of a Tunnel Triode" by W. Fulop and S. Amer (*February*); and "Tunnel Devices as Switching Elements" by I. Aleksander and R. W. A. Scarr (*March*). Reprints may be ordered at the usual price of 3s. 6d. per copy.

New Date for Special General Meeting

The Special General Meeting of Corporate Members of the Institution, announced in the March *Journal* for 2nd May, will now take place on Wednesday, 23rd May 1962, at 6 p.m., in the London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, London, W.C.1. The motion before the meeting will be the adoption of the Bye-Laws, as required by the Charter of Incorporation.

This meeting will follow the symposium arranged by the Education Group to discuss "Laboratory Work in Advanced Radio and Electronics Engineering Education".

Brit.I.R.E. Convention in India

Progress has been made by the Indian Advisory Committee in its plans for the Commonwealth Electronic and Radio Convention which is to be held in Bangalore in January/February 1963.

The Convention will last altogether three days with two sessions on each of the mornings, whilst the afternoons will be devoted to visits, general lectures and discussion periods.

The subjects of the sessions are:

Trends of Radio Communication and Associated Problems

Industrial Electronics—Aid for Production and Management

Electronics in Automation

Electronics in Defence.

Papers will be published in advance for all delegates and presented in summary at the Convention. Full papers should be submitted by the end of August 1962, accompanied by a 150-word abstract, to the Honorary Secretary, I.A.C.-Brit.I.R.E., Post Box No. 109, Bangalore 1, from whom all further information may be obtained.

Back Copies of the *Journal*

Because of the increasing volume of requests by new subscribers, notably libraries overseas, for previous volumes of the *Brit.I.R.E. Journal*, several issues for 1959 and 1960 are now out of print, namely: June, September, October 1959; May, July, October, November 1960. Members who are willing to part with their copies of any or all of the above seven issues (in good condition) are invited to send them to the Publications Department, Brit.I.R.E., 9 Bedford Square, London, W.C.1; payment of 5s. per copy will be made. Please note that these are the *only* issues required.

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A Directly-Coupled Serial Adder designed for use in a Digital Differential Analyser

By

B. A. BOULTER, *(Graduate)*†

Summary: A brief introduction to the technique of directly-coupled logical circuits is given together with basic logical circuit diagrams. It is proposed that for maximum economy and optimum operational reliability, a single type of transistor and a single value of resistor should be used throughout the equipment and that design reliability should be based on the probability of worst-case parameters not being exceeded. Practical designs based on the above theories are shown and limited reliability figures quoted.

1. Introduction

This paper describes the design of a directly-coupled serial adder and its associated timing equipment, to be used as second generation circuits for the CORSAIR[1] digital differential analyser which was designed and constructed at the Royal Aircraft Establishment, Farnborough.

The use of directly-coupled transistors in high-speed logical circuits[2] has become realizable only since the introduction of the surface barrier and micro-alloy types of transistor, since these types have the combined advantages of a low bottoming voltage and good high-frequency performance at these low voltages. Conventional alloy junction types of transistor are less satisfactory for directly coupled circuits.

A technique for designing a directly-coupled circuit for a specific logical requirement has been evolved.[3] Little account was taken of expected parameter spreads in transistors, but the results showed that different collector load resistors were required in different circuits. With such a technique, circuits must be designed separately for each different logical requirement and this necessitates the use of different resistor values throughout the equipment.

It is proposed that a better solution would be to design all circuits around a single value of resistor, and then provide limitations to the amount of logic that can be performed in any gating circuit. This carries the following advantages: it is easier to construct an equipment with but one component value; the equipment tends to be more reliable on constructional grounds; and, if faults are to be repaired by component replacement, it is easier and cheaper to replace one of a single value than to carry stocks of all. Furthermore, the electrical design of the equipment is simplified to its limit, and the restrictions to the logic which may be performed are not nearly so serious a drawback as might be imagined.

† Formerly Royal Aircraft Establishment, Farnborough, Hants; now with Semiconductors Ltd., Swindon, Wilts.

2. The Directly-Coupled Technique

A common method of coupling alloy junction switching transistors when in grounded emitter configuration is to connect the collector of one to the base of another by means of a capacitor in parallel with a resistor. Reverse biasing of the base may be effected by a second resistor connected to a positive supply. Referring to Fig. 1 (*a*) the switching-off time of VT 2 is accelerated by the charge on the capacitor tending to neutralize the charge remaining in the base region of VT 2 as this transistor is switched off. This switching time is generally dependent upon the values of all the passive components associated with the two transistors.

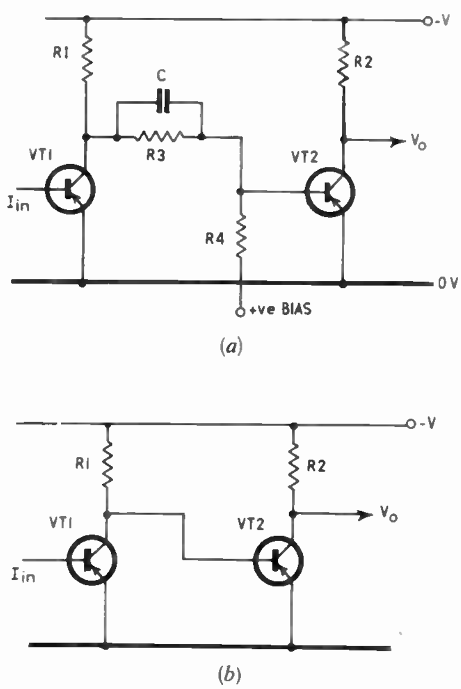


Fig. 1. (*a*) Resistance-capacitance coupled stages.
(*b*) Directly-coupled stages.

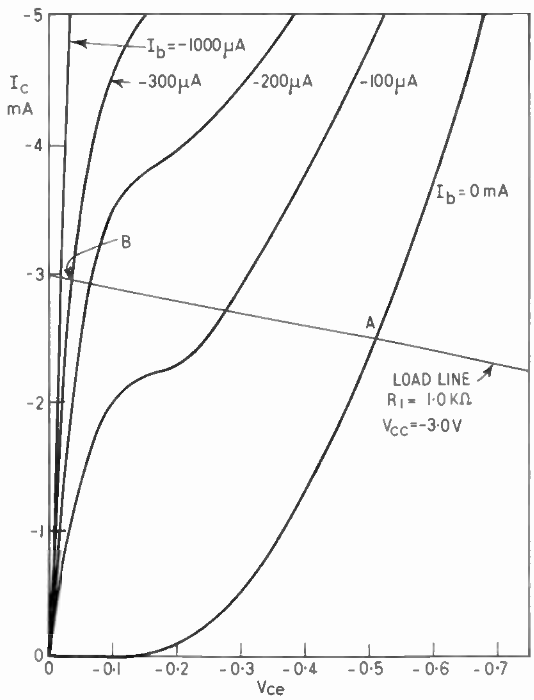


Fig. 2. Typical collector characteristics of directly-coupled SB 240.

Consider now a surface barrier transistor. The base region is extremely thin, and therefore will not allow a large charge to accumulate in it. As a direct result of this, a surface barrier transistor may be switched at a rate in the order of ten times faster than an alloy junction type, when bottomed in common emitter configuration. Thus for switching applications up to about 5 Mc/s, it is possible to eliminate the capacitor from the circuit in Fig. 1 (*a*), provided suitable transistors are used. Further, with a suitable choice of collector load resistor, it is possible to eliminate the bias supply and coupling resistor, a direct connection being substituted, as shown in Fig. 1 (*b*).

To appreciate transistor operation in the directly-coupled mode, reference should be made to the collector and base characteristics of the transistors. Since the base-emitter junction of VT 2 is effectively in parallel with the collector-base junction of VT 1, the collector characteristics of VT 1 are modified by the base characteristics of VT 2 as shown in Fig. 2. The load line of R1 then defines, for VT 1, the non-conducting state at A and the conducting state at B. Input characteristics are shown in Fig. 3.

Now if VT 1 is non-conducting, the potential at point A is sufficient to bias VT 2 into the saturation region. In order to reverse the states of these transistors, it is merely necessary to make the base-emitter potential of VT 1 sufficiently negative for a base current of at least *I* to flow. The operating point moves to B, when VT 1 saturates, the collector-emitter potential of VT 1 then being small enough to cut off VT 2.

It is important to note that if a base current of less than *I* is applied to VT 1, the operating point of this transistor cannot move to point B. The conducting state of this transistor will not then be accurately defined, and this possibility should be avoided at all times. A base current greater than *I* will have no significant effect on the collector-emitter potential of VT 1, and is permissible.

2.1. *Basic Logical Elements*

2.1.1. The inverter

The inverter circuit, shown in Fig. 4 (*a*) is a single transistor operating as described above. The two states of the device may be tabulated:

Non-Conducting	Conducting
$V_{be} \simeq -0{\cdot}08$ V	$V_{be} \simeq -0{\cdot}4$ V (on load)
$V_{ce} \simeq -0{\cdot}4$ V (on load)	$V_{ce} \simeq -0{\cdot}08$ V

For convenience, these approximate potentials are related to a binary code, the least negative representing a "0" whilst the most negative represents a "1".

Thus it will be seen that if the input to an inverter is a "0", the output will be a "1" and vice versa.

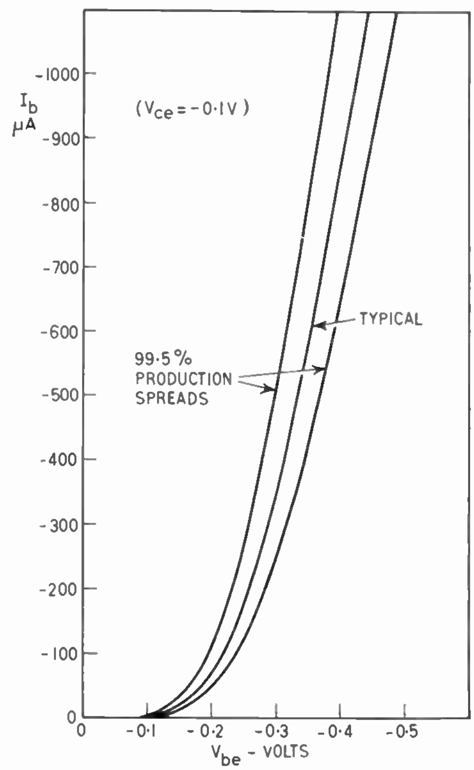


Fig. 3. Input characteristic of the SB 240.

2.1.2. Parallel gate configuration

Since the "off" current of an SB240 is small (in the order of 100 μA at 25° C), these transistors may be connected in parallel to a common load resistor.

Then if all the transistors are in the non-conducting state, an output will be obtained between the common collector point and earth, but if any transistor is switched to the conducting state, no output will be obtained. A two-input gate of this type is shown in Fig. 4 (*b*).

The operation of this gate may be represented in Boolean form:

For inputs of A or B, the output C is $\overline{A+B}$, the NOT symbol indicating the inversion in the gate. But for inputs of $\overline{A}$ and $\overline{B}$ (that is, the A and B signals separately inverted), the output $C = \overline{\overline{A}+\overline{B}} = A.B$. Thus, having regard for inversions, this circuit may be used either as an OR- or as an AND-gate.

2.1.3. Series gate configuration

Since the potential difference across a conducting surface-barrier transistor need not exceed about −0·08 V, two or more of these transistors may be connected in series to a common collector load, shown for two transistors in the circuit of Fig. 4 (*c*).

When both transistors are conducting, no output will be obtained. Thus with inputs of A and B,

$$C = \overline{A.B}$$

With inputs of $\overline{A}$ or $\overline{B}$,

$$C = \overline{\overline{A}.\overline{B}}. = A+B$$

Again, having regard for inversions, this gate may be used for AND or OR functions but for reasons discussed later, it is recommended that the series gate should be limited to containing two transistors only.

2.1.4. The bistable storage circuit

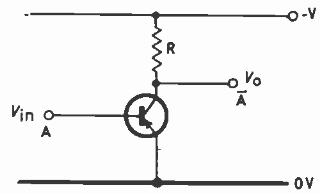
Consider two directly-coupled inverters as shown in Fig. 1 (*a*). If the input of VT 1 is held at less than −0·08 V, this transistor is non-conducting and its collector will be at about −0·4 V. Enough base current may thus be provided through R1 to bottom VT 2 and therefore, the collector of this transistor is about −0·08 V. Similarly, if the potential of the base of VT 1 is held at −0·4 V, the collector of VT 2 will also be at about this potential.

Thus it is possible to provide a direct feedback loop from VT 2 collector to VT 1 base, and once the state of one transistor is fixed, so the state of the other transistor is fixed in the opposite condition. The circuit may be redrawn as in Fig. 4 (*d*).

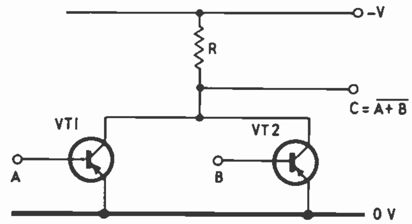
To change the state of this device, it is necessary only to short-circuit to earth the collector of the transistor originally in the non-conducting state, for a time sufficiently long to switch off the other transistor. The collector of this transistor then falls to about −0·4 V and provides enough signal to hold the first transistor in the conducting state, even when the original short-circuit has been removed.

Inverters or gates as described above form excellent short-circuiting links for switching a bistable store, and usually it is possible to operate the gate plus half the bistable from a common load resistor, thereby maintaining component economy.

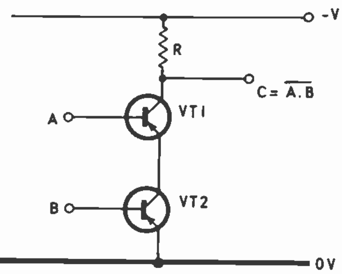
It should, perhaps, be stressed that a bistable of this form can be switched only by a conventional



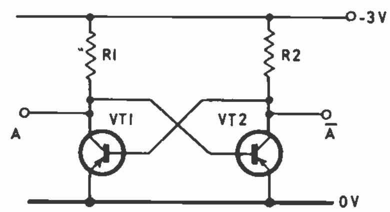
(*a*) Inverter.



(*b*) Two-input parallel gate.



(*c*) Two-input series gate.



(*d*) Bistable memory.

Fig. 4. Logical elements suitable for direct coupling.

"0" signal: a "1" signal on the other collector will not operate the device.

2.2. *Design Reliability*

Designing for the worst case of all transistor parameters is not likely to prove the best way of achieving a reliable and economic equipment, since this method presumes no failures in the completed equipment until the components are aged out of their worst-case tolerances. In fact it is well known that failures occur in such worst-case designed equipment before the expected lifetime has elapsed, the failure rate decreasing approximately exponentially with time.[4] Most failures occur randomly and are catastrophic, occurring mainly during the first 1000 hours of the equipment's life.

Now if circuits are designed less conservatively than guaranteed worst-case, the complete equipment could be made less complex than otherwise, and its failure rate would be reduced. In the event of a circuit falling outside its probable worst-case limit, the fault would appear during the first hours of operation. Since it is usually necessary to have more than one transistor outside specific worst-case limits to constitute a fault, it is expected that faults due to taking non-guaranteed worst-case limits will be small compared with those saved by using a simpler design initially. Thus an enhanced equipment reliability might well result from this technique, together with a saving in capital cost of equipment.

A directly-coupled logical circuit contains many transistors, and in general a failure of this circuit will be caused only by more than one of the component transistors falling outside worst-case limits. Thus if the worst-case design level is taken such that, say, 99% of the transistors will be acceptable, the probability that the circuit will operate is considerably more than 99%. No estimate of equipment reliability has been made here, but practical figures for the reliability of a limited sample of directly coupled transistors are quoted in the conclusion.

The design technique is to assume a worst case of the relevant parameter limits which in each case would be passed by, say, 99% of the transistors. Much of the required information about spreads in parameters is obtainable from the transistor manufacturers, but certain requirements for the direct coupling of transistors are not quoted on the data sheet and no figures of spreads are available. For these, separate tests were made, the results being obtained from a statistical method.[5] This method requires test results from a random sample of, say, 25 units, the results being plotted on a linear/probability graph sheet according to a table published by Chernoff and Lieberman.[6] For a random sample of units (a Gaussian parameter distribution in the sample) the resulting curve should be linear. In the tests carried out by the author, this was obtained to a very close approximation, giving confidence in the technique. Only the relevant results from these tests are quoted below.

2.2.1. Design consideration for the SB240

For reasons of compatibility with existing equipment, a collector supply voltage of -3 V $\pm$ 5% was employed and at this potential experience has shown that a suitable collector load resistor for general-purpose use has a value of 1000Ω $\pm$ 5%.

In general all transistors in a logical arrangement such as that to be described will be fed from the same voltage source. Thus in designing these circuits, account need not be taken of high and low supply voltage conditions occurring simultaneously as has been the practice.[7] The worst case occurs when this voltage is 5% below nominal, and this has been assumed throughout the calculations. Resistors throughout the equipment may have values randomly distributed $\pm$ 5% from nominal and this full tolerance has been allowed.

In common emitter configuration, if a transistor is bottomed, the collector current is given by $\frac{V_{cc}-V_c}{R_c}$ and the worst case of this is 3000 μA. Then assuming a worst case current gain of 10 for a bottomed transistor, the base current required to achieve this collector current is 300 μA.

It will be appreciated that if a number of transistor bases are connected to a single collector terminal of a transistor in the "off" condition (non-conducting), the potential of this common connecting point will be determined primarily by the input characteristic of the worst-case transistor. Production spread limits of 99·5% for a SB240 input characteristic are shown in Fig. 3. From these curves, it will be seen that for a worst-case base current of 300 μA, a base voltage of $-0{\cdot}315$ V is required and a best transistor base current will be 600 μA. Thus the worst loading conditions for an inverter or parallel gate are realized when one worst case and $(n-1)$ best case base-emitter diodes are connected to its collector, where n is the total number of base-emitter diodes connected to the collector.

A 10 deg rise in temperature from 25° C has the effect of moving the curves in Fig. 3 by about 20 mV towards the ordinate. Thus increase in temperature has a negligible effect on transistors which are in the "on" condition.

Considering an m input parallel gate, 99·7% of these transistors will have an "off" current of less than 100 μA at 25° C, when their base is held at 100 mV. But since the bases of these transistors will be driven from the collectors of other transistors which will bottom to 80 mV or less with a 99·7% probability, the "off" current of a transistor driven from an inverter or parallel gate will be much less than 100 μA at 25° C. The worst "off" current occurs at elevated temperatures. For a 10 deg rise of temperature, the input voltage of a SB240 at a low level of base current falls by about 20 mV. Thus for the directly-coupled gates described above, the worst "off" current is 100 μA at 35° C with a probability that about 1 transistor in 10^5 will fail to meet this worst case.

Hence an m input parallel gate driving n outputs demands a minimum current from the load resistor of the gate of $100\,m+300+600\,(n-1)$ μA and the maximum current that can be supplied from a high-value resistor is $\frac{2{\cdot}85-0{\cdot}315}{1050} = 2410$ μA. Thus the maximum permitted number of outputs is limited to four; these may be controlled by up to three inputs and if more inputs are required, the number of outputs must be reduced.

It has been quoted that up to five SB240 transistors may be connected in series with a common load to form a gate.[3] Whilst this may be possible, it is not economic since a large base drive is required to bottom each transistor sufficiently.

For a standard circuit compatible with the system described let the number of transistors in a series gate be limited to two (a "two-high" gate). There is a probability that 97% of the transistors will bottom to less than 70 mV under the input conditions already described and by making a random selection of two transistors to be used in a two-high gate, there is a probability that more than 99·1% of these pairs will together bottom to less than 140 mV.

A test was then carried out to discover the "off" current that would flow in an SB240 with a base voltage of −140 mV. The results of this test were that 99·7% of the units would have an "off" current of less than 680 μA at 25° C. Since the main effect of temperature on the "off" current results from the change in input characteristic of the transistor it will be seen that under constant voltage input conditions, the base current doubles for a 10 deg temperature rise, and since the collector current changes in (very nearly) the same ratio, the "off" current under these conditions is 1360 μA at 35° C.

Thus the output from an inverter following a two-high gate must be limited to (2410−1360) μA = 1050 μA. Practically, this means that this inverter will drive no more than two transistors, which together can take up to 900 μA, and that two inverters driven from a two-high gate may not be used directly in a parallel gate, since the "off" condition of this gate would be similar to its "on" condition.

Since the "off" current in a two-high gate will be less than 100 μA three of these gates may be connected in parallel to form an AND–OR combination, the output of this feeding up to four transistors provided each of these has a maximum loading of two bases.

3. The Detailed Design

3.1. *Logical Design of the Adder*

Signals in the CORSAIR arithmetic unit are in serial form. Thus addition may be economically performed bit by bit.

In practice, the addition of two words starts by adding the two least significant bits to obtain sum and carry terms. The sum term obtained is the least significant digit of the required answer, whilst the carry term is delayed by one digit period and added to the next two digits of the word inputs. This process is repeated until the addition is complete.

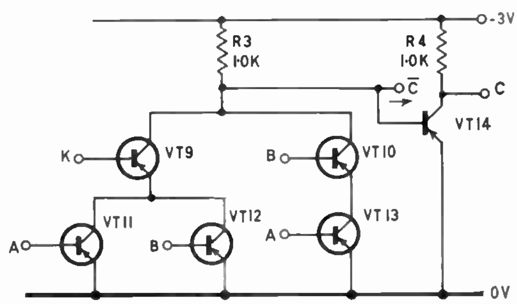
The logical design of such an adder has been adequately described in the literature[8] and the results, expressed in Boolean form, may be arranged:

$$C = A.B.+K.(A+B) \qquad \ldots.(1)$$

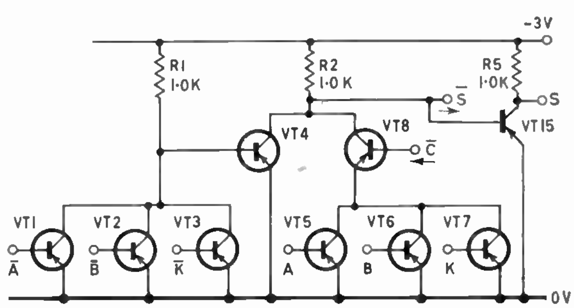
$$S = \bar{C}(A+B+K)+A.B.K \qquad \ldots.(2)$$

where A and B represent the two inputs to be added,

C the carry term produced,
K the delayed carry term,
S the required sum output.



(*a*) Carry generator.



(*b*) Sum generator.

Fig. 5. The adder circuit.

3.2. *Electrical Design of the Adder*

For carry terms, equation (1) may be mechanized in one gate and an inverter, as shown in Fig. 5 (*a*). Outputs of both C and $\bar{C}$ are available.

The sum generator consists of a number of gates including a three-input AND and a three-input OR. Using directly-coupled SB240 transistors in this generator, it is essential that both these gates be of the parallel type. A suitable circuit is shown in Fig. 5 (*b*), the outputs required being one from each of S and $\bar{S}$.

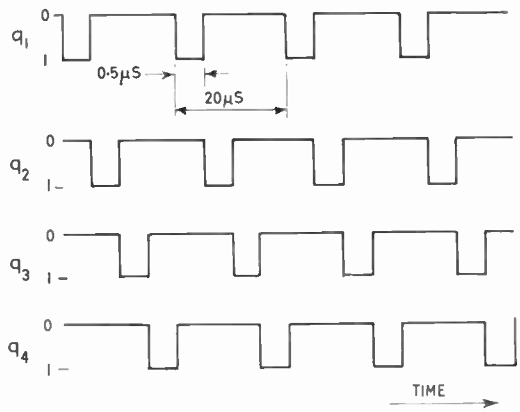


Fig. 6. q-pulse relationship.

3.3. *Input and Carry Delay Circuits*

If it is remembered that the input words are to be added bit by bit in a time sequence, it will be seen to be imperative that all three inputs arrive at the adder simultaneously. Four q pulses are used to time the adder. They are obtained from circuits described later, and shown diagrammatically in Fig. 6.

The principle of operation of the input circuitry is that the three inputs, A, B and K are gated, by q_1, into bistable memories which are cleared on q_4. Adder inputs are taken directly from their associated bistables.

All input and adder switching for any digit is deemed to be completed before the q_3 pulse arrives. Thus the carry output, C, may be gated by q_3 into a delay bistable, which is cleared on the next q_2 pulse. On the q_1 pulse, the delayed carry is gated into the K bistable, to be added to the next A and B digits.

The sum outputs, S and $\bar{S}$, are gated into succeeding circuits on q_3, but these gates are not shown here.

The circuit diagram is shown in Fig. 7. Timing pulses are connected to the bases of the lower transistors in the two-high gates, so that the load presented to the pulse generator is not dependent upon the input signal appearing on these gates. Stability of the q-pulse waveforms is essential to minimize interference, as these pulses are used elsewhere in the computer.

From an inspection of the circuit diagram, it would appear that VT 10 and VT 15 are effectively in parallel and could be replaced by a single transistor. Unfortunately, this is not possible, if a reliable output is to be obtained. The proposed arrangement is shown in Fig. 8 (*a*) from whence a spurious pulse in the sum output may be obtained.

Consider a q_3 period when the sum output should be 0 and the carry, C changes from 0 to 1. Then VT 8 will be conducting and VT 13, non-conducting. Now $C.q_3$ will appear on the base of VT 14 as a 1. Since q_1 is not present, VT 21 is non-conducting and may, therefore, be neglected in this argument. Then if B is a 1 signal, the circuit of VT 8, VT 9, VT 13 and VT 14 may be re-drawn as in Fig. 8 (*b*), where it will

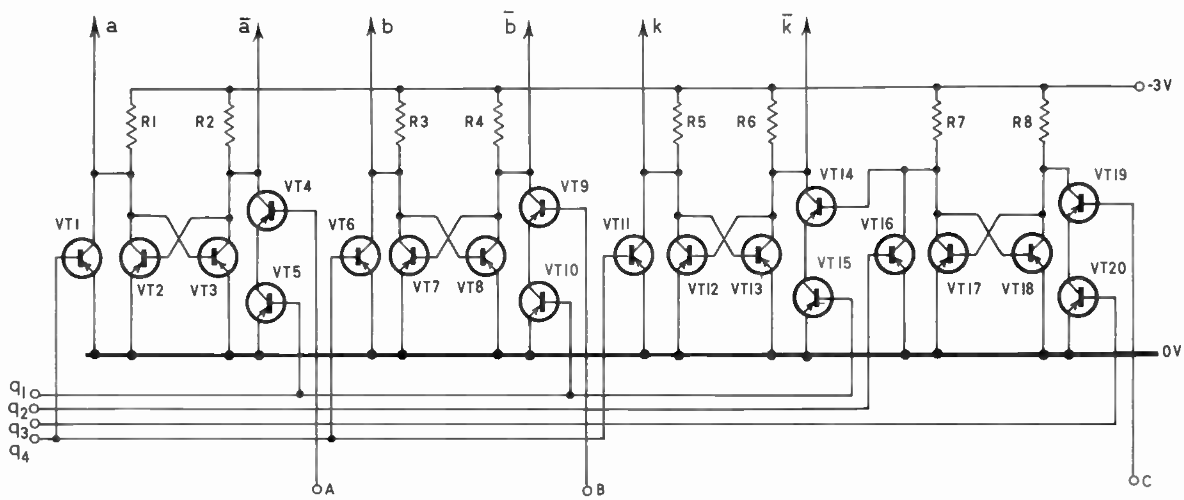
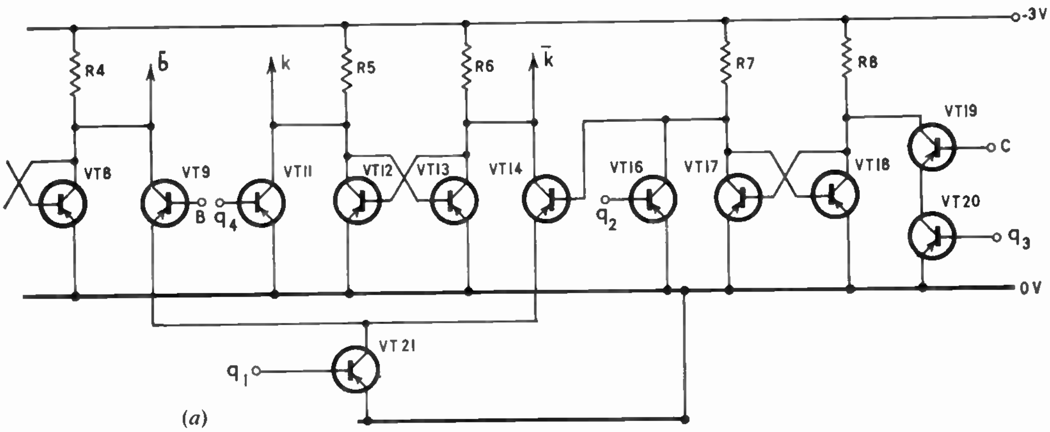
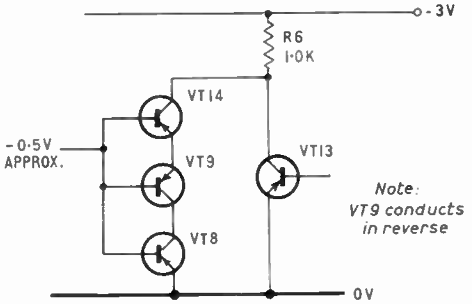


Fig. 7. Adder input bistables.



(a)



(b)

Fig. 8. (a) Proposed economy to the circuit of Fig. 7.
(b) Reversal effect in Fig. 8 (a).

be seen that VT 8, VT 9, and VT 14 are in the conducting condition (VT 9 being reversed) bringing the collector of VT 13 to a near-earth potential.

This effect appears as a spurious 1 pulse on the sum output, S.

It occurs only for the duration of a q pulse when the input and delay conditions are suitable. The solution is to use the original circuit of Fig. 7.

3.4. *The* q-*Pulse Generator*

The problem here is to produce four pulse trains, each with a pulse length of 0·5 μs and mark/space ratio of 1 : 3, with pulses in any one train being delayed from the corresponding pulses in the previous train by 0·5 μs. The pulse trains are called q_1, q_2, q_3, and q_4, in order of occurrence and are represented diagrammatically in Fig. 6.

To obtain true waveforms, it is essential that no indeterminate states of the switching circuits can be obtained, even for a short time. Although the tolerances of the SB240 are closely controlled, it is possible that their switching speeds might vary by up to 100 ns. Thus indeterminacy in output state must be avoided by ensuring that no gate contains two transistors which are changing state simultaneously.

The required output may be obtained by suitably gating two 500 kc/s square waves, one of which is delayed 0·5 μs on the other. These pulses are obtained from the cyclic binary unit, which is timed by the 1 Mc/s signal from the master crystal clock.

3.4.1. The cyclic binary unit

This consists of two bistable memories, timed by the master clock. The clock output is a 1·0 Mc/s square wave and one bistable in this unit changes state only during the "mark" period of the clock pulse, while the other changes only during the "space" period. By steering one bistable from the state of the other, each acts as a store to instruct the other as to its next move. Suitable cross-connections ensure that the required output sequence is always obtained, regardless of the initial switching on condition.

The method of logical design is to draw up a truth table (Table 1) showing the state of each bistable corresponding to a particular q-pulse. The bistable outputs are called M and $\overline{M}$, N and $\overline{N}$ respectively.

Table 1

M	$\overline{M}$	N	$\overline{N}$	q-pulse.
1	0	0	1	q_1
0	1	0	1	q_2
0	1	1	0	q_3
1	0	1	0	q_4

To determine the connections to the steering gates, it is necessary to consider only the side of the bistable to be switched which, before switching, is in the 1 condition; then to ensure that a clock and steering signal are applied simultaneously to a gate in such a way as to change the state of the bistable, and that these gating signals are unique to this particular change. This process must be performed four times—once for each gate.

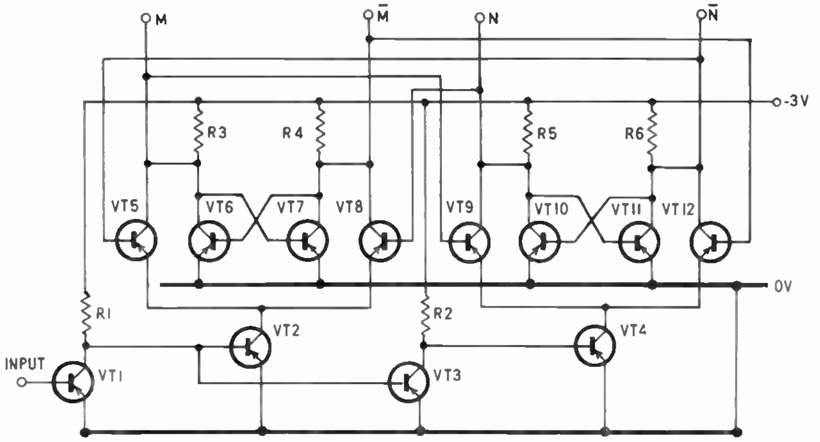


Fig. 9. Cyclic binary unit.

Transistor economy can be obtained by gating the clock pulse to both sides of one bistable by a single transistor, provided that this is at the bottom of both two-high gates. The complete circuit is shown in Fig. 9.

The clock signal is fed into this device through an inverter, used as a buffer stage to isolate the clock from this unit. A second inverter is used in order to obtain a suitable gating signal from the "space" period of the clock signal.

3.4.2. The pulse divider

This is purely a gating circuit. Since no transistor economy can be obtained by using two-high gates, the preferred parallel arrangement is made. The inputs required for given outputs may be read out of the table above. They are:

$$q_1 = M.\overline{N} = \overline{\overline{M}+N}$$

$$q_2 = \overline{M}.\overline{N} = \overline{M+N}$$

$$q_3 = \overline{M}.N = \overline{M+\overline{N}}$$

$$q_4 = M.N = \overline{\overline{M}+\overline{N}}$$

The circuit arrangement is shown in Fig. 10.

3.4.3. The master clock

This is a crystal oscillator, Rank Cintel type 7034 A, modified by the addition of a square wave shaper.

The oscillator section is crystal-controlled and contains two RC-coupled OC45 alloy junction transistors in a common collector configuration. This arrangement has the advantage of good frequency stability with temperature variations.

The pulse shaper is of some interest, because it incorporates a negative feedback loop around the first of two directly-coupled SB240 transistors in an attempt to stabilize the circuit to give an output of equal mark/space ratio, irrespective of transistors or of variations in operating conditions.

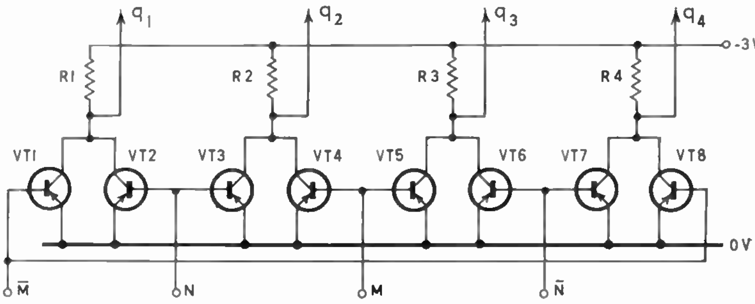
The complete circuit is shown in Fig. 11.

4. Testing

The complete adder was tested by using it to sum the two outputs from a word generator. As well as timing the adder, q-pulses were used to trigger a pulse generator having a 20-bit parallel output. This output was then serialized into two 16-bit words in a word generator, the actual words being selected on 32 toggle switches. Sum and carry outputs were observed on an oscilloscope. Figure 12 shows the arrangement of the units for testing.

It will be appreciated that with three binary inputs to the adder, there will be only 2^3 different input conditions. Thus by using the testing arrangement above, it is possible to test the adder with all the inputs that can ever be obtained.

Fig. 10. The pulse divider.



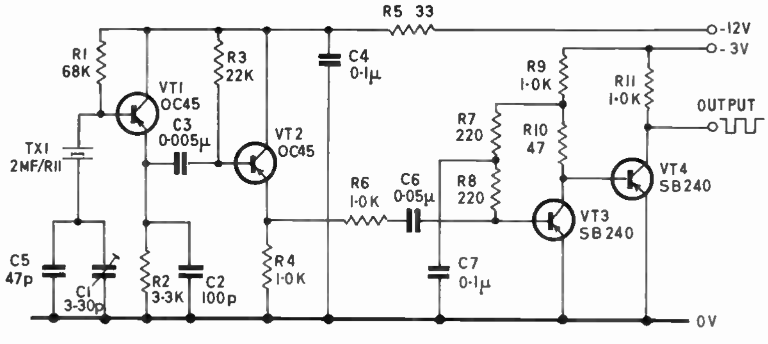


Fig. 11. The master clock

Correct addition was obtained in this arrangement, at a bit frequency of 500 kc/s, when the temperature was varied over the range of 18 to 42° C and with the supply voltage varied between −2·0 V and −4·0 V.

These tests indicate that, although the design was based on a maximum ambient temperature of 35° C and a maximum voltage tolerance of ± 5%, it is sufficiently conservative for the circuits to operate outside these limits.

5. Conclusion

Directly-coupled logical circuits can be constructed with only one type of transistor, one value of resistor, and one voltage level. After the electrical performance of the basic logical elements has been assessed, the design of an equipment need involve only logical considerations.

Since few passive components are used in directly-coupled circuits, the physical size of equipment may be very small. Each of the circuits described above fits on to a printed circuit board 4¼ in. square, although no attempt at miniaturization was made. Furthermore, the absence of coupling components and bias supplies leads to a high order of reliability.

It would appear to be desirable to design less conservatively than to worst-case transistor limits. A worst-case design procedure may be followed, but with limits chosen so that more than 99% of the transistors will be accepted. Since the remaining 1% have a good chance of being matched with better than average transistors, equipment failures are likely to be much less than 1% of its components.

By designing thus, it is possible to obtain a more economical use of transistors. This leads to a reduction in the number of components in an equipment and a consequent reduction in the failure rate. Thus it might be possible to reduce the overall failure rate of an equipment and at the same time reduce its complexity.

A limitation to the directly-coupled technique is the adverse effect of elevated temperatures on transistor "off" currents. With a germanium transistor, this effect becomes serious above an ambient of about 40° C. Considerable advantage in this respect may be obtained with a silicon alloy transistor such as the SAC40. Other properties of this transistor would indicate that it could be used in series gates with more than two inputs.

It is possible that transistors in directly-coupled circuits will have a longer life than in other logical arrangements, owing to the fact that the collector voltages rarely exceed about −0·5 V. Another advantage of the small collector voltage swing is that the effect of stray capacitance is small.

No failures in the equipment described here have been recorded during its 1000 hours of operation. The prototype CORSAIR equipment, containing 600 SB240 transistors, has been operating for about 2000 hours, and provided two transistor failures early in its life. It is believed that these were caused by over-

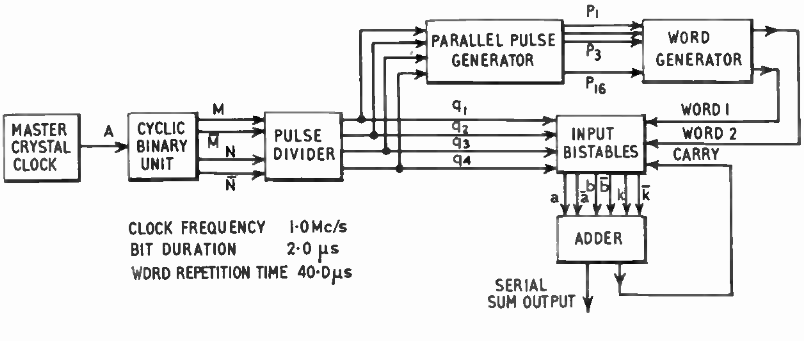


Fig. 12. Arrangement for testing.

heating with a soldering iron during the experimental stage. One of these transistors was well below specification whilst the other was open-circuited.

Directly-coupled circuits lend themselves to microminiaturization techniques because of their low component count. At present it is easier to fabricate active elements within a semi-conductor material. Thus the high transistor population in directly-coupled logical circuits makes this an ideal system to use in a solid circuit. It is probable that power dissipation levels will have to be reduced from the conventional, in order to prevent an excessive temperature rise in the very high component packing density.

6. Acknowledgments

Acknowledgment is due to Messrs. P. L. Owen, M. F. Partridge, and T. R. H. Sizer of I.A.P. Department, Royal Aircraft Establishment, Farnborough, for their encouragement during the course of the work, and to Mr. Sizer for his constructive criticism of the manuscript.

The author is also indebted to his colleagues at Semiconductors Limited for providing information about transistor parameter spreads.

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Manuscript first received by the Institution on 16th February 1961 and in final form on 28th September 1961 (Paper No. 716).

News from the Sections . . .

Southern Section

For the first time since the formation of the Section, Portsmouth was chosen as the venue for the presentation of a paper; "Recent Advances in Low Noise Microwave Valves", was read by Dr. D. G. Kiely on 10th November, at the College of Technology.

After reviewing the significance of noise in radio transmission systems and the economic importance of reducing receiver noise level as opposed to increasing transmitter power to improve the performance of a system, Dr. Kiely outlined the progress made in reducing noise factor over the past six years. He went on to describe the basic principles of the travelling wave tube, the maser, the parametric amplifier and parametric frequency changers, all devices which have contributed to this reduction. Low noise oscillators were also discussed and some examples of modern microwave valves showing their construction were on view.

The paper, "Data Acquisition Systems", was presented by Mr. K. L. Smith at Farnborough Technical College on 28th November. The basic requirements of data acquisition systems were first of all considered and Mr. Smith drew attention to the need to determine a series of standard interfaces at which similar signals (both input and internal) could be multiplexed and controlled to enable systems organization to be rationalized. Data acquisition systems although similar to data collection systems were different in the method of control.

Mr. Smith outlined some typical engineering techniques employed in the basic switching, amplifier and converting elements and these were examined briefly both from the point of view of performance and cost. He ended by giving some examples of system configurations for data reduction and alarm limit detection. The techniques described in the paper were demonstrated by an experimental 20-channel model.

J. M. P.

South Western Section

A joint meeting with the Royal Aeronautical Society was held on 14th February in the Engineering Lecture Theatre of the University of Bristol. The South Western Section Chairman, Mr. H. H. Harper, opened the proceedings with a welcome to the members of the Royal Aeronautical Society, pointing out that this was the Section's first joint meeting with another professional body since its formation in 1958. Mr. Harper then invited Professor Emrys Williams (a Vice-President of the Institution) to take the Chair on behalf of the Institution.

Mr. R. H. A. Carter, in presenting his paper on "The Royal Radar Establishment's Radio Telescope" opened with a brief explanation of the physical principles of radio-interferometry. He then proceeded to discuss the engineering aspects of the design parameters with particular reference to the installation at Defford. This instrument is levelled to within 5 minutes of arc and will measure azimuth and elevation to 8 minutes of arc. A feature of the design is a computer which translates right ascension and declination into azimuth and elevation, and so permits the aerials to be "steered" directly from astronomical references.

Among the uses of this radio telescope are echo-sounding in the ionosphere, the investigation of turbulence in the ionosphere, the study of echoes from meteor trails and from the moon and planets, and radio astronomy. Mr. Carter concluded his paper by showing a film of the erection of the interferometer aerials.

D. R. M.

Editorial note:—A picture of the radio-interferometer at Defford and an account of some of the ionospheric work which is to be undertaken was given in the 1961 Convention paper "Radar investigations of the upper atmosphere" by J. S. Greenhow and C. D. Watkins (*J.Brit.I.R.E.*, **22**, No. 6, pp. 477–80, December 1961).

London Note

On 20th December the Technical Committee once again presented a programme of Technical Films in London. These shows are organized whenever sufficient new technical films are available and their popularity to date indicates that if more films were forthcoming regular showings would attract good support.

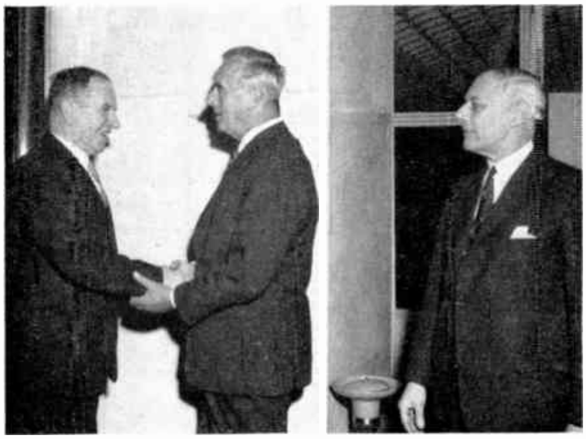
The programme which was presented by the Committee's Chairman, Mr. F. G. Diver, M.B.E., was well balanced and concerned items of wide interest. The first entitled "Project Echo" was an account of the work leading to the launching of the Echo experimental communication satellite in the summer of 1960. There followed a film on "The A.E.I. 1010 in Industry", illustrating how a digital computer may be used as an aid to management and for high-speed data processing in modern industry. The third item was a demonstration of Ekco weather radar displays showing how radar is used in aircraft to locate potentially dangerous clouds and to produce "map painting" of ground objects.

The penultimate film was an excellent production by the Mullard organization entitled "Transistors", which supersedes the Company's well-known films on transistors that have been produced during the past four years. Finally, the evening was rounded off by an imaginative German film entitled "The Magic Tape" which dealt in a light manner with the uses of magnetic recording tape.

Reception for Commonwealth Delegates to the Conference on Communication Satellites

Delegates representing the telecommunications authorities of ten Commonwealth countries met in London at the end of March for the first Commonwealth Conference on Communication Satellites. In addition to discussing the technical, financial and political aspects of inter-Commonwealth communications using satellites, delegates visited a number of establishments in Great Britain which are concerned with the future development of this new technique; these included the installation at Goonhilly Down, in South West Cornwall, which will be a receiving station for the forthcoming Project TELSTAR (an active repeater satellite developed by the Bell System for co-operative trials with Britain and other Western European countries).

The President, Admiral of the Fleet the Earl Mountbatten of Burma, and other Officers of the Institution held a reception on 29th March at the Savoy Hotel, London, to welcome the Commonwealth delegates and to enable them to meet members who are concerned with space research and communications. Other guests at the reception included the High Commissioners for Ceylon, Nigeria and Pakistan, and representatives of the High Commissioners for India, and Rhodesia and Nyasaland. The British Government was represented by the Joint Under-Secretary for Commonwealth Relations, His Grace the Duke of Devonshire, M.C., and Sir Henry Hardman, C.B., Permanent Secretary, Ministry of Aviation.



The President greets The Honourable T. L. Macdonald, High Commissioner for New Zealand.

The Chairman of the Commonwealth Telecommunications Board, Sir Ben Barnett, K.B.E., C.B., M.C., and Mr. W. Stubbs, C.B.E., M.C. (Member), the Secretary of the Board, were also present, as well as the Director General of the Post Office, Sir Ronald German, C.M.G., and the Director of the Post Office Research Station, Mr. R. J. Halsey, C.M.G.

The Commonwealth delegates expressed great interest in a small exhibition which had been arranged by the Institution. This included a model of the

Obviously an amusing comment by Lord Mountbatten to three Vice-Presidents of the Institution—(from right to left W. E. Miller, L. H. Bedford and J. L. Thompson). Perhaps some sequel to last year's Convention on Space Research?

High Commissioners in discussion. A group of guests at the reception includes (left to right): His Excellency The High Commissioner for Ceylon, The Honourable R. S. S. Gunewardene; Sir Lynn Ungoed-Thomas, Q.C.; His Excellency The High Commissioner for New Zealand, The Honourable T. L. Macdonald; His Excellency The High Commissioner for Pakistan, Lieutenant-General Mohammed Yousuf; Mr. George Searle, Deputy Director of the New Zealand Post Office.

launching site at Woomera, Australia, for the Blue Streak satellite launcher,† shown by de Havilland Aircraft Ltd., and a demonstration by English Electric Aviation Ltd. of the effect of long delays on speech transmitted via a satellite repeater.

The equipment demonstrated the effect of the long propagation time occurring in the case of a 24-hour satellite, that is, the so-called synchronous satellite on a 22,300-mile equatorial orbit which, since it circles the Earth in exactly 24 hours, remains apparently stationary in the sky. In the case of stations at the edge of the coverage area of the 24-hour satellite, the propagation time from ground to satellite or satellite to ground is 0·135 seconds, so that the extra delay in receiving a reply experienced by each subscriber is 0·54 seconds.

Examining the model of the Blue Streak *launching site, an Australian delegate, Mr. T. A. Housley, C.B.E. (General Manager of the Overseas Telecommunications Commission), seems to be wondering whether the photographer's flash is a prelude to a satellite going into orbit!*

Briefly the set-up consisted of two entirely independent one-way circuits, each containing a microphone, an amplifier, a tape delay and a receiver, constituting a four-wire link between two telephone sets. The tape delays were adjusted so that the total delay in getting a reply was 0·54 seconds, corresponding to the delay on the satellite link. The general consensus of opinion among the many engineers and others who spoke over this simulated link was that the delay was almost imperceptible and not at all hampering to normal telephone conversation.

A series of charts comparing frequency modulation and pulse code modulation for communication satellite links was also shown. The conclusion to be drawn from these charts was that until the relative importance of economy in satellite r.f. power and economy in band width can clearly be established and expressed, it is not possible to say from considerations of these quantities whether frequency modulation or pulse code modulation is preferred. Frequency modulation is undoubtedly preferable to binary p.c.m., but has not such a clear advantage over other p.c.m. systems unless considerations of r.f. power in the satellite dominate those of economy in frequency band width. It was, however, pointed out p.c.m. has an advantage over any system of f.m. providing channel dropping in that the equipment in the satellite is simpler and therefore likely to be more reliable.

† See Fig. 10 of the Brit.I.R.E. 1961 Convention paper, "The Engineering Aspects of Satellites and their Launching Rockets", by G. K. C. Pardoe, *J. Brit.I.R.E.*, **22**, pp. 143–60, August 1961.

Conference on
"New Electronic Techniques in Non-Destructive Testing"

Organized by the West Midlands Section and held at Wolverhampton on 6th December, 1961

This one-day Conference was attended by over 100 delegates and was one of the most ambitious meetings organized to date by a Local Section. The Conference Sub-Committee under its chairman, Mr. P. Huggins (Member), assembled a notable series of six papers dealing with such aspects as eddy current and magnetic flux leakage techniques, photo-electrics, ultrasonics, x-ray techniques and signal data processing.

After a few opening remarks by the Conference Chairman, an introductory address was given by Mr. J. A. Sargrove (Member).

AUTOMATIC INSPECTION AND NON-DESTRUCTIVE TESTING

J. A. SARGROVE (*Member*)†

I have been asked to open this Conference on Non-Destructive Testing by giving a very brief review of the history of the subject to show that the philosophy of the art is quite old. In fact it has gone along with the evolution of machines.

To mention but a few examples, we have from the end of the eighteenth century the automatic curve tracing device: Watt's steam engine indicator which traced a curve of steam pressure versus piston displacement automatically. This technique of automatic performance curve writing was further developed later by Crossby, McNaught and McInnes, and such devices are to-day commonplace. A very sophisticated example is described in one of to-day's papers.

Another form of technique, a typical non-destructive testing machine was developed in the laboratories of the British Post Office at the beginning of the twentieth century, for testing the continuous enamelled insulation coating on fine copper wires used in telephone relays, transformers, etc. This device consists of a finished wire unreeling and re-reeling arrangement and between these a mercury filled bath is positioned through which the wire passes at a regular speed. An ohm-meter circuit searches for pin holes in the insulation.

An even more subtle device in this class of testing machine, is one developed in electric lamp factories for searching out the invisible spots along a tungsten filament, when it is still in the straight drawn condition, where it is likely to fail during life. This was developed in 1932, and the device had similar reeling features as the above, but the filament was passed vertically over two contact saddles arranged at the half wavelength points of a short wave radio frequency power oscillator circuit. Thus at the mid-point between the saddles the maximum current in the standing wave is set up giving a small glow. At the spots where the crystal cleavage within the metal is great, a passing hot spot is produced as the wire is reeled through the device, and this is photo-electrically detected and drives a counter. To avoid the wire becoming contaminated it is passed through a hydrogen-filled glass tube while the above process takes place. The spools of wire are then labelled manually and those which have the least number of faults are used for long filament lamps and valves, whilst the others are used for short filaments. This device made it possible to introduce the series-heated high voltage valves around 1932/33 with a reasonable life expectation.

A testing method was introduced for vibrator choppers and rectifiers during the Second World War, which made use of the sonic vibration analysis of the reed of these components. Reeds showing a higher degree of overtones, i.e. a large number of prominent harmonics, were known to have a shorter life expectation, and it is fairly obvious with our present day knowledge that these overtones were the result of minute fractures in the spring metal. Such non-destructive testing by sonic means enabled a considerable increase in useful life to be obtained from vibrators.

The beginnings of ultrasonics are to be found in the work of the Admiralty research organization during the First World War, although its use for the

† Automation Consultants and Associates Ltd.

detection of flaws in metals had to await the development of radar and the perfection of the modern oscillograph before any true assessment of the presence of flaws in metal structures could be attempted. As Mr. Kay, our first speaker will show, the whole theory of this technique is still not fully understood.

Automatic testing of complete radio and radar circuits was developed during the War to the extent that many hundreds of circuit components already wired in could be compared with a standard accepted circuit by the use of electronic comparator circuits with limit setting alarm triggers. A motorised uniselector switch makes contact with the various parts of the circuits undergoing test by inserting plugs instead of valves in the valve holders. Lead testing and cable testing by similar means are now commonplace, but their early beginnings can be traced to the shortages in man-power compared to the production tasks involved and to-day the urge to test circuits and components in an automatic manner is due to the same compelling reason, i.e. to obtain more productivity in testing operations. Again, one of the papers to-day will deal with this aspect.

As one of the Conference papers deals with x-ray techniques using an image intensifier, it is interesting to remember that Roentgen towards the end of the last century had already observed flaws in metals by using primitive x-ray non-destructive testing, and to reflect that the use of x-rays in medical work is really a non-destructive testing technique! It is mainly due to the need to make medical x-ray even less harmful that the image intensifier owes its development in this context. However, the image intensifier itself owes its conception to much earlier work by Lenard, Wehnelt, Szell, van den Bosch and Fries to name but a few early pioneers, and has now developed to an art of ever widening promise. The detection of flaws in geological specimens seems to have been first attempted around 1900 by Couriot, in coal.

I regret I have not been able to trace the beginnings of eddy-current flaw detection. I became personally interested in this possibility during the war in connection with testing ball-races and steel balls, but it was not a new suggestion at the time. I would be interested if someone else could point to the originator of this idea. It may be as old as Faraday.

I would like, in passing, to refer to the many automatic inspection devices which have been developed in connection with environmental testing of materials and electronic components which has taken place in British and U.S. Government Laboratories. A particularly interesting device was developed at the Royal Radar Establishment during the 1952–55 period. It combines automatic testing facilities both electrical and pan-climatic for 1000 components; plotting the readings on a 1000 chart automatic recorder, and is controlled by a punched tape program. This automatic tester is known as ACTE (Automatic Component Testing Equipment).

[At the end of the Conference Mr. Sargrove showed a film dealing with this equipment.]

Mr. P. Huggins, Mr. Aldridge-Cox and Mr. D. Ball and others in my research team worked on this machine and others during the period 1950–55. We evolved many of the early decision-taking test equipments which have pointed the way to more ambitious devices such as the automatic evaluation system which will be described by Mr. Aldridge-Cox. An early statistical data evaluating analogue computing arrangement will be shown later in a film connected with the production of bread; this was conceived as early as 1953 and described at the Institution's 1957 Convention.†

I hope that this brief sketch of early work will help you to see the work of the following speakers as part of an ever-evolving process and that it will also clearly indicate the enormous scope for further research and development that exists in this very interesting field.

Manuscript received by the Institution on 13th December, 1961 (Address No. 32)

The following papers were then presented. (*Expected publication dates are shown.*)

"The Physical Factors Affecting the Reliability of Ultrasonic Non-Destructive Testing—A Review of Current Research"—L. Kay, B.Sc., E. Whipp, B.Sc., and M. J. Bishop, B.Sc. (*May*).

"Automic Charting of Ultrasonically Detected Flaws in Bar"—M. D. Chattaway (*April*).

"The Ultra-Sound Image Camera"—C. N. Smyth, M.A., B.Sc.(Eng.), B.M., B.Ch.

"Detecting Flaws in Steel Tube or Bar with a Rotating Coil in a Magnetic Saturating Field"—W. H. Baker (Associate) (*May*).

"X-ray Image Intensifier as an Inspection Tool and its Application to Stroboscopic Examination"—C. E. Paine (*May*).

† P. Huggins, "Statistical computers as applied to industrial control", *J. Brit.I.R.E.*, **14**, pp. 309–21, July 1954.

"Automatic Evaluation of Defect Severity by Shape and Size"—D. R. Aldridge-Cox (*April*).

The Conference proceedings were very ably summed up at the end of the day by Mr. P. Huggins.

Mr. Huggins pointed out that, in a sense, several of the papers answered each other. The co-authors of the first paper stated that many "uncertainties" would be resolved if the operator could be presented with the equivalent optical picture. This was in fact what Dr. Smyth and Mr. Chattaway were doing, as described in their papers. Mr. Paine, too, was giving us a visual picture—though in his case the beam was x-rays, not ultrasonics. Again, Mr. Kay made the point that the information available from ultrasonic echo-sounding flaw location should be increased by some form of signal processing. Mr. Aldridge-Cox's paper showed that he was working on such lines in the field of optical inspection: improving the signal-noise conditions by correlation techniques.

Mr. Huggins then went on to show how, by interplaying the ideas in one paper against those in another, one might foresee trends in non-destructive testing. Two examples he quoted were:

Bar Inspection and Grading. The spatial position of defects in bar was probably just as significant as defect size. This was implied by Mr. Chattaway's preoccupation with charting ultrasonically detected flaws down the length of the bar. However, it is often important to know the position of defects (and their number and size) in the transverse plane. Paper charts showing both would be unwieldy. It is probable that the technique outlined in the last paper (Mr. Aldridge-Cox) could be used to advantage in this context. A multi-element array of probes could be used to "comb" the bar, and information desired therefrom would be electronically processed in such a way that the bar would be marked if the sum total of the defect evaluation indicated that the bar was unsuitable for certain particular uses. The combination of the two techniques would therefore seem to give a means of classifying bars according to their suitability for different production processes.

X-rays on the Fly. Although the resolution of the x-ray image intensifier is still a limitation for many applications, nevertheless it is probable that the quality of such tubes will improve. Remembering that Mr. Paine sometimes used closed loop television as an output monitor, and that Mr. Aldridge-Cox had used a television camera as a source for his automatic signal processor and evaluator, it was therefore possible to foresee that the two techniques could be managed in such a way that x-ray examination of, say, a weld in a large pipe, could be non-visual. The advantages would be the absence of expensive and time-consuming photographic processing, or visual fluoroscopy with its problems of dark adaption and operator fatigue. In fact x-rays "on the fly" would be achieved.

Finally, Mr. Huggins summarized his impressions of the Conference, saying that more fundamental work is needed, that in the absence of any really new techniques, we must concentrate on making better use of the information we can get out of present techniques, and that increasing demands on resolution are leading to smaller transducers which in turn means increasing complexity of signal processing equipment.

A Symposium on Practical Training for Radio and Electronic Engineers

Held in London on 27th September 1961

U.D.C. 378.002 : 621.37/9

The Co-ordination of Academic and Practical Training

By E. MAY, M.Sc., A.C.G.I.†

1. Introduction

The term "co-ordination" is used here in the sense of bringing parts into proper relation to make a satisfying whole. The whole is the education and training of the professional electronic engineer: the parts are his academic education in which he is introduced to the fundamental theories of engineering science, and his practical training in which he obtains knowledge and experience of good practice. "Sandwich" courses in which periods of full-time study in college alternate with periods of industrial training provide one means of achieving the whole.

The information and observations which follow are based on our experience in the Department of Electrical Engineering at the College of Advanced Technology, Birmingham, in the operation of the "thin sandwich" course leading to the award of the Diploma in Technology.

2. Thin Sandwich Course for Dip. Tech. (Eng.)

The course is of four years' duration, six months of each year being spent in college and six in industry. About 90% of the students are industry-based, i.e. are student apprentices; the rest are college-based, and the Department is responsible for arranging their industrial training. Initially all our students were from one group of companies, but now over 40 firms and organizations take part and represent almost every aspect of electrical engineering in both heavy and light branches. Successful students qualify for the award of the Diploma in Technology (Dip. Tech. (Eng.)), graduate membership of the Institution of Electrical Engineers and the British Institution of Radio Engineers, and the College Associateship.

The curriculum for electrical engineering students involves seven of the ten departments of the College, and academic standards are set and maintained by the College Academic Board and by External Examiners appointed by the College and approved by the National College for Technological Awards (N.C.T.A.).

The number of students is fairly large—an average of 70 in each year of the course and the Department has a large number of students in other courses (both full time and part time). In order to obtain a reasonably balanced load over the whole session two separate Dip. Tech. groups are arranged, and each of these groups is sub-divided for laboratory work and tutorials into sets of from 14 to 20 students.

The selection of "Sandwich" students always requires consultation between the firms' training officers and the staff of the Department—for industry-based students to check entry qualifications, and for college-based students to assure training facilities. About two-thirds of our students offer G.C.E. "A" level plus " O " level entry qualifications; most of the others have a good O.N.C. in electrical engineering, and a small third category offers other qualifications, generally equivalent to those of the Advanced-level G.C.E. entrant.

3. Co-ordination of Education and Training

Co-ordination, bringing the parts into proper relation, involves two main considerations—timing and content—and when these are decided a means of implementing them is required.

Firstly consider timing, i.e. the phasing and duration of periods in College and in industry. There are several variations even within the Dip. Tech. scheme, so that clearly opinions differ as to what is the best. Between the limits of three-monthly and twelve-monthly periods within which most Dip. Tech. schemes operate there is, I think, room for experiment, and we are not displeased with results at Birmingham on a six-monthly basis.

† College of Advanced Technology, Birmingham.

Turning now to content, there is perhaps a danger that we might be persuaded to be too rigid. Persuaded that is, that "integration" of education and training must be arranged in meticulous detail. It is the nature of the work, and not the detail, which is important. The work in College should be fundamental in character and broad in outlook, as free as possible from ephemeral techniques.

Industrial training should also be planned on a broad basis. It is the responsibility of the College to certify that each Dip. Tech. student has received suitable practical training, and training is regarded by the N.C.T.A. as being just as much a part of the course as the academic study. It is particularly important to recognize that training schemes designed for craftsmen and technicians "are not suitable accompaniment to a student apprentice's theoretical studies".[1]

At Birmingham the Governing Body has set up Industrial Training Certification Committees whose terms of reference are:

> To approve schemes of training in industry for students attending relevant sandwich courses at the College; to devise means for ensuring the effectiveness of these training schemes; to assess each student's training in industry and record therein; and to bring any relevant matters to the notice of the Governors, the Board of Studies and the Advisory Committees respectively.

The Committee responsible for the training aspect of engineering courses has prepared a brochure "Notes for Guidance on Industrial Training—Mechanical, Electrical and Production Engineering".[2] This is intended to assist firms interested in supporting sandwich courses by setting out what is expected from them under the scheme as a whole and at particular stages during each student's training.

Briefly, each participating firm is required to submit its proposed scheme (or schemes) of training for approval by the Committee. The procedure for doing this is given together with a broad outline of the industrial training required as an integral part of a course leading to the Dip. Tech. (Eng.). After each training period a report is required from the firm on the nature of the training received by the student and his performance. The College arranges for a member of the academic staff to visit the student at his work at appropriate intervals throughout his periods of training—usually twice during each period.

On completion of the final period of training all documents relating to the student's training are submitted to the Committee for final assessment and certification. Certification of each student's actual training is a condition of the award of the Diploma, and this together with his final examination results is considered by the N.C.T.A. for the conferment of the Dip. Tech.

4. Observations

(1) We are fortunate in the electrical industry in having a good record of industrial training going back over many years, and some of the difficulties experienced in obtaining proper training, and the criticisms that are heard do not apply in most branches of our own industry. I am not suggesting that we can afford to be complacent, but we can be encouraged by knowing that the importance of industrial training is widely recognized in the industry.

(2) I have referred to the broad outlines of training schemes offered to firms for guidance in drawing up their own proposals. These are contained in the brochure "Notes for Guidance on Industrial Train ing"[2] and so are not repeated in these notes. They follow closely the recommendations[1,3] of the Joint Committee on Practical Training in the Electrical Engineering Industry, set up by the Institution of Electrical Engineers.

(3) It is one thing to have a scheme on paper: how does it show up in practice?

Four "generations" of sandwich course electrical engineering students have now taken their final examinations. The first of these qualified in 1958. No organized survey of their performance and progress has yet been made, but we have had some good reports. In particular, the good honours man has been found to be very good indeed; I think this is significant for it may indicate that the sandwich student of honours standard is unlikely to be a misfit in industry.

Each final year student undertakes a project, the carrying out of which requires him to draw on both his academic studies and his practical training. He brings a remarkably mature attitude to this work, a feature which has brought most favourable comment from our External Examiners and which clearly springs from the student's industrial experience.

(4) The duties and responsibilities which firms must undertake in order to provide industrial training suitable for the intending professional engineer are not light. Yet we have had no single case where there has been any unwillingness to co-operate. On the contrary it is normal for the firms' Education and Training Officers to work with us to agree suitable training programmes, always with the view towards what is likely to be best for the student. The visits of tutors to their students during industrial training periods are welcomed; these are normally arranged through the Training Officer, who not infrequently

discusses students' progress with tutors on these occasions, and may travel considerable distances to do so if students are working away from headquarters. Publicity has been given to the opposite case, and I am glad to have this opportunity to mention our own experience, which I am sure is not unique. It is possible that attitudes vary in different areas of the country and that we in the Midlands have been particularly fortunate, but we draw our students from firms in many areas.

(5) Ultimately, however good the academic curriculum and the training programme, results depend very largely upon the personal qualities of those directly involved, and not least of the student. The importance of adequately qualified and experienced teaching staff in the Colleges, and of their integrity, is obvious; the firms with good training records recognize the importance of similar qualities in the men and women (training officers, departmental heads, section leaders, superintendents, foremen, etc.) who must accept some responsibility for the students' training. It is essential that all are aware of what is required: we are all teachers.

5. References

1. "The Education and Training of Student Apprentices". Report of the Joint Committee on Practical Training in the Electrical Industry. Published by the Institution of Electrical Engineers, London, June 1958. (Price 2s.)
2. "Notes for Guidance on Industrial Training" (Mechanical, Electrical and Production Engineering, Diploma in Technology), College of Advanced Technology, Birmingham.
3. "The Training of Graduates". Report of the Joint Committee on Practical Training in the Electrical Engineering Industry. Published by the Institution of Electrical Engineers, London, January 1957. (Price 2s.)

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Practical Training for Sandwich Diploma Courses

By B. F. GRAY, B.Sc.(Eng.) (*Member*)†

1. Introduction

The 4-year Sandwich Diploma Scheme provided by many of the technical colleges is based on academic periods of six months' duration separated by periods of similar length in which the student undergoes his practical training. This arrangement (the "thin" sandwich) has one obvious advantage over other schemes in that the full integration of both the academic and the practical side of the training is possible.

The majority of students studying by this method are industry-based—that is, they are sponsored by some industrial undertaking which agrees to provide the necessary practical training under the guidance of the college at which the students are studying. Tutors are appointed by the college to consult with the Training and Education Officers of the various firms participating in the scheme in planning the details of the programme of training carried out by each student. It is the responsibility of the college to ensure that this programme is adhered to and, in fact, the Principal must sign a declaration to this effect when the student has completed his training before the award of a Diploma in Technology can be made.

† Head of Electrical Engineering Department, Hatfield College of Technology.

The Higher National Diploma Scheme follows a somewhat similar pattern, but there are certain differences:

(1) The course is of three years' duration for the award of the National Diploma, a fourth year being provided in some instances for the award of a College Diploma.

(2) The industrial training is not mandatory, that is, the award of the H.N.D. does not depend upon a period of practical training.

Where all students studying for a Diploma at one college are employed by one or two local firms the full integration of the academic and practical training can usually be achieved without undue difficulty. It is very much more difficult where a number of firms, whose training programmes and facilities show considerable variation, are participating in the scheme. A case can be made for more college-based students to overcome this and other difficulties brought about by the "thin" sandwich scheme.

2. The College-based Student

The college-based student is not sponsored by industry but usually attends the college with the aid of a County Grant or some National Award so that a heavy financial burden is removed from his parents.

Some form of practical experience is however still necessary and must be provided, and it is usually left to the college to arrange for this training with one or more local firms. The student may or may not receive payment from the firm during this period, and obviously any payment can be considered only as a nominal sum. The County Grants usually stop when the student is no longer receiving academic training. In consequence, the college-based student of the thin sandwich scheme is somewhat of a rarity.

With the number of school leavers increasing (in some areas such as Hertfordshire a doubling in three years), it would seem that there will be more and more boys (and girls) qualified to enter Dip. Tech. and H.N.D. courses who will not receive the sponsorship of industry.

Although the technical colleges will be willing to accept these school leavers into the sandwich courses, a big problem is set in finding firms willing to accept trainees. Industry will complain that it has difficulty in providing training for its own apprentices, especially as during the months of July, August and September the whole of its apprentice strength will be back in the works. The problem is made no easier by requests from university students for practical training during their long vacation.

A plea is constantly made by industry for "end on" sandwich courses in the technical colleges—a shift system in education! However difficult for the colleges, this plea would be extremely hard to ignore if all apprentices were following sandwich courses. But while part-time day release is still the route followed by the majority of apprentices (who are admittedly usually following a technician's training) "end on" courses will not overcome all these difficulties.

3. A Possible Solution

There is another possibility which has not received as much attention as it might.

In many technical colleges which have developed sandwich courses the engineering workshops remain unused by students during the months of June, July, August and early September. In some colleges where the lower grade work has been moved out the loading on the workshops may be even lighter. It is not then possible for the college to take on the practical side of the training as well as the theoretical side?

The problem of integration is by this method very neatly solved (at least during the earlier years of the course) as the training programme is completely under the wing of the college and its execution is in the hands of the college teaching staff.

There are of course some difficulties. Firstly, a longer annual training period than the three and a half months during which time the college workshops are relatively idle is needed and consequently more workshop space and equipment would have to be provided at the college.

Secondly, suitable instructors would have to be recruited to look after the practical training and these persons would have to accept a class contact timetable extending from, say, May to November (this assumes a one stream entry of students with no "end on" arrangements).

Finally, the college student would receive practical training with no industrial experience. But it is not impossible to make some sort of compromise.

The practical training provided by many industries supporting the sandwich scheme (especially the larger organizations) is often planned on the following lines:

Twelve months (in two roughly equal periods) in the training school of the firm concerned, often completely divorced from the main section of the works, followed by twelve months in the various departments of the firm.

Although there is nothing basically wrong with this scheme one is left with the question—could not the college provide equally satisfactorily the first half of this training?

There is, of course, the point that a student trained by this method would have little time to sink his roots with the firm in the latter half of his training. On the other hand, industry would recruit its embryo technologist after he had gone through the initial screening and after he had some idea what "engineering" was about. There would be a much greater guarantee that the student would be successful in his studies and furthermore some of the financial burden would be removed from the shoulders of industry. It is assumed that the County Grants would be made available to the student during his period of practical training at the college. Finally, he would join an organization at a stage in his training when he was potentially more useful to the firm.

This arrangement would, of course, apply only to the "A" level intake as the O.N.C. student has normally completed his basic training before entering the Diploma Course.

This scheme should appeal also to the smaller firms who say they cannot support the sandwich scheme because of limited funds or limited training facilities.

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Student Reaction to Formal Postgraduate Training

By A. J. KENWARD, B.Sc. (*Associate Member*)†

1. Introduction

A survey of graduates, who qualified in the period 1956–59, from the Department of Electrical Engineering at the University of Birmingham, the Department of Electronic Engineering at the University College of North Wales, Bangor, and from the Department of Electronics of the University of Southampton, was made in connection with the Institution's recent report on practical training.‡ The main purpose of this survey was to determine if students regarded formal postgraduate training as valuable and to what extent those who did not take a formal postgraduate training course considered their training incomplete.

Replies were received from sixty-five graduates, thirty-six of whom had taken a formal graduate apprenticeship and twenty-nine had not. A number of graduates did not reply possibly because they had not taken a postgraduate apprenticeship and did not feel they had anything positive to contribute. Thus the ratio of apprentices to non-apprentices is not entirely representative.

Whilst this sample is not sufficiently big to produce any positive conclusions, in many cases the questionnaires were completed in such detail that it is possible to confirm a number of impressions which had previously been obtained from individual contacts.

2. Type of Training Organizations Involved

Of the thirty-six graduates who completed graduate apprenticeships, only six received their training in organizations which were primarily users rather than manufacturers of radio and electronic equipment. They included machine tool industry, textile industry, the National Coal Board, British Railways and the Central Electricity Generating Board. The remaining thirty graduates were trained by twenty different electrical or electronic engineering manufacturing organizations. These varied in size from the very largest companies to medium size organizations with only limited training facilities and included two aircraft companies.

The graduates who secured employment direct from the University were employed by industrial research laboratories on Government contracts, the Civil Service and by a number of smaller organizations, including five companies not primarily concerned with electronics.

3. Views on the Length of Postgraduate Training

Only three graduates completed training schemes differing from two years in duration; one was of twelve months only, another of eighteen months and a third of $2\frac{1}{2}$ years. It is significant that the comments of these graduates on the length of their training were "a waste of time", "too short", and "too long", respectively. Of the remaining thirty-three, twenty-three considered that the two-year training scheme was just about the right length. Nine thought that two years was too long and the remaining candidate, who had completed a "thick sandwich", considered that it was a little too short. He considered that it was only in the second industrial session (after graduation) that he secured any real value from the practical training. If this is a typical view it is a very significant observation.

The nine graduates who thought two years was too long had a number of suggestions for its reduction. With one exception they were all trained in large organizations from which other graduates who had completed the questionnaire had thought that the training was the right length.

Suggestions for reducing it included better planning, less "helping with the job", and less observation training. Specific items of training which came under severe criticism were workshop training and other semi-skilled repetitive jobs and the period in the test department. In many cases it was suggested that vacation training, where it was properly organized, had covered most of the workshop training which was provided in the postgraduate apprenticeship.

There was a suggestion in two cases that had the apprenticeship been better planned and organized, a great deal of time and effort could have been saved.

4. Is a Postgraduate Apprenticeship Worth While?

Although thirty-three of the thirty-six candidates who completed a graduate apprenticeship considered that it was valuable, the answers were usually qualified and these included a number of suggestions for making it more worth while.

Graduates were agreed that the main positive benefit of formal postgraduate training is that it gave a

† Education Officer, The British Institution of Radio Engineers.
‡ "The Practical Training of Professional Radar and Electronic Engineers", *J. Brit.I.R.E.*, **23**, pp. 171–6, March 1962.

breadth of industrial experience from which a graduate could decide his eventual type of employment. It also provided an opportunity to get to know the employees at all levels and their attitudes to problems. Several graduates referred to the opportunity that it provided to take early responsibility and to secure confidence in one's own ability. It was an experience which balanced the years of academic training, thus easing the transfer from the academic atmosphere in a university to life in industry. For those engineers who intend eventually to seek employment in management, a postgraduate apprenticeship would seem to be an essential part of their training—a fact borne out in practice.

The criticisms, whilst minor, appeared to be based on irritations. They were certainly not universally expressed and in many instances one had the impression that there was really something at fault with the firm's scheme of training. Several graduates made the point that for the mature graduate with fixed ideas on what he wishes to do, the apprenticeship had tended to be a very frustrating experience. Apparently there were training schemes where there was little opportunity to take any responsibility or to inquire into matters which were of great interest. Others pointed to an insufficiently varied experience and becoming a source of cheap labour in the final year.

One criticism which is probably applicable to many of the schemes suggested that there should be a greater opportunity for further academic work on a part-time basis.

5. The View of the Graduate Accepted into Direct Employment

Twenty-nine of these graduates entered into employment directly of whom six entered the Scientific Civil Service and two went into teaching. Of the twenty-five who answered the specific question whether or not they considered an apprenticeship worth while in the light of their subsequent experience, ten thought it was, whereas twelve did not and three still had not made up their mind. The reasons why so many of these graduates did not consider it worth while seem to indicate some self-satisfaction.

A common statement was that a great deal of experience is secured in day-to-day employment in a research or development laboratory. In the view of these graduates it provided the contact necessary with most of the departments in the organization. Those engineers who were in research seemed to think that they were not so concerned with a wide engineering background and their efforts were directed more to securing highly specialized knowledge and experience.

These graduates also stressed that the value of an apprenticeship was entirely dependent upon the company and the quality of training it provided. All were agreed that this type of training was essential for those engaged in the manufacturing industry or alternatively for the immature graduate with little practical ability.

Only one graduate expressed the opinion that a postgraduate apprenticeship was a form of indoctrination to ensure that the engineer was trained to follow traditional methods and the "system".

6. The Value of Academic Training

The remaining questions put to these graduates were designed to ascertain if they used the academic training which was provided in university degree courses. The questions were not easy to answer and were rather abstract as will be seen in Appendix 1. In most cases it was the opinion of the graduates that they had little opportunity to apply the ideas which they developed during their academic training. However, they were all agreed that the analytical and logical approach which their degree had instilled in them was particularly valuable. Research engineers in most instances had a greater opportunity to apply their academic knowledge to their work.

It was rather over-optimistic to expect graduates, after a short time in industry, to judge whether the engineers with whom they had been in touch worked from experience or from first principles. However, it seemed that the general view was that very few engineers in industry used an analytical approach to their work, mostly drawing on their own and others' experience.

7. Conclusions

Nothing conclusive can be drawn from this very limited survey, particularly as it appears that most of the graduates who did not reply were those who had not had a graduate apprenticeship. Nevertheless, it is reassuring to learn that by far the majority of university graduates embraced in this survey believed that postgraduate training is a valuable integral part of their further education. Those criticisms which have been made seem limited in their application, although perhaps what emerges is that every firm which is undertaking this form of training should closely examine its own scheme to ensure that these criticisms do not apply.

It is rather disconcerting to learn that not only had some graduates found the training uninspiring but they had little opportunity subsequently to apply the ideas which are developed in their academic training. The use of university graduates on routine development work seems to be a waste of good material, particularly as many graduates admitted they find that those trained by other methods, particularly by the National Certificate route, are equally effective in this form of employment.

8. Acknowledgments

The author is grateful to the graduates who co-operated in this survey and provided such detailed information on this very important subject.

9. Appendix 1

The questions submitted to graduates to determine their reaction to postgraduate training:

Questionnaire to Past Students

1. Did you have a graduate apprenticeship? If so please give details below:
   (*a*) firm
   (*b*) nature of business of firm
   (*c*) total length of training—
   indicate how this training was divided into:
   (1) workshops
   (2) production and test
   (3) installation and maintenance
   (4) drawing office
   (5) design and development
   (6) management
   (7) others—please specify

2. If the answer to Question 1 is NO, please give:
   (*a*) name of your first firm after graduation
   (*b*) nature of business of firm
   (*c*) title of your first appointment
   (*d*) did it provide a variety of experience?
   (*e*) what was the nature of the employment?
   (*f*) how long did you remain in the employment of that company?

3. As a result of your experience, whether or not you had a graduate apprenticeship, do you think a graduate apprenticeship is worth while? Give some reasons, if possible.

4. If you took a graduate apprenticeship, do you think it was:
   (*a*) too long?
   (*b*) too short?
   (*c*) just right?
   If too long, how would you reduce its length?
   If too short, how would you lengthen it?

5. During your academic training you must have developed certain ideas. Do you find it possible to apply these in your present employment? Please give a few details.

6. Was it your impression after leaving university that most professional engineers work
   (*a*) from first principles?
   (*b*) from experience?
   What proportion of engineers whom you meet use an analytical approach to their work?
   Do you?

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Vacation Training for University Electrical and Electronic Engineering Students

By J. C. CLULEY, M.Sc.†

1. Introduction

The electrical, and more particularly the electronic industry, always needing to develop new products and processes of manufacture, has made increasingly rapid technical progress during the last twenty years. Transistors, for example, ten years ago rarely seen outside research laboratories, are now made by the million for apparatus as diverse as telephone repeaters, electronic computers and machine controls.

Consequently the engineering graduate leaving University is expected to have, as well as some specialist knowledge in a particular field, some acquaintance with an ever-widening range of electrical engineering products and applications.

In order to assist and encourage the student to extend his knowledge, particularly in the practical application of his work, it has been the practice of this department, as of most engineering departments, to require students to undertake at least two periods of training, during the summer vacation, each lasting preferably six weeks or longer.

2. Administration

The duty of obtaining suitable employment is placed upon the student, who is assisted by the

† Electrical Engineering Department, University of Birmingham.

University Appointments Board and advised by the tutor in the department. Most of the large firms and many government and public authorities send representatives to the University during the spring term to interview final year students and arrange post-graduate training and employment, and the majority also interview first and second year students requiring vacation training. A list of organizations offering vacation work is also prepared and circulated by the Appointments Board, and includes those which do not visit the University but require the students to apply directly.

The above arrangements cater for the majority of students, but in addition some arrangements, for example for work in the Engineering Department of the Post Office, are made directly by the departmental tutor, and a few students make private arrangements for work in industry. Those students who have been awarded scholarships are required to return to the industry which provided the scholarship for a certain time in the long vacation, and thus automatically obtain suitable training. The same arrangement also applies to students on "thick" sandwich courses, but since they have already had a year's works experience, they are encouraged to obtain work in a different field of the profession, and can occasionally visit firms abroad associated with their parent company.

Second year students are also eligible for work abroad under the I.A.E.S.T.E. scheme, but vacancies for only about six students are allotted to the department, about half the number of applicants.

In all cases the course must be approved by the head of the department. This is generally a formality, but is an important provision to ensure that the occasional student anxious to make money is prevented from undertaking some unskilled job with little technical interest.

As can be seen from Fig. 1, a proportion of students undertake rather more than the suggested six weeks in vacation employment. It is not possible, as yet, to insist on this as a minimum, as a few firms offer only a four-week course, and take in two batches of students during the summer. It is interesting to compare this diagram with the results of a survey of 500 students from all faculties of eight universities relating to vacation work during 1960.† This gave the average duration of paid employment as seven weeks; 77% of all students did some paid work during the vacation, and 88% of male science students. It thus appears that we ask no more working time from our students during the long vacation than the average student would undertake voluntarily.

† Norman MacKenzie, "The long vacation", *New Statesman*, 26th May 1961.

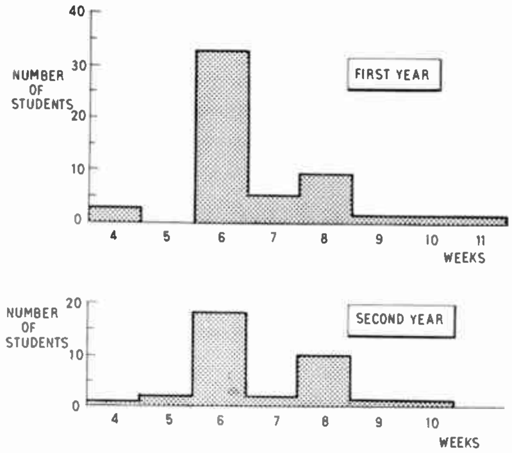

Fig. 1. Duration of vacation training at the Electrical Engineering Department, University of Birmingham, 1960. Total number of students 89.

3. Sources of Vacation Work

The motives of organizations providing vacation work appear to vary between altruism and self-interest. A number of them, particularly government departments and such public bodies as the G.P.O. and the B.B.C., have a policy of taking more vacation students than they can subsequently employ, and are prepared to regard the vacation training of the remainder as their contribution to the professional training of electrical students.

Most firms regard the vacation course as an extended opportunity to attract and assess prospective employees, and attempt to make the work varied and interesting. Students frequently decide upon their possible future employers during their second year of study, and then look for a vacation course with one of their competitors. This is probably in the student's interest, but it gives some personnel managers the impression that there is little correlation between the student's choice for vacation work and for subsequent employment.

Table 1 shows that, in a typical year, counting government and public authorities as generally large concerns (that is, having more than 3,000 employees) over six times as many places are offered in large organizations as in small ones. This probably results from the more highly organized facilities available for training and handling apprentices, but is not necessarily good for the student, as he generally gains more in a small concern from the variety of tasks available than he loses through lack of organization.

Students are generally advised to take their first vacation training with a firm concerned with manufacture, preferably of the heavier kind. This advice is particularly directed at those students who have previously lived in areas remote from large-scale industry and have had no previous contact with any branch of electrical engineering. The second vacation course is more suitably spent in the electronics or communications industries when the student intends (as the greater proportion does) to specialize in these fields. But the student is ultimately governed by the availability of vacation work, and in general fewer opportunities of the right sort are available than there are students in need.

Table 1

Vacation Courses, Electrical Engineering Department, University of Birmingham, Summer 1960

	1st year No.	*1st year* %	*2nd year* No.	*2nd year* %	*Total* No.	*Total* %
TYPE OF WORK						
Mechanical Engineering	3	5·7	0	0	3	3·3
Heavy Electrical Engineering	27	51·0	14	39	41	46·1
Light Electrical Engineering and Electronics	23	43·3	22	61	45	50·6
Total	53	100%	36	100%	89	100%
TYPE OF ORGANIZATION						
Government and Public Authority	25	47·2	16	44·4	41	46·1
Private Industry						
Total	28	52·8	20	55·6	48	53·9
Large Firm	20	37·7	16	44·4	36	40·4
Small Firm	8	15·1	4	11·2	12	13·5
Overseas Course for British Students	3	5·7	8	22·4	11	12·4
Number of students from overseas in the Department	6	11·3	5	13·9	11	12·4

Number of organizations offering electrical engineering vacation work about 90.

Of the total of 89 courses, 20 were arranged through the Department, and all but 12 of the remainder through the University Appointments Board.

4. Student Reaction

Almost all students appear to benefit from their vacation work. Having chosen to become electrical engineers rather than physicists, they have an interest in the practical side of their profession, and welcome an opportunity to work with real equipment after a year's largely academic instruction. They are, in general, grateful for the trouble frequently taken to explain to them the nature and purpose of their work, and the help they are given. We hear occasional complaints, where mainly routine work is concerned, that engineers of sufficient status to answer difficult technical queries are not very accessible, but this is generally unavoidable with the present scarcity of qualified engineers, particularly in the "user" industries. For example, a vacation student in the G.P.O. who asks the particular question "How do you identify the pairs in a paper insulated cable?" can be handed the appropriate Engineering Instruction, giving the full details, but if he asks the general question "Why do you use mechanical switching, not electronic switching in this exchange?", he will need to move a fair distance up the hierarchy before getting a full and satisfactory reply.

Most concerns take some trouble to give the student an idea of their general organization and the nature of their business, often in the form of a brochure produced for recruiting staff or to help newcomers; when available, this is generally used (sometimes barely disguised) as the first page or two of the student's vacation report.

5. Some Comments on the Present System

A few years' experience of the present scheme reveals a number of difficulties and shortcomings. The introduction of the Dip. Tech. sandwich course has meant that most large firms, particularly those in the heavy engineering field, have a large number of students back at work for six months in the summer, and so have fewer places for university students. In all branches of the profession, the increase in the number of places available has barely kept place with the increase in the student population which has, in this department, doubled in six years.

Overseas students are often difficult to place; nearly all of them expect to return to their own country soon after graduation; and most firms thus conclude that, since they are not likely to become future employees, there is little point in offering them vacation work. Fortunately many such students are sponsored by a government or firm abroad, who make their own arrangements—often with suppliers in this country—for vacation work. A further difficulty is that many firms engaged on government contracts, and most government establishments, are permitted to employ only British nationals.

We have from time to time taken a few foreign first year students into our Departmental workshops for vacation work as a last resort, but this means that some technician's time has to be diverted from useful work to instruction, and our backlog of construction gets even longer. A step we are loth to take, but which may be forced upon us, is to reduce the minimum compulsory requirement to only one vacation course in place of the present two. On the other hand, if more "thick sandwich" students arrive at university, having already had a year's experience in industry, we may feel justified in modifying and probably reducing our vacation requirements.

Our present position is logically indefensible in that we require the student to undertake a vacation course, but cannot guarantee that he will be offered one. At present the University Appointments Board tries to encourage industry and public bodies to provide as many places as possible, but the demand tends to outrun the supply, and we would very much welcome some greater margin between the two. This would make it much easier to match the course to the student's requirements, a consideration which now has frequently to be ignored.

In a survey of this kind it is tempting to imagine oneself running a vacation scheme under ideal conditions. For a student intake of 60 per year, we would require 120 vacation courses every year. Of these, about 70 would be provided in Britain, and we would have the right to nominate the student for any particular course. The remaining 50 courses would be abroad, mainly in Europe, and we would be able to offer each student a grant of up to, say, £20 to cover travelling expenses. At present many more students would go abroad if work was available, and the prospect of Britain's closer link with Europe make this even more important.

For students who have already had some experience in industry, we might perhaps consider exchanging students with some other European university for a short summer term.

6. Conclusion

In conclusion, although the present scheme has many difficulties and imperfections, there is no doubt that it benefits the students considerably. It would thus seem desirable to try to improve it to the best of our ability, and a combined approach by industry and the electronic engineering profession seems the most fruitful prospect.

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Electronic Training in and for Non-Electronic Industry

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1. Introduction

The training being considered in this paper is the practical training needed to fit a man to assume responsibility at the professional level for electronic equipment in non-electronic industry. By responsibility at professional level is meant the kind of experience that would be recognized as qualifying for corporate membership of a professional institution. The practical training that is required cannot be divorced from the academic training, the two being complementary, and it depends, therefore, on the kind of person being recruited. It also depends on the work required to be done in non-electronic industry: an industry made up of a wide variety of small and large firms and organizations.

2. Requirements and Recruitment

2.1. *Requirements of Non-Electronic Industry*

The boundary between electronic and non-electronic industry is not an easily definable one, but for the purpose of this paper non-electronic industry is taken as the mass of industry which is concerned with producing all kinds of things other than electronic equipment but in which electronics is becoming increasingly applied. The Services and large organizations in the communications field will not be included in this survey. While non-electronic industry will cover a wide range of electronic applications, it is felt that by and large we are essentially concerned with instrumentation and control. This needs to be interpreted liberally, and would certainly include computers. The main problem, therefore, would appear to be the practical training of instruments engineers, and it is this which is now considered in some detail. Although a wide variety of instruments is to be found in industry, there is an increasing tendency to use electronic instruments and the terms instruments engineer and electronic engineer are largely synonymous.

The need for an instruments engineer depends on the size of the firm or organization and the degree of instrumentation and control employed. The following generalizations may be made:—

(*a*) In some firms there will be a little need for an instruments engineer at all, and in these cases the maintenance service of the instrument suppliers will probably be used and general oversight vested in the works engineer.

(*b*) Where there is a moderate need, some engineer or scientist may be given responsibility for instruments as part only of his job. This man is required to be an instruments engineer for only part of his time, and he may be referred to briefly as a part-time instruments engineer.

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(*c*) As the need becomes greater the point is reached when a full-time instruments engineer is required. He will have to cover the full range of instruments used, although electronic instruments may well be predominant, and versatility is therefore required. Experience would indicate that of engineers and scientists, the electrical engineer and the physicist, because of their academic training, are particularly suitable.

(*d*) Finally there is the much greater need of large-scale industry when an instruments department with sections for different types of instruments, often on a sectional plant basis, is required. In very large organizations the development is towards works instruments departments dealing with maintenance and minor development work, backed by a central instruments department dealing with design and development. In central instruments departments it is possible to get a much greater degree of specialization, and it is here that the electronic engineer is really able to specialize.

2.2. *Field of Recruitment*

Having considered the kind of people required by non-electronic industry, it remains to look at the sources from which the instruments engineers can be recruited in order to see what practical training is needed. These sources are summarized as follows:

(*a*) There is the already professionally qualified engineer or scientist who wishes to specialize in the instruments field.

(*b*) There is the newly qualified engineer or scientist, fresh from college with a degree or equivalent academic qualification, with no previous industrial experience.

(*c*) As a special case of the newly qualified engineer or scientist, with a degree or diploma in technology, there is the man who has just completed a student apprenticeship.

(*d*) There is the man who has had industrial experience, often as a draughtsman or technician, who has gained an academic qualification which entitles him to be considered for professional level work.

(*e*) Lastly there is the ex-Services man, who has completed a regular training.

3. Practical Training

3.1. *The Part-Time Instruments Engineer*

We need not spend much time on the part-time instruments engineer (see 2.1 (*b*) above). If he is newly-graduated, he should receive proper practical training for his broad duties as an engineer or scientist, but bearing in mind his part-time specialization this training should incorporate a certain amount concerning instruments. The main elements of this instruments training should ideally be: (i) a postgraduate course in instrumentation and control, (ii) short periods of attachment to one or two appropriate instruments manufacturers and, if time can be spared, (iii) a short period of attachment to a medium-sized firm employing a full-time instruments engineer. If the part-time instruments engineer is already professionally qualified in his main field, then he should have these three elements as further training as soon as possible. In the main, however, the part-time specialist will learn a lot from actually doing the job.

3.2. *The Full-Time Instruments Engineer*

The main consideration is the training needed by the full-time instruments engineer (see 2.1 (*c*) and (*d*) above). The versatility required of the instruments engineer working on his own has already been mentioned but it is quite a widely held view among senior instruments engineers that even the specialist electronic engineer should be widely trained so that he had an adequate appreciation of other types of instruments. When the electronic engineer comes to take up more senior positions in the instruments field, it is important that he should not consider all instrumentation problems have to be solved electronically; sometimes there is a relatively simple physical solution. Moreover, the field of instrumentation and control is in a rapid state of development, and if the instruments engineer is going to keep abreast of innovations and new techniques he needs to have that wide appreciation which stems from broad-based training. The general philosophy applied, therefore, in considering the practical training of the engineer, is that a wide initial training is required. This is considered in more detail for the different categories of recruit.

3.3. *The Professionally Qualified Engineer or Scientist*

He needs his training only in instruments technology, and this training will include college courses, a limited amount of planned experience using internal and external resources, and specialist industrial courses on instruments which may be run internally or by instrument manufacturers. The programme of training will be individual and based on the needs of the job and the man's previous experience, but typical programmes are given in Appendix 1. It should be made clear that this programme is of formal training as opposed to the incidental training which a man inevitably receives while working in an established job; at the same time the formal training may well consist largely of active participation in various jobs of a temporary nature selected for their training value.

3.4. *The Newly-qualified Engineer or Scientist*

This is probably the most important category to consider. Not only is it the more readily available source of recruitment, but the newly-graduated man needs careful treatment if we are to get the best out of him and make best use of his ability. Most large firms and organizations consider that practical training of the graduate is necessary, although how this is done varies. Some organizations favour formal training programmes of two or three years' duration, while others favour short spells of formal training interspersed with experience-on-the-job over a lengthier period. Most experience to date has been with the training of mechanical and electrical engineers, physicists and chemists, many of whom have specialized in electronics, but it should be recognized that new courses of degree and diploma standard in instrumentation and control are being developed and products from these courses may well need quite different treatment.

Another factor which can considerably influence the kind of practical training needed is the extent to which it is considered necessary to meet the requirements of professional institutions and so have the training given recognized by them for corporate membership purposes. Certain institutions require a broad-based graduate apprenticeship, and this can be so broad that by itself it gives insufficient instruments training to the would-be instruments engineer. There is also a tendency for large organizations to lay down rigid rules about the qualifications needed for entry into the different classes of scientific and professional work, and this can make it important that corporate membership of a particular institution should be obtained if the new entrant is to have wide career prospects and the employing organization is to have flexibility in the use of staff. It is worth noting that this same factor can have an important bearing on academic training too.

It may be interesting at this stage to see the kind of practical training which has been formulated by a particular organization. Instrumentation and control is an important aspect of the work carried out by the United Kingdom Atomic Energy Authority, and the training schemes used in the Production and Engineering Groups (two of the five Groups of the Authority) are here briefly described. The training varies in the two Groups, since in Production Group we are training for employment in a works instruments department while in Engineering Group we are training for work in a central instruments department.

In Production Group all engineers are given a two-year graduate apprenticeship if they have not already had a form of apprenticeship. Mostly electrical engineers, with varying degrees of specialization in electronics, are recruited for instruments work, and it has been the policy of the Group to give a graduate apprenticeship which would be recognized as being appropriate to a professional electrical engineer. This has meant a practical training which was wider in scope than many senior instruments engineers thought desirable, but to a considerable extent it has been found possible to give the width of training within the Authority and still connected with instruments work. An outline of the present graduate apprentice training is given in Appendix 2(*1*). After graduate apprenticeship an engineer joins the graduate scientists on a management training scheme. This is designed to fit a graduate to take his first responsible post at one of the Works, and is a blend of formal management training and practising experience. The maximum length of training is two years, but this is pruned considerably for those who have completed a graduate apprenticeship with the Authority. In this management training scheme the electrical engineer would continue to receive specialist training in the instruments field. A typical full two-year programme for an instruments engineer is given in Appendix 2(*2*).

In Engineering Group, engineers and scientists are being trained for instruments design and development work. A typical programme for a physicist is given in Appendix 2(*3*). There is no formal management training scheme in Engineering Group and after completion of apprenticeship the graduates take up their first job. Most of the training outlined in Appendix 1(*1*) will have been covered in the graduate apprenticeship, but any outstanding parts would now be completed as soon as possible.

3.5. *The ex-Student Apprentice*

This man during his student apprenticeship will have completed a recognized apprenticeship and will have received a certain amount of experience with his parent organization. In the Authority it has been the aim to give a broad-based apprenticeship so that this would be recognized by the appropriate professional institution, but nevertheless a useful amount of instruments training can be given. A typical training programme for an electrical engineering student apprentice who wishes to become an instruments engineer is given in Appendix 3. So far student apprentice training has been confined to Production Group, and in this Group an ex-student apprentice would require only a short time, of the order of one year, in the management training scheme as an instruments engineer. It is proposed to extend the scheme to Engineering Group in the near future.

3.6. *The Draughtsman and ex-Technician*

On obtaining professional qualifications this kind of man can be a most valuable asset as an instruments engineer. His practical experience in the instruments field enables him to make a contribution which, to a large extent, is complementary to that of the newly-recruited graduate. On the Works side, some management training is needed and attendance on a post-graduate specialist course may be desirable. For work in a central instruments department, some experience on a construction project followed by operational experience would still be beneficial.

3.7. *The Services Trained Man*

This is a special category of recruit who has made a significant contribution in the field of instruments engineering in industry. The training and experience received by officers is in many cases recognized for corporate membership of professional institutions and there is no difficulty in recruiting them direct into the professional ranks. The training received by other ranks, however, is not generally equated to any generally recognized academic standard, and it is not possible to recruit them in large organizations with rigid entry qualifications with any hope of absorbing them quickly into the professional grades. This is unfortunate, because many N.C.O.'s have had training and experience which would enable them to make quick and effective contributions as instrument engineers. They would need only brief practical training on the lines indicated in Appendix 1.

4. The Problem of the Small Firm

The big organization can be very largely self-sufficient in the kind of practical training described. It can even supply its own postgraduate courses on instrumentation and control, although it is still dependent on instruments manufacturers and the electronics industry for certain specialist courses and periods of attachment. The small firm may well find that it can supply very little of the training required from its own resources. In the broad engineering field, however, the interchange of newly-recruited staff for training purposes is well established, and the small firm can hope to get sympathetic attention from the rest of industry should it ask for help in the training of instruments engineers. The main task is to decide what training is required and to make the detailed arrangements with firms and organizations willing and able to provide this training. It may be necessary to call on the resources of several firms in this way. This takes time and effort, but it should be amply justified by the benefits to be obtained from the training.

5. The Place of Women

Throughout this paper reference has been made to men. This is because the author has personally not come across any women in the instruments field. Should suitable women engineers and scientists be available for this kind of work, there is little doubt that what has been said about men would apply equally to women.

6. Conclusions

(i) The main need of non-electronic industry for the electronic engineer is in the field of instrumentation and control.

(ii) It is desirable that the electronic instruments engineer should have a knowledge of other instruments and of measurement generally.

(iii) The main training problem is that of the newly-recruited graduate who has had no previous industrial experience. It is considered that he should have a broad-based graduate apprenticeship and that this may need to be followed by further specialist instruments training and some management training. It is open to question whether it is desirable to broaden the graduate apprentice training to the extent that is required to enable the engineer and scientist to have it counted for professional recognition as an electrical engineer.

(iv) The student apprentice scheme can provide a valuable source of instruments engineers; it can produce a reasonably broadly trained electrical engineer who has also had some specialist experience in the instruments field.

(v) The Services trained man can be a great asset in the instruments engineering field and needs only a small amount of broadening, but there is some difficulty in recruiting him into professional grades where rigid entry qualifications exist.

(vi) The largest firms and organizations can provide internally most of the practical training required, but the smaller firms need the assistance of the larger firms and organizations, of instruments manufacturers, and of post-graduate courses provided by colleges and other organizations.

7. Appendix 1

Typical Training Programmes for the Professionally Qualified Engineer or Scientist

(*1*). *For a Works Instruments Department*

(i) Short works induction course (2–3 days).

(ii) Induction period of about 2 months in Works Instruments Department, acquiring information on organization and range of work. One month of this would be taken up by internal instruments courses.

(iii) A specialist course on Instrumentation and Control. This is likely to be of the order of 6–9 months if a college course is used, but could be reduced to 2–3 months if provided internally and designed specially to meet the needs of the particular firm or organization.

(iv) A final month, part of which is spent in the Central Instruments Department and part paying short visits to main suppliers of instruments.

The total time can vary from 5 to 9 months.

(*3*). *For a Central Instruments Department (concerned with design and development)*

(i) Short central induction course run by the organization (usually 2–3 days).

(ii) A short induction period, of perhaps 2 weeks, in parent branch, getting broad knowledge of the organization and functions.

(iii) Three months on a Construction Project, seeing instruments installed, tested and commissioned.

(iv) Immediately following, 3 months with the operational staff of the new plant.

A year on the job would follow, preferably in a small number of different sections.

(v) A specialist course on Instrumentation and Control. This may be done in 2–3 months when provided internally (see (*a*) 3 above), but can take up to 9 months if a postgraduate college course is used.

The total training time can vary from 9 to 16 months.

8. Appendix 2

United Kingdom Atomic Energy Authority

Production Group Training Schemes

(*1*). *Graduate Apprenticeship*

Outline Programme for Electrical Engineer (Instruments)

	Months
Appreciation of hand and machine tools and workshop organization	3
Watchmaker's work and panel wiring	1
Site installation work	1
Physical instruments; course and practical experience	2
Electronic instruments; course and practical experience	2
Experience with electronics manufacture	3
Generating and instrumentation experience on power reactors	3
Chemical plant instrumentation and operation	2
Laboratory instrumentation, including counting principles	1
Experience with instrument manufacturer	3
Design office experience	3
Total	24

(*2*). *Management Training Scheme*

Typical Programme for Instruments Engineer

	Months
Internal management training courses	1
Specialist instruments courses	6
Work instruments department	7
Plant operation	3
Health physics department	2
Reactor operation	2
Laboratory instrumentation	1
Central instruments department—design and development	1
Works administration	1
Total	24

Engineering Group Training Scheme

(*3*). *Graduate Apprenticeship*

Typical Programme for Physicist

	Months
Production engineering course (including basic workshop processes)	3
Experience with large electronics manufacturer (including design, fabrication, testing and commissioning)	9
Site construction of instrumentation and control systems, supervision of contractors' work on chemical plants and reactors	3
Instruments maintenance work	3
Central instruments department—design and development	3
Instrumentation and control course	3
Total	24

9. Appendix 3

United Kingdom Atomic Energy Authority Student Apprenticeship Scheme

Typical Practical Training Programme for a Student Apprentice taking an Electrical Engineering Sandwich Course and intending to become an Instruments Engineer.

	Months
1st Year	
Use of hand and machine tools—Apprentice Training Centre	6
2nd Year	
Advanced machining—Apprentice Training Centre	3
Construction of instrument panels, installation of plant instrumentation	3
3rd Year	
Physical instruments course and experience	3
Electronic instruments course and experience	3
4th Year	
Work on electronic instruments	2
Laboratory instrumentation	1
Experience with electronics manufacturer	3
5th Year (Academic course having been completed)	
Generating experience and instrumentation—power reactors	3
Instrumentation in conditions of heavy radioactivity	3
Experimental instrumentation work	3
Experience with instruments manufacturer	3

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Automatic Evaluation of Defect Severity by Shape and Size

By
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Presented at the West Midland Section's Symposium on "New Electronic Techniques in Non-Destructive Testing" in Wolverhampton on 6th December 1961.

Summary: Two experimental devices for the classification and measurement of surface defects, using photoelectric detectors (banks of photocells or flying spot scanner) are described which have been applied to the automatic inspection of tubes. The first system, which was developed to cover a particular inspection specification, has defect length as the only criterion. In the second system, defect length, width, and to some degree depth is taken into consideration. A technique of homing and defect following is employed, which ignores neighbouring irrelevancies that otherwise falsify the pattern evaluation. Variations of the second system could be applied to other visual inspection problems. The technique generally is not restricted to optical transducers, but could be applied to eddy currents, and ultrasonics, where a scanning system is incorporated.

1. Introduction

The main objective in inspection is to control the quality of a product. Traditionally this inspection is carried out by humans who make good inspectors because they are versatile, logical and easily retrained to meet changing situations. The human failings are: fatigue, inconsistency and comparative slowness.

In the case of automatic inspection devices the situation is usually reversed. The machine is tireless, consistent and faster. But it is inflexible, needs detailed instructions, and is at a loss even in slightly changing situations.

In general, automatic inspection devices have defect indication systems of the GO/NO-GO type, that is, they tell the operator whether or not a defect is present. This can be displayed on a cathode-ray tube screen or recorded as a trace on a pen recorder. Whatever method of defect indication is used, the onus of determining the real severity of the defect and whether or not it is rejectable, is vested in the operator or possibly upon some other responsible person.

This paper describes work in progress toward the design of inspection machines which contain an element of in-built flexibility in assessing the shape and size of a defect, and take on the responsibility of making decisions as to whether or not a defect is rejectable. Two experimental devices will be described. The first is a machine designed to work to a fixed specification. The second is far more flexible, all parameters are adjustable and can be set to suit a wide range of specifications. Both machines were built to detect cracks, etc., on round tubes or bars having good reflective surfaces.

The work has been carried out using photo-optical scanning devices. However, the general principle could be applied to other transducers using, for example, eddy currents, ultrasonics and x-ray techniques.

2. The Rigid Classification System

The first system to be described, which is the simplest, is designed to work to a fixed specification with regard to defect length, but has a degree of flexibility on defect width. The system was designed around the following inspection specification:

> The presence of score marks, fissures and other surface defects greater than ½ in. length, shall be sufficient cause for rejection.
>
> Not more than two surface defects less than ½ in. in length shall be present in any 6 in. length.
>
> Pock marks 0·008 in. dia. or greater shall be rejected.

Figure 1 shows typical defects.

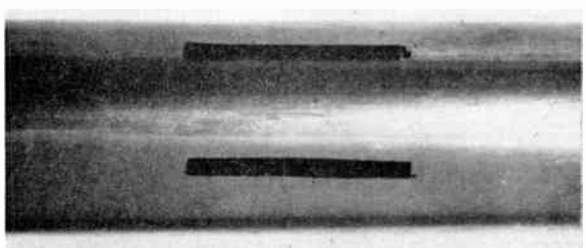

Fig. 1. Tube showing typical defects (Approximately full size).

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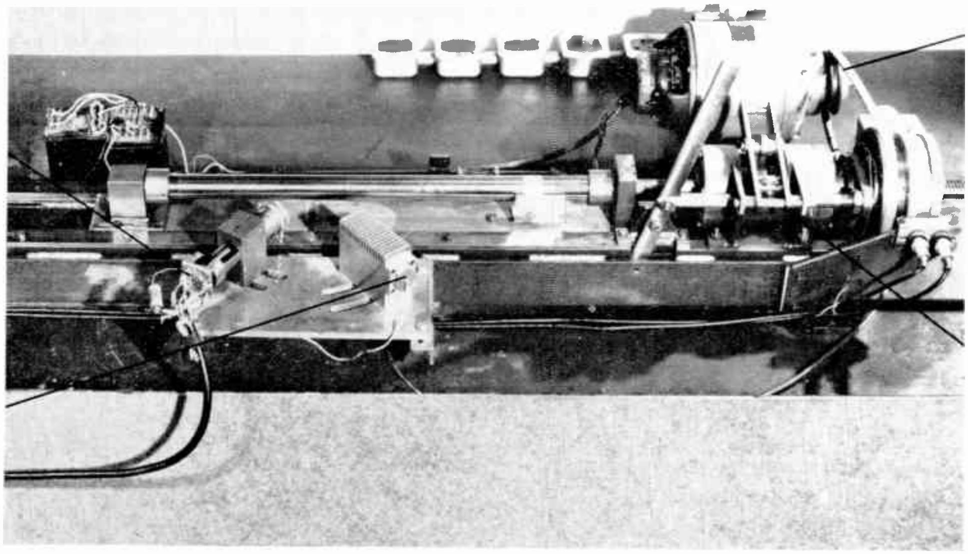


Fig. 2. Experimental rig for investigating photo-electric cell scanning (1250 rev/min) and a forward speed of 40 ft/min.

As transverse defects seldom occur we are predominantly interested in longitudinal defects. We have therefore limited the inspection to defects at angles to the axis of the tube from 0 deg to ± 60 deg.

The problem here is to convert the information received from the transducers into the three specified categories. Not only will the transducer give relevant information but also a considerable quantity of redundant data; therefore some form of separation is required.

The transducer consists of a row of photocells lying parallel with the axis of the tube or bar. If the defect on the tube surface is axial, all photocells detect the defect simultaneously. If the defect lies at an angle to the axis, all cells will not detect it simultaneously; at the maximum angle (60 deg) they see the defect as a series of disconnected bits.

To determine whether each bit is related to its immediate neighbour simple storage circuits are used, which take the form of mono-stable multivibrators having time-constants just long enough to coincide with its consecutive neighbour. This time determines the maximum angle of detection, for if the angle is greater than 60 deg. no coincidence will occur and therefore no correlation of bits.

From the circuit description that follows it will be seen that all information on a defect need not necessarily be collected together, but may be, and in fact generally will be, made up of two separate components. To join these components together in correct order, some form of storage is required so that the defect can be evaluated as a whole.

It was decided, in order to inspect the whole surface of the tube, to use a helical scanning system. An experimental rig was built (Fig. 2) to rotate a sample tube and also impart a forward motion, thus permitting the optical system to remain stationary. The tube rotation and the forward feed were geared together to ensure that the helix had no gaps between turns.

2.1. *The Scanning Head*

The scanning head consisted of a light source and a receiver. The light from a 48-watt pre-focus lamp

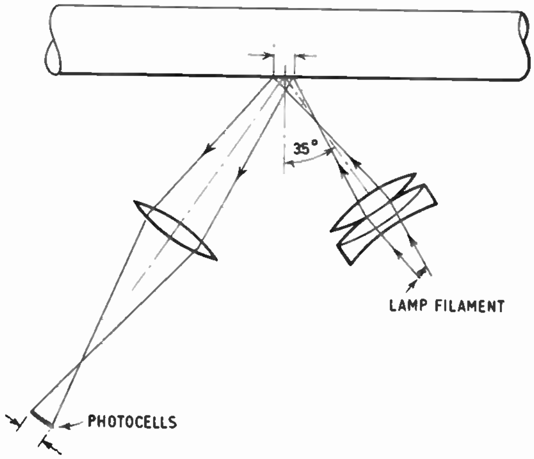


Fig. 3. Optical configuration.

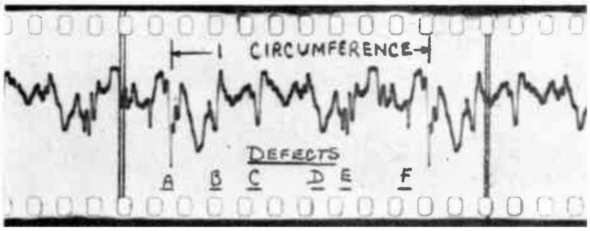


Fig. 4. Typical waveform emanating from a single photocell.

was projected onto the tube to illuminate the immediate area under inspection, the important dimension being the length along the tube. The receiver consists of a row of 18 miniature photocells (0·05 in. × 0·1 in.), with a lens system focusing on the tube and giving a magnification of 2·14 times (Fig. 3). Defects on the surface of the tube cause shadows on the cells which give signals as typified by Fig. 4.

Of the 18 photocells, 15 are used as defect detectors, 2 as pre-knowledge detectors and 1 as a post-knowledge detector. The reason for the last three cells will become apparent later. The 15 cells placed side by side cover a total width of 0·75 in., which is equivalent to 0·5 in. on the tube surface because of the optical system.

For a given rate of throughput the rotational speed to give complete coverage of the tube surface can be determined.

2.2. *Signal Processing*

Each photocell is fed to an individual two-stage amplifier and from there to high-pass filters. The filters are used to eliminate the low-frequency signals generated by tube surface conditions such as variations in reflectivity and discolouration, leaving only those signals having a fast rate of change, such as are caused by surface defects. These signals are now fed to the mono-stable pulse lengtheners, which in turn are coupled in pairs to diode AND gates. The square wave produced by the mono-stables have a width equal to

$$\frac{\tan \theta \times 0{\cdot}05}{\omega \times 2\pi R}$$

where θ equals the 60 deg limit of defect angle, 0·05 is the pitch of the cells, ω is the rotational speed in rev/min and R is the radius of the tube. This means that if two consecutive cells detect a defect lying at the maximum angle of 60 deg, a coincidence will just occur in the AND gate between the two square waves generated. This coincidence generates a further square wave of equal length, which anticipates a coincidence with the next consecutive pair of cells. Figure 5 is a simplified block diagram and Fig. 6 shows the appropriate waveforms.

The coincidence of the square waves is detected by three simple diode AND gates, which determine

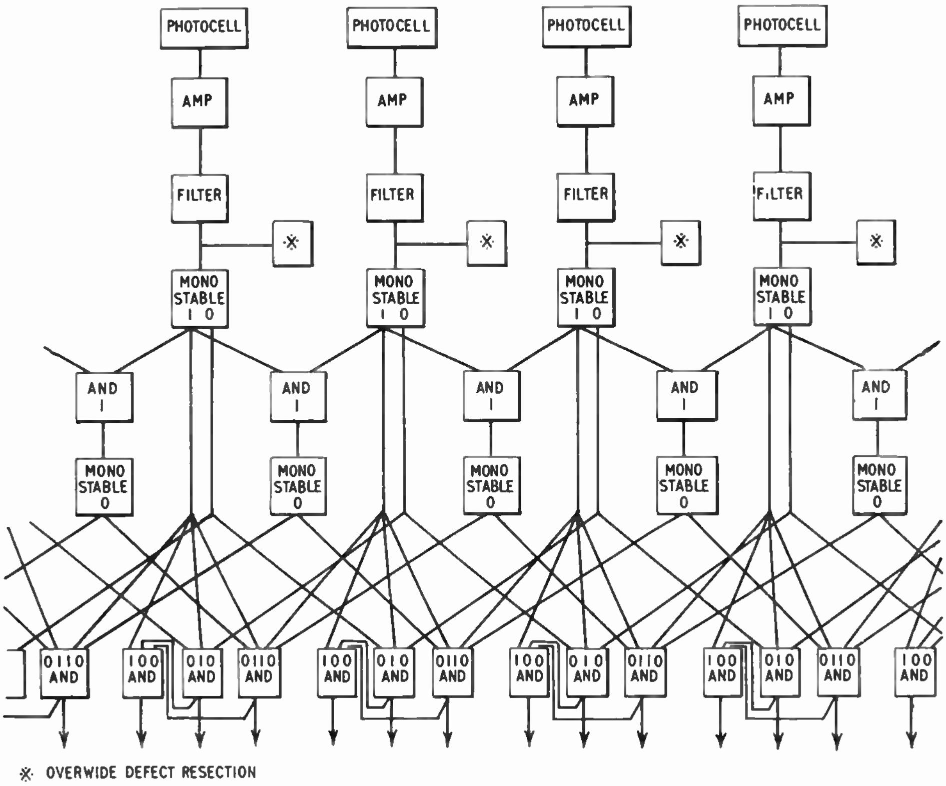


Fig. 5. Simplified block diagram of system.

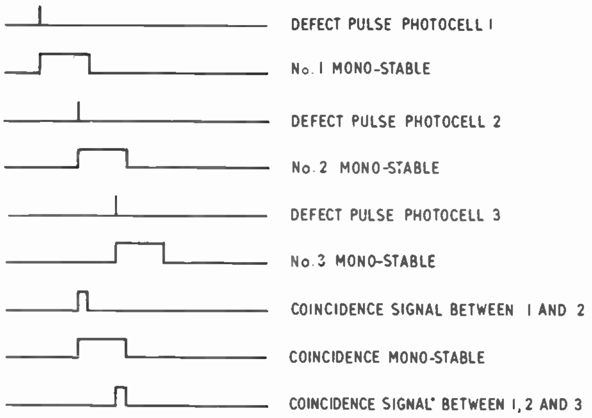


Fig. 6. Waveforms illustrating the generation of coincidences.

whether the signal received is emitted by 1, 2 or 3 consecutive cells.

This puts the defect into one of three categories:

(1) Pock mark seen by one cell only.

(2) Pock mark seen by two cells.

(3) Line defects, which must be checked for being greater or less than 0·5 in. in length.

(Because it is not possible to guarantee that a pock-mark reflection will only fall on a single cell, any signal from a consecutive pair of cells must be accepted as a possible pock-mark. Unfortunately this means that line defects 0·066 in. long will fall into the pock-mark category. However, it was not thought desirable to go to the added complexity of correcting this.)

Dependent on these categories the signals are now passed to 30-bit binary stores. The binary stores, of which there are two, are subdivided into 15-bit pock-mark stores and 15-bit line defect stores. The two main divisions are arranged so that while writing occurs in one the other is being read.

During the read-out any signal occurring in the pock-mark store causes immediate marking of the tube to indicate the location of the defect. Signals from the line defect stores are integrated to determine whether the flaw is greater or less than 0·5 in. in length, i.e. whether or not 15 consecutive binary stores have been actuated. A typical train of stored impulses is shown in Fig. 7. If the integration indicates a greater than 0·5 in. defect, the tube is marked; if however the integration indicates a less than 0·5 in. defect this fact is stored for a period equivalent to 6 in. of throughput. If by the end of this time no other defect is detected, the stored information is cancelled. On the other hand, if additional flaw information of any category is detected the tube is marked.

2.3. *Special Precautions*

In a simple system such as this, and even in more sophisticated systems, it is always possible to postulate a defect situation that the equipment will misinterpret. One such eventuality catered for was a defect "less than 0·5 in. long" but very wide: say 0·050 in. Such a defect, if not followed by another defect within 6 in., would be passed as an acceptable defect: a situation which cannot be tolerated, since it is obviously bigger than a pock mark. The output from each cell after amplification and filtering is connected to an integrator and trigger circuit with a time-constant set to reject any defect wider than the maximum acceptable dimension. Since no width dimension is called for in the specification, this parameter has been arranged to be pre-set in the range 0·020 in.–0·050 in.

It was stated earlier that apart from the 15 cells used for defect detection, three additional cells are used for pre- and post-knowledge of a defect. These additional cells form a safeguard. If there were no such cells the logic circuits easily misinterpret the situation when defects extend from one helical scan into an adjacent one. These guard cells are used to warn the logic circuit of the true situation; Fig. 8 illustrates this.

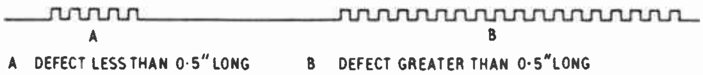
Results obtained from a laboratory model showed that the equipment performed satisfactorily within the limitations of the circuits used. It successfully segregated the flaws into 3 categories: pock-marks, defects less than 0·5 in. and defects greater than 0·5 in.

The equipment had certain shortcomings. In two respects the machine gives a fallacious answer:

(1) If there are a number of longitudinal cracks around the tube so deployed that in one revolution of the scanning head a continuous succession of adjacent binary stores are energized, the integrator interprets this information as one continuous flaw, since no knowledge of the circumferential positions is stored.

(2) If a line defect is detected that lies at an angle to the tube axis of more than 60 deg it is not completely ignored, but is recorded as a series of pock marks. This is because of the difficulty in differentiating between a series of pulses from the photocells caused by this type of defect and the identical series caused by actual pock marks.

Fig. 7. Typical train of stored impulses as fed to integrator.



Fortunately the quality of the tubes to be examined is such that condition (2) above is comparatively rare. Condition (1) does exist, and in fact the circuit analyses them into the wrong category.

The inspection problem just described has two fortuitous features that make it possible to use fairly simple logic circuits to categorize the flaws as required. These are: (a) the tube itself has a high-grade regular finish (cf. Fig. 1), which means that the flaw signals are uncluttered by pseudo-flaw signals emanating from other surface marks; (b) the inspection specification is simple and rigid, referring to two clearly specified "shapes" (straight lines and pock marks). The majority of visual inspection problems are not this simple. Tube surfaces are less regular in shape and reflectivity, defects vary considerably in shape and size, and there are many marks on the tube which are visible but not significant. For this reason a really effective general purpose automatic inspection machine must more nearly approach the mental attributes of the human inspector.

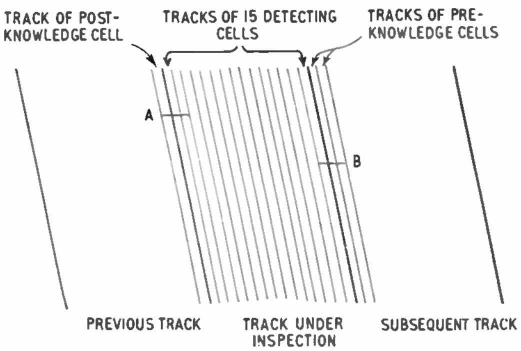


Fig. 8. The application of guard cells.

3. The Homing and Pattern Following System

The second and more sophisticated equipment examines and evaluates the signals received retrospectively, rather than immediately categorizing the defect. In this respect the equipment is akin to the human inspector. No final assessment of the defect is made until the defect has been evaluated in its entirety with reference to its surrounding background. This machine was designed so that all the possible parameters relating to whether a defect is rejectable or not are adjustable. Once again the defects of interest are those whose mean line of progress is within a maximum angle of $\pm$ 60 deg of the axis of the tube.

Like the previous system, a helical scanning path is employed and a similar light source and detecting head. The only difference in the detecting head is the type and number of cells used. These are silicon photo-conductive cells, 0·1 in. in diameter, seven of which are placed in a row. Tube throughput requirements are 40 ft/min.

The waveform shown in Fig. 4 is the output from one photocell in one scan round a typical tube; as can be seen, a number of defect signals appear. In the previous system these signals would be lumped together, but in this design the intention is to study each defect individually. To do this, the peripheral position of each defect on the tube must be identified so that on the next turn round the tube the signals derived can be correlated to the appropriate signals in the previous turn. Also from Fig. 4 it will be noted that considerable background noise is present, generated in the main by roughness of the tube surface, and by dirt or stains. This poses a data processing problem to extract the real defect signal from the background.

The human inspector holds a tube still and looks at a defect as a whole. With this equipment, the tube is continually moving forward, and the information is collected by travelling around the tube. Information about a defect is collected a piece at a time, and it is therefore necessary to store these individual pieces until the defect can be studied as a whole.

3.1. *Outline of Electronic Apparatus*

Broadly, the electronic circuits can be lumped into four groups:

1. The image of the tube surface falls on a line of photocells whose output signals are fed to independent parallel signal processing circuits. These processing circuits each consist of:

(i) *Automatic contrast control.* This caters for variations in reflected light level by referring the output signal to a mean background level.

(ii) *Filters.* Band-pass filters reject lower frequency interference signals from such causes as mechanical vibrations, tube deformation, etc.

(iii) *Clipper.* Interference, amplifier noise, and small signals caused by minor blemishes are removed by conventional amplitude clipping.

(iv) *Amplifier and squarer.* The remaining signals after clipping, are amplified and squared to a constant finite amplitude, but having a time duration equal to the pulse width at the clipping level.

(v) *Self-sampler.* The amplified square pulses are used to sample the incoming signal (before filtering, i.e. after contrast controlling). The signal emerging from the self-sampler is therefore a thin slice or sample of the incoming signal, abstracted during the period when a potential flaw pattern is passing through the optical field of view.

(vi) The output of all seven self samplers is fed into one analogue adder having a single line output.

Thus the signal emerging from this single line will contain information about all seven photoelectric input channels.

II. From the output of I, the signal emerges on a single line and is fed to a channel selector switch. This switch serves three independent identical data processing channels (A, B and C). Under normal (quiescent) circumstances the through connection is to channel A. If, however, channel A is actively engaged in following and analysing a particular pattern configuration, channel B also becomes connected, so that information gathered from some concurrent pattern can be processed independently. Similarly, if A and B are both engaged, channel C is made available to follow and evaluate any third concurrent pattern.

III. Electromagnetically-produced marker pulses from line and frame pulse generators are fed in parallel to all three channels of data sampling and processing (A, B and C). The data sampling and processing is the heart of the pattern analysis system. The serial signals provided via the channel selector switch are collated and edited so that information relating to probable flaw patterns emerges quantitatively for feeding into an evaluating circuit.

IV. All three evaluating circuits feed into a common alarm circuit. This alarm simply energizes the tube marking solenoid.

3.2. *Operation of Pattern Following Circuits*

To examine a defect more closely, a system of pattern following was devised so that once a defect was detected, its path as it extended along the tube was followed by electronic guidance, provided it did not deviate by more than ± 60 deg from the longitudinal axis.

As this pattern was followed to the exclusion of any other defect in the immediate vicinity, the final design of the equipment should have three channels which work independently from the point of view of detection and pattern following, but operate from a common set of photocells and have a certain common output equipment.

One of the advantages of the pattern following system is that it reduces the otherwise substantial amount of storage facilities required. In fact the storage for each channel consisted of two linear diode pumps feeding into capacitive stores, one as a buffer store, the other as a final store.

To follow the defect pattern it was necessary to locate the last known position of the defect around the tube for each turn of the helix. To do this, and also to minimize the storage capacity requirement of the buffer store, the helical path of the photocells was divided into "fields". These fields were the width of the scanning track and as nearly 0·25 in. long as the circumference of the tube under inspection would allow in order to have an exact multiple (see Fig. 9). These fields become the unit of inspection and the pulses marking these fields in time were generated by an electro-mechanical pulse generator coupled through suitable variable gearing to the rotating mechanism. This permits adjustment of the number of fields to suit different tube diameters and ensure accurate positioning of the fields despite any speed variation.

As in the case of the simpler equipment the presence of defects in the surface of the tube is seen by the photocells as black shadows. An experiment with a piece of tube having a ground surface and machined defects ranging from 0·001 in. wide by 0·001 in. deep, in 0·001 in. steps to 0·017 in. wide by 0·017 in. deep, showed distinct differences in signal, both in amplitude and pulse width as illustrated in Fig. 10.

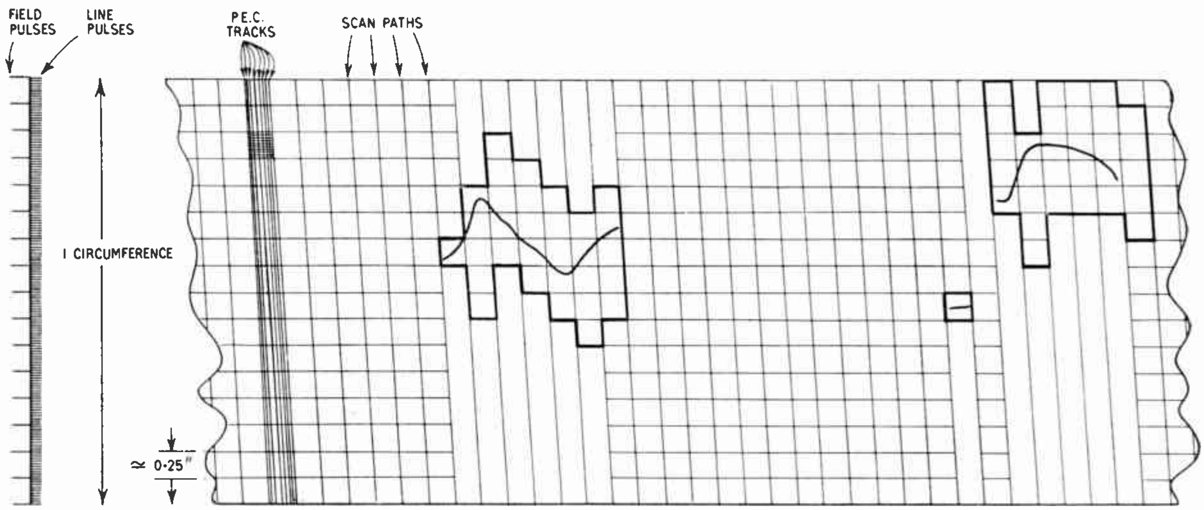


Fig. 9. Division of the tube surface into fields and illustrating pattern following.

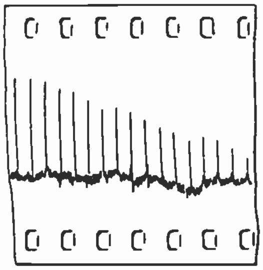


Fig. 10. Oscillograph recording of signals from one photocell viewing a ground bar, containing 17 longitudinal artificial defects graded in steps of 0·001 in. The smallest is 0·001 in. Note variations in amplitude caused by variations in the mean reflected light level.

To simplify the description of the circuit operation a single channel only will be considered. As the circuit for the correlation of the outputs of the three channels has not yet been designed, no anticipatory explanation will be attempted.

Defect signals from the seven photocells are fed via individual amplifiers to seven band-pass filters which are adjustable. This adjustment is provided in order to pre-determine the size or range of size of defects to be inspected while suppressing all unwanted signals as stated in the simpler device. After filtering the signals are amplified and squared. These square waves are then used to sample the original waveform which in turn has been suitably delayed to compensate for the phase delays through the amplifiers and filters. The object of this "self-sampling" is illustrated in Fig. 11. As the amplitude of a defect signal is proportional to the contrast between defect shadow and background light level, two defects of equal severity, one on a bright background, the other on a discoloured background, will give different pulse amplitudes and so give false information. If, however, the self-sampling technique is used, the true amplitude of the defect pulse is obtained, because the signal is normalized to the maximum reflection level. After self-sampling, the resultant signals from all seven cells are continuously summated by an analogue adder. The resultant waveform is sampled 10 times per field. The output from this line sampling is summated and stored in the buffer store. This buffer store holds information from one field at a time and upon receipt of a field pulse, the analogue value of the store is read and the store emptied ready to start storing the next field.

The signal read off the buffer store is fed to an adjustable level detecting switch set to operate according to the severity of defect it is wished to reject. If the amplitude of the pulse is insufficient to operate the switches then nothing is passed through it; if, however, the signal is greater than the trip level, its full amplitude is passed through (not just the difference between the pulse received and the switching level). Information not passed through by the switch is erased and the equipment then continues to examine the tube field by field until a signal is found that will operate the switch.

When this does occur the signal passed through the switch is held in the final store, and the field evaluation ceases. At this instant a field counter comes into operation and counts off the number of fields required to arrive at a point in the next scan path two fields in advance of the initiation field. Three examples of this are shown in Fig. 9. It will be noted that the field-by-field scanning recommences and continues for a maximum of five fields. These five fields adjacent and astride the field of origin, sets the limits of the defect following angle ($\pm$ 60 deg about longitudinal centre line of defect).

Because the main interest is in longitudinal defects, the nearer a defect comes to being transverse the less its significance. Consequently, during the five-field examination period, a derating system is applied to the output of the field summation signals prior to line sampling. This derating is zero over the centre field increasing linearly to a maximum over the first and last field. The degree of derating is adjustable which means that a defect running truly axially through the field of origin and the centre field of the five fields is evaluated higher than a similar one which deviates into, say, number one field.

During the scanning of the five fields, as soon as a field summation is found that is of sufficient value to open the level switch again, this signal is transferred and added to the final store. The scanning is then shut off whether or not all five fields have been scanned and once more the field counter comes into operation and the sequence continues as before.

The final store has a trigger circuit arranged to discharge the store at any predetermined value, and at the same time mark the position of the defect on the tube.

If, however, no defect is found in any of the five fields, the derating system is removed and normal field-by-field scanning is continued. Under these conditions any defect information held in the final store will gradually decay at a controllable rate. Thus, where a discontinuous defect is detected, the value of its individual parts are derated with time in a manner such that a defect with a total length of, say, 1 in. constituting three broken parts spread over 2 in. length of tube receives a lower evaluation than would a continuous 1 in. defect.

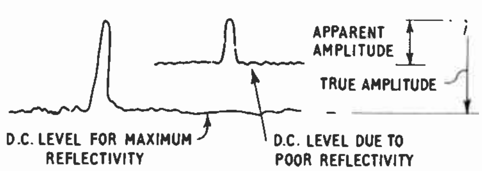


Fig. 11. The reason for self sampling.

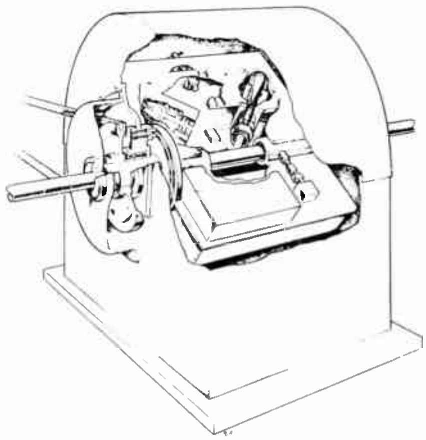


Fig. 12. Artist's impression of a future design.

With the controls available it is possible to adjust:

The width range of the defect to be examined.

The severity of defect to be considered for rejection.

The length of defect corresponding to this severity.

The amount of derating of the component parts of a discontinuous defect.

With three channels it will be possible to examine three defects simultaneously and when the correlation circuitry is designed, the relationship between what each individual channel sees can be made to have an additional bearing on what is and is not rejected.

3.3. *Results Obtained*

Tests were carried out using the "breadboard" circuits and the mechanical test rig. These tests were done at a throughput speed of 40 ft/min and a rotational speed of 1250 rev/min. Under these conditions defects 0·001 in. wide on a prepared surface were detected and correctly evaluated, the equipment having been set to reject defects of this size and 1 in. long. This of course was a reasonably simple test due to the near perfection of the background. On tube samples having a normal production finish and the removal of lubricant the only preparation, defects 0·005 in. were detected and rejected when 1 in. long; discontinuous defects of equal severity were evaluated and rejected much as was expected.

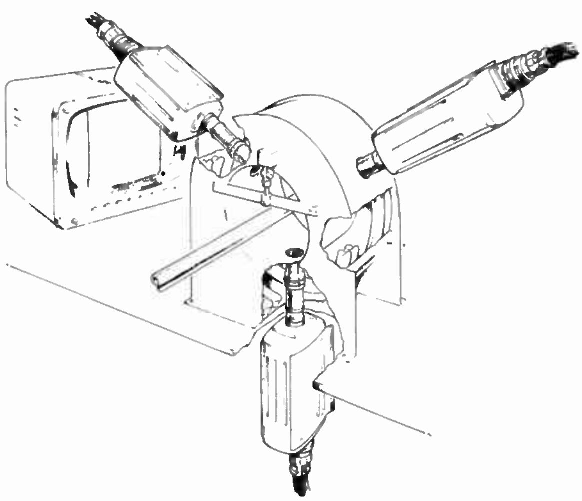


Fig. 13. Artist's impression of a three-camera television system.

4. Future Development

At the present time no work has been carried out using transducers other than photo-optical.

Ultimately it is intended that, instead of the tube being rotated, the optical system and the electronics will rotate about the tube. Figure 12 is an artist's impression which is applicable to both systems. The circuitry will be made in potted units, and, in the case of the second equipment, assembled after the style of an analogue computer, in order that like a computer, the basic circuits can be changed around to suit varying applications, for example using ultrasonics as the detecting medium instead of light.

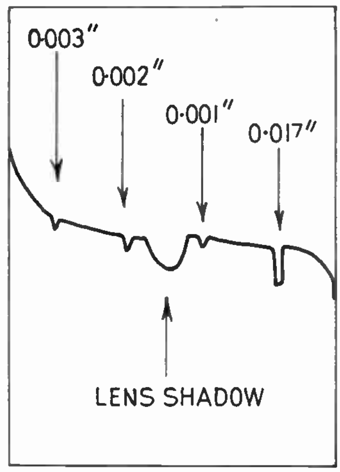


Fig. 14. Signals from a vidicon television camera tube for that quadrant of the same bar (Fig. 10) that contains the largest and the smallest defects. An optical technique for removal of the "lens shadow" is known.

The behaviour of the apparatus using the mechanical test rig was slightly erratic. This was thought to be due to mechanical vibration of the spinning tube.

Additional work has also been done, using three television cameras set at 120 deg spacing which eliminates the mechanical rotation. By the use of suitable time-bases and switching techniques, similar helical scan and field-by-field inspection can be achieved. Figures 13 and 14 show the equipment layout and the waveform generated respectively.

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U.D.C. 620.192 : 534.8

Automatic Charting of Ultrasonically Detected Flaws in Bar

By

M. D. CHATTAWAY†

Presented at the West Midland Section's Symposium on "New Electronic Techniques in Non-Destructive Testing" in Wolverhampton on 6th December 1961.

Summary: The problems associated with ultrasonic testing of bar and billets are described and the advantages and disadvantages of an immersion technique considered. A semi-immersion system employing probe scanning which has been successfully used on steel bar is described. The need for a physical picture of the location of defects and the limitations of the conventional oscilloscope display in this respect are pointed out. Details are given of an electronic unit for coupling an ultrasonic test set to a standard 4-channel pen recorder, to obtain analogue representation of the depth, severity and longitudinal positions of internal defects. Typical records and results achieved in practice are presented.

1. Introduction

This paper describes the development of relatively compact apparatus for testing and recording the position of defects in round steel bar using ultrasonic techniques.

It is generally recognized that immersion gives a more consistent ultrasonic coupling between the probe and material under test than does the usual contact probe test. The disadvantage of the conventional immersion technique is that the object being tested has to be completely immersed in a water tank. This is acceptable for small parts, but the steel bars to be tested in this application were comparable in size to telegraph poles; a tank to immerse these completely would be large, costly and far from portable. The movement of the ultrasonic probe in immersion testing is usually controlled by a gantry system attached to the tank and, unless the part under test is adjusted and remains accurately aligned to the probe so that the ultrasonic beam may enter normal to the top surface of the part, results obtained will be inconsistent. As the steel bars to be tested in this instance are not perfectly straight, maintaining this probe alignment would be a difficulty.

Desirable features of apparatus that is to be used for this kind of investigation are that it shall permit detailed examination of faulty areas, freedom of movement to allow the operator to obtain the optimum signal from a defect, and provide means for keeping the ultrasonic probe correctly aligned to the surface of the bar.

The above considerations, and results of a few simple experiments led to the design of the following piece of apparatus.

† Tube Investments Technological Centre, Walsall, Staffs.

2. Manually Operated Test Head ‡

The testing head described incorporates the advantage of the immersion system and yet obviates the necessity of completely immersing the object being tested. It is a completely portable, manually operated unit, that has been tested on several hundred feet of steel bar stock and has given satisfactory performance.

The construction finally adopted can be seen in the sectional view (Fig. 1), and its operation is as follows. The ultrasonic energy from the probe A travels down through the water filled cavity B, passes through the diaphragm C and the lower chamber D into the steel bar E.

The purpose of the diaphragm C is to retain the water in the cavity B, thus preventing the loss of this water when the unit is lifted from the steel. It also prevents clouds of dirt and air bubbles rising towards the probe creating false signals and attenuating the echoes from defects etc. The diaphragm is made of thin plastic sheet that has a low ultrasonic attenuation, and is inclined slightly to the horizontal so that ultrasonic echoes from it are reduced.

The lower chamber D is made watertight on the steel bar surface by the seal F. This seal consists of a double layer of flexible plastic sheet with a round aperture in the centre that is pressed into intimate contact with the contour of the steel bar by a circular pad L of non-porous foam rubber (see Fig. 2(b)). The chamber is kept filled by a supply of water from the reservoir G, trapped air being leaked away by the air bleed tubes H.

The design is such that a complete water column is maintained between the ultrasonic probe and the

‡ British Patent Application No. 9855/60.

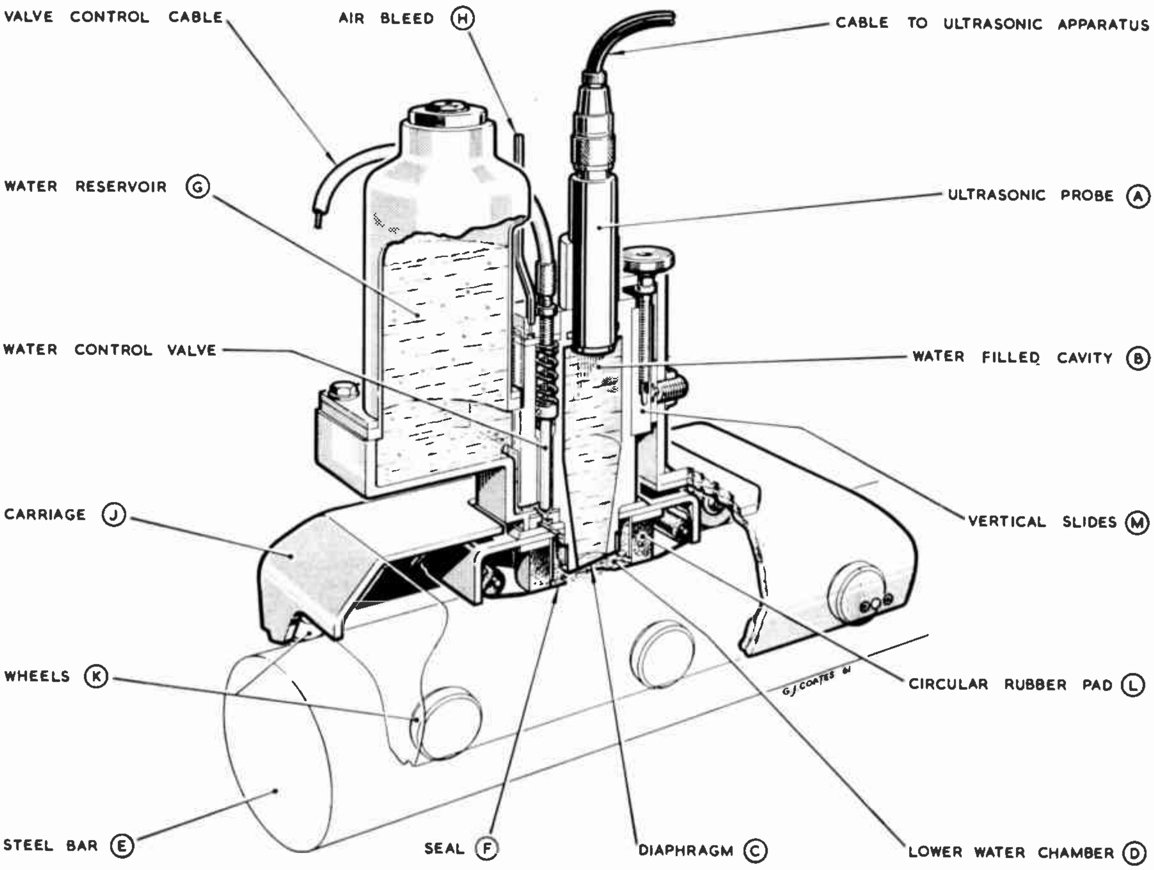

Fig. 1. Manually operated test head.

surface of the bar being tested. The seal unit, together with the probe and cavity, can be lowered down on to the steel bar by means of the vertical slides M mounted on the carriage J. This has three pairs of wheels K that operate in a similar manner to a "vee" block, to maintain the carriage and probe etc., aligned with the surface of the bar as the unit is moved along. Figure 2(a) is a photograph of the complete test head and the mounting carriage shown can be adjusted to allow steel from 5 in. diameter to flat plate to be tested.

3. Results Obtained with the Test Head

Experience has shown that a very low leakage rate of water occurs from the seal unit, even on relatively rough surfaces, and wetted area seems to be the major source of consumption. The life of the plastic sheets on the water seal depends on the surface roughness of the steel under test. Bars having rough scale surface gave an average life of approximately 500 ft of travel, and as the replacement sheets are very cheap and simple to replace this was not considered to be a serious drawback. Greater life is possible if the steel bar is lightly wetted ahead of the seal to reduce the friction.

Results with this test head are much more consistent than those previously obtained with a contact testing probe. The echo from the bottom of the steel bar remains relatively constant while testing good quality bar, which is an indication of good ultrasonic coupling to the steel.

Using the ultrasonic testing head it was soon discovered that for the operator to keep pace with the rate of testing now possible, and still retain the maximum amount of information regarding defects for records, statistics etc., some form of data recording system would be desirable, if only to reduce the risk of error due to operator fatigue caused by watching the cathode-ray tube for long periods.

4. Problem of Recording Ultrasonic Signals

To assess the importance of a flaw it is necessary to know its size and location in the object under test, and also the amplitude of the echo signal obtained from it. It is also useful to have information regarding the strength of the echo from the bottom of the object in order to estimate the degree of coupling. Simple systems are available that will record all of these parameters, except the depth of the flaw beneath the

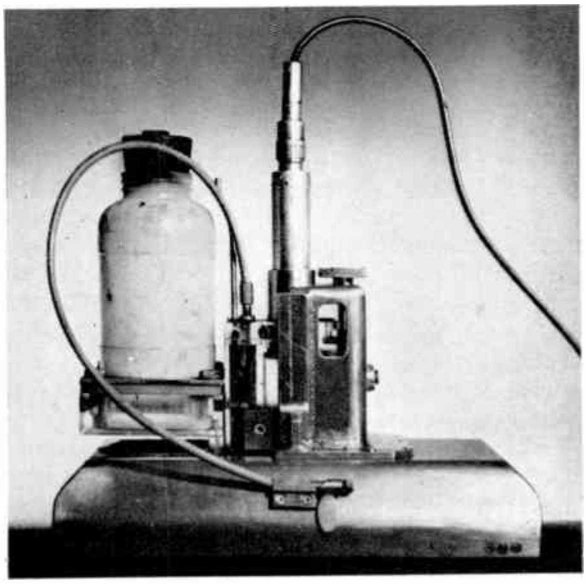

Fig. 2. (*a*) Side view of complete test head.

surface. To date there is no apparatus commercially available that can provide this information without duplicated electronics or time-consuming photographical techniques.

Recording this information on the type of pen recorder used for the other parameters requires that the frequency response of the pen should be approximately 25 000 c/s. As 50–100 c/s is typical of the frequency response of the type of recorder to be used, some form of reduction is required. To achieve this reduction a sampling system was developed and adapted to a standard recording system.

5. Description of Recording System†

In ultrasonic testing the depth of a defect below the top surface is usually found by the position in time of its echo relative to that of the top and bottom surface echoes as displayed on the cathode-ray tube of the ultrasonic apparatus. It was decided to develop a system which would record these relative echo positions. The fundamentals of the system can be seen by referring to Fig. 3. A pen is used to record these signals that will only mark the recording paper when it is supplied with an electrical potential. This pen zigzags across the paper at a frequency of 50 c/s, the ultrasonic transmitter and time-base repetition rate being synchronized to a multiple of this frequency, for example 500 c/s. Thus during every single oscillation of the pen the ultrasonic transmitter produces ten pulses. It is so arranged that for the first five pulses a delayed sampling gate is initiated, the time delay being linearly increased as the pen swings to the right. No gates are produced as the pen returns to the left, thus muting the pen on the return stroke.

The result of this is that the position of the sampling gate moves in relation to the ultrasonic echo signals and in synchronism with the recording pen. The movement of the sampling gate is so arranged that the gates at extreme ends of the excursion embrace the top and bottom echo signals, and each of the inter-

† British Patent Application No. 12354/60.

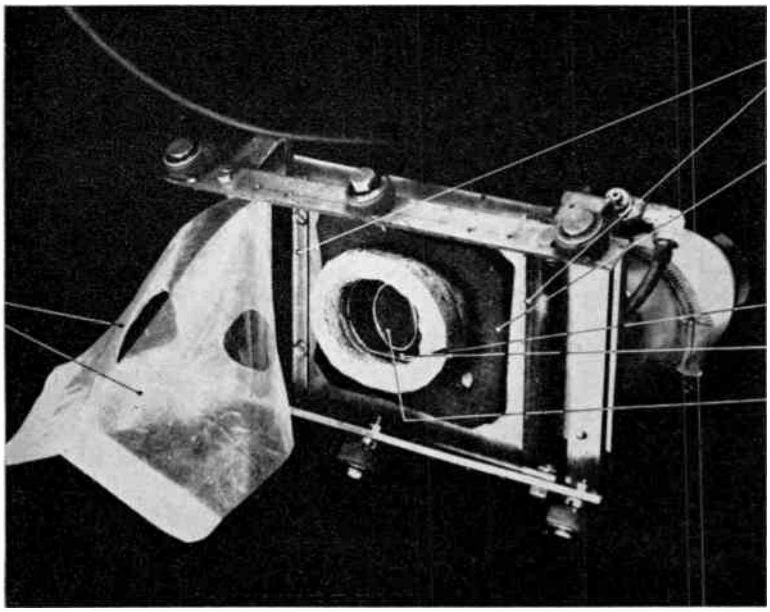

Fig. 2. (*b*) Underside view of test head showing seal construction.

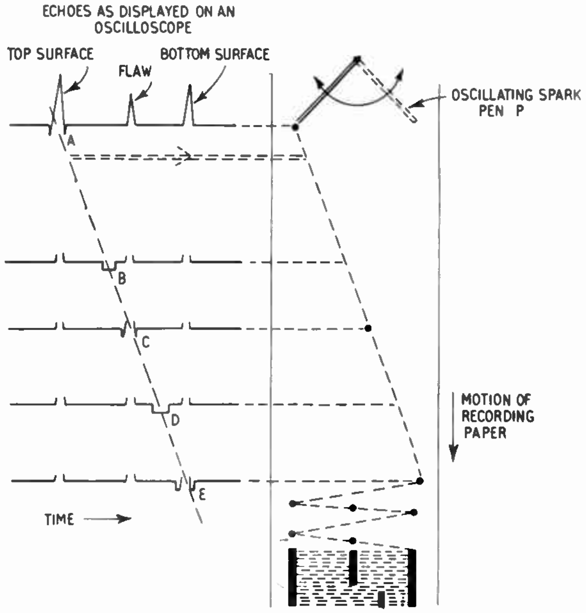

Fig. 3. Fundamental operation of depth recording system (sampling gate motion).

mediate gates monitor a strata between these. When an echo signal appears in any gate the recording pen is caused to mark the paper. Since the recording paper is in motion the pen will produce two lines which represent the position of the top and bottom echo signals, and also mark the occurrence of any other sampled signals appearing between them as further lines (see Fig. 3 and bottom trace of Fig. 6).

The block diagram in Fig. 4 shows the operation of the complete depth recording system.

A 50-c/s reference waveform is passed into both the triangular waveform and the square waveform generators. A phase shift network is included in these generators to compensate for the phase shift due to the inductance of the pen recorder coils. The triangular waveform passes into the pen recorder deflection amplifier, and the square waveform into the ramp function generator U. The output of the latter generator is added to the 500 c/s time-base waveform in the mixer V and produces the complex waveform W. This waveform W is then applied to the grid of a valve which is normally held beyond cut-off in the manner shown in Fig. 5 so that only the highest peaks of the complex waveform will cause the valve to conduct. The leading edge of the output pulses from the valve is selected with a differentiator, and used to initiate the moving sampling gates in the generator X. These appear, as in Fig. 3, consecutively in positions A B C D E in relation to the ultrasonic echo signals.

The moving sampling gates are now applied to a coincidence selector circuit Y together with the echo signals. When an echo signal coincides with a sampling gate it is allowed to pass on, via a pulse-lengthening circuit, to the pen modulator Z. Pulse lengthening is required so that ample time is available for the recording pen to make a clear mark. The resulting pattern on the recording paper can be seen in Fig. 3 (bottom right).

To complete the information it is necessary to

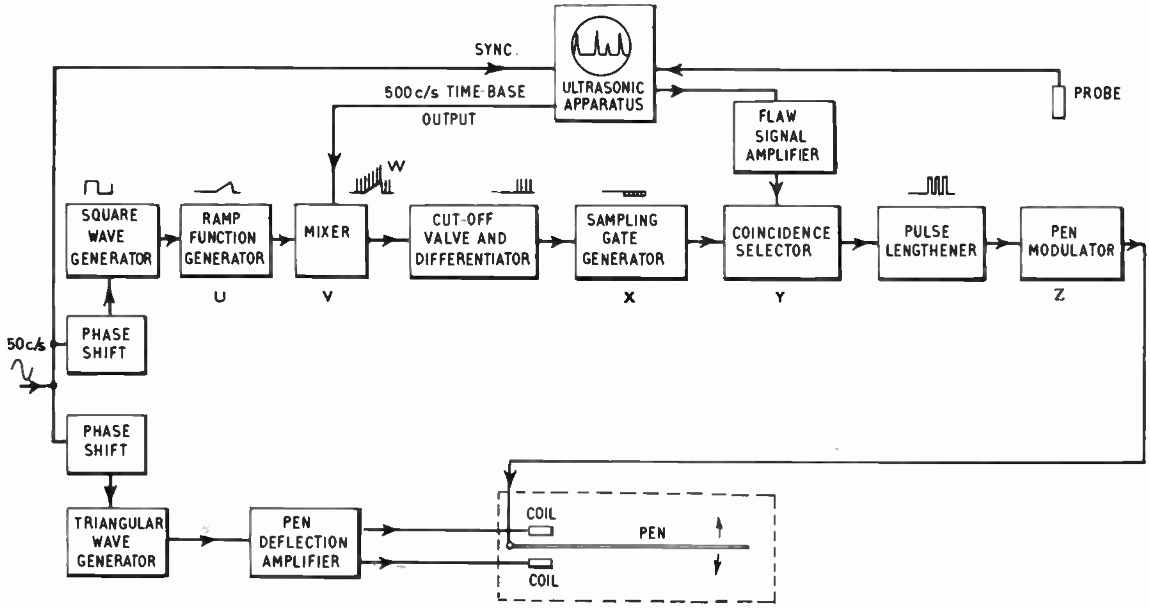

Fig. 4. Block diagram of depth recording system.

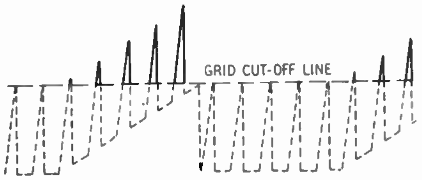

Fig. 5. Grid waveform of cut-off valve.

record all data regarding the position and amplitude of defect and back echo signals simultaneously. A typical sample of the recording made on a four-channel recorder is shown in Fig. 6.

Standard techniques for recording the amplitude of defect and back echo signal were incorporated, separate pens being used for each signal and for the distance marker. A modulating circuit is included to "shade in" the area between the d.c. level of the signal and the zero line of the recording papers. This has the advantage of showing the position of the zero level thus indicating any d.c. drift, and it also makes the occurrence of flaw signals appear as definite black patches on the recording.

6. Results and Conclusions

When using this recording system under works conditions it was found that after initial setting-up it was unnecessary to watch the cathode-ray tube display, and testing could be carried out by one operator.

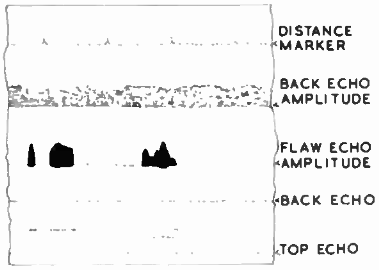

Fig. 6. Typical recording of ultrasonically-detected flaws.

Results from testing quantities of bar suggest that more information about the quality of steel can be obtained by this graphical method than by the conventional oscilloscope display.

It is thought that the principal use of the apparatus is as a statistical tool for operational research or quality control studies rather than for continuous production inspection.

Further development will probably take the lines of (a) making the test head automatic instead of manual, (b) altering the recording system so that print-out only takes place when flaws occur.

Manuscript received by the Institution on 19th October 1961 (Paper No. 718).

APPLICANTS FOR ELECTION AND TRANSFER

As a result of its meeting on 29th March 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

BRAYSHAW, John David. *Sale, Cheshire.*

Direct Election to Associate Member

BRYANT, Roger Ian. *Harrow, Middlesex.*
DELLOW, Frank. *Portsmouth, Hampshire.*
FISHER, Derek. *Harlow, Essex.*
HILLS, Squadron Leader Douglas William. *Kolsas, Norway.*
HOBSON, Kenneth. *Liverpool.*
SELBY, Gordon Rainton, B.Sc.(Eng.). *Wells, Somerset.*
SINHA, Naresh Kumar, Ph.D., B.Sc., (Eng.). *Tennessee, U.S.A.*
SMITH, Derek, B.Sc.(Eng.). *Loughborough, Leicestershire.*
WILLIAMS, Trevor, B.Sc. *Fareham, Hampshire.*

Transfer from Associate to Associate Member

BURLING, Kenneth George. *St. Albans, Hertfordshire.*
HUMPHREYS, Humphrey Ioan. *Stevenage, Hertfordshire.*
WLODARCZYK, Stefan. *Harrow, Middlesex.*

Transfer from Graduate to Associate Member

CHERRY, Clive John. *Lancing, Sussex.*
BURRIDGE, Michael Vincent. *Ottawa, Canada.*
DHAWAN, Flight Lieutenant Prem, B.A., R.A.F. *New Delhi, India.*
FEEK, Derrick Townley. *Wick, Caithness.*
HALTON, Dennis Lewin. *Northampton.*
SMEED, Norman Peter. *Slough, Bucks.*
STAYTON-DAVIS, Anthony Maurice. *London, W.11.*
TRAVIS, Flight Lieutenant Robert Charles, B.Sc., R.A.F. *Henlow, Beds.*

Transfer from Student to Associate Member

KORB, Hans Arno Fritz. *Ennetbaden, Switzerland.*
SCOTT, Walter. *London, N.6.*

Direct Election to Associate

EVERITT, George Francis Valentine. *Stevenage, Hertfordshire.*
GIBBS, Reginald Robert James. *Boreham Wood, Hertfordshire.*
IBBOTSON, Lemuel, B.Sc. *Crawley, Sussex.*
LINES, Frederick Herbert, B.Sc. *Guildford, Surrey.*

Transfer from Student to Associate

NICHOLAS, Peter Chaston. *Cambridge.*
ROSS, Walter Finlay. *Bolton, Lancashire.*
SIBLEY, George Brian. *Pierre Fonds, Canada.*

Direct Election to Graduate

BRAZIER, Malcolm David. *Liverpool.*
BULCOCK, Clifford James. *Reading, Berkshire.*
CLIFTON, Michael Joseph. *Harlow, Essex.*
DELANEY, Reginald. *Manchester.*
DES-FORGES, Howard Alan. *West Moseley, Surrey.*
HANKS, Leonard Edward, B.Sc.(Eng.). *Liverpool.*
JACOBS, Murray Herbert. *Leigh-on-Sea, Essex.*
LENNON, Leo. *Basingstoke, Hampshire.*
LOUFTE, John Claude. *London, S.W.15.*
SIMPSON, Alfred. *Redhill, Surrey.*
VERMEULEN, Adrian Isaac. *Southern Rhodesia.*
WARD, Michael Henry Evans. *Cambridge.*
WILKINSON, Terrence George. *Stevenage, Hertfordshire.*

Transfer from Student to Graduate

BARRY, Roy. *Blackpool, Lancashire.*
BOWMAN, Alan Michael Arthur. *Dartford, Kent.*
BRADLEY, Harold Leonard. *Havant, Hampshire.*
DAVIS, Charles Emanuel John. *London, S.W.17.*
DAVIS, John Graham. *Bristol.*
HENDERSON, Alan James. *Largs, Ayrshire.*
JONES, Robert Philip. *Twyford, Berkshire.*
LANGSTONE, Peter George. *West Drayton, Middlesex.*
NEWRICK, Roy William. *Singapore.*
RICHARDS, David John. *Salisbury, S. Rhodesia.*
SHAMBAVI DEVI, P. S. *Delhi, India.*
SHILLONG, Leo Andrew. *Newark, U.S.A.*
WATSON, Brian David. *Harlow, Essex.*
WEISSBERG, Ernest Michael. *Ramat Gan, Israel.*
WILLIAMS, Paul David. *Carlingford, Australia.*
WILD, William George. *Sidcup, Kent.*

STUDENTSHIP REGISTRATIONS

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

ACHEBE, Theodore O. *London, S.E.27.*
ADCOCK, David John. *Stafford.*
AHARON, Edelstein. *Jerusalem, Israel.*
ALEXANDER, Richard Hugh L. *Surbiton.*
BARKER, John Pax. *Worthing.*
BARLOW, Derek M. G. *Auckland, New Zealand.*
BARRATT, Kenneth H., B.Sc. *Woking, Surrey.*
BIDDISCOMBE, Michael. *Newport, Mon.*
BLEE, David Thomas. *Plymouth.*
BOCARRO, Noel E. B. *London, N.W.2.*
BROWN, Michael N. D. *Virginia Water.*
CHAMBERLAIN, Savvas G. *London, N.5.*
CHILDS, John B. *London, S.W.19.*
CORBETT, Dennis J. *Evesham, Worcestershire.*
COULTER, John P. *Stanmore.*
CUMMINGS, Patrick D. *Staines.*
DANDO, Alan. *London, N.11.*
DAVIES, Peter. *Woomera, South Australia.*
*DEEKSHITULU, Sreekrishna Venkata Yagnanarayana Rayaprolu. *Agra Cantt, India.*
DORON, Itzhak. *Tel-Aviv.*
DUNN, Paul S. *London, S.E.27.*
EADS, Robert Dennis. *Corby, Northamptonshire.*
EVANS, John. *Morden, Surrey.*
FISHER, Vincent C. A. *Dartford, Kent.*
FLITCROFT, Frank Roger. *Malvern.*
FOORD, N. C. *Borough Green, Kent.*
FURDAL, Blarne O. *Bergen, Norway.*
GARRETT, Ronald A. *c/o G.P.O., London.*
GANGOLLI, Kishore N. *Bombay.*
GARNETT, John R. *B.F.P.O. 34.*
GHOSE, Saibal. *Bangalore.*
HAMPTON, Ronald H. *Hampton, Middlesex.*
HARRISON, Captain Albert John, R.Sigs. *Catterick Camp, Yorkshire.*
HARTLEY, Edward J. R. *Evesham, Worcs.*
HOPKINS, Terence Peter. *Wolverhampton.*
HINSON, Robin H. *Wells, Somerset.*
INGYON, David J. *Willington, Bedfordshire.*
KALYAN, Singh. *Kanpur, India.*
KAMAT, Vasant G. *Bombay.*
KERR, Donald. *Driffield, Yorkshire.*
LANDEN, Joseph, B.Sc. *Ramat Gan, Israel.*
LEE SENG KHOON. *Singapore.*
LOTSU, Emmanuel M. K. *Calne, Wiltshire.*
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MEADE, John J. *Ashford, Middlesex.*
MILES, David F. *Smethwick, Staffordshire.*
MONRO, Richard B. *Hemel Hempstead.*
MORRIS, Douglas H. *Bromley, Kent.*
MUNDAY, Charles L. *Sheffield.*
*NOAKES, Michael E. *Lasalle, Canada.*
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OKONYIA, Andrew. *Kaduna, Nigeria.*
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OSBORNE, Derek. *London, N.W.4.*
*PADMANABHAN, A. Chidambara I. *Madras.*
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ROGERS, Daniel R. *London, N.W.1.*
ROSS, Walter F. *Bolton, Lancashire.*
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SANSOM, Desmond J. *Salisbury, S. Rhodesia.*
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WHELAN, John. *Stevenage, Hertfordshire.*
WILLIAMS, Ernest. *Bolton, Lancashire.*
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ANDREWS, Donald Frank. *Gosport.*
ARMAN, David John. *Stevenage, Herts.*
BAGGOTT, S. E. *Cannock, Staffordshire.*
BAGULEY, James. *Hayes, Middlesex.*
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CUTLER, David S. *Leighton Buzzard, Beds.*
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EALES, Brian E. J. *Singapore.*
EASAW, George J. *Johore Bahru, Malaya.*
EZEH, Matthias I. E. *Lagos.*
GHALEIGH, Bhupinder S. *London, S.E.27.*
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GRIFFITHS, Roy Alan. *Smethwick, Staffs.*
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Reliability of Electronic Equipment †

A Report prepared by the Institution's Technical Committee. This report is in the nature of observations on the necessity and practice of introducing philosophical approaches into the subject of reliability of electronic equipment. The report was stimulated by comments made by Admiral of the Fleet the Rt. Hon. the Earl Mountbatten of Burma, K.G., in his Presidential Address in June 1961.

Summary: A selected list of references on the topic of electronic equipment reliability is prefaced by some precepts and observations on the philosophical and administrative approach to the subject.

1. Introduction

In the last decade very considerable efforts have been devoted to improving the reliability of electronic equipment and many papers and reports have been written dealing exhaustively with the theoretical and practical factors involved and describing in considerable detail the many investigational programmes conducted. This published material concerns itself almost exclusively with equipment intended for military use, but this in no way invalidates its application to electronics in general; indeed it confers the advantage of presenting the problem in one of its most rigorous and compelling aspects. These study programmes have also given information which has enabled improvements to be made which would otherwise have taken much longer.

The present contribution is based mainly on a belief that the available technological knowledge is, in many instances, inadequately supported by administrative and procedural practices. It is considered timely to attempt to redress this balance whilst at the same time including a selected list of references giving appropriate emphasis to the existing substantial and authoritative technological contributions on the subject.

Reliability must be considered at all stages from the conception to the use of the product but particularly in the design and utilization phases. In the design phase engineering technology predominates in conditions capable of direct engineering control. When, however, the project reaches the utilization phase engineering control lessens or ceases to exist and administrative procedures, notably feedback of fault incidence information, become of greater significance.

The achievement in the design phase of an acceptable level of reliability—whether specifically stated or not—is an essential part of the engineer's responsibility. Such "designed-in" reliability is the ideal at which to aim and a rapidly growing amount of technological and statistical knowledge is available. In appropriate cases it should also be the engineer's responsibility to devise a system of planned maintenance to be applied throughout the utilization phase—an essential to maintaining reliability which too often is ignored, overlooked or vetoed.

However, it would be wrong to assume that in all cases this " designed-in " reliability will be adequate in the presence of ever-changing techniques and applications. Some part of the total contribution to a project's ultimate reliability must be drawn from the utilization phase. It is in this context that it becomes especially necessary to maintain a lively awareness of the many problems besides the technological ones which must be met. Not the least is the unconstructive attitude so readily associated with failure investigation.

2. The Essential Concept

Reliability is, in essence, the achievement of a given safety margin under all conditions of specified operation and of equipment deterioration with life. The electronic engineer must decide on his own safety margins which are often determined by price or the penalty for failure, and in doing so he must encompass many aspects in his thinking. All the individual components must be capable of withstanding the environment or if they do not, the amount of isolation which they need to protect them from it must be calculated. With components of known tolerances and changes with working conditions, environment and time, a circuit must be produced which operates reliably, meeting the performance specification in all conditions. In equipment of any complexity it must be determined that all elements of the system will work together to achieve the desired overall reliability.

Reliability can be defined as "Freedom from failure" or "The probability of adequately performing a specified function or functions for a specified time under specified conditions". In this technical definition, the essential concept of reliability is the "probability of adequate performance". Thus reliability is a probability and must be a statistical concept. Reports of reliability measurement will therefore include or imply specific sample sizes, limits and sampling procedures.

† Approved for publication by the Council on 15th December 1961 (Report No. 24).

2.1. *Reliability is a Vital Factor*

The Radio and Electronic Engineer is concerned with equipment demanding a wide variety of performance characteristics, for example, picture and sound quality for domestic entertainment purposes, speed and accuracy for computers, and accuracy and lethality in guided weapons. Reliability must be considered as a vital factor in all equipment design no matter how complex or how simple it may be. Like so much in engineering, it is a compromise between the application, the environment and the cost. For instance, in domestic equipment a fine balance must be held between reliability and cost; in complex early-warning radars, reliability is worth almost any price.

2.2. *Reliability is not Basically a Specialization*

There is a growing tendency to introduce a " reliability engineer " into larger teams of engineers associated with more complex projects or organizations. While administratively sound where the situation demands a breakdown into smaller units of specialization, it would be deplorable for engineers generally to accept either consciously or subconsciously that reliability was not the very direct concern of each of them.

It is vitally necessary that any specialized reliability facility is regarded first, as a source of information, and secondly as a proving ground to verify that chosen techniques are compatible with the service required from the product: not as a facility provided to rectify the shortcomings of original design.

Any assumption that reliability can ensue only from the specialized efforts of engineers specifically appointed to hold responsibility for it, is a serious misconception. On the contrary, reliability involves all concerned with designing, constructing, operating and maintaining equipment together with their administrative associates. An acceptable standard of reliability will be reached only when all participants are collaborating fully and striving consciously to that end. Today the links between these various groups are often tenuous. In many cases practical circumstances make this inevitable, but in others only traditional divisions are responsible. The most obvious example is still to be found in the many instances where electronic and mechanical design activities have not yet been sufficiently integrated. No longer can mechanical design be considered a secondary facet of electronic engineering but its natural trend toward integration should be accelerated.

2.3. *Reliability is Needed in all Classes of Products*

The weight of effort which has been devoted exclusively to the reliability problem has been a natural consequence of equipment complexity combined with environmental severity. So much so in fact, that there is a danger that ordinary products may be regarded as not qualifying for any special attention. The consequences of unreliability are manifold in nature and importance; they affect products of all orders of complexity and for all purposes. The need for the means of attaining a standard of reliability appropriate to the intended application of the product should be a conscious regard of all concerned in the administration and engineering associated with the product's inception, irrespective of its technical complexity.

2.4. *Reliability is Essentially a Simple Concept*

It is unacceptable to present the fundamentally simple factors involved in reliability programmes and assessments in other than strictly simple and practical terms when these are intended for the widest assimilation. Statistical and mathematical tools are a means to an end; when a conclusion is reached every endeavour should be made to present it in a manner which is readily assimilated by all engineers, a vast number of whom are not implicated in a narrow reliability specialization or in highly complex electronic systems. An example of an attempt to state a result in a simple manner is—"these have completed an overall total of $137{\cdot}2{\cdot}7 \times 10^6$ component-hours operation, with a simple failure rate of 0·0087% per 1000 hours". An arithmetical conversion of the latter figures resolves the rate as one per 1313 years! A more practical presentation of the result would be achieved by adding, for example, that the result indicates that an equipment using a thousand of these components would average one failure per 16 months of operation.

3. The Need for Realistic Planning

The attainment of the fundamental ideals is often made more difficult by increased complexity of the product itself, the time available for its development, the circumstances of its application, and the personnel organization needed to initiate and support it. Solutions short of the ideal more often than not have to be applied. It has been stated that sufficient time is rarely allowed between the development of a product and its manufacture for adequate reliability evaluation and it was argued "that production be postponed until adequate engineering tests prove that the item in question fully meets the reliability requirements". As an ideal this is unchallengeable but it is at once apparent at the initiation of many projects that it is most unlikely to be attainable. A practical solution is for the engineer on whom responsibility rests to state at the outset the situation that is likely to develop and to insist that a tapered programme from nominal completion of engineering development to full scale and finalized production is instituted and implemented in the spirit as well as the letter. By enlisting the cooperation of those to whom the pre-production or early production models will be made available, the period prior to ultimate bulk production can be utilized not only for reliability evaluation conducted under simulated working conditions but for the embodiment of any modifications shown necessary by user experiences gained from these preliminary models.

It is common experience to find an apparently hard and fast line drawn between development and production. In a practical engineering sense this line is purely imaginary—an administrative convenience which too often becomes a real obstacle hampering the engineering approach to reliability. In so many actual cases the development process must inevitably continue beyond the time at which production commences; this needs wider recognition and an active rather than passive acceptance.

Underlying all the phases of an engineering programme should be a spirit of readiness to give immediate effect to changes dictated by user experience. A reliability evaluation programme carried out under simulated working conditions before the product is available to the ultimate user will not necessarily lead to complete freedom from the need for modifications after line production has commenced. The word "modifications" conjures up in the minds of many, and particularly those implicated in production management, a formidable and costly hiatus. In fact it often means no more than subtle changes of detail of no great practical embarrassment, a state of affairs which will obtain to an increasing extent as more attention is given to pre-production reliability evaluation.

4. Reliability and Failure Reporting

References to the "feedback" of information on failures in use have frequently been made in appraising the problem of reliability, but generally their character is little more than nominal.

It does not appear to have been said often enough with sufficient clarity and emphasis that a principal key to attaining an acceptable degree of reliability is accurate information from the ultimate user of equipment on the nature of and circumstances attending failures experienced by him. It is unfortunate that these users are often, for perfectly good reasons, either insufficiently rigorous or technically inadequate in their reporting. That the point is obvious and has indeed been taken care of in various ways, is not a sufficient reason for not referring to it here. The highest level of alertness is demanded in seeking and assessing reports of failures in use.

Evaluations of the reliability of specific equipment in its appropriate field of use have been made using procedures which in theory are acceptable but in practice can result in the acquisition of evidence which is not entirely true to the normal life history. To quote from one report of an evaluation programme on a U.S. military project—"The data collection phase at each site was initiated by a field team visit. Programme objectives were explained and instructions given to the operating and maintenance personnel relative to the method of reporting. The indoctrination phase consisted of the following elements: . . . " Perhaps the word "indoctrination" is an unhappy choice, but it is not inappropriate in the context of a carefully planned exercise to extract factors which can be assumed not to have been readily available otherwise. Further on in this same report "Data Processing" is explained, the first step in the process being "Technical editing to insure completeness and accuracy". Here again is disclosed a possible distortion of the true facts which can invalidate a final assessment. The point of these present observations is not to criticize the principles employed in set programmes for evaluating and improving reliability but to stress the need for a continuous awareness of the distortions and omissions which are inseparable from such specially conducted enquiries.

There is a mass of adverse experience which justifies drawing attention to the imperative need for the feedback channel to be kept as short, simple and direct as possible, and operated in a manner which provides a positive encouragement to use it. The latter is more likely to be achieved if each failure report is given a specific and direct response as early as practicable. The time interval between reporting a failure and receiving constructive comment or notice of action is inevitably variable, but every effort must be made to restrict it. Even if factors enforce a long delay, the reporter's confidence is maintained when he knows that the system is planned and practised always to provide a direct response. This confidence is essential to encourage accurate and speedy reports to be made in every instance of failure; the man in whose hands failure occurs must be made to realize that he is an active and essential part of a closed loop system, not an input to a one-way channel, and that the system is there to provide positive benefit to him. Lack of direct evidence that failure reports are receiving the attention they demand, leads most certainly to a lack of enthusiasm in utilizing the reporting channel. A tool of great potential for the improvement of reliability is thereby blunted before it is put to work.

Equipment of considerable technical complexity is often employed in quantity in widely dispersed areas. A proportionately large and dispersed administrative structure is inevitably associated with it. In these circumstances unwieldy and protracted failure investigating and correcting procedures only too readily develop. The prime essentials stand self-evident in relatively uncomplicated cases; as complexity increases so the clarity of these essentials tends to decrease and the greater opportunity afforded by a large dispersed structure for inconclusive or evasive action may obscure them still more. Therefore a high order of disciplined and responsible attention to the prime essentials becomes imperative.

In such complex and widespread cases the periodic distribution of a consolidated summary of defect incidents with their symptoms and remedies, is of the greatest value since the experiences of each reporting source are then available to all. Even in the case of the defect for which a proven remedy is not yet known there is considerable worth in such a summary. It must, of course, be revised and redistributed very frequently. A procedure of this character cannot be contemplated, of course, in other than a very large scale and solely professional operation throughout which there is a common purpose, as in the case of military equipment. Where these conditions do not exist, as in products intended for non-professional use, the methods of acquiring and processing failure information must vary in both nature and extent, but the fundamental principles are no different.

It is axiomatic that a defect investigating facility, whether formally constituted as such or not, must be exhaustive and searching in its methods and able not only to provide the information needed for immediate remedial action on particular defects, but also to draw valid conclusions from the volume of data it receives. It must also be capable of disseminating these conclusions so that reliability may be "designed in" when the next project is at an early stage of conception. The facility must continuously be inspired by a sense of urgency born of a recognition that the penalty of a failure increases with the time over which it remains unremedied.

5. Conclusion

Philosophical and administrative factors are of prime importance in both the design and utilization phases of a project; they require a specially attentive attitude by technical management which must remain conscious of the possibility that such factors can be obliterated by the volume of purely technological considerations.

Those who design and produce equipment must be prepared to welcome and heed conclusions and recommendations bearing on reliability in an atmosphere quite devoid of favour or recrimination. In this connection there is an undoubted need for a more open and forthright approach, within the professional circle, to those essentially human failings which do themselves largely contribute to the pattern of unreliability. Too often are there factors of an economic, competitive or merely aesthetic nature which conspire to delay the issue and obscure the facts.

Only by making the maximum use of every available piece of information on the mode of failure, may we hope to increase our knowledge of engineering for reliability. Unless we are successful in this, we shall, on the one hand, fail to provide the trouble-free products to which this technological age is entitled, and, on the other hand, find ourselves unable to produce the more complex systems that will be demanded in the future.

Unreliability of a product in use poses a pressing challenge. The apparent impossibility of an immediate and complete cure in some cases should enhance rather than lessen efforts to find partial remedies. It is better to achieve reliability by a series of small improvements at relatively short time intervals rather than by one improvement made only after a long, indeterminate period.

BIBLIOGRAPHY ON RELIABILITY

Foreword

The first reference is to the most extensive bibliography then prepared on the subject. For this and other reasons the subsequent references do not include papers published earlier than 1956.

ABBREVIATIONS AND CONTRACTIONS

Abbreviations used for the names of periodical and other publications are in accordance with the usual practice of the *Brit.I.R.E. Journal*, which is based on the principles laid down in the "World List of Scientific Periodicals" (1950 edition). To avoid lengthy repetitions for some frequently quoted sources, the following contractions have been adopted.

I.R.E. Wescon Conv. Rec. The Convention Record of the Wescon Convention of the Institute of Radio Engineers.

I.R.E. Conv. Rec. The Convention Record of the Institute of Radio Engineers (America), known as the "National Convention" to 1959 and the "International Convention" since 1960.

Trans.I.R.E., RQC — . . Transactions of the Institute of Radio Engineers Professional Group on Reliability and Quality Control. (Other I.R.E. Professional Groups are shown in similar form but with the names of the Group specifically stated.)

Proc. Nth N.S.R.Q.C. Proceedings of the Nth National Symposium on Reliability and Quality Control in Electronics. Sponsored by the Institute of Radio Engineers, the Electronic Industries Association, the American Institute of Electrical Engineers, and the American Society for Quality Control.

Note: I.R.E. publications may be obtained from the Institute at 1 East 79th Street, New York 21, U.S.A.

Proc. N.E.C. Proceedings of the National Electronics Conference. Sponsored by the American Institute of Electrical Engineers and various American technical bodies. Obtainable from National Electronics Conference, 228 N. La Salle, Chicago, Ill., U.S.A.

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I. Specifications, Standards and Guides

Note: The "AGREE" Report (ref. no. B3) initiated many U.S. Government documents devised specifically to govern or influence the reliability of military electronic components and equipment. The following is a selection from those of most general interest and significance.

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New Cables in the North Atlantic

Two new telephone cables have just been laid in the North Atlantic; the first, CANTAT, is from Great Britain to Canada and the second, SCOTICE, is from Scotland to Iceland.

CANTAT, the first telephone cable to link Britain with Canada direct, is also the first stage of a telephone cable system linking the Commonwealth countries. The second stage, COMPAC, will run from Vancouver via Hawaii to New Zealand and Australia, and will be followed by a cable to New Guinea, Singapore and Hong Kong.

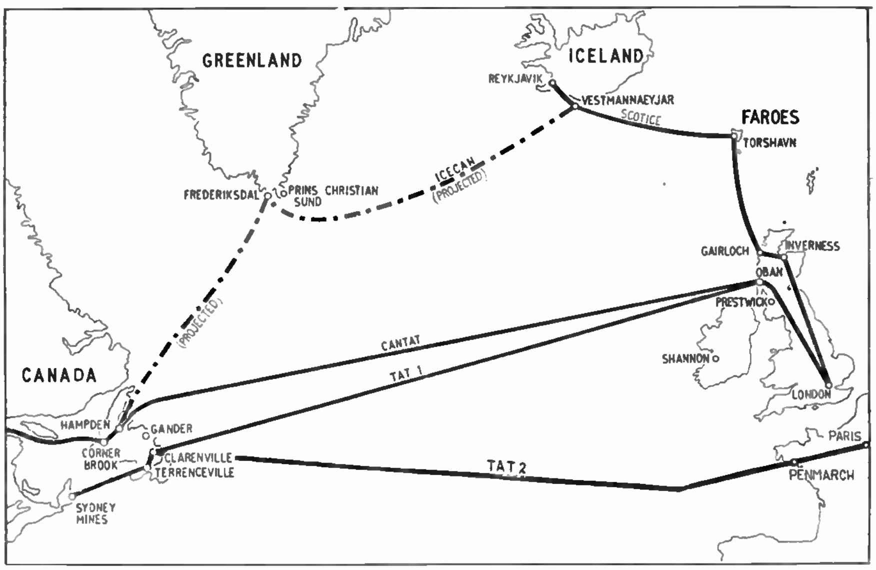
The first transatlantic telephone cable, TAT-1† laid jointly by the British Post Office, the American Telephone and Telegraph Company and the Canadian Overseas Telecommunication Corporation, employed two separate one-way cables each with fifty-one repeaters. The second cable TAT-2, opened in 1959 was a direct repeat of the TAT-1 design and was a joint undertaking by American, French and German telecommunications interests.

CANTAT is thus the third transatlantic cable and crosses from Oban, Scotland, to Hampden on the north coast of Newfoundland. Except for the shore ends, this section covering 2000 nautical miles consists of a new lightweight coaxial cable. Previous cables depended on external armouring for their strength and protection, but it was found that in deep water this is not necessary. From Hampden CANTAT continues across Newfoundland for seventy miles and the mainland is reached by a further 440 nautical miles of submarine cable from Corner Brook to Grosses Roches. The Oban to Corner Brook section provides sixty telephone circuits at 4 kc/s spacing in the 60–108 kc/s group bands, which can be adapted to eighty circuits with 3 kc/s spacing if the need arises. This section has ninety two-way repeaters and eight equalizers. The portion of cable from Corner Brook to Grosses Roches provides for ten 60–108 kc/s groups in both directions and with 4 kc/s spacing gives 120 circuits. This system is equipped with twenty repeaters and three equalizers, two of which are incorporated with repeaters.

The cable has a coaxial structure comprising a solid copper inner conductor of external diameter of 0·26 in with polythene insulation extruded on to it; the outer conductor consists of a layer of six annealed copper tapes uniformly applied over the polythene. High-tensile steel armouring is used throughout.

SCOTICE, which was completed in December 1961, is the first half of a system intended primarily to provide reliable speech and telegraph communication between air traffic controllers covering the North Atlantic. It runs from Gairloch, Scotland, to Torshavn in the Faroes and thence to Vestmannseyjar in Iceland a distance of 700 nautical miles. To complete the system a further section of cable, ICECAN, is to be laid from Iceland to Greenland and thence to Canada. These cables fulfil the requirements of the International Civil Aeronautical Organization (I.C.A.O.) and will supply air traffic controllers at Shannon, Prestwick, Reykjavik, Prins Christian Sund, and Gander with information concerning weather conditions and aircraft movements. SCOTICE, which is made of similar cable to that used in CANTAT, has twenty telephone circuits and possesses fifteen repeaters in the section between Iceland and the Faroes and ten more in that between the Faroes and Scotland.

† See "Inauguration of Trans-Atlantic telephone cable system". *J.Brit.I.R.E.*, 16, p. 632, November 1956.



The North Atlantic telephone cable system.

U.D.C. 621.397.132

A Constant Luminance Colour Television System

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Summary: A colour television signal employing three basic components $E_Y^{1/\gamma}$, $(E_R^{1/\gamma}-E_Y^{1/\gamma})$ and $(E_B^{1/\gamma}-E_Y^{1/\gamma})$ is proposed for use in N.T.S.C. and SECAM type systems. It is shown that this leads to certain improvements both in the quantity and quality of the transmitted information. Methods of receiving such a signal are described and it is concluded that theoretical considerations of the system have reached such a stage that experimental work would be both desirable and justified.

1. Introduction

The necessity for gamma correction in colour television has resulted in a departure from the constant luminance principle in the N.T.S.C. system, and leads in a colour receiver to (*a*) loss of luminance detail in saturated colours, and (*b*) an increased susceptibility to noise and cross colour in saturated colours. In a monochrome receiver a reduction of luminance occurs in all areas of high saturation.

In addition, since the monochrome signal is normally produced by matrixing the outputs from three pick-up tubes (red, green and blue) the definition is usually degraded compared with the output from a single tube as, for example, where the taking characteristic is of the form

$$Y = 0{\cdot}3\,R+0{\cdot}59\,G+0{\cdot}11\,B.$$

Various proposals have been made to eradicate these defects. A comprehensive list of references is given by Richman.[1] However, there still appears to be room for improvement and in what follows, transmission signals which may be preferable to those specified by the N.T.S.C. are proposed. It will be apparent that these signals can be employed in other transmission systems such as the SECAM system.

2. The Luminance Signal

2.1. *Formulation of the Luminance Signal*

The luminance of a subject is measured by the C.I.E. tristimulus value Y, which can be expressed in terms of the red, green and blue primaries specified by the N.T.S.C. as

$$Y = 0{\cdot}3\,R+0{\cdot}59\,G+0{\cdot}11\,B \qquad \ldots\ldots(1)$$

The colour camera analyses the incoming light and produces electrical signals E_R, E_G, E_B. If it is assumed that the electrical signals are proportional to the light then the luminance signal is

$$E_Y = 0{\cdot}3\,E_R+0{\cdot}59\,E_G+0{\cdot}11\,E_B \qquad \ldots\ldots(2)$$

Since in present day display devices (light produced) is proportional to (voltage drive)$^\gamma$, pre-correction of the signals listed above is necessary to ensure that the light in the reproduction is proportional to the light in the original scene. Thus the luminance signal suitable for application to the receiver is

$$(E_Y)^{1/\gamma} = (0{\cdot}3\,E_R+0{\cdot}59\,E_G+0{\cdot}11\,E_B)^{1/\gamma} \qquad \ldots\ldots(3)$$

However in the N.T.S.C. system the monochrome signal has been formulated as

$$E'_Y = 0{\cdot}3\,E_R^{1/\gamma}+0{\cdot}59\,E_G^{1/\gamma}+0{\cdot}11\,E_B^{1/\gamma} \qquad \ldots\ldots(4)$$

This is obviously not the same as the true luminance signal.

2.2. *Monochrome Luminance Fidelity and its Interpretation*[2]

2.2.1. Definition of monochrome luminance fidelity F_M

A measure of the luminance information carried by the monochrome signal is the monochrome luminance fidelity F_M defined as:

$$\frac{\text{luminance reproduced on a monochrome receiver}}{\text{luminance in the original scene}}$$

F_M should ideally be unity and this is the case if the monochrome signal is $(E_Y)^{1/\gamma}$. In the N.T.S.C. system, however,

$$F_M = \frac{(E'_Y)^\gamma}{E_Y} \qquad \ldots\ldots(5)$$

The value of this expression changes from colour to colour and its variation over the chromaticity diagram is shown in Fig. 1 for $\gamma = 2{\cdot}2$.

2.2.2. Interpretation of F_M assuming an idealized, perfectly registered camera

Figure 1 shows that for saturated colours, the luminance is very much smaller than it should be.

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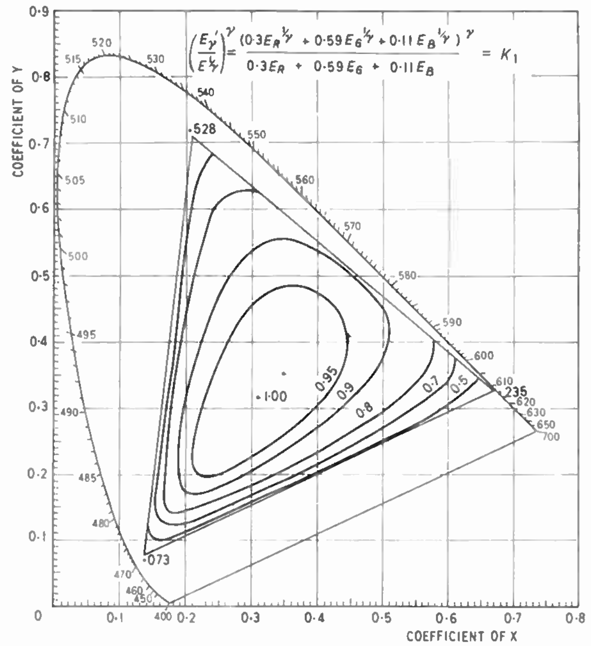

Fig. 1. Constant luminance index K_1 and monochrome luminance fidelity F_M for the N.T.S.C. system.

For example, for a saturated blue signal the reproduced luminance is only one-fourteenth of the original luminance and for saturated red, the reproduced luminance is only one-fourth of its correct value. This means, that not only does the monochrome picture have luminance errors compared with the original scene, but also since resolution is the rate of change of contrast the detail resolution for saturated colours is very low. In Fig. 1 colours located outside of the locus 0·7 are subject to 3 dB or more reduction in luminance compared with their correct value. These colours include signal red, peony red, claret, magenta, fuchsia, petunia, royal purple, violet, empire blue, smalt, spectrum blue, ultramarine, kingfisher blue and peacock green. It will be noticed that the majority of these colours occur along the blue/red part of the colour triangle and quite a number are the colours of common flowers. Now most of these colours are of relatively low luminance and it seems a great pity that colours that are already lacking in brightness should also be produced with even less brightness and definition than they need.

Addition of the subcarrier dots to the monochrome signal produces a partial correction for this luminance error by self-rectification in the cathode ray tube. However, this does not correct for the missing high-frequency information, as can be seen by considering the transmission of a standard black-and-white test chart. If the test chart is illuminated in the normal manner by a white light, then the reproduced test chart on a monochrome receiver in the absence of registration errors in the transmitting equipment is very good, from the point of view of definition. However, if the test chart is illuminated now by a saturated blue illuminant, as for example, by placing a Wratten filter No. 47 between the lamp and the test chart, it will be found that in this case, the luminance reproduced using an N.T.S.C. transmission would be less than 10% of its true value and, in fact, would be practically invisible since the actual value is only about 1% of peak white luminance. The addition of a rectified dot pattern would add no high-frequency intelligence to the picture.

It should be noted that not only is horizontal definition lost but so also is vertical definition. The maintenance of good vertical resolution, which unlike horizontal resolution does not depend on bandwidth, is very important especially for transmission through long relay links, through magnetic tape recordings and through system converters.

2.2.3. Luminance reproduction assuming a practical camera

A practical camera suffers from a defect caused by the problem of beam bending in low velocity pick-up tubes, such as the image orthicon.[3] It is well known that in such pick-up tubes the beam approaching the target in the pick-up tube can be deflected or bent by as much as several picture elements from its true landing position due to the charge pattern on the mosaic representing picture information. In the case of grey scale signals where the three tubes red, green and blue have substantially identical charge patterns, although beam bending may take place it is the same in all three pick-up tubes, and therefore it is theoretically possible to register the camera for a grey scale test chart. However, for saturated colours where one has, perhaps, a different charge pattern on one tube from another, there will be relative differences in the beam bending in the tubes causing time differences between the outputs and therefore the signals making up the gamma-corrected luminance signal will not be completely registered. Thus, when the three signals, red, green and blue are added together to form the luminance signal, the definition will be lower than it should be. In the case of the colour receiver, this will show itself not only as a reduced horizontal definition but also as a reduced vertical definition, particularly since the beam bending effect is normally worse in the vertical direction. In the case of monochrome reception, the definition will also be reduced in the vertical and horizontal directions. For saturated colour transitions, the only way of eliminating this effect is to obtain the luminance signal from one pick-up tube only, instead of matrixing the outputs from three pick-up tubes. Unfortunately, because in the N.T.S.C. system the luminance signal is formed as the sum of the gamma-corrected primary signals, it is not possible to derive it from a single pick-up tube. This problem can be solved if the true luminance signal $E_Y^{1/\gamma}$ is specified since it is more flexible than the E_Y' signal of the N.T.S.C. system. Thus, it is possible to obtain the luminance signal either from one tube or from two or more tubes by matrixing, if required.

2.3. *Constant Luminance Operation*

2.3.1. The constant luminance principle and index

The constant luminance principle implies that in a band-shared colour television system it is desirable that all the luminance information in a televised scene should travel through the wide-band luminance channel, and that the narrow-band chrominance channel should only contain chrominance information.[2] Some of the advantages of adherence to this principle are as follows.

(1) High frequency interference, such as oscillator radiation from other receivers, or co-channel interference is less visible.

(2) Noise present in the chrominance channel is less visible.

(3) Cross-talk of high-frequency luminance components into the chrominance channel (cross-colour) is less noticeable, resulting in less "shimmer".

(4) In the RYB camera (see section 3.3), as the luminance signal is independent of registration of the three pick-up devices, misregistration can only produce signals in the chrominance channel and since the eye is less sensitive to chromaticity changes than it is to luminance changes, errors in registration are less objectionable.

The degree of adherence to the constant luminance principle is measured by the constant luminance index, which is defined as the ratio of the portion of the reproduced luminance on a colour receiver due to the monochrome signal to the total reproduced luminance, due to both the monochrome and colour difference signals.

In the N.T.S.C. system the constant luminance index K_1 is equal to the monochrome luminance fidelity F_M and so both parameters are shown in Fig. 1.

2.3.2. Interpretation of K_1 assuming an idealized, perfectly-registered camera and colour receiver

For the grey scale test chart with a white light source the definition is a maximum and is equivalent to that on a monochrome receiver. For a saturated blue test chart the luminance is correct for low-frequencies (up to approximately $\frac{1}{2}$ Mc/s) and therefore the vertical definition is correct, but the horizontal definition is limited to approximately $\frac{1}{2}$ Mc/s. The fine detail definition is therefore only transmitted in the vertical direction.

2.3.3. Interpretation of K_1 assuming a practical camera and a perfectly registered colour receiver

As mentioned in the case of a monochrome receiver, beam bending effects will reduce the definition of the monochrome signal for rapid transitions from one primary colour to another (additive and/or subtractive). In general, this will be worse in the vertical direction, where preferably it should be better.

Misregistration of R, G and B signals will also degrade the definition of the luminance signal for all colours—including the grey scale—both in the horizontal and vertical directions.

2.4. *Conclusion on Luminance Signal*

It is concluded therefore that the luminance (or monochrome) signal should be specified as a true luminance signal $E_Y^{1/\gamma}$.

The original colour gamut specified by the N.T.S.C. primaries was chosen to cover a considerable range based on data provided by Wintringham about 10 years ago. Since then, developments in printing inks, dyes and other colouring media have improved them, and colours covering an even greater range will, no doubt, become available in the future. Many colours occurring in natural scenes, too, are of a high saturation as mentioned in Section 2.2.2. Thus the gamut of constant luminance should cover as wide an area of the colour triangle as possible. Since saturated colours are almost invariably of relatively low luminance (the main exceptions are yellows and cyans) any degradation in luminance is to be deplored.

The maintenance of the highest possible definition in a system will become of greater importance as transmitting and receiving equipment improves, and this will apply particularly with large-screen colour displays, which are now becoming popular with the ever-growing applications of closed-circuit colour television.

3. Transmission of the Constant Luminance Signal

3.1. *The Colour Difference Signals*

In the N.T.S.C. system the colour difference signals $(E_R^{1/\gamma}-E_Y')$ and $(E_B^{1/\gamma}-E_Y')$ are used to form the chrominance signal. Since in a true constant luminance system the luminance signal is $E_Y^{1/\gamma}$ it is expedient to form the chrominance signal for such a system from $(E_R^{1/\gamma}-E_Y^{1/\gamma})$ and $(E_B^{1/\gamma}-E_Y^{1/\gamma})$.

3.2. *The Transmitted Signal*

The transmitted signal contains a luminance signal $E_Y^{1/\gamma}$ and two colour difference signals $(E_R^{1/\gamma}-E_Y^{1/\gamma})$

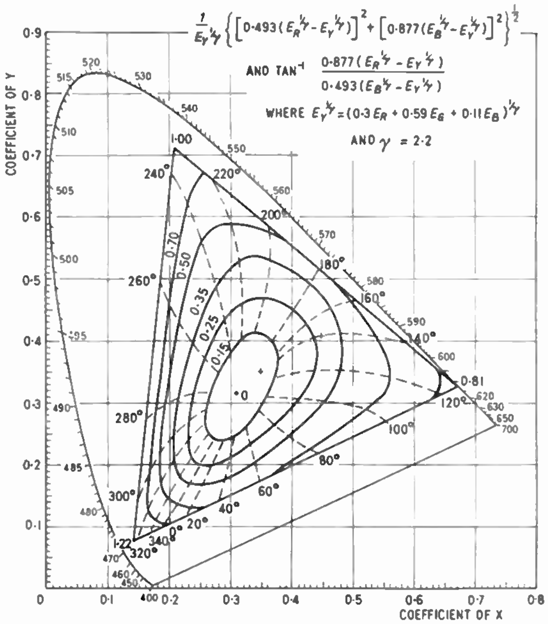

Fig. 2. Loci of constant colour-carrier phase and amplitude per unit luminance for the constant luminance transmission.

and $(E_B^{1/\gamma} - E_Y^{1/\gamma})$. If the colour difference signals are proportioned to form the chrominance signal as in the N.T.S.C. system, then the total signal is

$$E_M = E_Y^{1/\gamma} + \frac{E_B^{1/\gamma} - E_Y^{1/\gamma}}{2{\cdot}03} \sin \omega_c t + \frac{E_R^{1/\gamma} - E_Y^{1/\gamma}}{1{\cdot}14} \cos \omega_c t \qquad \ldots\ldots(6)$$

The subcarrier amplitude per unit luminance and phase have been plotted in Fig. 2.

The signals formed when 100% and 75% saturation

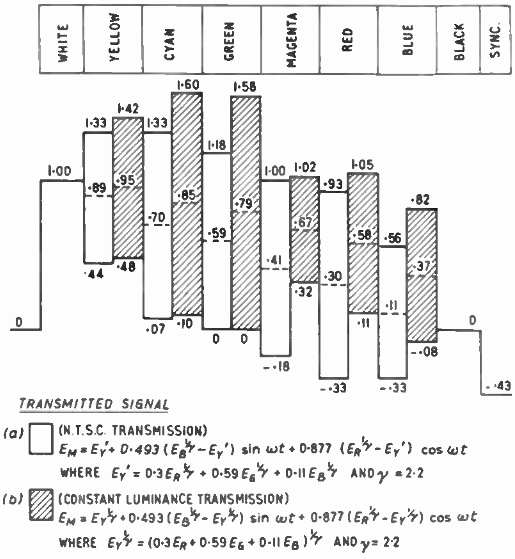

Fig. 3. Colour bars for 100% saturation colours.

colour bars of 100% luminance are televised are shown in Figs. 3 and 4, side-by-side with N.T.S.C. colour bars.

It can be seen that the 100% saturated colour bars produce a signal which overloads the transmitter significantly more than the N.T.S.C. bars, but this is not true for the 75% bars. Although it is possible to reduce the overloads by suitably adjusting the coefficients of the colour difference signals in the expression for the subcarrier, this is probably unnecessary because high-luminance fully-saturated colours rarely occur and so the ability to reproduce them accurately is not of major importance. However, it is possible that some modification of the coefficients may be beneficial.

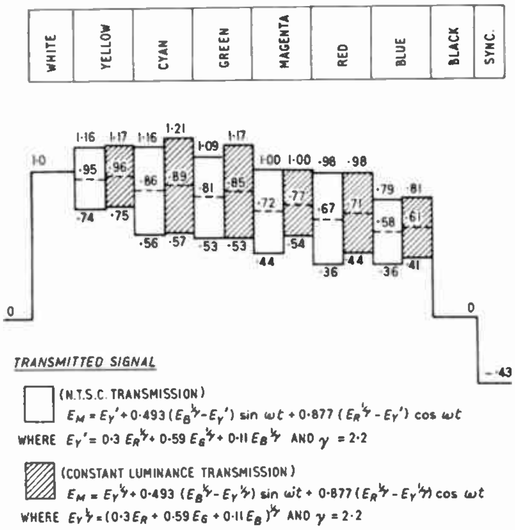

Fig. 4. Colour bars for 75% saturation colours.

3.3. *General Comments on Transmission*

3.3.1. Type of camera

There are two main types of camera which may be used with this system, namely, those in which the three pick-up tubes produce respectively R, G and B signals, and those in which the signals produced by the three tubes are R, Y and B (cameras using other primaries such as X, Y, Z are not considered here). There are also two classes of pick-up tube commonly in use—those with linear light input-signal output characteristics and those with non-linear characteristics. In the former category is the image-orthicon and in the latter category is the vidicon. In the case of flying-spot slide and film scanners the transducers are linear. It is instructive to consider the signal processing required with the four main alternative signal sources and the block diagrams Figs. 5 and 6, which are self-explanatory, illustrate the relative complexity of the different arrangements.

3.3.2. Resolution

Since the luminance signal is derived from only one pick-up device in the RYB camera, it is apparent that the luminance definition is considerably better than that obtainable by matrixing the outputs of three separate devices. In fact, it should only be worse than that of the standard monochrome camera because of the more complex optical system necessary for colour. Not only will the definition be better in the horizontal direction but also, and probably more important, in the vertical direction as already outlined. Aperture correction of the luminance can be applied more effectively to the output from a single tube especially in the vertical direction by means described in ref. 4. Horizontal aperture correction can be applied in the normal manner by means of a phase-corrected high-frequency boost or by "crispening" methods.

It should be noted that accurate registration of the three pick-up devices in the RYB camera is still necessary if the *colour* signal is to be registered adequately.

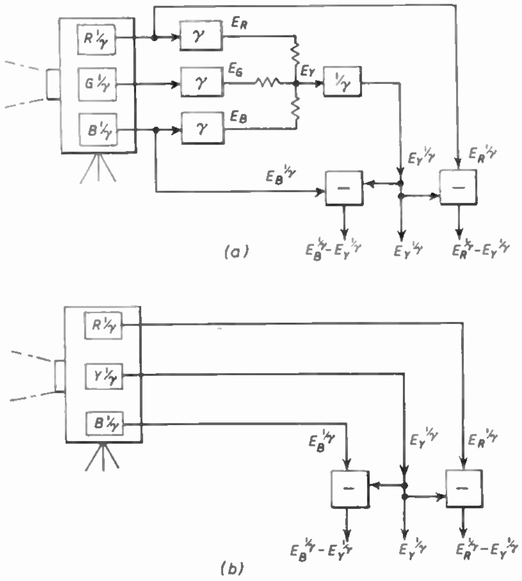

Fig. 6. (*a*) "RGB" camera using self-gamma tubes (e.g. Vidicon). (*b*) "RYB" camera using self-gamma tubes.

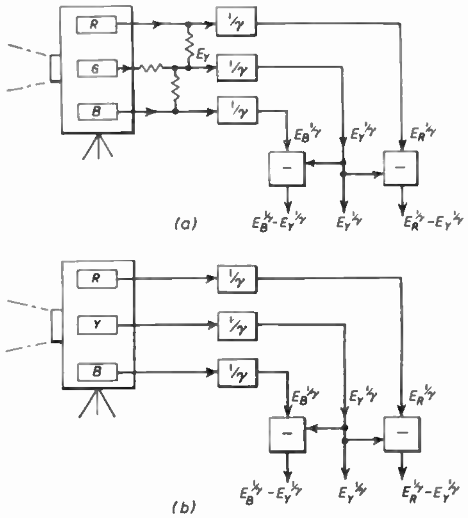

Fig. 5. (*a*) "RGB" camera using linear-gamma tubes (e.g. C.P.S. Emitron, image orthicon or flying-spot telecine).
(*b*) "RYB" camera using linear-gamma tubes.

3.3.3. Signal-to-noise considerations

The signal/noise ratio of the luminance signal at the transmitting end needs consideration and the analysis given in Appendix 1 applies to the vidicon tube camera. From this analysis it appears that the signal/noise ratio is 3·5 dB better with E'_Y than with $E_Y^{1/\gamma}$ derived from a single tube. This figure is applicable to grey scale and diminishes with saturation according to the factor $(K_1)^{1/\gamma}$ which is plotted in Fig. 7. When $E_Y^{1/\gamma}$ is derived by matrixing, the expression is more complicated and a general conclusion is more difficult to reach. For grey scale, however, the signal/noise ratio is the same as for E'_Y.

The analysis does not take into account noise introduced subsequently to transmission. However, this is believed to be on average better than with the N.T.S.C. system.

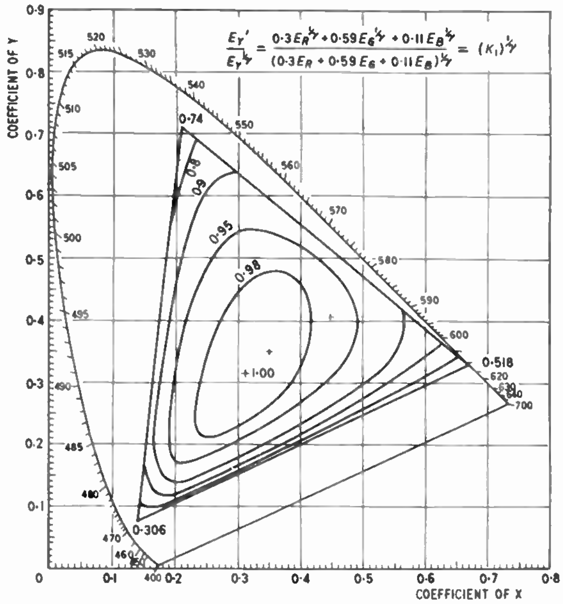

Fig. 7. Map of $(K_1)^{1/\gamma}$.

3.3.4. Shading

It is anticipated that colour shading errors will be rather more critical with this system, since, whereas the RGB system is symmetrical in form, the RYB system is not. This can be seen by examining the matrix equation required for obtaining the green signal

$$G = 1{\cdot}7Y - 0{\cdot}51R - 0{\cdot}19B \qquad \ldots\ldots(7)$$

As an example, assume a white picture is being transmitted, that is $R=G=B=1$. If the R and B tubes are free of shading but the G tube has a $+2\%$ shading error, then in the RGB system $R = B = 1$, and $G = 1{\cdot}02$. With the G tube used for Y in the RYB camera, $R = B = 1$, but $G = 1{\cdot}034$.

Considerable thought has been given to the problems of automatic shading correction of television pictures[5] and it is suggested that the time has arrived when apparatus for eliminating such errors should be standard equipment in television broadcasting. Such equipment will not only produce better pictures but will eliminate the plethora of shading controls and the time and labour involved in their adjustment.

4. Reception of the Constant Luminance Signal

4.1. *Ideal Receivers*

A receiver having circuits suitable for decoding the constant luminance signal is shown in block form in Fig. 8, and a possible realization of the non-linear circuits is shown in Fig. 9. The matrixing equations involved and the resultant constant luminance operation are described in Appendix 2. Perfect colour and luminance fidelity within the colour triangle specified by the receiver primaries is achieved with the ideal receiver. This ignores minor distortions due to other effects such as vestigial sideband detection, etc., to which the N.T.S.C. system is also subject.

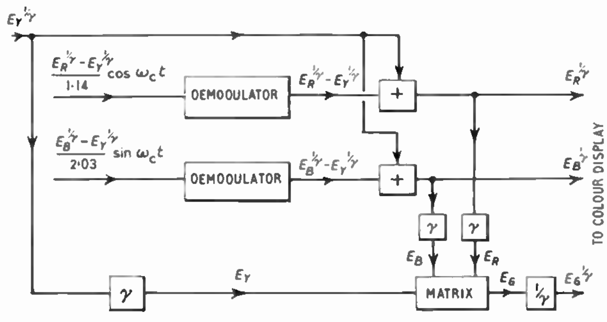

Fig. 8. Ideal decoder for constant luminance system.

Although the decoding circuits are relatively complicated, it is felt that there are many applications where correct constant luminance decoding will be worthwhile, although economic considerations may not justify this for normal broadcast reception.

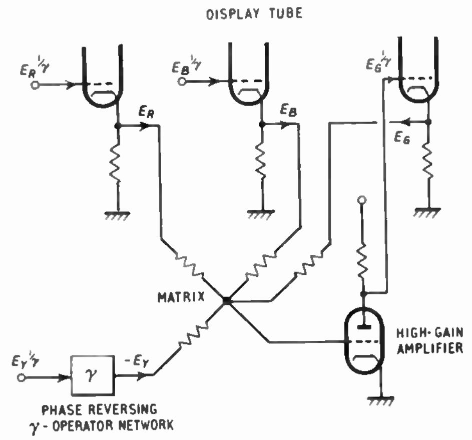

Fig. 9. Non-linear circuit for decoding a constant luminance signal.

4.2. *Linear Receiver of N.T.S.C. Type*

As shown in Appendix 3, a linear receiver will decode the constant luminance signal erroneously. The errors occur in the decoded green signal which is larger than it should be. The chromaticity and luminance errors resulting from such decoding are shown in Fig. 10. These errors are mostly small except in the region of saturated colours where they become serious. The constant luminance index K_2 for this type of operation is shown in Fig. 11 and should be compared with the N.T.S.C. constant luminance index K_1 as shown in Fig. 1.

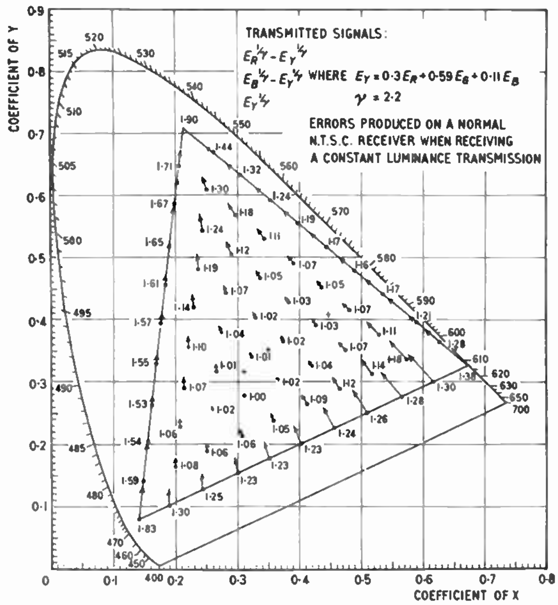

Fig. 10. Chromaticity and luminance errors resulting from incorrect decoding of constant luminance signal in linear receiver. Arrows indicate the change in chromaticity of colours defined by dots, the numbers against dots are ratios of reproduced to original luminance.

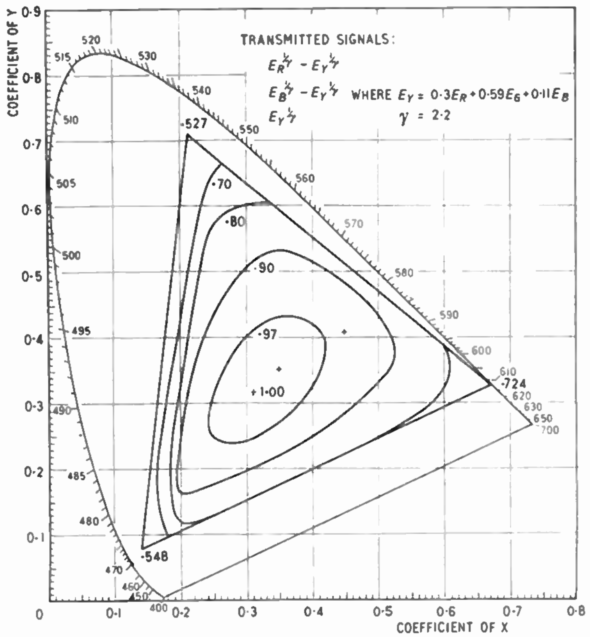

Fig. 11. Constant luminance index K_2 resulting from the reception of a constant luminance transmission on a normal N.T.S.C. receiver.

The chromaticity errors in the region of saturated red and blue are of the order of 70 MacAdam σ units which is probably more than can be tolerated. Simple methods of correcting these errors are therefore sought and one such method will be described.

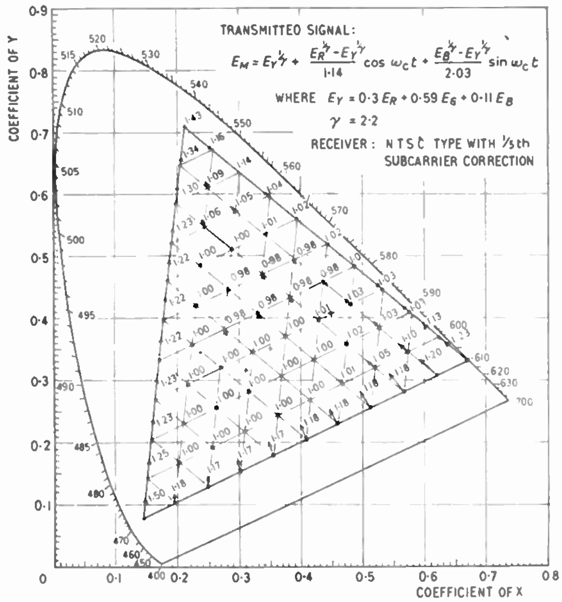

Fig. 12. Reduced errors in chromaticity and luminance by using one-fifth of subcarrier amplitude as correcting signal. Arrows indicate the change in chromaticity of colours defined by dots, the numbers against dots are ratios of reproduced to original luminance.

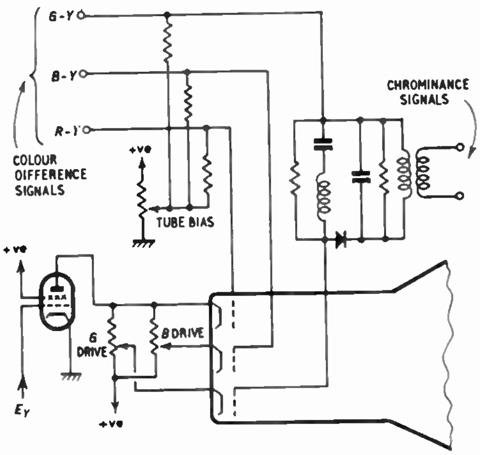

Fig. 13. Green signal correction circuit.

4.3. *Corrected Linear Receiver*

Appendix 4 shows that if a fraction of the rectified subcarrier amplitude is subtracted from the erroneous green signal a closer approximation to $E_G^{1/\gamma}$ is obtained. The reduced errors are shown in Fig. 12 using one-fifth of the subcarrier amplitude as the correcting signal. A circuit for this type of correction is shown in Fig. 13. The chromaticity errors in the red and blue regions are now of the order of 40 MacAdam σ units. These errors will probably be acceptable, especially since they decrease rapidly away from the edges of the colour triangle.

4.4. *Single Gun Tubes*

The constant luminance signal described is also applicable to single-gun tubes. If the received signals are converted into simultaneous red, green and blue signals before application to the display, then non-linear decoding can be used to give substantially correct luminance and chromatic reproduction. The approximate correction described above can also be

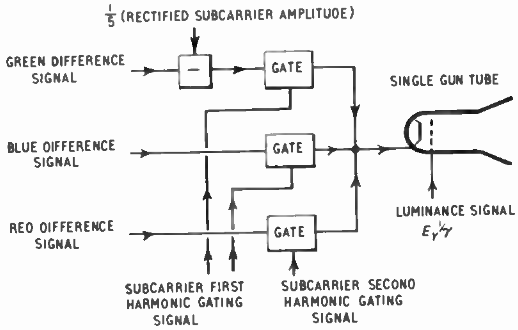

Fig. 14. Schematic of a single gun receiver with gated colour-difference signals.

applied to this type of receiver, and a suitable circuit for use with a chromatron tube[6] is shown in Fig. 14 in block form. Here the red, green and blue colour-difference signals are obtained by synchronous decoding. The green colour-difference signal is incorrect and is approximately corrected as described in the foregoing section. The three colour-difference signals are then applied to the three gates and then to the chromatron tube. This is a horizontal stripe tube and the electron beam is sinusoidally switched to follow the colour sequence GR BR GR BR etc. In this sequence R occurs twice as frequently as G and B and so the gating circuits, too, must gate $R-Y$ twice as often as $G-Y$ and $B-Y$. Hence a first-harmonic gating signal is used in the Green and Blue gates and a second-harmonic signal in the Red gate.

The possibility of applying the constant luminance signal to a self-decoding type of single-gun receiver has not yet been fully investigated.

5. Conclusion

In formulating the N.T.S.C. monochrome signal E'_Y, a certain quantity of information is rejected. This information is permanently lost and cannot be recovered at the receiver. The loss can be avoided if E'_Y is replaced by $E_Y^{1/\gamma}$ but in order to make use of the extra information a more complicated, non-linear receiver is needed.

From a purely scientific standpoint, the transmission employing $E_Y^{1/\gamma}$ is obviously preferable. That standpoint, however, is not always a permitted one and economic considerations make it necessary to weigh any advantages gained against the costs involved. Because of this, there is a need for experimental work on the system and subjective tests would almost certainly be necessary.

At the moment no decision has been made concerning colour television standards in Europe, and, therefore, we should make the most of up-to-date developments so that we adopt the best system possible. We should make very certain that we do not saddle ourselves with a system losing much of its appeal to viewers because of its inferior resolution.

6. Acknowledgments

A number of contributions by various authors on the above system have been considered by the Television Advisory Committee Technical Sub-Committee Ad Hoc Working Party on Constant Luminance, and the helpful criticisms and discussions arising therefrom are gratefully acknowledged.

The authors wish to thank Dr. L. F. Broadway, Head of Research Laboratories, E.M.I. Ltd., for encouragement and permission to publish the paper.

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8. Appendix 1: Signal-to-Noise Considerations for a Vidicon Camera

The signal/noise ratio for head amplifier noise in the luminance signal only will be evaluated.

8.1. *Derivation of Signal/Noise Ratios*

Assume that each pick-up tube gives a gamma-corrected output with equal noise voltages E_N and consider the following cases:

(*a*) RYB camera as in Fig. 6 (*b*) ($E_Y^{1/\gamma}$ obtained directly): the output of the luminance channel is $E_Y^{1/\gamma}+E_N$ and so the signal/noise ratio is

$$\left(\frac{S}{N}\right)_1 = \frac{E_Y^{1/\gamma}}{E_N} \qquad \ldots\ldots(8)$$

With a vidicon camera generating a peak-white signal of 0·25 microamps, $(S/N)_1$ will typically be better than 40 dB with a 5 Mc/s bandwidth.

(*b*) RGB camera as in Fig 6 (*a*) ($E_Y^{1/\gamma}$ obtained by matrixing): the outputs from the head amplifiers of the pick-up tubes are

$$E_R^{1/\gamma}+E_N$$
$$E_G^{1/\gamma}+E_N$$
$$E_B^{1/\gamma}+E_N$$

To obtain the luminance signal these outputs are first raised to the power γ (see Fig. 6 (*a*)) giving

$$(E_R^{1/\gamma}+E_N)^\gamma \simeq E_R + \frac{E_R}{E_R^{1/\gamma}}E_N$$

$$(E_G^{1/\gamma}+E_N)^\gamma \simeq E_G + \frac{E_G}{E_G^{1/\gamma}}E_N$$

$$(E_B^{1/\gamma}+E_N)^\gamma \simeq E_B + \frac{E_B}{E_B^{1/\gamma}}E_N$$

provided the wanted signals (E_R, E_G, E_B) are greater than E_N.

These are then added in the proportions 0·3, 0·59, 0·11; and remembering that the resulting noise voltage is the r.m.s. of the input noise voltages, we obtain

$$0{\cdot}3\,E_R+0{\cdot}59\,E_G+0{\cdot}11\,E_B+E_N\sqrt{\left(0{\cdot}3\frac{E_R}{E_R^{1/\gamma}}\right)^2+\left(0{\cdot}59\frac{E_G}{E_G^{1/\gamma}}\right)^2+\left(0{\cdot}11\frac{E_B}{E_B^{1/\gamma}}\right)^2}$$

$$=E_Y+E_N\sqrt{\left(0{\cdot}3\frac{E_R}{E_R^{1/\gamma}}\right)^2+\left(0{\cdot}59\frac{E_G}{E_G^{1/\gamma}}\right)^2+\left(0{\cdot}11\frac{E_B}{E_B^{1/\gamma}}\right)^2}$$

which is then γ-corrected for transmission so that the output is approximately

$$E_Y^{1/\gamma}+\frac{E_Y^{1/\gamma}}{E_Y}E_N\sqrt{\left(0{\cdot}3\frac{E_R}{E_R^{1/\gamma}}\right)^2+\left(0{\cdot}59\frac{E_G}{E_G^{1/\gamma}}\right)^2+\left(0{\cdot}11\frac{E_B}{E_B^{1/\gamma}}\right)^2}$$

if we assume that E_Y is greater than the noise voltage. The signal/noise ratio is then

$$\left(\frac{S}{N}\right)_2=\frac{E_Y}{E_N\sqrt{\left(0{\cdot}3\frac{E_R}{E_R^{1/\gamma}}\right)^2+\left(0{\cdot}59\frac{E_G}{E_G^{1/\gamma}}\right)^2+\left(0{\cdot}11\frac{E_B}{E_B^{1/\gamma}}\right)^2}} \qquad \text{......(9)}$$

(c) RGB camera as used in the N.T.S.C. system (E_Y' obtained by matrixing): here again the outputs of the pick-up tube head amplifiers are

$$E_R^{1/\gamma}+E_N$$
$$E_G^{1/\gamma}+E_N$$
$$E_B^{1/\gamma}+E_N$$

and these are added in the proportions 0·3, 0·59, 0·11 to give

$$0{\cdot}3\,E_R^{1/\gamma}+0{\cdot}59\,E_G^{1/\gamma}+0{\cdot}11\,E_B^{1/\gamma}+ +E_N\sqrt{(0{\cdot}3)^2+(0{\cdot}59)^2+(0{\cdot}11)^2}=E_Y'+E_N/1{\cdot}5$$

Hence the signal/noise ratio is

$$\left(\frac{S}{N}\right)_3=1{\cdot}5\frac{E_Y'}{E_N} \qquad \text{......(10)}$$

8.2. *Comparison of Signal/Noise Ratios*

(a) Signal/noise of $E_Y'/E_Y^{1/\gamma}$ direct

$$_3\left(\frac{S}{N}\right)_1=\left(\frac{S}{N}\right)_3\times\left(\frac{N}{S}\right)_1=1{\cdot}5\frac{E_Y'}{E_N}\times\frac{E_N}{E_Y^{1/\gamma}}$$

$$=1{\cdot}5\frac{E_Y'}{E_Y^{1/\gamma}}=1{\cdot}5(K_1)^{1/\gamma} \qquad \text{......(11)}$$

A map of $(K_1)^{1/\gamma}$ is given in Fig. 7. For the grey scale where K_1 is unity

$$_3\left(\frac{S}{N}\right)_1=1{\cdot}5$$

(b) Signal/noise of $E_Y'/E_Y^{1/\gamma}$ matrixed

$$_3\left(\frac{S}{N}\right)_2=\left(\frac{S}{N}\right)_3\times\left(\frac{N}{S}\right)_2=1{\cdot}5\frac{E_Y'\sqrt{\left(0{\cdot}3\frac{E_R}{E_R^{1/\gamma}}\right)^2+\left(0{\cdot}59\frac{E_G}{E_G^{1/\gamma}}\right)^2+\left(0{\cdot}11\frac{E_B}{E_B^{1/\gamma}}\right)^2}}{E_Y} \qquad \text{......(12)}$$

For the grey scale $E_R=E_G=E_B=E$

$$E_Y'=0{\cdot}3\,E^{1/\gamma}+0{\cdot}59\,E^{1/\gamma}+0{\cdot}11\,E^{1/\gamma}=E^{1/\gamma}$$
$$E_Y=0{\cdot}3\,E+0{\cdot}59\,E+0{\cdot}11\,E=E$$

Therefore

$$_3\left(\frac{S}{N}\right)_2=1{\cdot}5\frac{E^{1/\gamma}\sqrt{\left(0{\cdot}3\frac{E}{E^{1/\gamma}}\right)^2+\left(0{\cdot}59\frac{E}{E^{1/\gamma}}\right)^2+\left(0{\cdot}11\frac{E}{E^{1/\gamma}}\right)^2}}{E}$$

$$=1{\cdot}5\frac{E^{1/\gamma}\frac{E}{E^{1/\gamma}}\sqrt{(0{\cdot}3)^2+(0{\cdot}59)^2+(0{\cdot}11)^2}}{E}=1$$

Thus $_3(S/N)_2=1$ for the grey scale.

It should be noticed that the analysis in this appendix does not take into account noise introduced subsequently to transmission.

9. Appendix 2: Ideal Receiver

9.1. *Matrixing Operations*

Referring to Fig. 8, the colour difference signals $(E_R^{1/\gamma}-E_Y^{1/\gamma})$ and $(E_B^{1/\gamma}-E_Y^{1/\gamma})$ and the luminance signal $E_Y^{1/\gamma}$ are obtained by conventional means. The luminance signal is added to each of the colour difference signals to yield the signals $E_R^{1/\gamma}$, $E_B^{1/\gamma}$ suitable for application to the red and blue guns. The green signal is obtained by non-linear processing of the signals $E_Y^{1/\gamma}$, $E_R^{1/\gamma}$, $E_B^{1/\gamma}$. These are first converted into E_Y, E_R, E_B by passing them through γ-circuits. Addition in the proportions demanded by the equation $E_Y = 0{\cdot}3\,E_R+0{\cdot}59\,E_G+0{\cdot}11\,E_B$ results in the signal E_G. This is passed through a $1/\gamma$ circuit giving $E_G^{1/\gamma}$ which is suitable for application to the green gun.

9.2. *Constant Luminance Operation*

The reproduced luminance Y_1 is given by

$$Y_1 = 0{\cdot}3\,L_R+0{\cdot}59\,L_G+0{\cdot}11\,L_B \qquad \ldots\ldots(13)$$

where L_R, L_G, L_B are the lights from the red, green and blue phosphors.

$$Y_1 = 0{\cdot}3(S_R)^\gamma+0{\cdot}59(S_G)^\gamma+0{\cdot}11(S_B)^\gamma \ \ldots\ldots(14)$$

where S_R, S_G, S_B are the signals applied to the red, green and blue guns and the constant of proportionality between reproduced light and applied voltage is assumed to be numerically equal to unity.

Now from the considerations of Section 9.1

$$S_R = E_R^{1/\gamma}$$

$$S_B = E_B^{1/\gamma}$$

$$S_G = \left[\frac{1}{0{\cdot}59}(E_Y-0{\cdot}3\,E_R-0{\cdot}11\,E_B)\right]^{1/\gamma}$$

Therefore

$$Y_1 = 0{\cdot}3\,E_R+0{\cdot}11\,E_B+ +0{\cdot}59\left\{\left[\frac{1}{0{\cdot}59}(E_Y-0{\cdot}3\,E_R-0{\cdot}11\,E_B)\right]^{1/\gamma}\right\}^\gamma = E_Y$$

i.e. all luminance arrives via the luminance channel and the constant luminance index is unity throughout the chromaticity diagram.

10. Appendix 3: Linear Decoding by N.T.S.C. System Receiver

In a linear decoder the colour difference signals E_{RD} and E_{BD} and the luminance signal E_L are obtained by conventional means. The luminance signal is then added to the colour difference signals to give colour signals. The colour signals S_R S_B are then further matrixed with the luminance signal to give the green signal S_G according to the equation

$$S_G = \frac{1}{0{\cdot}59}[E_L-0{\cdot}3\,S_R-0{\cdot}11\,S_B]$$

For the N.T.S.C. system

$$E_L = E'_Y, \quad S_R = E_R^{1/\gamma}, \quad S_B = E_B^{1/\gamma}$$

which gives

$$S_G = \frac{1}{0{\cdot}59}[E'_Y-0{\cdot}3\,E_R^{1/\gamma}-0{\cdot}11\,E_B^{1/\gamma}] = E_G^{1/\gamma}$$

This is the correct signal.

For the suggested constant luminance system

$$E_L = E_Y^{1/\gamma}, \quad S_R = E_R^{1/\gamma}, \quad S_B = E_B^{1/\gamma}$$

giving

$$S_G = \frac{1}{0{\cdot}59}[E_Y^{1/\gamma}-0{\cdot}3\,E_R^{1/\gamma}-0{\cdot}11\,E_B^{1/\gamma}]$$

$$= E_G^{1/\gamma}+1{\cdot}7[E_Y^{1/\gamma}-E'_Y] = E_V^{1/\gamma}$$

$E_V^{1/\gamma}$ is always larger than $E_G^{1/\gamma}$ and this gives errors as shown in Fig. 10.

11. Appendix 4: Linear Decoding Using Sub-carrier Correction

It was shown in Appendix 3 that the signal applied to the green gun of a receiver using a linear decoder on the suggested constant luminance transmission is

$$E_V^{1/\gamma} = E_G^{1/\gamma}+1{\cdot}7(E_Y^{1/\gamma}-E'_Y)$$

Therefore

$$E_V^{1/\gamma}-E_G^{1/\gamma} = 1{\cdot}7\,E_Y^{1/\gamma}\left(1-\frac{E'_Y}{E_Y^{1/\gamma}}\right) = 1{\cdot}7\,E_Y^{1/\gamma}(1-(K_1)^{1/\gamma})$$

The function $(1-(K_1)^{1/\gamma})$ has a form which can be deduced from the plot of $(K_1)^{1/\gamma}$ shown in Fig. 7. It is zero at Illuminant C and increases with saturation. From Fig. 2 it can be seen that the subcarrier amplitude per unit luminance has a similar form. If the subcarrier is rectified and a fraction of it is subtracted from $E_V^{1/\gamma}$ by using a circuit as in Fig. 13, a value closer to $E_G^{1/\gamma}$ should be obtained. This is, in fact, so and the chromaticity and luminance errors obtained by employing one-fifth of the subcarrier amplitude are shown in Fig. 12.

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[*The discussion on this paper starts on page 320.*]

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The Relative Visibility of Random Noise Over the Grey-Scale

By

K. HACKING, B.Sc.†

Presented at a meeting of the Television Group in London on 14th December 1961.

Summary: The main factors which influence the relative visibility of random fluctuation noise over the grey-scale of a television display are examined. By applying existing data relating to the perception of small differences in luminance, theoretical relative visibility curves are deduced for three elementary types of noise source encountered in television systems.

1. Introduction

In the theoretical analysis of random noise in television systems it is often valuable to know not only the magnitude of the signal-to-noise ratio to be expected at the reproducer input, but also, how the luminance-noise produced will be distributed, in terms of relative visibility, over the available tonal range of the reproducer. Suppose, for instance, that the displayed television picture takes the form of a stepped grey-scale wedge ranging from "black" to "peak white", corresponding to a range of picture signal extending from zero to maximum, then it is usually found that there is a region of the wedge where the luminance-noise is more easily visible.

Four main factors influence the distribution of noise visibility. These are:

(*a*) The variation in the Fechner fraction $\Delta Y/Y$ with luminance level Y.

(*b*) The transfer characteristic of the system between the noise source and the displayed picture.

(*c*) The maximum available luminance contrast in the displayed picture as viewed, (e.g. the effect of ambient illumination on the screen).

(*d*) The type of noise source.

Taking these factors into account, approximate relative visibility distributions can be deduced which are expected to be qualitatively valid for both monochrome and colour television displays. An analysis has been given by Mertz[1] which deals with both added noise and noise modulating the signal. Maurice *et al.*[2] have investigated the visibility of several types of noise associated with television signal-generation equipment. Factor (*c*), however, was not considered by either of these authors.

† British Broadcasting Corporation, Research Department, Kingswood Warren, Tadworth, Surrey.

2. The Fechner Fraction

It is known that, in visual photometry, the fractional increment in luminance (i.e. Fechner fraction $= \Delta Y/Y$) just detectable between two adjacent fields increases as the luminance level Y decreases. The rate of increase of $\Delta Y/Y$ depends on a number of factors, one important factor being the state of adaptation of the eye. Following Mertz, the empirical data given by Moon and Spencer[3] for the variation in Fechner fraction with luminance level have been used here. The results for two conditions of adaptation are shown by the full-line curves in Fig. 1, where $\Delta Y/Y$ is plotted against Y for the range 0·1 to 20 ft-L (foot lamberts), using logarithmic co-ordinate scales. These threshold curves relate to optical experiments employing a circular object-field concentric with a (larger) test field, the fields subtending angles of 1 deg and 1½ deg at the fovea of the eye, respectively. Curve A is the result obtained when the test field has a black surround and curve B refers to the higher-adaptation condition produced by a surround having a uniform luminance of 10 ft-L. These two states of adaptation can be considered as representing the extreme conditions of view encountered in a television display whose maximum luminance is also 10 ft-L; hence it seems reasonable to assume that the appropriate Fechner threshold curve for a given picture will lie somewhere between the curves A and B shown.

Although these data refer to luminance discrimination between steady fields of photometric size which are, clearly, different in character to the scintillating "graininess" associated with random noise, it is assumed here (in the absence of more relevant data) that the application of the results is, at least, qualitatively valid.

3. The Distribution of Added Noise

If the r.m.s. level of random noise introduced is small compared with its attendant signal, and the

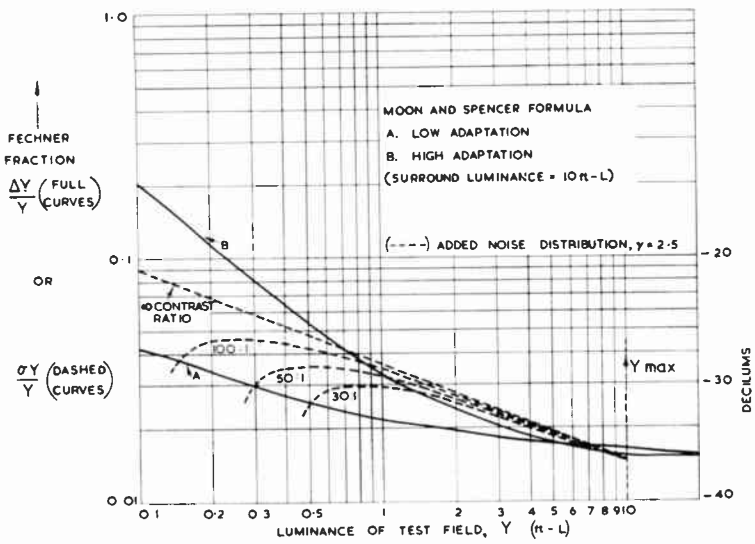

Fig. 1.
——— Fechner threshold curves, derived from the Moon and Spencer formula, for two states of adaptation of the eye.
– – – Luminance-noise distribution curves for noise added at the television reproducer input (shown for four different maximum contrast ratios).

transfer characteristic between the noise source and the displayed picture is known, one may deduce readily, for example, the approximate ratio $\sigma Y/Y$ of the r.m.s. luminance deviation to the mean luminance† as a function of mean luminance. Assuming a simple power-law transfer characteristic for the display tube of the form,

$$Y - Y_{\min} = kE^{\gamma} \qquad \ldots\ldots\ldots(1)$$

(where E is the voltage of the picture signal and k and γ are constants) and that a small, but constant, amount of random noise is added to the signal input, we obtain luminance-noise distribution curves of the form shown by the dashed-line curves of Fig. 1. Here $\sigma Y/Y$ is plotted against Y for the various maximum contrast ratios $Y_{\max}/Y_{\min}$ indicated. The curves all relate to a display tube with $\gamma = 2{\cdot}5$ and $Y_{\max} = 10$ ft-L. Increasing or decreasing the amount of noise added to the signal input simply shifts the family of curves vertically on the diagram: the vertical positioning shown in the figure is chosen to coincide with the Fechner threshold curves for easier comparison.

When the maximum picture contrast is not limited by, for instance, ambient illumination of the screen and/or flare originating in the display tube (i.e. when $Y_{\min} = 0$ in eqn. (1)), it will be seen that a straight-line distribution is obtained. The slope of this line is equal to $-1/\gamma$, hence the gamma of the tube is, clearly, an important factor affecting the uniformity of the distribution.

Under normal viewing conditions the maximum available contrast ratio is often determined by the ambient room illumination. The effect on the noise distribution is shown by the curves labelled 100 : 1, 50 : 1 and 30 : 1, respectively, in Fig. 1, which are derived by assuming that sufficient steady ambient illumination falls on the screen, limiting the (otherwise infinite) contrast ratio to the above mentioned values. For the special case when a linear transfer characteristic exists ($\gamma = 1$ in eqn. (1)) the distribution for added noise may be shown to be independent of the maximum contrast ratio.

4. Relative Visibility

Referring again to the combined data in Fig. 1, suppose that we select a particular Fechner threshold curve (curve A, say) and that we adjust the magnitude of the added noise so that it is just visible at maximum luminance. Then, from the form of the noise distribution curves, it is clear that there is a range of the grey-scale where the noise will be somewhat above the threshold and, therefore, more easily visible. If, now, the relative attenuation of the noise amplitude required to obtain constant (threshold) visibility at each point in the grey-scale is deduced, we obtain, for the data given in Fig. 1, curves of the form shown by the full lines in Fig. 2. In this figure, the relative attenuation, in decibels, required to maintain constant visibility (low-adaptation threshold) is plotted against relative luminance $Y/Y_{\max}$. For the purpose of description we may regard the relative luminance range, 0·01 to 0·1, as demarcating the black—dark-grey—mid-grey region of the grey-scale and the range, 0·1 to 1·0, the mid-grey—light-grey—white region. It will be seen (Fig. 2) that for each contrast ratio there is a (broad) maximum to the curve centred in the dark to mid-grey region of the grey-scale and, further, the effect of reducing the maximum contrast

† This quantity is sometimes expressed in "decilums" ($= 20 \log_{10} \sigma Y/Y$) to denote that a ratio of luminance amplitudes is involved.[1]

ratio is to shift the maximum of the curve towards the lighter greys.

Relative visibility is a subjective term and its precise relation to the objective measure of the noise amplitude, when the threshold has been exceeded, has not been determined. However, in view of the general logarithmic behaviour of the eye found in other contrast perception experiments, it seems reasonable to assume that noise visibility is proportional, for a given luminance level, to the logarithm of the ratio of the r.m.s. deviation in luminance σY to the Fechner threshold increment ΔY. Hence, with this assumption, the curves shown in Fig. 2 may be regarded as approximate relative visibility curves.

0·86 ft-L with a peak-white luminance at 10 ft-L. There appears to be good qualitative agreement between these experimental results and the deduced visibility curves.

5. Other Types of Random Noise Source

In addition to noise added at the input to the display tube, relative visibility curves have been deduced for two other common types of random noise source encountered in television. The results are shown, together with that obtained for added noise, in Fig. 3, where relative visibility in decilums ($20 \log_{10} \sigma Y/\Delta Y$) is plotted against relative luminance. The dashed-line curve refers to random noise, whose r.m.s. value

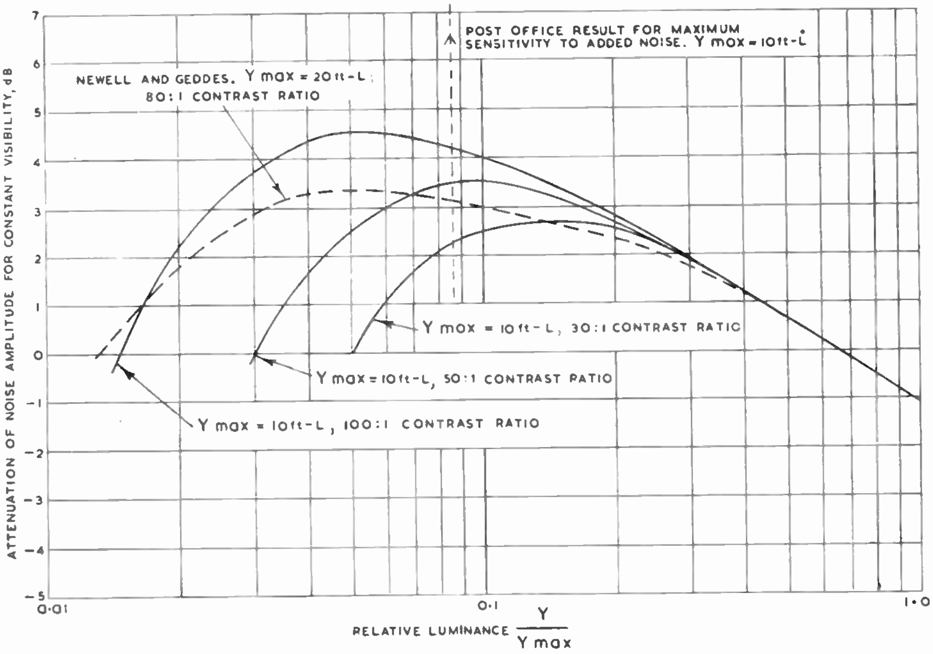

Fig. 2

——— Relative visibility curves for added noise (deduced from the data given in Fig. 1) showing the effect of limiting the maximum contrast ratio.

– – – – Some related experimental results of other workers.

The dashed-line curve in Fig. 2 is an experimental result obtained by G. F. Newell and K. Geddes† relating to the perception of numerals superimposed on the grey-scale of a test card displayed by a television picture monitor (peak-white luminance at 20 ft-L, and a maximum contrast ratio of 80 : 1). Earlier subjective experiments on the visibility of added "flat" noise over the grey-scale, carried out by the Post Office Engineering Department,[4] showed the region of maximum sensitivity to be centred at

† B.B.C. Research Department, private communication.

is proportional to the square root of the signal amplitude (e.g. photo-emission noise), introduced in a linear part of the system (i.e. the overall transfer characteristic is given by eqn. (1) with $\gamma = 1$). The chain-line curve refers to photographic-film granularity and has been deduced assuming the film to be a normal positive release print of a "grainy" negative and that maximum luminance corresponds to a print density of 0·2 above base. In deducing the curves shown in Fig. 3 an ambient-limited contrast ratio of 50 : 1, a maximum luminance of 10 ft-L and the low-adaptation Fechner threshold were assumed.

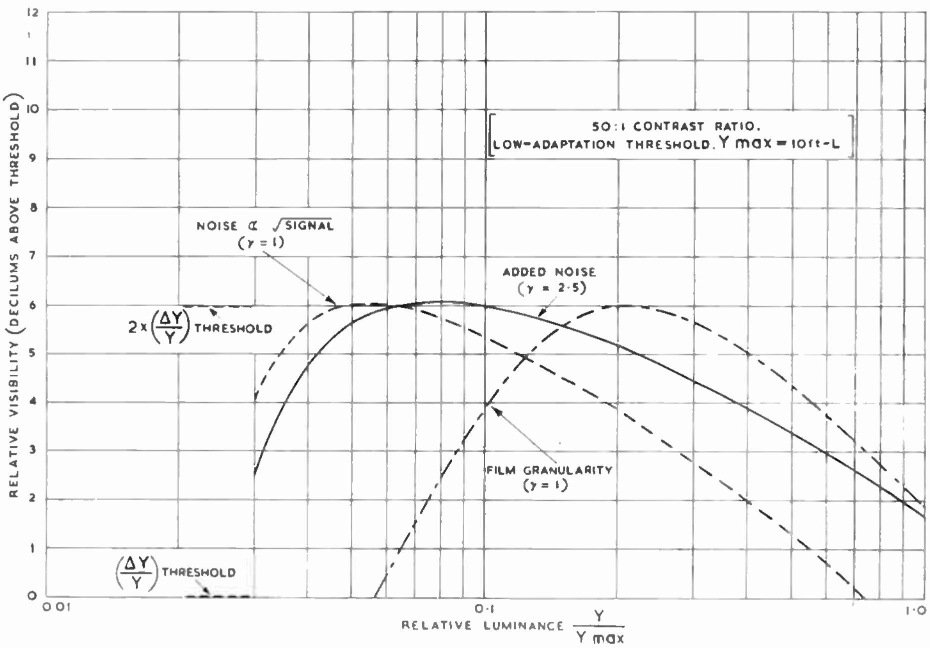

Fig. 3. Comparison of the relative visibility curves for three types of random noise source.

The three curves are normalized so that the peak visibility level occurs at twice (i.e. 6 decilums above) the just perceptible threshold.

Comparing the three types of noise source, added noise appears to be the most uniformly distributed, with a peak visibility occurring in the dark greys, while for noise proportional to the square root of the signal amplitude there is considerable emphasis in the near blacks. Noise caused by film grain is markedly different in that it is much more visible in the lighter tones of the grey-scale. It should be emphasized, in conclusion, that the relative visibility curves shown in this paper will be substantially modified if the noise is inserted at other points in the television chain, where a different overall transfer characteristic between source and picture exists. For example, noise added in a linear part of the system (not at the reproducer input) would have a very non-uniform visibility distribution with a sharp maximum in the extreme blacks.

6. Acknowledgments

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A Colorimetric Study of a Constant Luminance System

By

W. N. SPROSON, M.A.†

Presented at a meeting of the Television Group in London on 14th December 1961.

Summary: The assessment of any system of colour television depends to some extent on the colours chosen for the test. Electronically-generated colour bars may show faults which are non-existent in the transmission of ordinary pictures. A set of standard colours, which is typical of modern pigments and printing inks, is proposed for the purpose of assessing the colour and luminance fidelity of a colour television system. The method is illustrated for a constant-luminance colour television system (proposed by James and Karwowski) under two conditions: (i) ideal analysis, (ii) analysis by an existing colour scanner. The use of a uniform chromaticity diagram gives a convenient means of assessing the colour errors in subjective terms.

1. Introduction

One of the most convenient methods of testing colour television equipment involves the use of electronically-generated colour bars. In their simplest form, these produce, at the display, the primary colours red, green and blue (R, G, B) together with their complements yellow, magenta and cyan, at full saturation (100%) and at the maximum luminance consistent with a stated peak-white signal. Certainly any system or equipment that works well under these conditions (i.e. without overload or non-linear distortion) will operate well for all the colours (and their associated luminances) which are produced by ordinary scenes and whose R, G, B signals are generated either in a flying-spot scanner or a colour camera. However, this demand to withstand high levels of luminance and subcarrier amplitudes is, in general, an unnecessary extravagance and it would be more reasonable (and certainly more economic) to make a survey of present coloured materials and to decide on performance levels appropriate to the most "colourful" materials available. (Colourful for colour television means a combination of luminance and saturation since the subcarrier amplitude depends on the product of the two.)

Such a survey was made a short while ago and the thirteen colours‡ selected were those having maximum saturation consistent with reasonable luminance factors; this means that very saturated colours at (say) 1% luminance factor or less were not included. The list of colours (Table 1 and Fig. 1) shows that the lowest luminance factor is 1·5% in terms of a magnesium carbonate standard white; this is equivalent to 1·8% in terms of white paper (of 83% reflectance with respect to magnesium carbonate).

The chromaticity coordinates were computed from measurements of spectral reflectance taken on a Unicam spectrophotometer type SP 500 using the diffuse reflectance attachment. The measurements were taken at 10 mμ intervals in the range 400 to 740 mμ. A more extensive search might have revealed colours which are slightly more saturated (for a given luminance), nevertheless, the range given in Fig. 1 somewhat exceeds that quoted by Wintringham.[1] In the view of the writer, a colour television system

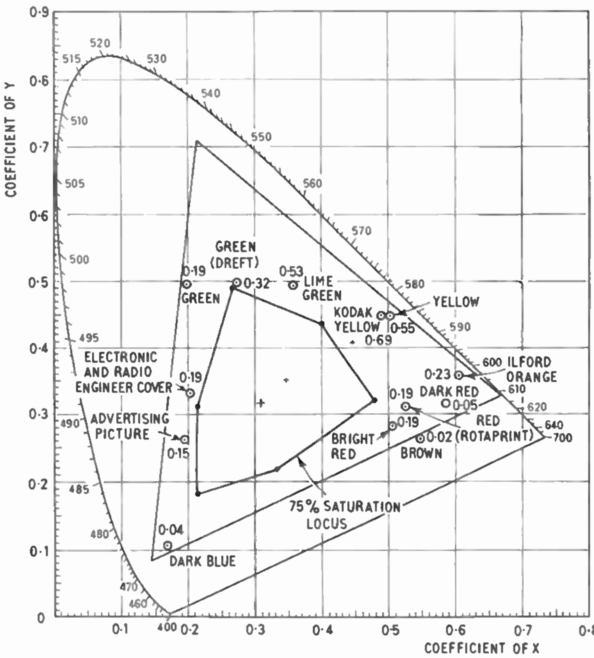

Fig. 1. Chromaticities of the thirteen standard colours.

† British Broadcasting Corporation, Research Department, Kingswood Warren, Tadworth, Surrey.

‡ All the colours selected were non-fluorescent.

should be tested using colours such as those shown in Table 1 and Fig. 1; however, it is not asserted that these specific colours are the optimum set (although it is considered that they are not far from such a set).

2. Application of the Set of Standard Colours

2.1. *Perfect Analysis with either Constant-Luminance Transmission and Normal N.T.S.C. Reception or Normal N.T.S.C. Transmission and Reception*

The R, G, B signals generated from the colours specified in Table 1 can be computed from the following matrix:

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1{\cdot}910 & -0{\cdot}532 & -0{\cdot}288 \\ -0{\cdot}985 & 1{\cdot}999 & -0{\cdot}028 \\ 0{\cdot}058 & -0{\cdot}118 & 0{\cdot}898 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

where X, Y, Z are the tristimulus values of the colours in Table 1. This is based on the use of (i) standard N.T.S.C. synthesis primaries, (ii) illuminant C for the white point, and (iii) perfect analysis characteristics, including negative lobes.

The manner in which such a set of R G B signals would be processed in a constant-luminance system has been dealt with by James and Karwowski.[2] The result of applying these processes is given in Fig. 2 (compare this with Fig. 10 of James and Karwowski's paper).

A disadvantage of the standard C.I.E. chromaticity diagram is that equal distances in different parts of the diagram do not correspond to equally noticeable colour differences. A number of uniform chromaticity charts have been proposed in an attempt to overcome this difficulty and although no simple linear transformation appears to give a completely uniform chromaticity scale over the whole colour diagram,

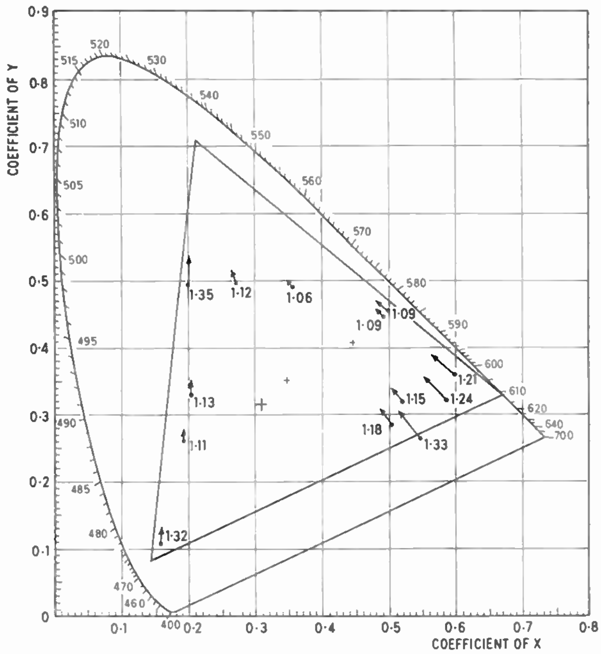

Fig. 2. Reproduction of the thirteen standard colours by standard N.T.S.C. receiver when receiving a constant-luminance transmission (ideal analysis).

nevertheless a substantial improvement is possible. Thus the rectangular-uniform-chromaticity-scale[3] diagram reduces a variation of 20 to 1 in the original C.I.E. diagram to one of 4 to 1. The uniform chromaticity chart of MacAdam[4] achieves a similar result and has the advantage of representing a numerically simpler transformation, viz.

$$u = \frac{2x}{(6y - x + 1{\cdot}5)} \qquad v = \frac{3y}{(6y - x + 1{\cdot}5)}$$

Table 1

Thirteen " Standard " Colours

Colour		Chromaticity coordinates		Luminance factor ref. $MgCO_3$	Tristimulus values† ref. white paper			Saturation %
		x	y	Y	X	Y	Z	
1. Red	Rotaprint	0·521	0·316	0·158	0·312	0·189	0·097	85·4
2. Orange	Ilford	0·601	0·357	0·193	0·391	0·232	0·027	96·8
3. Yellow	Kodak	0·493	0·447	0·576	0·762	0·691	0·093	95·6
4. Green	Dreft	0·270	0·498	0·268	0·175	0·322	0·150	77·2
5. Blue-green	(*Electronic and Radio Engineer*)	0·205	0·331	0·158	0·118	0·190	0·266	81·7
6. Blue	(Advertising plate)	0·195	0·263	0·127	0·113	0·153	0·315	83·7
7. Bright red		0·503	0·283	0·161	0·342	0·192	0·145	91·4
8. Dark red		0·588	0·318	0·045	0·102	0·055	0·016	94·2
9. Brown		0·548	0·260	0·015	0·038	0·018	0·013	102·9
10. Yellow		0·500	0·455	0·458	0·603	0·549	0·054	97·7
11. Lime Green		0·356	0·491	0·440	0·383	0·528	0·165	84·0
12. Green		0·200	0·497	0·154	0·074	0·184	0·112	96·2
13. Dark Blue		0·161	0·106	0·037	0·068	0·045	0·311	95·0

† White paper of reflection factor 0·833 with reference to $MgCO_3$ is regarded as a reasonable peak-white for a colour television scene. White point = Illuminant C. Saturation is specified in terms of the N.T.S.C. RGB triangle (see Fig. 1).

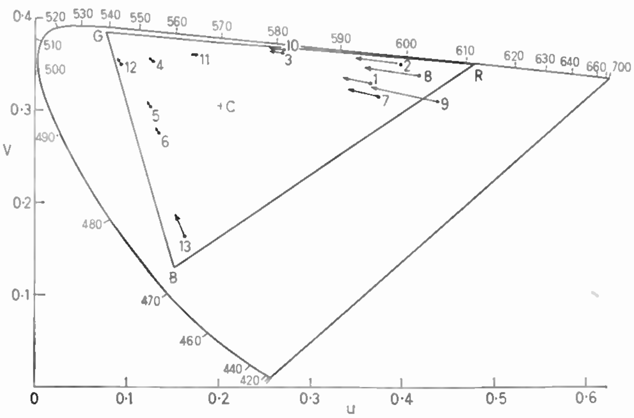

Fig. 3. Data of Fig. 2 plotted on the MacAdam u.c.s. diagram. The numbers refer to the colours as listed in the tables.

where x and y are the chromaticity coordinates in the standard C.I.E. diagram and u and v are the corresponding coordinates in the MacAdam diagram. Figure 3 shows the data of Fig. 2 plotted on the MacAdam u.c.s. diagram. In this diagram the length of the lines drawn between the original and the reproduced colour are directly proportional to the noticeability of the colour difference with an accuracy as stated above. The errors are tabulated in units of just-noticeable-difference (j.n.d.s) in Table 2, which also includes the luminance errors.

It should be noted that a standard N.T.S.C. transmission with a standard N.T.S.C. receiver would show no colour or luminance errors, except for colour No. 9 which is outside the RGB triangle. The principal defect of the N.T.S.C. transmission is that some of the luminance information is carried by the low-bandwidth chrominance channels, but reference to Fig. 1 of James and Karwowski's paper shows that for the twelve colours within the RGB triangle, the constant luminance index (K_1) of the standard N.T.S.C. transmission is never less than 0·5 and has a mean value of 0·80. If colour No. 9 is included then the lowest value of K_1 becomes 0·33 and the mean value for the thirteen colours becomes 0·76. This implies that with existing saturated colours, a high proportion of the luminance signal is transmitted by the luminance channel and hence the definition is likely to be satisfactory.

2.2. *Practical Analysis with either Constant-Luminance Transmission and Normal N.T.S.C. Reception or Normal N.T.S.C. Transmission and Reception*

The matrix quoted in section 2.1 only applies when the sensitivity curves describing the colorimetric analysis performed by the camera or the scanner are ideal. In practice the sensitivity curves are usually restricted to the major positive parts and, although a fairly good approximation to these parts can be

Table 2

Chromaticity and Luminance Errors for Ideal Analysis, Constant Luminance Transmission, N.T.S.C. Reception

Colour	Chromaticity shift in j.n.d.s	Luminance shift in j.n.d.s
1. Red	8·6	6·7
2. Orange	14·1	9·2
3. Yellow	3·9	5·5
4. Green	1·6	6·0
5. Blue-green	2·1	5·9
6. Blue	2·3	4·2
7. Red	9·6	8·0
8. Red	16·7	5·6
9. Brown	19·8	4·7
10. Yellow	4·7	2·5
11. Green	1·3	1·7
12. Green	5·2	14·4
13. Blue	7·3	6·7
Mean	7·5	6·2

Note that for ideal analysis, N.T.S.C. transmission and N.T.S.C. reception the chromaticity (and luminance) shift is ZERO except for colour No. 9 where the chromatic error is 4 j.n.d.

achieved, the absence of the subsidiary parts (both positive and negative) inevitably means the introduction of some errors. As an example, the sensitivity curves of a B.B.C. Research Department colour scanner were used and the colour reproduction was estimated both for a normal N.T.S.C. transmission and reception and also for the case of a constant-luminance transmission with normal N.T.S.C. reception; the performance of this scanner was sufficiently good to permit side-by-side comparison of the original picture and a colour television reproduction during the 1956 demonstrations to Study Group XI of the C.C.I.R.

The results of this analysis for the constant-luminance transmission, with normal N.T.S.C. reception, are shown by solid lines in Fig. 4. The dashed lines show the reproduction when the transmission, as well as the reception conforms to the N.T.S.C. standards. It will be seen that in some cases (e.g. colours 1 and 3), the errors of the constant-luminance system partially cancel the errors of analysis. In general, however, the errors produced by the constant-luminance system are greater than those produced by colour analysis, and Table 3 shows that the mean colour error increases from 5·1 j.n.d.s to 8·0 j.n.d.s.

3. Discussion of Colour Reproduction when using the Constant-Luminance System (N.T.S.C. receiver)

The effect of receiving the constant-luminance transmission on a normal N.T.S.C. receiver is invariably to add a spurious green signal. This means that

Table 3

Chromaticity and Luminance Errors for a Case of Practical Analysis

Colour	N.T.S.C. Transmission Chromaticity shift in j.n.d.s	N.T.S.C. Transmission Luminance shift in j.n.d.s	Constant-Luminance Transmission Chromaticity shift in j.n.d.s	Constant-Luminance Transmission Luminance shift in j.n.d.s
1. Red	8·8	4·1	6·8	10·0
2. Orange	3·4	0·5	11·5	10·0
3. Yellow	5·7	9·5	1·6	4·6
4. Green	4·2	2·1	2·9	6·0
5. Blue-green	1·6	4·1	2·3	8·8
6. Blue	1·0	3·5	1·8	6·4
7. Red	3·9	4·6	12·2	11·5
8. Red	7·3	5·6	19·3	9·9
9. Brown	4·7	3·0	20·8	7·1
10. Yellow	6·5	5·1	2·1	2·4
11. Green	2·3	2·4	1·6	1·2
12. Green	4·9	3·7	3·1	11·5
13. Blue	11·7	10·0	18·2	14·7
Mean	5·1	4·5	8·0	8·0

all the errors (Figs. 3 and 4) are in the same direction, in spite of the fact that the neutral scale is correctly reproduced. Thus the picture will have the appearance of a green trend in colour balance and it is perhaps unfortunate that observers do not like colour pictures which are distorted in either the green or magenta direction (e.g. consider the effect on flesh tones). The eye is much more tolerant to changes in the orange to cyan direction particularly when this coincides with the black-body locus.

The red primary suffers considerable distortion and in fact becomes a yellowish-orange of dominant wavelength 596 mμ. This is the longest wavelength that the system can reproduce and it is certainly not very satisfactory. The distortion of the blue primary is possibly not so objectionable in practice because saturated blues of the same colour as the blue primary are of rare occurrence. Saturated reds are of much more frequent occurrence (e.g. colours 2 and 8).

The green primary is not distorted in colour but it exhibits considerable luminance error. Apart from tending to give colours a fluorescent appearance, there is another unfortunate consequence of the enhanced luminance: if one is to avoid overloading the individual RGB channels in the receiver, the peak white must be reduced by a factor depending on the gamut of colours. If the primaries are included, then the factor is 0·53 (i.e. a peak white of 10 ft-L would have to be reduced to 5·3 ft-L). If the thirteen standard colours are taken as limiting the range of colours, then the factor is 0·74.

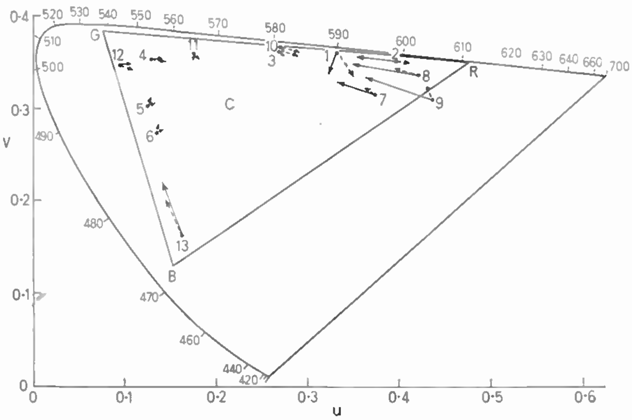

Fig. 4. Reproduction using practical analysis of original colours. Solid lines connect original and reproduction obtained with a constant-luminance transmission and standard N.T.S.C. receiver. Dashed lines connect original and reproduction obtained with a standard N.T.S.C. transmission and a standard N.T.S.C. receiver.

4. Modification of the N.T.S.C. Receiver incorporating one-fifth Subcarrier Correction

The errors of chromaticity and luminance which are produced when a constant luminance transmission is received on a standard N.T.S.C. receiver are considerable (Tables 2 and 3). In Section 4.3 of James and Karwowski's paper, a variant is suggested whereby the green signal is reduced by feeding a fraction of the rectified subcarrier back to the green grid. For the case of one-fifth subcarrier correction, the results are plotted in Fig. 12 of James and Karwowski's paper. The results for the thirteen colours of Table 1 and Fig. 1 are shown in Fig. 5 and Table 4; the analysis is assumed to be perfect in this case (cf. Fig. 3). Undoubtedly there is considerable improvement both in rendering of colour and of luminance. Six of the colours now have less than 1 j.n.d. error in colour (colours 3, 4, 6, 10, 11, 12). The two largest colour errors are now 14·8 j.n.d.s (for colour No. 9) and 10·9 j.n.d.s (for colour No. 8). Luminance distortion is also considerably reduced, the maximum error is a 22% increase for colour No. 9, which corresponds to about 3·3 j.n.d.s for the low luminance of colour No. 9.

From the colorimetric aspect, this subcarrier correction scheme is a fairly good compromise. Two points, however, can be made: (i) the standard N.T.S.C. transmission with a standard N.T.S.C. receiver produces no error of colour or luminance† (except for colour No. 9), and (ii) why adopt a "half-way" solution between a standard N.T.S.C. receiver and the properly designed receiver for a constant-luminance transmission? The dominant wavelength of the reproduced red primary is now

† Ideal analysis.

Table 4

Chromaticity and Luminance Errors for Ideal Analysis, Constant Luminance Transmission, N.T.S.C. Receiver Modified with One-fifth Subcarrier Correction

Colour	Chromaticity shift in j.n.d.s	Luminance shift in j.n.d.s
1. Red	3·6	2·8
2. Orange	6·5	4·1
3. Yellow	0·5	0·6
4. Green	0·0	0·0
5. Blue-green	1·6	3·5
6. Blue	0·3	0·4
7. Red	3·1	4·6
8. Red	10·9	3·4
9. Brown	14·8	3·3
10. Yellow	0·5	0·3
11. Green	0·5	0·6
12. Green	0·8	4·6
13. Blue	4·2	3·6
Mean	3·6	2·4

about 601 mμ, which is certainly an improvement over 596 mμ but it is still an orange rather than a red and is 18 j.n.d.s from the original red primary.

5. Size of the Just Noticeable Difference (j.n.d.)

Several investigators[5, 6, 7] have determined the size of the just-noticeable-difference over the standard colour diagram. When these results are converted to the MacAdam *u*, *v* scale the following situation appears:

	Approx. mean j.n.d.	Size of field	Luminance
MacAdam	0·00384	2°	16 ft-L
Wright	0·008	2°	25 ft-L
Judd	0·00035	6°	3–25 ft-L

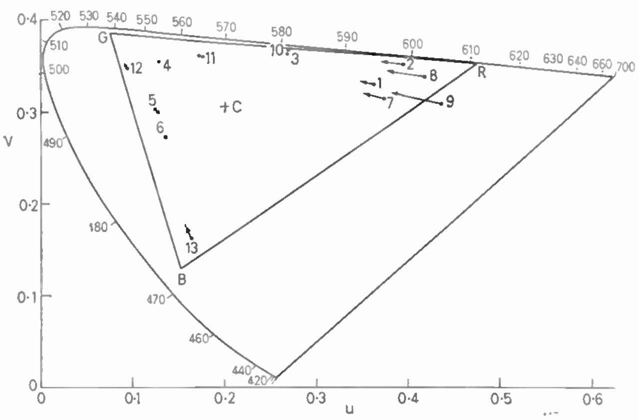

Fig. 5. Reproduction using ideal analysis, constant-luminance transmission and a N.T.S.C. receiver modified to feed back one-fifth rectified subcarrier on to green grid.

There is considerable variation in the magnitude of the j.n.d. Without doubt, a large part of this variation is due to differences in the conditions of measurement, as size of test field (angular subtense), geometrical nature of test field (e.g. bipartite division), presence or absence of surround to test field, brightness of test field and surround field all have considerable effect upon the final result. The viewing conditions most relevant to the assessment of colour television pictures have yet to be determined: the j.n.d.s of colour difference quoted in the previous sections of this paper are all based on the MacAdam figure of 0·00384. Clearly if the conditions were more critical, a smaller unit would be required; however, the present impression is that a larger unit might be more relevant. It will be obvious that the comparison of different systems given in Sections 2.1, 2.2 and 4 is valid independently of the size of unit chosen.

The size of the j.n.d. for luminance variations has been taken from a paper by Hacking[8]: allowance has been made for the brightness of the test colour (assuming a peak white of 10 ft-L) and a condition of adaptation intermediate between low adaptation and high adaptation (curves A and B of Hacking's Fig. 1) has been assumed.

6. Acknowledgments

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Some Aspects of V.S.B. Transmission of Colour Television with Envelope Detection

By

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Presented at a meeting of the Television Group in London on 14th December 1961.

Summary: The assessment of the merits of a colour television system in fulfilling the principle of constant luminance must take into account the errors that can result from the use of a vestigial-sideband emission with envelope detection. Comparison is made between the N.T.S.C. system and the modified form of this proposed by James and Karwowski. As regards the reproduction of colour in large areas, the N.T.S.C. system is in some respects superior to the James and Karwowski system.

1. Introduction

The recovery of the video modulation from a television transmission is normally achieved by the use of an envelope detector in the receiver. This detector produces an output waveform proportional to the envelope of the input modulated carrier. Conventional forms of this circuit employing either valve, or crystal diodes are almost perfectly adequate for the recovery of the modulation of a signal if only one parameter, the amplitude, of the signal is varied by the modulation. This condition can be met if the input to the detector is a double-sideband amplitude-modulated signal, but if the sideband amplitudes are unbalanced or if an interfering carrier is added, the resultant signal will vary in phase from that of the original carrier. In these conditions the envelope of the resultant signal will not represent the original modulation, and neither will the detector output.

The limitations of asymmetric-sideband reception using an envelope detector have been fully dealt with by Cherry,[1] and in this paper we consider only two aspects which affect the accuracy of the reproduction of the chromaticity of large areas of colour in television pictures. Consider the representation of a double-sideband amplitude-modulated signal shown in Fig. 1(*a*) and the output of an envelope detector 1(*b*). If one sideband is removed from the signal as depicted in Fig. 1(*c*), the output of the detector is as represented in 1(*d*). The removal of one sideband has reduced the sideband power by 3 dB but the amplitude of the modulation component has dropped by 6 dB. It is interesting to note that the mean level of the detector output has increased as a result of removing one sideband. It can be shown that this increase represents an amount of power slightly greater than

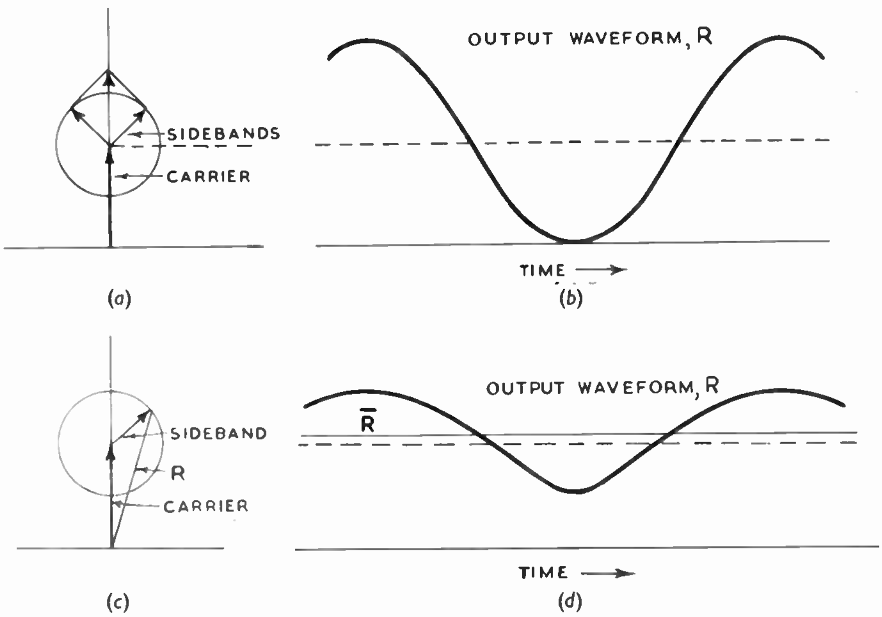

Fig. 1.
(*a*) Double sideband signal.
(*b*) Waveform at output of envelope detector for d.s.b. signal.
(*c*) Single sideband signal.
(*d*) Waveform at output of envelope detector for s.s.b. signal

$R = (1 + C^2 + 2C\cos\theta)^{\frac{1}{2}}$

$\bar{R}^2 \simeq 1 + \frac{C^2}{2}$

† British Broadcasting Corporation, Research Department, Kingswood Warren, Tadworth, Surrey.

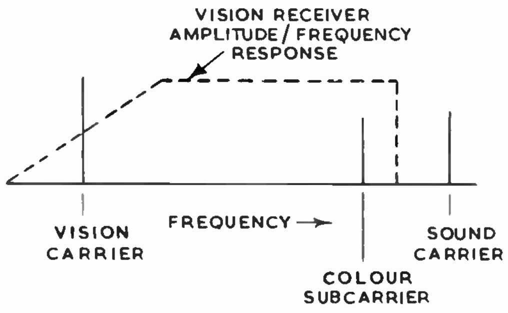

Fig. 2. Vestigial sideband transmission.

that contained in the modulation component. In fact, slightly more than half the sideband power radiated in a single-sideband transmission received with an envelope detector, is converted into an increase of the mean, or "d.c. component" of the signal.

2. Luminance and Chrominance Errors

The vestigial-sideband transmission of the type of colour-television systems in which we are interested can be considered as single-sideband as regards the colour information (Fig. 2). If a transmitted colour picture has a large area of uniform colour, the signal representing this area can be considered as consisting of a carrier, $\cos \omega t$, containing the luminance and synchronizing components, and a sideband $C \cos(\omega+p)t$ containing the colour component. The combination of these two cosine waves can be expressed as a function of time, f (t).

$$f(t) = R \cos(\omega t + \Phi) \qquad \ldots.(1)$$

where $R = (1+C^2+2C \cos \theta)^{\frac{1}{2}}$,

and $\theta = pt$,

and $\tan \Phi = (C \sin \theta)/(1+C \cos \theta)$

If f (t) is the input to an envelope detector, the output waveform will be proportional to R. A solution for R in the form of a series has been given by Colebrook.[2]

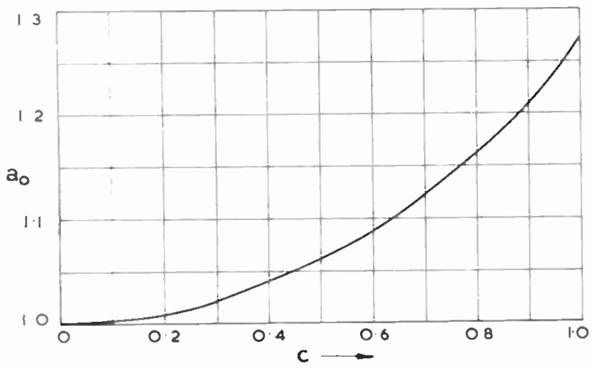

Fig. 3. a_0 versus sideband amplitude C.

$$R = a_0+a_1 \cos \theta - a_2 \cos 2\theta + \ldots \qquad \ldots.(2)$$

We need consider only the first two terms because the harmonics of the colour component will not be passed through the video circuits. The value of a_0 is plotted in Fig. 3 as a function of the sideband amplitude C. Figure 4 shows the reduction of the colour component as a percentage, that is $100(C-a_1)/C$, as a function of C.

The power contained in the mean or "d.c. component" is

$$\bar{R}_0^2 = a^2 \simeq 1+C^2/2 \text{ when } C \text{ is small}$$

but when C is equal to the amplitude of the carrier, i.e. $C = 1$ in eqn (1),

$$\bar{R}^2 = 1+0{\cdot}62C^2$$

From this we see that at least half the power contained in the colour signal is converted into an increase of the mean level. In addition to this loss of power a further decrease of the colour signal results from the

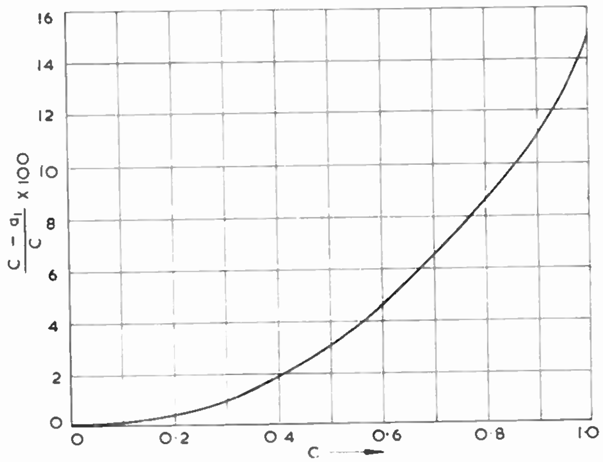

Fig. 4. Reduction of colour component as a function of sideband amplitude.

power lost in harmonic distortion terms, but these are not serious. The mean value of Φ is zero and there is no error in the hue of the colour. If the system uses positive modulation, the increase of the mean component represents an increase of luminance, but if negative modulation is employed a reduction of luminance results. If the system is of the so-called constant luminance variety as in the case of that proposed by James and Karwowski,[3] the reduction of the colour signal amplitude results in a small change of saturation. In the case of the N.T.S.C. system which does not completely fulfil the constant luminance principle the colour signal contains some of the luminance component. If the modulation has positive polarity, the reduction of the chrominance signal amplitude causes a decrease of luminance which can partly compensate for the increase caused by the increase of the mean component. If negative modulation is employed, both effects produce a decrease of luminance. The luminance errors for a number of colours, including most of those proposed as test colours by Sproson,[4] and the saturated primaries red, green and blue, were computed for the N.T.S.C. system and for that proposed by James and Karwowski. These errors, shown in Table 1 for both positive and negative modulation, are expressed in just noticeable differences (j.n.d.s), one j.n.d. being a 3% luminance change.† For positive modulation the luminance signal was assumed to be confined between the limits of 35% of carrier amplitude (black) and 100% (white). For negative modulation the limits were taken as 75% (black) and 10% (white) of the carrier amplitude.

luminance system, the receiver used was of the "ideal" variety proposed for use with this system.

The problems of transmitting the N.T.S.C. waveform with negative modulation have been discussed by Fredendall.[5] The reception problems can be considerably reduced by the use of the "exalted carrier"[6] technique in the receiver. This requires that the i.f. amplifier is designed to produce a much higher gain at the vision-carrier frequency than at the sideband frequencies. The result is that the input to the envelope detector has a much smaller depth of modulation than would be the case with a conventional i.f. amplifier. As is shown by Figs. 3 and 4, the reduction of the relative amplitude of the chrominance sidebands at the detector input results in a reduction of the effects discussed. The video-frequency amplifier must be designed to have a non-uniform gain over the frequency band in order to equalize the overall response. It is interesting to note, however, that receivers designed for the reception of the 405-line, positive-modulation, experimental colour emissions in the United Kingdom employ i.f. amplifiers identical with those used for domestic monochrome reception except for a little extra preservation of the gain uniformity over the chrominance signal frequencies. In fact, lack of constant luminance in large areas was not one of the

Table 1

Luminance Errors in "Just Noticeable Differences" in Colour Receivers

	Colour	Positive Modulation		Negative Modulation	
		N.T.S.C.	Modified N.T.S.C. with "Ideal" Receiver	N.T.S.C.	Modified N.T.S.C. with "Ideal" Receiver
1	RED (Rotaprint)	2·2	1·9	3	2·5
2	ORANGE (Ilford)	4·1	3·2	5	5·5
3	YELLOW (Kodak)	1·6	1·9	9	7
4	GREEN (Dreft)	1	1·3	2	2·5
5	BLUE-GREEN	1	1·3	2	2
6	BLUE	0·7	11·6	1·5	1
7	BRIGHT RED	2·5	1·9	3·5	3·5
8	DARK RED	2·2	1·9	2	1
9					
10	YELLOW	2·5	2·2	6	7
11	LIME-GREEN	1·3	1	1·5	2·5
12	GREEN	2·5	2·9	2·5	6
13	DARK BLUE	2·5	2·5	2	1·5
14	RED (Saturated)	6	7	13	13
15	GREEN (Saturated)	4	11	17	10
16	BLUE (Saturated)	2·5	11	10	14

Examination shows that the constant luminance system offers no marked superiority. In fact, with positive modulation, the N.T.S.C. system is superior for the saturated colours. The computations were based on the assumption that, for the constant

† The value of 3% was chosen as a compromise between the more generally accepted figure of 2% and that of 4·5% measured by Brown and MacAdam.[9] To correct the errors in Table 1 to 2% j.n.d.'s, multiply by 1·5; to obtain the errors in terms of 4·5% j.n.d.'s, multiply by 0·67.

criticisms remarked upon during the colour trials in this country.

3. Reception of Colour Emissions by Monochrome Receivers

Although receivers intended for colour reception can be specially designed for the system used, it is important to consider the effect of the colour emissions on monochrome reception. This is important because large numbers of monochrome receivers may be in use before the colour emissions commence.

The tonal range of the grey scale reproduced by monochrome reception of colour emissions is not the same as the luminance range produced by colour receivers. The chrominance signal is passed by the video amplifier of the monochrome receiver and appears as a dot pattern in the displayed picture. As was shown by Maurice,[7] the non-linear relationship between the c.r.t. drive voltage and the displayed brightness partly rectifies the chrominance signal, and alters the mean brightness of areas containing colour in the transmitted picture.

Table 2 shows the computed brightness errors for monochrome reception of the same colours considered for the colour receiver. The c.r.t. brightness/voltage characteristic was assumed to be:

$$B = v^{\gamma} + B_0$$

where B = the reproduced brightness
v = the c.r.t. drive voltage
$\gamma = 2{\cdot}5$
B_0 = the brightness reflected from the c.r.t. screen by the ambient illumination of the room containing the receiver.

The ambient reflected light, B_0, was assumed to be one-fortieth of the peak-white brightness. The computed errors include those caused by the envelope detection of the v.s.b. signal and those caused by the c.r.t. non-linearity. The errors are shown as percentages of the correct brightness of the transmitted colours. This method of showing the errors was chosen in preference to the "just noticeable difference" method because the latter does not indicate whether the error is in the form of increased or decreased brightness. The panchromatic reproduction is likely to be more seriously marred if large brightness errors are in opposite sense for various colours.

Table 2

Percentage Brightness Errors for Monochrome Receivers

	Colour	Positive Modulation		Negative Modulation	
		N.T.S.C.	Modified N.T.S.C.	N.T.S.C.	Modified N.T.S.C.
		%	%	%	%
1	RED (Rotaprint)	− 17·9	21·0	− 31·2	6·0
2	ORANGE (Ilford)	− 5·6	33·3	− 2·8	6·0
3	YELLOW (Kodak)	4·5	19·2	− 29·6	− 22·0
4	GREEN (Dreft)	− 13·7	15·0	− 17·4	0
5	BLUE-GREEN	− 18·4	16·8	− 25·8	4·0
6	BLUE	− 17·6	15·0	− 24·8	4·8
7	BRIGHT RED	− 18·8	25·2	− 94·8	7·0
8	DARK RED	− 41·8	24·9	− 45·6	14·4
9					
10	YELLOW	2·2	24·0	− 25·9	− 12·0
11	LIME-GREEN	− 6·4	8·0	− 16·6	− 4·0
12	GREEN	− 22·8	45·0	− 33·7	10·8
13	DARK BLUE	− 51·1	27·0	− 53·3	13·8
14	RED (Saturated)	2·6	52·5	− 53·2	2·5
15	GREEN (Saturated)	− 2·6	131·1	− 54·3	− 89·7
16	BLUE (Saturated)	− 23·3	136·4	− 60·3	102·0

Table 2 shows that with negative modulation the modified N.T.S.C. system is superior except for saturated green and blue, but it must be remembered that saturated green does not occur frequently in nature. For positive modulation the N.T.S.C. system is not inferior to the constant luminance system and is in fact superior for the saturated colours.

It is interesting to note that during the compatibility trials[8] of the N.T.S.C. system as adapted for the 405-line positive-modulation system the grey scale reproduction was not criticized.

4. Conclusions

The computed errors of luminance for colour reception and brightness for monochrome reception show that the distortion introduced by v.s.b. reception using an envelope detector nullifies some of the advantages of the modified N.T.S.C. system proposed by James and Karwowski. Colour receivers can be designed to minimize the effects of envelope detection and in these conditions the modified system would be superior. If positive modulation is used the N.T.S.C. system possesses good constant-luminance qualities if the receiver has an i.f. amplifier with the conventional gain/frequency characteristic.

Reception of negative-modulation colour emissions with monochrome receivers would result in good grey scale reproduction except for some saturated colours if the modified N.T.S.C. system were employed. With positive modulation, however, the N.T.S.C. system is likely to prove superior.

It has been shown that assessment of the constant-luminance qualities of a colour television system must take account of the effects of vestigial sideband transmission with envelope detection.

5. Acknowledgments

The author wishes to thank the Director of Engineering of the B.B.C. for permission to publish this paper and to acknowledge the help of his colleague, Mr. D. Howorth who carried out the computations involved in the two tables.

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DISCUSSION ON "CONSTANT LUMINANCE COLOUR TELEVISION"

Dr. R. D. A. Maurice: In Section 2.2 (*b*) Messrs. James and Karwowski conclude that the N.T.S.C. compatible picture will have low resolution because patches of saturated colour are reproduced in monochrome with low luminance. This is a statistical matter, depending upon programme content, and it can equally well be claimed that this lack of luminance will increase the resolution because it depends entirely upon the luminance of the surrounding areas.

In Section 2.3 (*a*) it is claimed that co-channel interference in a colour receiver is less visible with the constant-luminance system, but tests† have shown that the improvement must be so small as to be masked by other features. It was found that the co-channel protection ratios required by monochrome (compatible) and colour reception of an N.T.S.C. colour emission were equal; in other words, an N.T.S.C. colour transmission is no more vulnerable to interference when the chrominance channel is operating than it is when there is no chrominance channel in the receiver.

The authors point out that their system is well adapted to the use of a luminance camera tube alongside two colour tubes and that such arrangement gives an excellent, well-registered luminance signal. This is undoubtedly true and important; it ought, however, to be stated that when a saturated colour occurs, the N.T.S.C. camera has a better chance of giving a well-registered picture because, at least for the positive primaries, only one tube will contribute to the picture signal whereas in the authors' system at least two tubes will be contributing.

With regards to Figs. 10 and 12, which show the chromatic errors introduced when the constant-luminance emission is received on an ordinary N.T.S.C. receiver and on a cheaply modified N.T.S.C. receiver. I should like to ask the authors to convert into degrees of subcarrier phase angle the chromatic errors to which a saturated red is subject.

†VIIIth Plenary Assembly, C.C.I.R., Warsaw, 1956, Doc. 605.

In Section 4.3, the authors state that an error of 40 MacAdam σ units will probably be acceptable because they won't often appear. Now first, Mr. James had agreed, elsewhere, to the following description.

0σ < good < 10σ	20σ < poor < 30σ
10σ < fair < 20σ	30σ < bad

and secondly, the argument that such errors won't often occur is precisely the same one as can be used to justify the N.T.S.C. system. In fact the adoption of reduced colour bars is an indication of this very point.

In conclusion, may I remark that none of the more important objections to the N.T.S.C. system which were revealed by the B.B.C.'s field trials was due to lack of constant-luminance operation and that the introduction of a constant-luminance emission without a legal restraint on the sale of receivers other than those designed (more expensively) for that system would result in a number of disappointed viewers which might appreciably retard the satisfactory increase of sales of colour receivers.

Messrs. I. J. P. James and W. A. Karwowski (*in reply*): The saturated-colour areas would stand out as patches of light. The resolution within these areas is reduced and details, e.g. of a woman's dress, or of the petal structure of a flower, are more difficult to discern.

Theoretically, the constant-luminance system is less susceptible to co-channel interference than the N.T.S.C. system. To date, no practical tests have been made to compare the N.T.S.C. and constant-luminance systems with respect to interference, and therefore it is impossible to give a direct answer to this question, especially since the result will be affected appreciably by the design of the colour receiver and possibly by the sign of modulation in the transmitter.

It is surprising that Dr. Maurice has to resort to 100% saturated colours to introduce this point. In both systems all colours inside the colour triangle produce outputs from the three pick-up tubes, and any differences occur only for colours located along the red–blue side of the triangle. The fact that it is not necessary to register three pick-up tubes to a fraction of a picture element in the R Y B system considerably eases the registration problem, especially since misregistration errors do not introduce luminance changes.

The differences, expressed as changes of subcarrier phase angle, between saturated red and the colour reproduced for the cases shown in Figs. 10 and 12 are 11° and 7°, respectively.

The maximum chromatic errors in Fig. 12 occur along the red–blue side of the colour triangle, being 44 MacAdam units at red, dropping to 23 units at magenta and rising to 37 units at blue. Elsewhere in the triangle the errors are less than 20 MacAdam units. It is considered that these few colour errors are not a great penalty to pay for the considerable improvement in definition and ease of camera registration.

As regards the adoption of reduced saturation colour bars, it is important to distinguish between highly saturated, highly luminous colours, which may affect the overload characteristic of the system, and highly saturated low luminance colours, which are more likely to occur in practice.

The most objectionable feature of the N.T.S.C. system revealed by the field trials of the B.B.C. was misregistration (see, e.g., pages 10, 16 and 22 of B.B.C. Monograph No. 32). The employment of the constant-luminance system permits the luminance signals to be derived from a single pick-up tube and this not only improves the registration and definition of the colour picture, but also improves the definition and panchromaticity of the compatible monochrome picture. The extra cost to the manufacturer (5s.) of the subcarrier corrector is not likely to retard the sale of colour receivers. Competition within the industry should ensure that the public will obtain a satisfactory standard of colour reproduction.

Mr. P. M. Thompson (*Associate Member*): In this evening's discussion, considerable stress has been laid upon two things, the quality of a colour signal when viewed on an unmodified black and white receiver, and the ability of a colour system to reproduce several fairly saturated colours. Speaking as one who has observed a fair number of colour television programmes on both colour and monochrome receivers, rather than a specialist in colour television, I feel that the black and white picture resulting from an N.T.S.C. system is entirely adequate, and that the colour picture should not be sacrificed to improve it. Regarding the colour picture, most viewers will accept small distortions in all colours except flesh tones which do not appear to have been used in the evaluations we have heard to-day. I should suggest that in evaluating a colour system we should consider the colour picture primarily, laying particular stress on flesh tones, and let the monochrome picture take care of itself.

Messrs. James and Karwowski (*in reply*): The average shift of reproduced flesh colour from its original colour amounts to about 3° of subcarrier phase in both Figs. 10 and 12, which is well within the normal tolerance for acceptability of flesh reproduction. Since the colour receiver is provided with a phase control, no trouble need therefore be anticipated with flesh reproduction.

Mr. G. B. Townsend: These papers have all dealt with the application of constant-luminance operation to N.T.S.C. colour television, but very similar considerations apply also to their application to SECAM transmissions. Further advantages accrue to SECAM if the chrominance signals are not carrying luminance information: for instance, it may be possible to operate a constant luminance SECAM system synchronously with the public utility mains supply, since the slow perturbation of the delayed chrominance signal with respect to the rest of the picture is probably then tolerable as a not-very-frequently-occurring fault condition.

Dr. E. L. C. White: The advantages claimed in the first paper for the Constant-Luminance System have not been queried in any of the later papers or in the discussion so far, so one may presume that they are generally admitted as valid.

Recapitulating, the advantages comprise improved definition both for the colour receivers and for the monochrome receivers which will almost certainly remain in

(*Discussion continued on page 328*)

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Fluctuation Noise in Two Forms of the N.T.S.C. Colour Television System

By

A. V. LORD, B.Sc.Tech.†

Presented at a meeting of the Television Group in London on 14th December 1961

Summary: A recently proposed modification to the coding of N.T.S.C.-type colour television claims to offer some improvements in the picture displayed by both colour and black-and-white receivers. The effects of fluctuation noise in colour receivers are investigated for both the modified system and the normal form of N.T.S.C. system. The analysis assumes that "flat-spectrum" noise is added to the signal at a point prior to decoding in the receiver, and the visibility of this noise is calculated for a series of test colours; the results given include allowance for the reduction of receiver ratio by ambient light falling upon the screen. It is shown that both systems have a substantially similar sensitivity to fluctuation noise. These findings are discussed in the light of experiments carried out in the U.S.A. and Britain.

1. Introduction

A modification to the coding of N.T.S.C.-type colour television signals has been proposed recently.[1] It is claimed that this modification offers some improvements in the pictures displayed by both colour and monochrome receivers. In this paper, the effects of fluctuation noise in colour receivers are investigated for both the modified and the normal forms of the N.T.S.C. system.

In general, the composite colour signal presented to the decoding circuits of a colour receiver will be accompanied by fluctuation noise; this noise is added to the signal in the radio-frequency stages of the receiver, including the aerial. The spectrum of the added noise is determined by the shape of the receiver pass-band and, in the case of vestigial-sideband reception, is non-uniform. Further, such a receiver introduces colour-signal distortion which results in crosstalk between the luminance and chrominance signals.[2, 3]

For the purposes of comparison it has been assumed here that double-sideband reception is used; this form of reception introduces no inherent distortion and the noise added to the signal has a uniform spectrum.

2. General Considerations

Figure 1 shows the spectrum of a typical "equiband"‡ colour signal and Fig. 2 illustrates the form of a decoder used to convert the composite signal at the receiver detector into signals suitable for a three-gun display.

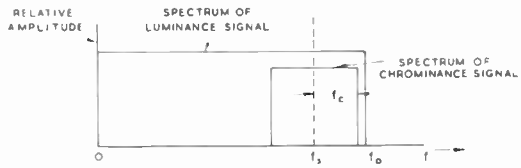

Fig. 1. Composite signal spectrum.

The composite signal has the form

$$E_M = E_L + \frac{1}{K_1}(E_R^{1/\gamma} - E_L)\cos\omega_s t + \frac{1}{K_2}(E_B^{1/\gamma} - E_L)\sin\omega_s t \quad \ldots(1)$$

where E_L represents a general form of luminance signal, and K_1 and K_2 determine the relative amplitudes of the chrominance components in the composite signal. If "flat" noise, of bandwidth f_0, is added to the signal before the decoder, wideband noise N_Y (r.m.s. amplitude $[\overline{N_Y^2}]^{\frac{1}{2}}$) will accompany the signal E_L and the outputs of the two synchronous demodulators will be accompanied by noise of bandwidth f_c. The two low-bandwidth noise fluctuations will have equal r.m.s. values, but will have a quadrature relationship.

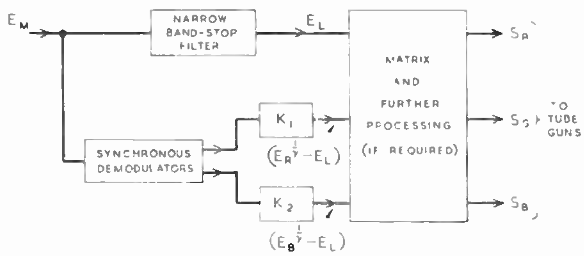

Fig. 2. General form of decoder.

† British Broadcasting Corporation, Research Department, Kingswood Warren, Tadworth, Surrey.

‡ It is assumed that "colour-difference-signal" decoding is employed, and that asymmetric-sideband chrominance components are eliminated by a filter located before the decoder.

Let the two components be represented by N_c' and N_c''. If the synchronous demodulators are regarded as devices producing two outputs equal to the input signal multiplied by 2 cos $\omega_s t$ and 2 sin $\omega_s t$ respectively, it can be shown (see Appendix) that the r.m.s. values of N_c' and N_c'',

$$[\overline{N_c'^2}]^{\frac{1}{2}} \quad \text{and} \quad [\overline{N_c''^2}]^{\frac{1}{2}}$$

are given by

$$[\overline{N_c'^2}]^{\frac{1}{2}} = [\overline{N_c''^2}]^{\frac{1}{2}} = [\overline{N_Y^2}]^{\frac{1}{2}} . \sqrt{\frac{2f_c}{f_0}} \qquad \ldots\ldots(2)$$

Such low-bandwidth noise fluctuations cause two forms of disturbance to the reproduced picture. First, they upset the relative proportions of the colour-difference signals $(E_R^{1/\gamma} - E_L)$ and $(E_B^{1/\gamma} - E_L)$ thus affecting the hue and saturation of the reproduction. Secondly, the properties of the decoder together with the non-linear brightness-against-drive-voltage characteristics of the display tube may prevent full exploitation of the "Constant Luminance Principle".[4] In such circumstances the colour-difference signals contribute to the luminance of the reproduction; the accompanying noise thus causes fluctuations of reproduced luminance.

This paper is concerned solely with the total *luminance* contributions of the noise portrayed by the display, fluctuations of hue and saturation being relatively less visible by some 6 to 8 dB.[4]

The noise contributing to luminance may be considered as two separate parts. First, the luminance channel contains noise between zero frequency and f_c to which further contributions may be made by noise (of the same bandwidth) from the chrominance channels. Secondly, the luminance channel alone contributes noise between f_c and f_0. The amplitudes of these various contributions are determined by the decoding and display processes and are denoted, in the ensuing discussion, by the coefficients a (luminance channel), b ($E_R^{1/\gamma} - E_L$ chrominance channel) and c ($E_B^{1/\gamma} - E_L$ chrominance channel).

Recalling that the noise at the decoder input is N_Y and the synchronous detectors provide noise components N_c' and N_c'', then the total low-frequency noise $(0 - f_c)$ is

$$N_{LF} = N_Y \left\{ a\sqrt{\frac{f_c}{f_0}} + b\sqrt{\frac{2f_c}{f_0}} + c\sqrt{\frac{2f_c}{f_0}} \right\}$$

and the r.m.s. value

$$[\overline{N_{LF}^2}]^{\frac{1}{2}} = [\overline{N_Y^2}]^{\frac{1}{2}} . \sqrt{\frac{f_c}{f_0}} . \sqrt{a^2 + 2b^2 + 2c^2} \quad \ldots(3)$$

The high-frequency noise, contributed by the luminance channel only, may be expressed by

$$N_{HF} = N_Y . a . \sqrt{\frac{f_0 - f_c}{f_0}}$$

and the r.m.s. value

$$[\overline{N_{HF}^2}]^{\frac{1}{2}} = [\overline{N_Y^2}]^{\frac{1}{2}} . a . \sqrt{\frac{f_0 - f_c}{f_0}} \qquad \ldots\ldots(4)$$

Having detailed expressions for the luminance contributions for low- and high-frequency noise, it remains to deduce relationships defining their visibility in relatively large picture areas; in areas containing considerable detail, effects such as beating between signal and noise may introduce added complications.

If the average brightness of the area is Y, the "r.m.s. visibility"† of l.f. noise will be, from (3)

$$\frac{\Delta Y_{LF}}{Y} = \left[\frac{\overline{N_Y^2}}{Y}\right]^{\frac{1}{2}} . \sqrt{\frac{f_c}{f_0}(a^2 + 2b^2 + 2c^2)} \quad \ldots\ldots(5)$$

and for h.f. noise, from (4)

$$\frac{\Delta Y_{HF}}{Y} = \left[\frac{\overline{N_Y^2}}{Y}\right]^{\frac{1}{2}} . a . \sqrt{\frac{f_0 - f_c}{f_c}} \qquad \ldots\ldots(6$$

3. Linear Decoding

Colour receivers employ display tubes whose "light output" against drive-voltage characteristics may be represented by a power law of exponent approximating to 2·2. In the interests of receiver economics and reliability the decoders used are of a form employing linear processes of detection, addition and subtraction.

Referring to Fig. 2 it will be seen that $E_R^{1/\gamma}$ and $E_B^{1/\gamma}$ may be recovered by adding E_L to $(E_R^{1/\gamma} - E_L)$ and $(E_B^{1/\gamma} - E_L)$. In the linear decoder the green colour-difference signal is recovered by the "matrixing" (taking a suitably weighted sum) of $(E_R^{1/\gamma} - E_L)$ and $(E_B^{1/\gamma} - E_L)$.

Repeating eqn. (1)

$$E_M = E_L + \frac{1}{K_1}(E_R^{1/\gamma} - E_L)\cos\omega_s t + \\ + \frac{1}{K_2}(E_B^{1/\gamma} - E_L)\sin\omega_s t$$

in the presence of noise

$$S_R = E_R^{1/\gamma} + N_Y + K_1 N_c' \qquad \ldots\ldots(7)$$

$$S_B = E_B^{1/\gamma} + N_Y + K_2 N_c'' \qquad \ldots\ldots(8)$$

where S_R and S_B are signals applied to the tube guns.

The "matrixing" operation is defined by

$$E_{G\,\text{diff}} = -0{\cdot}51(E_R^{1/\gamma} - E_L) - 0{\cdot}19(E_B^{1/\gamma} - E_L) \quad \ldots(9)$$

where $E_{G\,\text{diff}}$ represents the green colour-difference signal, whence

$$S_G = E_L + N_Y - 0{\cdot}51\{(E_R^{1/\gamma} - E_L) + K_1 N_c'\} - \\ - 0{\cdot}19\{(E_B^{1/\gamma} - E_L) + K_2 N_c''\}$$

† This term is based upon the Fechner Fraction and, as used here, is defined as the ratio of the r.m.s. brightness fluctuation to the mean brightness.

$$= 1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma} + N_Y - \\ -0{\cdot}51.K_1.N_c' - 0{\cdot}19.K_2.N_c'' \quad \ldots(10)$$

Now each gun characteristic may be represented by

$$\left.\begin{array}{l} L = S^\gamma \\ \text{where } L \text{ is the "light output" from a phosphor as the result of an input signal } S. \\ \text{For small perturbations} \\ \dfrac{\delta L}{\delta S} = \gamma S^{\gamma-1} = \gamma\,.\,\dfrac{S^\gamma}{S} \\ \text{and} \quad \lim\limits_{S\to 0} \gamma\,.\,\dfrac{S^\gamma}{S} = 0(\gamma > 1) \end{array}\right\} \ldots(11)$$

Thus the "light outputs" from the three phosphors are, from (7), (8) and (10)

$$L_R = E_R + \gamma\,.\,\frac{E_R}{E_R^{1/\gamma}}\,.\,(N_Y + K_1 N_c') \quad \ldots\ldots(12)$$

$$L_B = E_B + \gamma\,.\,\frac{E_B}{E_B^{1/\gamma}}\,.\,(N_Y + K_2 N_c'') \quad \ldots\ldots(13)$$

$$L_G = (1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma})^\gamma + \\ + \gamma\,.\,\frac{(1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma})^\gamma}{1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma}}\,.\,(N_Y - 0{\cdot}51.K_1.N_c' - 0{\cdot}19.K_2.N_c'') \quad \ldots(14)$$

Therefore the total luminance

$$Y_T = 0{\cdot}3L_R + 0{\cdot}11L_B + 0{\cdot}59L_G \\ = 0{\cdot}3E_R + 0{\cdot}11E_B + 0{\cdot}59(1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma})^\gamma + \\ + \gamma.N_Y\left\{0{\cdot}3\frac{E_R}{E_R^{1/\gamma}} + 0{\cdot}11\frac{E_B}{E_B^{1/\gamma}} + 0{\cdot}59\frac{(1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma})^\gamma}{1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma}}\right\} + \\ + \gamma.N_c'\left\{0{\cdot}3.K_1\,.\,\frac{E_R}{E_R^{1/\gamma}} - 0{\cdot}59.0{\cdot}51.K_1\frac{(1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma})^\gamma}{1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma}}\right\} + \\ + \gamma.N_c''\left\{0{\cdot}11.K_2\,.\,\frac{E_B}{E_B^{1/\gamma}} - 0{\cdot}59.0{\cdot}19.K_2\frac{(1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma})^\gamma}{1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma}}\right\} \quad \ldots(15)$$

whence Y, a, b and c of eqn. (5) and (6) are

$$Y = 0{\cdot}3E_R + 0{\cdot}11E_B + 0{\cdot}59(1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma})^\gamma \quad \ldots\ldots(16)$$

$$a = \gamma\left\{0{\cdot}3\frac{E_R}{E_R^{1/\gamma}} + 0{\cdot}11\frac{E_B}{E_B^{1/\gamma}} + 0{\cdot}59\frac{(1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma})^\gamma}{1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma}}\right\} \quad \ldots\ldots(17)$$

$$b = \gamma.0{\cdot}3.K_1\left\{\frac{E_R}{E_R^{1/\gamma}} - \frac{(1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma})^\gamma}{1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma}}\right\} \quad \ldots\ldots(18)$$

$$c = \gamma.0{\cdot}11.K_2\left\{\frac{E_B}{E_B^{1/\gamma}} - \frac{(1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma})^\gamma}{1{\cdot}7E_L - 0{\cdot}51E_R^{1/\gamma} - 0{\cdot}19E_B^{1/\gamma}}\right\} \quad \ldots\ldots(19)$$

3.1 *Specific Systems with Linear Decoding*

The quantities Y, a, b and c may now be deduced for specific systems. For the N.T.S.C. system with N.T.S.C. decoding,

$$E_M = E_Y' + \frac{1}{1{\cdot}14}(E_R^{1/\gamma} - E_Y')\cos\omega_s t + \\ + \frac{1}{2{\cdot}03}(E_B^{1/\gamma} - E_Y')\sin\omega_s t$$

where $E_Y' = 0{\cdot}3E_R^{1/\gamma} + 0{\cdot}59E_G^{1/\gamma} + 0{\cdot}11E_B^{1/\gamma}$

Whence, from (16), (17), (18) and (19)

$$\left.\begin{array}{l} Y = 0{\cdot}3E_R + 0{\cdot}59E_G + 0{\cdot}11E_B \\ a = \gamma\left(0{\cdot}3\dfrac{E_R}{E_R^{1/\gamma}} + 0{\cdot}11\dfrac{E_B}{E_B^{1/\gamma}} + 0{\cdot}59\dfrac{E_G}{E_G^{1/\gamma}}\right) \\ b = \gamma.0{\cdot}342\left(\dfrac{E_R}{E_R^{1/\gamma}} - \dfrac{E_G}{E_G^{1/\gamma}}\right) \\ \text{and} \quad c = \gamma.0{\cdot}223\left(\dfrac{E_B}{E_B^{1/\gamma}} - \dfrac{E_G}{E_G^{1/\gamma}}\right) \end{array}\right\} \quad (20)$$

For the "modified N.T.S.C." system[1] with N.T.S.C. decoding

$$E_M = E_Y^{1/\gamma} + \frac{1}{1{\cdot}14}(E_R^{1/\gamma} - E_Y^{1/\gamma})\cos\omega_s t + \\ + \frac{1}{2{\cdot}03}(E_B^{1/\gamma} - E_Y^{1/\gamma})\sin\omega_s t$$

where $E_Y^{1/\gamma} = (0{\cdot}3E_R + 0{\cdot}59E_G + 0{\cdot}11E_B)^{1/\gamma}$

Again from (16), (17), (18) and (19)

$$\left.\begin{aligned} Y &= 0{\cdot}3E_R+0{\cdot}11E_B+0{\cdot}59(1{\cdot}7E_Y^{1/\gamma}-0{\cdot}51E_R^{1/\gamma}-0{\cdot}19E_B^{1/\gamma})^{\gamma} \\ a &= \gamma\left\{0{\cdot}3\frac{E_R}{E_R^{1/\gamma}}+0{\cdot}11\frac{E_B}{E_B^{1/\gamma}}+0{\cdot}59\frac{(1{\cdot}7E_Y^{1/\gamma}-0{\cdot}51E_R^{1/\gamma}-0{\cdot}19E_B^{1/\gamma})^{\gamma}}{1{\cdot}7E_Y^{1/\gamma}-0{\cdot}51E_R^{1/\gamma}-0{\cdot}19E_B^{1/\gamma}}\right\} \\ b &= \gamma.0{\cdot}342\left\{\frac{E_R}{E_R^{1/\gamma}}-\frac{(1{\cdot}7E_Y^{1/\gamma}-0{\cdot}51E_R^{1/\gamma}-0{\cdot}19E_B^{1/\gamma})^{\gamma}}{1{\cdot}7E_Y^{1/\gamma}-0{\cdot}51E_R^{1/\gamma}-0{\cdot}19E_B^{1/\gamma}}\right\} \\ \text{and}\quad c &= \gamma.0{\cdot}223\left\{\frac{E_B}{E_B^{1/\gamma}}-\frac{(1{\cdot}7E_Y^{1/\gamma}-0{\cdot}51E_R^{1/\gamma}-0{\cdot}19E_B^{1/\gamma})^{\gamma}}{1{\cdot}7E_Y^{1/\gamma}-0{\cdot}51E_R^{1/\gamma}-0{\cdot}19E_B^{1/\gamma}}\right\} \end{aligned}\right\} \quad \ldots\ldots(21)$$

4. Non-linear Decoding

If certain non-linear processes are incorporated, the decoder of Fig. 2 may be used to derive $E_G^{1/\gamma}$ correctly from a composite signal of the "Modified N.T.S.C." type. Figure 3 shows details of the non-linear decoder.

For the "modified" signal

$$E_M = E_Y^{1/\gamma}+\frac{1}{K_1}(E_R^{1/\gamma}-E_Y^{1/\gamma})\cos\omega_s t+\frac{1}{K_2}(E_B^{1/\gamma}-E_Y^{1/\gamma})\sin\omega_s t \quad \ldots\ldots(22)$$

In the presence of noise

$$S_R = E_B^{1/\gamma}+N_Y+K_1N_c' \quad \ldots\ldots(23)$$

$$S_B = E_B^{1/\gamma}+N_Y+K_2N_c'' \quad \ldots\ldots(24)$$

and

$$S_G = \{1{\cdot}7(E_Y^{1/\gamma}+N_Y)^{\gamma}-0{\cdot}51(E_R^{1/\gamma}+N_Y+K_1N_c')^{\gamma}-0{\cdot}19(E_B^{1/\gamma}+N_Y+K_2N_c'')^{\gamma}\}^{1/\gamma} \quad \ldots\ldots(25)$$

From (23), (24), (25) and (11)

$$L_R = E_R+\gamma\frac{E_R}{E_R^{1/\gamma}}(N_Y+K_1N_c') \quad \ldots\ldots(26)$$

$$L_B = E_B+\gamma\frac{E_B}{E_B^{1/\gamma}}(N_Y+K_2N_c'') \quad \ldots\ldots(27)$$

$$\begin{aligned} L_G &= 1{\cdot}7(E_Y^{1/\gamma}+N_Y)^{\gamma}-0{\cdot}51(E_R^{1/\gamma}+N_Y+K_1N_c')^{\gamma}-0{\cdot}19(E_B^{1/\gamma}+N_Y+K_2N_c'')^{\gamma} \\ &= E_G+\gamma\left\{N_Y\left(1{\cdot}7\frac{E_Y}{E_Y^{1/\gamma}}-0{\cdot}51\frac{E_R}{E_R^{1/\gamma}}\right)-0{\cdot}19\frac{E_B}{E_B^{1/\gamma}}-0{\cdot}51K_1N_c'\frac{E_R}{E_R^{1/\gamma}}-0{\cdot}19K_2N_c''\frac{E_B}{E_B^{1/\gamma}}\right\} \end{aligned} \quad \ldots(28)$$

From (26), (27) and (28), the total luminance

$$Y_T = 0{\cdot}3E_R+0{\cdot}59E_G+0{\cdot}11E_B+\gamma.N_Y.\frac{E_Y}{E_Y^{1/\gamma}} = E_Y+\gamma.N_Y.\frac{E_Y}{E_Y^{1/\gamma}} \quad \ldots\ldots(29)$$

whence

$$Y = E_Y$$

$$a = \gamma.\frac{E_Y}{E_Y^{1/\gamma}}$$

$$b = 0$$

and

$$c = 0$$

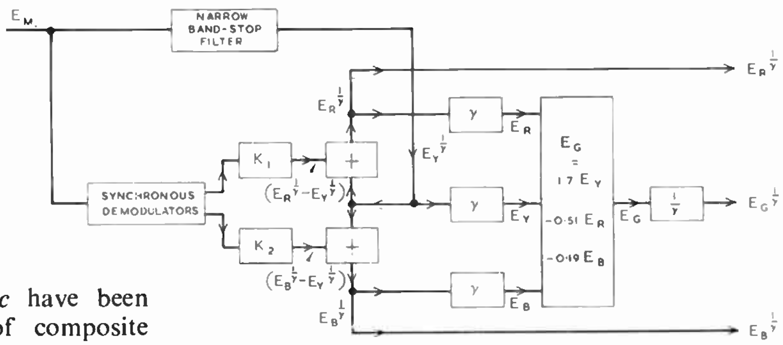

Fig. 3. Non-linear detector.

5. Results and Discussion

Expressions defining Y, a, b and c have been obtained for various combinations of composite signal and receiver decoder. By applying these expressions, the "r.m.s. visibilities" of l.f. and h.f. noise have been determined for a series of test colours[5] (after normalization for white luminance) together with the three saturated additive primaries and white. The ratio f_c/f_0 was assumed equal to $\frac{1}{8}$.

No attempt has been made to derive results representing the combined visibility of l.f. and h.f. noise. There is some evidence[6] that masking of low-frequency fluctuations by high-frequency components would make such a result rather suspect.

Table 1 shows the "visibilities" of the noise displayed when using three different signal/decoder combinations. The results are tabulated in terms of both the Fechner fraction $\Delta Y/Y$ and the relative unit, the decilum.†

An attempt has also been made, in Table 2, to present results corrected for two additional factors. These are:

(*a*) variation in the Fechner fraction $\Delta Y/Y$ as a function of luminance level Y and

(*b*) the available maximum contrast of the viewed picture.

The corrections[7] have been deduced assuming

† Relative visibility $= 20 \log_{10} \dfrac{\Delta Y_1/Y_1}{\Delta Y_2/Y_2}$ decilums.

Table 1

Uncorrected "Visibilities" of L.F. and H.F. Noise.

				N.T.S.C. System with N.T.S.C. Decoder				"Modified" System with N.T.S.C. Decoder				"Modified" System with Non-linear Decoder			
Colour	E_R	E_G	E_B	$\frac{\Delta Y_{LF}}{Y}$	L.F. Noise Vis. dl	$\frac{\Delta Y_{HF}}{Y}$	H.F. Noise Vis. dl	$\frac{\Delta Y_{LF}}{Y}$	L.F. Noise Vis. dl	$\frac{\Delta Y_{HF}}{Y}$	H.F. Noise Vis. dl	$\frac{\Delta Y_{LF}}{Y}$	L.F. Noise Vis. dl	$\frac{\Delta Y_{HF}}{Y}$	H.F. Noise Vis. dl
Red	0·468	0·068	0·084	1·70	6·79	3·91	5·62	1·56	6·04	3·82	5·39	1·63	6·42	4·32	6·44
Yellow	1·061	0·628	0·047	0·923	1·45	2·35	1·18	0·885	1·10	2·25	0·798	0·920	1·44	2·42	1·43
Green	0·119	0·467	0·107	1·34	4·71	3·28	4·08	1·09	2·92	3·07	3·50	1·30	4·45	3·43	4·45
Cyan	0·047	0·256	0·223	1·66	6·57	4·13	6·06	1·58	6·15	3·87	5·51	1·63	6·42	4·32	6·44
Blue	0·017	0·014	0·274	3·35	12·7	6·72	10·3	2·87	11·3	6·64	10·2	3·19	12·2	8·43	12·3
R	1·000	0	0	1·47	5·53	2·05	0	1·16	3·46	2·67	2·29	1·33	4·64	3·52	4·68
G	0	1·000	0	1·09	2·92	2·05	0	0·812	0·34	1·53	−2·53	0·984	2·01	2·60	2·06
B	0	0	1·000	2·38	9·71	2·05	0	1·61	6·32	3·29	4·11	2·10	8·61	5·55	8·66
White	1·000	1·000	1·000	0·779	0	2·05	0	0·779	0	2·05	0	0·779	0	2·05	0

Table 2.

Corrected Relative "Visibilities" of H.F. and L.F. Noise.

	N.T.S.C. System with N.T.S.C. Decoder						"Modified" System with N.T.S.C. Decoder						"Modified" System with Non-linear Decoder					
COLOUR	L.F. Noise Visibility 50 : 1 Contrast	Corrected L.F. Noise Vis. (Low Adapt.)	Corrected L.F. Noise Vis. (High Adapt.)	H.F. Noise Visibility 50 : 1 Contrast	Corrected H.F. Noise Vis. (Low Adapt.)	Corrected H.F. Noise Vis. (High Adapt.)	L.F. Noise Visibility 50 : 1 Contrast	Corrected L.F. Noise Vis. (Low Adapt.)	Corrected L.F. Noise Vis. (High Adapt.)	H.F. Noise Visibility 50 : 1 Contrast	Corrected H.F. Noise Vis. (Low Adapt.)	Corrected H.F. Noise Vis. (High Adapt.)	L.F. Noise Visibility 50 : 1 Contrast	Corrected L.F. Noise Vis. (Low Adapt.)	Corrected L.F. Noise Vis. (High Adapt.)	H.F. Noise Visibility 50 : 1 Contrast	Corrected H.F. Noise Vis. (Low Adapt.)	Corrected H.F. Noise Vis. (High Adapt.)
	dl	dl	dl	dl	dl	dl	dl	dl	dl	dl	dl	dl	dl	dl	dl	dl	dl	dl
Red	6·1	5·1	2·1	4·9	3·9	0·9	5·4	4·4	1·9	4·8	3·8	1·3	5·7	4·7	1·7	5·8	4·8	1·8
Yellow	1·4	1·4	0·9	1·1	1·1	0·6	1·0	1·0	0·5	0·7	0·7	0·2	1·4	1·4	0·9	1·4	1·4	0·9
Green	4·2	3·7	2·2	3·7	3·2	1·7	2·6	2·1	0·6	3·2	2·7	1·2	4·0	3·5	2·0	4·1	3·6	2·1
Cyan	5·9	4·9	1·9	5·3	4·3	1·3	5·5	4·5	2·0	4·9	3·9	1·4	5·7	4·7	1·7	5·8	4·8	1·8
Blue	9·5	6·5	−0·5	7·2	4·2	−2·8	8·9	6·4	0·9	7·8	5·3	−0·2	9·1	6·1	−0·9	9·2	6·2	−0·8
R	5·1	4·6	2·6	−0·4	−0·9	−2·9	3·2	2·7	1·7	2·1	1·6	0·6	4·2	3·7	1·7	4·3	3·8	1·8
G	2·7	2·7	1·7	−0·1	−0·1	−1·1	0·4	0·4	0·4	−2·6	−2·6	−2·6	1·8	1·8	0·8	1·9	1·9	0·9
B	8·4	6·4	2·4	−1·3	−3·3	−7·3	5·7	4·7	2·2	3·5	2·5	0	7·4	5·4	1·4	7·4	5·4	1·4
White	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(i) that the relative visibility of noise over a certain scale of luminance (with different colours) is the same as that over an equivalent grey scale.

(ii) that the peak-white display luminance is 10 foot-lamberts and the contrast ratio is limited, by ambient and flare light, to 50 : 1.

Tables 1 and 2 show that, for the saturated colours likely to be encountered in practice, the modified N.T.S.C. system is characterized by only a slightly reduced sensitivity to fluctuation noise when compared with the normal form of N.T.S.C. system. This is well illustrated in Table 2 where, for example, the l.f. noise visibility for any one of the five test colours (Red, Yellow, Green, Cyan and Blue), viewed in low-level ambient illumination, does not vary by more than 1·6 dl for the three signal/decoder combinations. Under these same conditions, the corresponding maximum variation of h.f. noise visibility is 2 dl.

Although the results quoted here have been obtained using a somewhat simplified theoretical approach, it would appear that there is a reasonable degree of agreement with practical experience. This may be illustrated by the following argument. A perfect constant-luminance colour television system may be regarded as a conventional monochrome system to which a signal describing chromaticity only has been added; the "noise sensitivity" of such a system would be essentially identical to that of the monochrome system alone. It has been shown, both in the U.S.A.[8] and in Britain,[9] that the normal form of N.T.S.C. system is only some 1 or 2 dB more sensitive to fluctuation noise than the equivalent monochrome system.

6. Acknowledgments

The author wishes to thank the Director of Engineering of the B.B.C. for permission to publish this paper and to acknowledge the helpful comments made by members of the T.A.C./T.S.C. Constant Luminance Working Party. Thanks are also due to Mr. J. G. Ingleton who computed Tables 1 and 2.

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8. Appendix

If a signal $E \cos \omega_s t$ is applied to a synchronous detector, the local carrier phase may be chosen such that the output of the detector is represented by

$$E \cos \omega_s t \,.\, \cos \omega_s t = \frac{E}{2}(1+\cos 2\omega_s t)$$

whence

$$E_s = \frac{E}{2} \text{ after filtering} \quad \ldots(30)$$

Referring to Fig. 1, the wide-band noise N_Y is first filtered to a band extending from $f_s - f_c$ to $f_s + f_c$.

This noise may be written:[10]

$$N = x(t)\cos \omega_s t + y(t) \sin \omega_s t \quad \ldots\ldots(31)$$

where $x(t)$ and $y(t)$ are "slowly varying" functions of time.

The r.m.s. value

$$[\overline{N^2}]^{\frac{1}{2}} = [\overline{N_Y^2}]^{\frac{1}{2}} \,.\, \sqrt{\frac{2f_c}{f_0}} \quad \ldots\ldots(32)$$

whence the r.m.s value of each component

$$[\overline{\{x(t)\cos \omega_s t\}^2}]^{\frac{1}{2}} = [\overline{\{y(t)\sin \omega_s t\}^2}]^{\frac{1}{2}} = [\overline{N_Y^2}]^{\frac{1}{2}} \sqrt{\frac{f_c}{f_0}} \quad \ldots\ldots(33)$$

Now

$$[\overline{\{x(t)\cos \omega_s t\}^2}]^{\frac{1}{2}} = \sqrt{\frac{1}{T}\int_0^T \{x(t)\cos \omega_s t\}^2 . dt}$$

$$= \sqrt{\frac{1}{2T}\int_0^T \{x(t)\}^2 . dt + \frac{1}{2T}\int_0^T \{x(t)\}^2 \cos 2\omega_s t \,.\, dt}$$

If T is large then

$$[\overline{\{x(t)\cos \omega_s t\}^2}]^{\frac{1}{2}} = \sqrt{\frac{1}{2T}\int_0^T \{x(t)\}^2 . dt}$$

$$= \frac{1}{\sqrt{2}}[\overline{\{x(t)\}^2}]^{\frac{1}{2}} \quad \ldots\ldots(34)$$

After synchronous detection, the noise is

$$N' = x(t)\cos\omega_s t \,.\, \cos\omega_s t$$

$$= \frac{x(t)}{2} \text{ (ignoring high frequency components)} \qquad \ldots\ldots(35)$$

whence r.m.s. noise

$$[\overline{N'^2}]^{\frac{1}{2}} = \tfrac{1}{2}[\overline{\{x(t)\}^2}]^{\frac{1}{2}}$$

$$= \frac{\sqrt{2}}{2} \,.\, [\overline{\{x(t)\cos\omega_s t\}^2}]^{\frac{1}{2}} \quad \text{(from (34))}$$

whence from (33)

$$[\overline{N'^2}]^{\frac{1}{2}} = \frac{\sqrt{2}}{2} \,.\, [\overline{N_Y^2}]^{\frac{1}{2}} \,.\, \sqrt{\frac{f_c}{f_0}} \qquad \ldots\ldots(36)$$

Normalizing both signal and noise amplitudes for unity gain we have, from (30) to (36).

$$\text{Signal component } E_s = E \qquad \ldots\ldots(37)$$

and the r.m.s. noise

$$[\overline{N'^2}]^{\frac{1}{2}} = [\overline{N_Y^2}]^{\frac{1}{2}} \,.\, \sqrt{\frac{2f_c}{f_0}} \qquad \ldots\ldots(38)$$

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DISCUSSION *(Continued)*

the majority for many years after the introduction of a colour service.

The objections to the system have been on the score that the simplest possible receiver for which the N.T.S.C.-type signal was designed, would give unacceptable colour distortion, and that a receiver to suit the Constant-Luminance signal exactly would be considerably more expensive. But there has been no agreement on the criteria to use on colour distortion. Mr. Sproson has proposed a range of extreme colours, but his colleagues have sometimes gone outside this range in order to make a point.

A fairly inexpensive way of improving the colour rendering of the simple receiver has been described and I have little doubt that if the Constant-Luminance System is adopted, receiver designers would lend their ingenuity to reducing the extra cost till it is negligible.

Messrs. James and Karwowski (*in reply*): We agree with Dr. White's comments, in particular with reference to the lack of accurate criteria on colour distortion in television reproducing systems. Most of the criticisms to date have been based on matching data, e.g. by MacAdam and by Judd, rather than on acceptability of reproduction, where the original scene is rarely available for comparison, and where viewing is seldom carried out under similar conditions of adaptation.

Mr. E. Ribchester: It is claimed that an advantage of negative modulation is that intercarrier sound detection is possible with frequency modulation of the sound carrier. The implication is that intercarrier detection will not be possible if positive modulation is employed.

This in fact is not the case. Provided the bottom of the sync. pulses is set at about 10% carrier instead of zero carrier then intercarrier detection is perfectly satisfactory and slightly less "intercarrier buzz" is present in the sound output.

Mr. I. J. P. James (*Member*): As a comment on Mr. G. F. Newell's paper, it is of interest to note that a patent by Dr. W. S. Percival (B.P. 665,267) shows that vestigial sideband errors in television receivers can be reduced by attenuating the higher frequency signal components prior to detection and subsequently "boosting" them.

Mr. G. D. Monteath (*Communicated*): One of the advantages claimed for a truly constant luminance system is the possibility of using a camera in which one of the three tubes (the "Y-tube") has a photopic response giving the luminance signal directly. Such a camera would avoid the impairment of luminance sharpness by misregistration of tubes and by beam-pulling. Would it not be reasonable to use a camera of this type with the existing N.T.S.C. system? The arrangement would be as follows:—

There are three linear camera tubes: Y (photopic), R (red) and B (blue). The outputs are matrixed before gamma-correction to produce an E_G (green) separation signal. The three separation signals, E_R, E_G and E_B are then treated like the outputs of three tubes in a conventional camera; in other words they are gamma-corrected and matrixed in the usual way.

It can be shown that in grey regions small errors in the outputs of the R and B tubes make only a second-order contribution to the luminance signal. One might therefore expect misregistration and beam-pulling to have less effect than in a conventional camera. In saturated green regions only one tube is operative. The advantages gained from the use of a Y tube would, however, tend to be lost in the presence of saturated colours remote from green, which are inherently less luminous. But sharpness is less important in the darker parts of the picture.

There can be no doubt that only a constant-luminance system will enable the advantages offered by a Y tube to be exploited fully. Nevertheless, it seems possible that a camera of this type could confer some benefit on the conventional N.T.S.C. system.

Messrs. James and Karwowski (*in reply*): With regard to the suggested camera arrangement, it is difficult to give a definite answer without very careful study. At first glance it would appear that the Y tube would introduce less beam-pulling, because of the presence of the red and blue components. However, it is doubtful whether any advantages would outweigh the disadvantages.

We agree that, to exploit the Y tube to the full, it is better to use the constant-luminance system.