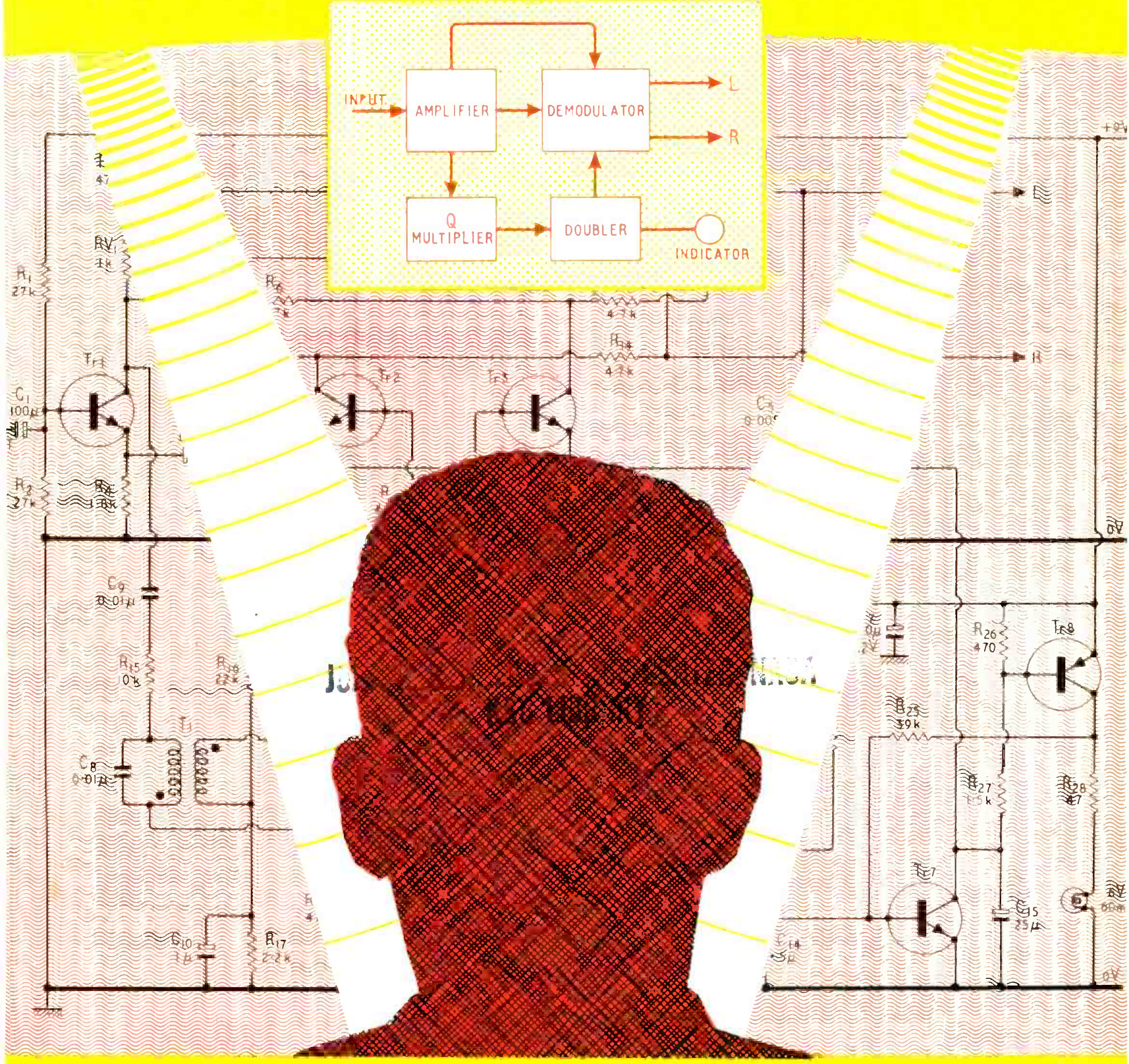
CONSTRUCTING A STEREO DECODER

JANUARY 1967
Three Shillings

# Wireless World

ELECTRONICS • TELEVISION • RADIO • AUDIO



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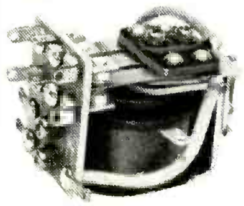

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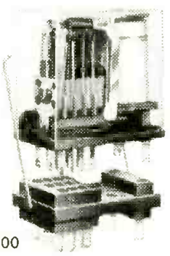

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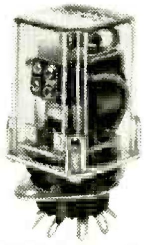

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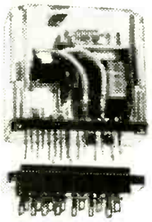

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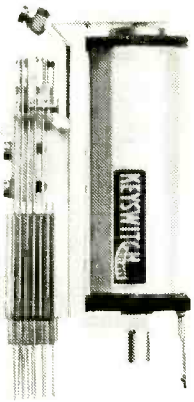

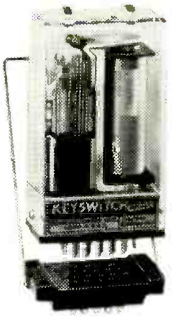

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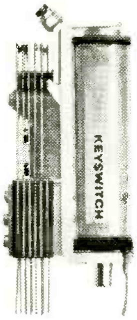

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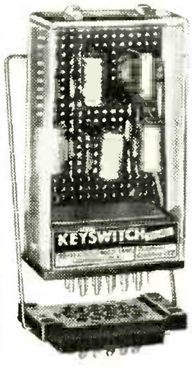

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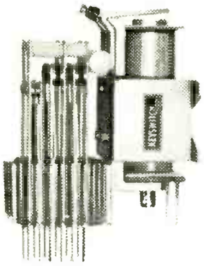

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## Symbols: the Common Language

THE Oslo decision, or rather indecision, on colour television last October, tended to obscure other happenings at this meeting of the C.C.I.R. One of these was the recommendation that the unit of frequency should in future be known as a Hertz instead of the familiar and meaningful cycles per second. The Germans and some other Continentals have used the unit, abbreviated Hz, for many years and when one has read an article in, say, a German journal in which the abbreviation is used one has mentally said "cycles per second." Now the Americans have adopted, or are adopting, Hz. What of the U.K.? Although no international decision can be taken on the C.C.I.R. recommendation until the next Plenary Assembly of the I.T.U., which will not be until 1970, some British organizations, including the B.B.C. in certain documents, are already adopting Hz. As will be seen in the advertisements in this journal some manufacturers are also using it, but editorially we have not yet done so.

Some will consider us to be out of step, but what are the pros and cons? Certainly standardization is to be encouraged to facilitate the easy exchange of information; and it also assists in the export field. Any change, no matter how justifiable is bound to raise the ire in some, and there are many in the industry and elsewhere who cannot see the justification for this change. The main criticism is that Hz does not directly indicate the property of frequency as does c/s. However, if the concensus of opinion is to use the name Hertz, to perpetuate the memory of the German scientist who in 1880 discovered "electric waves," then we will, of course, make the change. In the meantime we would welcome comments.

From literal to graphical symbols. A correspondent in *Electronics & Power* condemns some of the symbols introduced in the new British Standard "Graphical Symbols for Electrical Power, Telecommunications and Electronics Diagrams" (BS3939) which he says reduces a circuit diagram to "an amorphous mass." The symbols in this new Standard, to quote from the introduction, "are identical with those internationally agreed within the International Electrotechnical Commission except where established usage in this country makes acceptance of the international standard impracticable at the present time. When in such cases an 'objective symbol' is shown it is intended that it be adopted as soon as practicable in the future, the aim being to achieve complete conformity with the IEC Recommendation as early as practicable." One such "objective symbol" is a rectangle for a resistor in place of the familiar zig-zag. As the correspondent in *Electronics & Power* points out the place for such a rectangle depicting the physical shape of a component without any indication of its function is on the wiring diagram. The same symbol incidentally is also used for resistance in an equivalent circuit.

As graphical symbols are intended to be an international common language, standardization is, of course, of prime importance, but we question the value of a symbol which is as featureless and ambiguous as an open box.

The issuing of a British Standard has come to be regarded largely as a matter of giving formal ratification to what has already become accepted practice in the U.K. Why, we wonder in the case of graphical symbols have B.S.I. suddenly broken away from this well-tried procedure, which few quarrel with (or even notice)? It rather looks as if their lack of initiative has made them too compliant to what, in this case, the Continental members of I.E.C. have already decided.

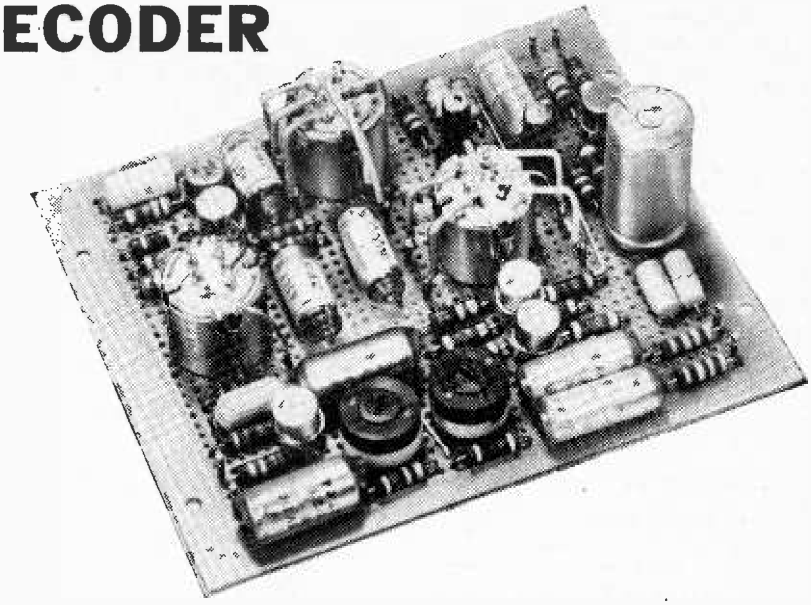
VOL 73 NO 1
JANUARY 1967

# A STEREO DECODER

## DESIGN USING N-P-N OR P-N-P TRANSISTORS

**Circuit based on silicon or germanium transistors ■ > 30dB channel separation ■ uses 19kc/s Q multiplier ■ shunt transistor switching demodulator ■ optional RC active filter ■ stereo indicator**

**By D. E. O'N. WADDINGTON***
**A.M.I.E.R.E.**



NOW that the transmission of stereophonic signals in the U.K. is a reality, albeit on a limited scale, interest in decoders to enable the reception of these programmes has naturally increased. The author has been investigating the problems involved, and the circuit and techniques to be described in this article are the result.

Before attempting to design, or build, a decoder, the first essential is to understand the nature of the signal to be processed.[1, 2] In the pilot tone system the signal is produced as follows (see Fig. 1). Two basic signals, $R$ corresponding to the audio frequency signal intended for the right-hand loudspeaker and $L$ corresponding to that intended for the left, are obtained from the microphones. $L$ and $R$ are then added in phase and in anti-phase to produce the two signals $L+R$ and $L-R$. The $L-R$ signal is then modulated on to a 38 kc/s carrier in a double balanced modulator circuit which ensures that only the modulation products emerge. The $L+R$ signal, the $L-R$ modulation products and a 19 kc/s pilot signal, which is phase coherent with the 38 kc/s subcarrier, are all added together and this forms the signal which is to be transmitted. Fig. 2 shows the spectrum of a signal carrying only 1 kc/s (slightly distorted) in one channel.

Although the signal is normally made up in this fashion, it could be generated by using a system which sampled the left- and right-hand channels alternately at a 38 kc/s rate using a sine wave (see Fig. 3). This produces the same effect as described above and is, possibly, easier to understand. This sampling concept for the generation of the signal offers an easy solution to the problem of reproducing the left- and right-hand channels information as it is only necessary to use two phase-sensitive rectifiers, coherent with the sampling signal. Thus, the tasks of the decoder are as follows:—

1. pick out the pilot tone (19 kc/s),
2. using the pilot tone as a reference, regenerate the sampling signal in the correct phase relationship,
3. extract the left- and right-hand channel information using phase sensitive detectors,
4. matrixing. (As the phase sensitive detectors will not be 100% efficient, it will be necessary to process the signal in order to obtain adequate channel separation.)

### Pilot tone extraction

The pilot tone may be extracted by a simple parallel tuned circuit as shown in Fig. 4. This method has the disadvantage that the $Q$ of the circuit is low thus per-

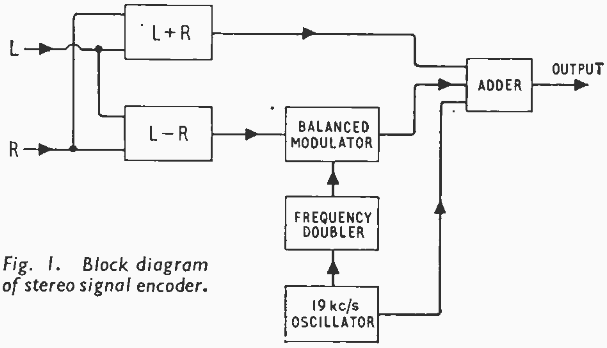


*Fig. 1. Block diagram of stereo signal encoder.*

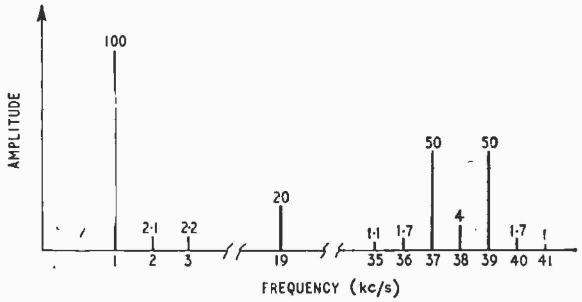


*Fig. 2. Frequency spectrum at output of stereo encoder with slightly distorted 1 kc/s signal in one channel.*

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*Marconi Instruments Ltd.

mitting other signals, besides the 19 kc/s, through. This, in itself, is no fault as it is possible to improve the quality of the signal by further filtering. However, there is always the possibility that some non-linearity in the circuit may cause the spurious signals to modulate the 19 kc/s tone. The effect of this is to cause a degradation of the channel separation. In order to overcome this problem a $Q$ multiplier circuit[3] as shown in Fig. 5 is used. This works as follows. The input signal across the tuned circuit is fed, in phase, *via* the transformer to the base of the transistor. The output at the emitter is fed directly to the bottom of the tuned circuit, thus causing it to follow the input. At resonance, therefore, the tuned circuit looks like a very high impedance but, as the frequency is changed, its impedance falls off rapidly. As only a moderate improvement in the $Q$ of the tuned circuit is necessary, the circuit has been designed to have a fairly wide stability margin.

## Sub-carrier or sampling signal regeneration

There are three main methods of doing this, namely: locking a 38 kc/s oscillator to the pilot, feeding the pilot to a tuned frequency doubling circuit or full-wave rectifying the pilot and then filtering. The author has tried out all three methods and has found that, although all three methods work, the first two tend to be unsatisfactory as the input/output phase relationship changes with pilot tone level. This means that the channel separation will be very dependent upon the input signal. The full-wave rectifier system does not suffer from this defect and thus was included in the circuit. It was found convenient to feed the rectified signal direct to a simple limiting amplifier with the collector tuned to 38 kc/s. (See Fig. 9.) The biasing of this amplifier is arranged such that, until the 19 kc/s signal reaches a sufficient amplitude, the transistor is cut off thus preventing any switching signal from reaching the bases of Tr2 and Tr3. When the pilot tone threshold is exceeded, however, the base of Tr6 becomes forward biased and the switching signal is amplified. At the same time Tr7 is switched on. This removes the reverse bias from the bases of Tr2 and Tr3 and permits them to operate as normal shunt gates. (Normally Tr2 and Tr3 are cut off so that they do not interfere with the mono signals.) This same switching action is used to operate a lamp so as to give an indication when a stereo signal is being received.

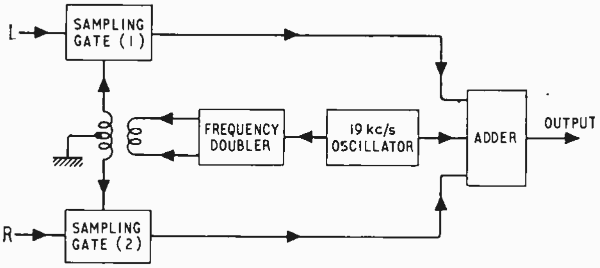


Fig. 3. Sampling method of stereo signal encoding.

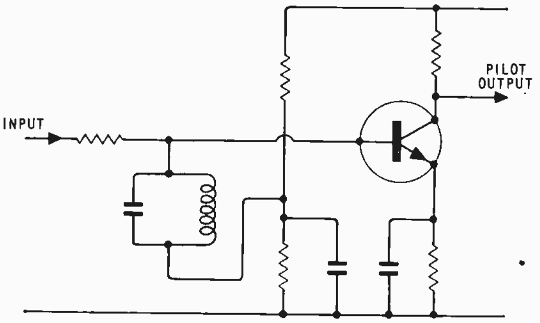


Fig. 4. Simple method of pilot tone extraction.

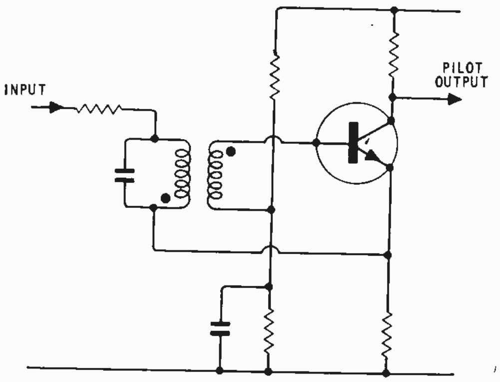


Fig. 5. Q multiplier method of pilot tone extraction.

**Main Performance Features**

Compatible with stereo or mono transmissions.
Stereo channel separation: 30 dB or better 50 c/s—15 kc/s.
Stereo gain: 0.3.
Mono gain: 0.6.
Input impedance: >10kΩ
Distortion: <0.1% (mono)
Noise: mono: <100 μV
stereo: no satisfactory measurement has been made.
Power: 9 V, 8 mA mono; 69 mA stereo.

## Phase sensitive detection

This may be accomplished either by shunt or series gating and either method may be designed to give satisfactory results. Whichever method is used, however, the important requirement of the switching element is that it should approximate, as nearly as possible, to a perfect switch, i.e., it should switch between open circuit and short circuit conditions without introducing any distortion or generating any "switch rate" potential in series with the output. While mechanical switches fulfil these requirements, they do not operate fast enough. Thus, we are left with semiconductors (or vacuum tubes) as switching elements.

**Diodes**—These are very effective switches as they have on/off resistance ratios varying from $10^3:1$ to $> 10^7:1$. However, in the "on" state there is always a potential drop across the diode, approximately 0.2 V for germanium and approximately 0.6 V for silicon. This makes them unsuitable for simple shunt gating as, inevitably, a voltage at the switching frequency is developed in series with the signal. By using two diodes in a series gate,

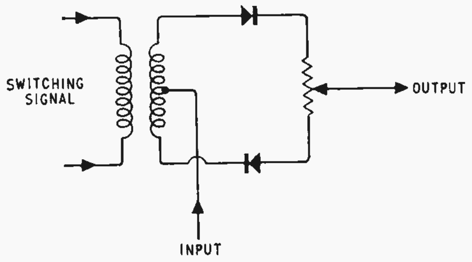


*Fig. 6. Balanced diode series gate.*

however, it is relatively easy to balance out the diode potentials (Fig. 6).

**Bipolar transistors.**—These may make very good switches as the on/off ratio is very high. The voltage drop across a transistor in the "on" state may well be less than 10 mV. Thus they are suitable both as series and shunt switches. However, when used as series switches they pose a problem as the current holding the transistor switched on must not be permitted to flow through any impedance in the signal path. This means that a transformer with an isolated secondary winding must be used. (Fig. 7.) The shunt gate poses no such problem and has been used in this design.

**Field effect transistors.**—These make the best semiconductor switch as the gate requires only a potential to switch the channel on and off and there is no voltage drop between the source and the drain when the device is on. F.E.Ts. may thus be used either as shunt or series gates without the necessity for any of the precautions required by diode and transistor switches. Fig. 8 shows a configuration which was tried, with a considerable degree of success. It was not used in the final version of the decoder because the performance of the bipolar shunt gate was good enough and, at present, the price of field effect transistors is much higher than that for bipolars.

## Matrixing

When using phase sensitive detection matrixing is an unfortunate necessity as a certain amount of the $L$ signal will always be present in the $R$ signal and vice versa. Thus if the right hand output is $R+0.1\ L$ it is necessary to add $-0.1\ L$ to this signal to cancel out the unwanted signal. In Fig. 9, it is seen that this antiphase signal is produced at the collector of Tr1 and is added to the signal at the output.

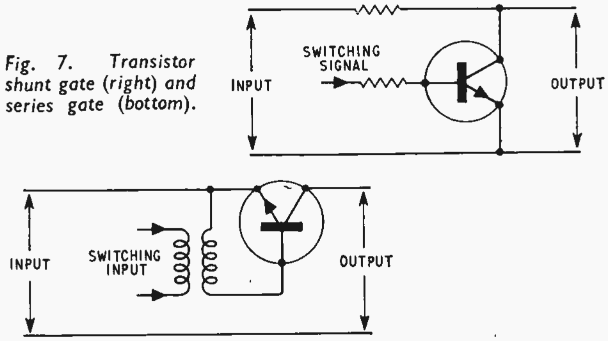


*Fig. 7. Transistor shunt gate (right) and series gate (bottom).*

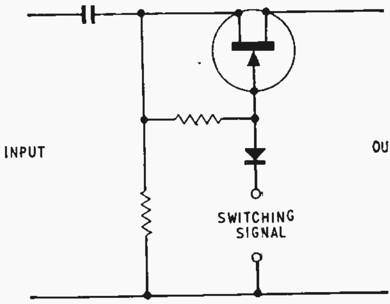


*Fig. 8. Series gate using field-effect transistor.*

## Construction

The layout of the decoder is not at all critical but the layout shown in Fig. 10 may be used as a guide. The main point to watch is the coil winding as, reversing the phase of T1 will result in the $Q$ multiplier not multiplying and a loss of 19 kc/s gain. Reversing the phase at T3 will invert the channels. The circuit may be used in two forms with either negative or positive earth. Three resistors and the transistors are different and are specified in the components list.

## Setting up

The performance of a decoder, unfortunately, depends very much on the accuracy with which it and the receiver with which it is to be used, have been set up. This setting up consists of three separate parts:—

1. Setting the pilot/sub-carrier phasing.
2. Adjusting the channel separation.
3. Tuning the receiver for optimum phase response.

**Phase adjustment.**—The test gear necessary to do this is an accurate 19 kc/s source and an oscilloscope. If no other method of checking the 19 kc/s source frequency is available, it is possible to use the transmitted pilot tone as a standard. This involves tuning T1 to approximately 19 kc/s, applying a multiplex signal to the input of the decoder and then, using the signal at the collector of Tr4 as a standard, to set the source to the same frequency (Lissajous figure method)[4]. Having obtained your accurate 19 kc/s source, the method is as follows. Connect the source to the input of the decoder and, keeping the input level low enough to prevent limiting, adjust T1 for maximum output at the collector of Tr4 and T2 and T3 for maximum output at the collector of Tr6. Increase the input until Tr6 limits when the input should be about 60 mV r.m.s. Compare the phase of the signal at the input with that at the point **B** by connecting the input signal to the $Y$ input of the oscilloscope and the signal at point **B** to the $X$ input. It will probably be necessary to adjust T2 in order to obtain the characteristic figure of eight (Fig. 11) which indicates that the phasing is correct.

**Channel separation.**—As far as the author knows, this may only be set up using a suitable stereo test signal. The technique is to apply a multiplex signal containing only $L$ information to the input and to adjust RV2 for minimum output on the $R$ channel. This is then repeated

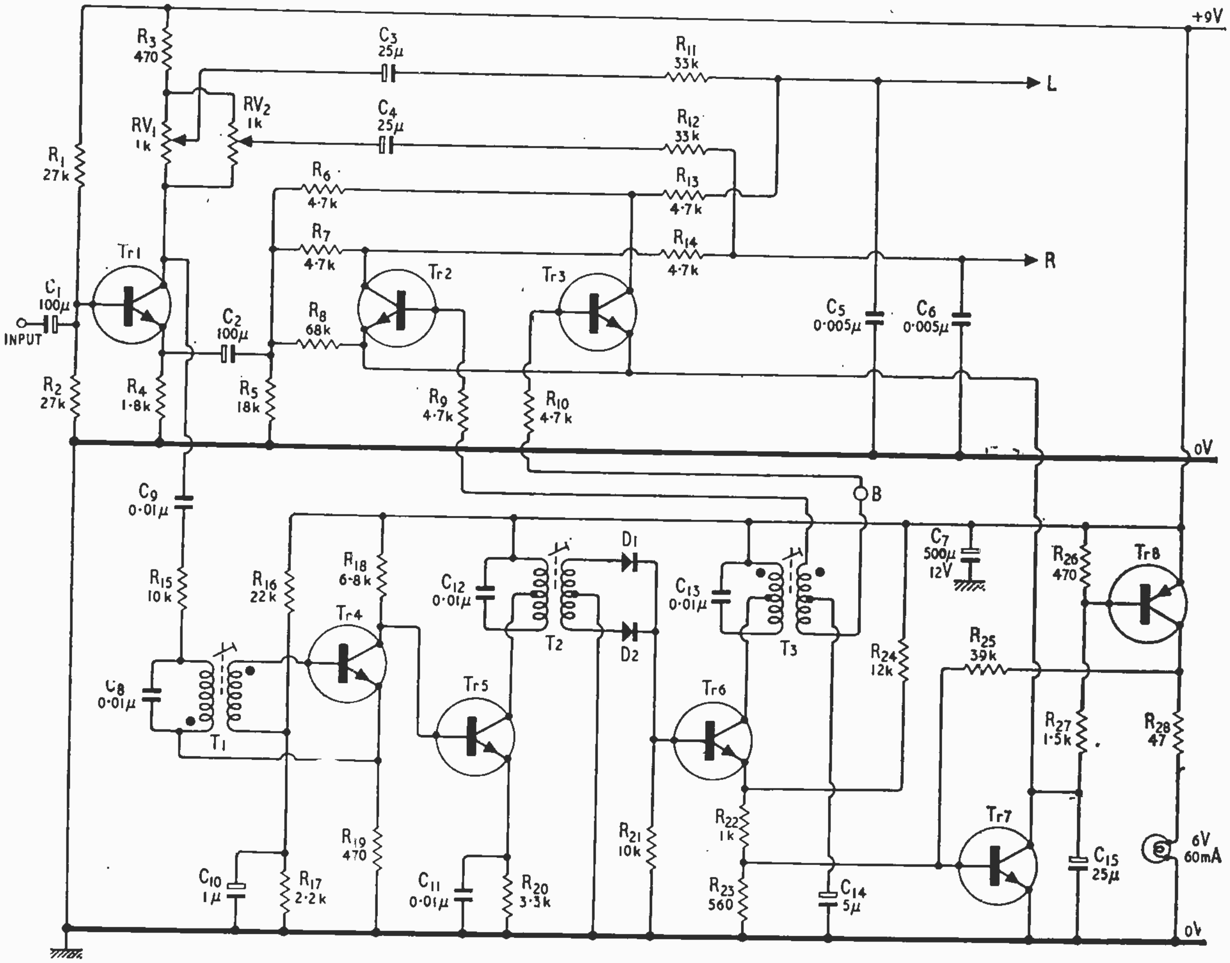


*Fig. 9. Stereo decoder circuit (negative earth version). In the positive earth version, polarity of electrolytic capacitors is reversed, resistors $R_1$, $R_{16}$ and $R_{18}$ altered in value and p-n-p transistors used (apart from Tr8).*

## LIST OF COMPONENTS

### Resistors

Values as shown in Fig. 9. For the positive earth version $R_1$, $R_{16}$ and $R_{18}$ are 47 kΩ, 27 kΩ and 5·6 kΩ respectively. $R_{28}$ should be made 150 Ω if 40 mA lamp is used.

### Capacitors

| | | |
|---|---|---|
| $C_1$ | 100 μF | 6 V |
| $C_2$ | 100 μF | 6 V |
| $C_3$ | 25 μF | 15 V |
| $C_4$ | 25 μF | 15 V |
| $C_5$ | 0.005 μF | paper |
| $C_6$ | 0.005 μF | paper |
| $C_7$ | 500 μF | 12 V |
| $C_8$ | 0.01 μF ±1% | polystyrene |
| $C_9$ | 0.01 μF | paper |
| $C_{10}$ | 1 μF | 50 V |
| $C_{11}$ | 0.01 μF | paper |
| $C_{12}$ | 0.01 μF ±1% | polystyrene |
| $C_{13}$ | 0.01 μF ±1% | polystyrene |
| $C_{14}$ | 5 μF | 15 V |
| $C_{15}$ | 25 μF | 15 V |

### Notes:

1. All resistors are 10% ½-watt types.
2. The voltage ratings of the electrolytic capacitors are not critical.
3. As mentioned in the text, the direction of winding of T1 and T3 is important. In each case, the dots denote the start of the winding.
4. The prototype was built on " Lektrokit " board.

### Semiconductor devices

| | *Negative earth version* | *Positive earth version* |
|---|---|---|
| Tr1, Tr4, Tr5 | BC108. (2N3706, 2N3707, BCY42, PEP5, 2N914, 2N929, 2N2926.) | 2N404. (NKT122, OC42, 2G302.) |
| Tr2, Tr3 | BC108. (2N914, OC139, 2N1304.) | 2N404. (NKT122, OC45, 2G308, OC201.) |
| Tr6, Tr7 | BC108. (2N3706, BCY42, PEP5, 2N914.) | OC201. (2N3703, NKT20441.) |
| Tr8 | ACY22. (OC72, OC83, NKT212, 2N404.) | 2N1304. (OC139.) |
| D1, D2 | OA47. (OA5, AAZ13, HG5004, CG85H.) | |

### Transformers

| | | | | | |
|---|---|---|---|---|---|
| T1 | Primary | 112 t | 36 s.w.g. | enam. (7.02 mH) | |
| | Secondary | 116 t | 36 s.w.g. | ,, | |
| T2 | Primary | 112 t | 36 s.w.g. | ,, | tapped at 56 t (7.02 mH) |
| | Secondary | 112 t | 36 s.w.g. | ,, | tapped at 56 t |
| T3 | Primary | 56 t | 32 s.w.g. | ,, | tapped at 28 t (1.755 mH) |
| | Secondary | 56 t | 32 s.w.g. | ,, | tapped at 28 t |

All coils wound on Mullard 18 mm ferrite core LA 2532.

using $R$ information and adjusting RV1 for minimum output on the $L$ channel. If no test gear is available, setting the controls to mid-travel will result in a channel separation of better than 20 dB.

**Receiver adjustment.**—In addition to the requirement for extra i.f. bandwidth it is desirable that the phase response should be good. A poor phase response results in non-linear distortion of audio frequency signals and also in degradation of the channel separation. Thus there are two relatively simple methods of setting up the phase response, provided always that access is available to suitable test gear.

The first method consists of applying a signal, modulated with a pure tone, to the input of the receiver and monitoring the output with a distortion factor meter. The tuning of the i.f. and discriminator transformers is then adjusted to give a compromise between maximum output and minimum distortion.

The second method is to apply a signal modulated with a multiplex signal to the input of the receiver. The i.f. and discriminator tuning is then adjusted to give minimum cross talk.

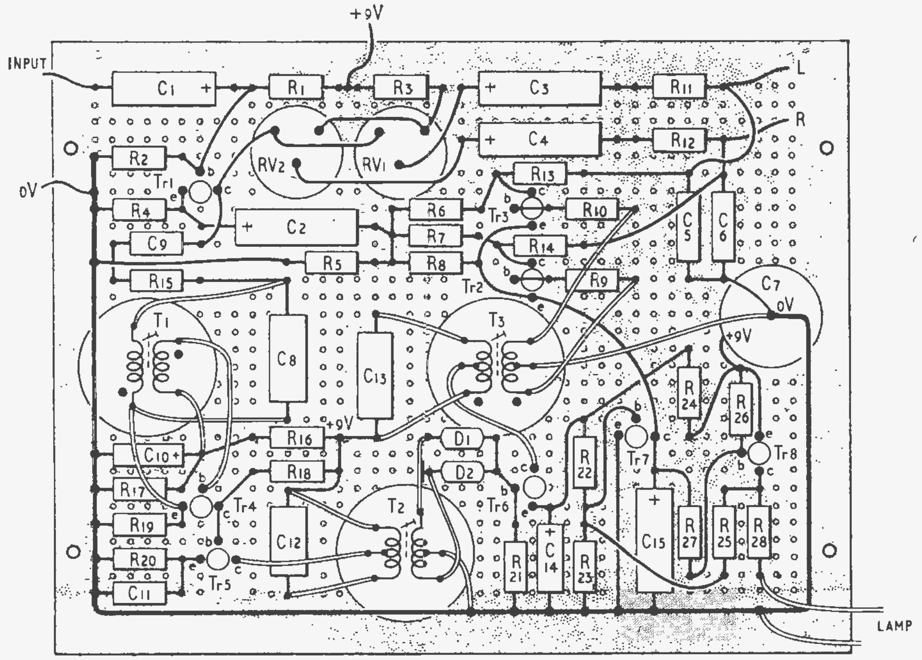
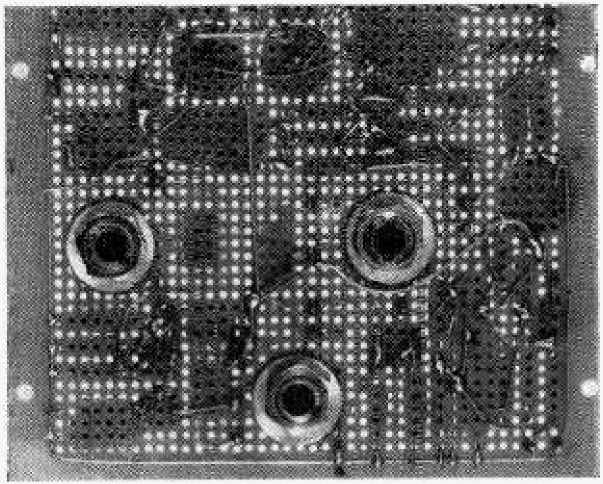


*Fig. 10. Diagram to show suggested layout and wiring. The components and wires shown unfilled are on the top side of the board (Lektrokit) and the wires shown solid on the other side, as made clear below ▼.*



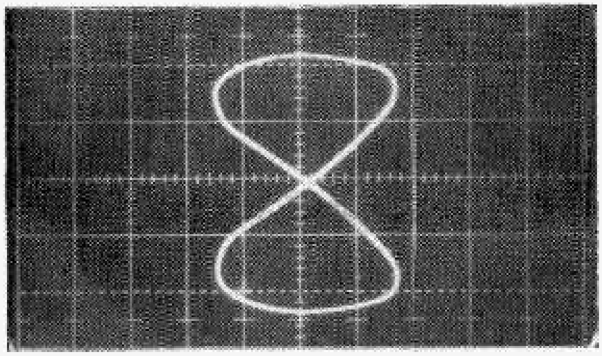


*Fig. 11. Pattern obtained when phase relationship between 39 kc/s waveform at B (Fig. 9.) and 19 kc/s input is correct.*

## Performance

Although an attempt has been made to draw up a comprehensive list of standard tests to be carried out on stereo decoders[5], it is difficult to decide which of these are necessary to specify the performance. In view of this, the author decided to treat it, as far as possible, as a simple audio amplifier and to assess the following:—

(a) frequency response.
(b) distortion.
(c) noise.
(d) maximum output.
(e) minimum pilot tone level.
(f) channel separation.

The last two tests are the only ones which are peculiar to stereo decoders.

(A) The frequency response was plotted with both mono and stereo signals and the results were so startlingly the same that is was only possible to draw one graph which is virtually the 50$\mu$s de-emphasis characteristic.

(B) Using a 1 kc/s signal to test under mono conditions, the total harmonic distortion was found to be 0.1%. The stereo test was more difficult to carry out satisfactorily as the only multiplex source available had the spectrum shown in Fig. 2. However, the author realized that the test could be carried out using a simulated test signal, i.e. if $L=R$, then there will be no $L-R$ information and a simple a.f. signal plus a 19 kc/s pilot tone is equivalent to the multiplex signal. This made the test quite easy to carry out and it was found that the distortion, although slightly worse than that for mono, was still less than 0.1%. (It is interesting to note that the spectrum shown in Fig. 12 is the output corresponding to the test signal shown in Fig. 2.)

(C) Noise was measured using a signal consisting only of the pilot tone. The total output from the decoder was then measured using a broad-band millivoltmeter and was found to be 5 mV. However, it should be appreciated that the output at 19kc/s was 5 mV and at 38 kc/s 3 mV.

(D) Due to the inefficiency of the phase sensitive detectors the maximum output with stereo signals will be about ⅓ of that with mono. Thus the maximum outputs are 0.3 V for stereo and 1 V for mono.

(E) The minimum pilot tone level required to operate the decoder (switch Tr7 on) is 40 mV.

(F) The channel separation was fairly difficult to measure accurately as it involved setting up the signal source for maximum separation at each test frequency. Due to distortion in the encoder, it was impossible to set the input channel separation to better than 40 dB with any degree of confidence. Despite this, the separation measured was better than 30 dB from 50 c/s to 15 kc/s (see Fig. 13).

## Some practical notes

(1) It is advisable to use the decoder with a receiver which has a.f.c. or is crystal controlled. If this is not done, channel separation will depend upon tuning accuracy and will also be liable to drift with the local oscillator.

(2) Although pulse-counting f.m. discriminators are ideal from the point of view of linearity and output, the fact that they use a low intermediate frequency may be an embarrassment. This is because it is possible for harmonics of the 38 kc/s subcarrier to beat with the i.f. signal. Thus an adequate low pass filter should be fitted at the input of the decoder. During tuning in, the decoder is likely to switch on at the instant when the i.f. goes through 19 kc/s.

(3) As the output of the decoder is high impedance (in order to provide de-emphasis simply), it is advisable to run it into an input impedance of not less than 50 kΩ.

(4) As there will probably be some variation in the inductance of coils wound by hand, the easiest way to ensure the correct inductance is to wind the secondary on first. The primary is then wound on the outside with a few extra turns added. The transformer may then be connected into the circuits on flying leads and the tuning checked. If the slug needs to be fully out of the coil to achieve resonance, fewer turns are required on the coil and vice versa.

(5) In some cases where the decoder is used in conjunction with a tape recorder, there is the possibility that residual high frequency components of the signal may beat with the bias oscillator producing undesirable "birdies." This may be overcome by connecting a low pass filter in the signal path. Fig. 14 shows the circuit of an active filter which has been designed to be connected directly to the output of the decoder. In order to obtain the frequency response shown, it is necessary to adjust the variable resistor to make the transmission at 10 kc/s equal to that at 1 kc/s. This method of filtering has been chosen because it produces results similar to an *LC* filter but does not present matching problems.

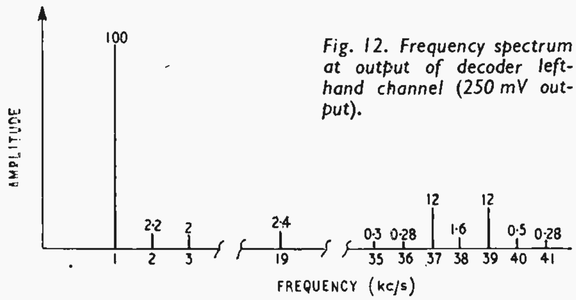


*Fig. 12. Frequency spectrum at output of decoder left-hand channel (250 mV output).*

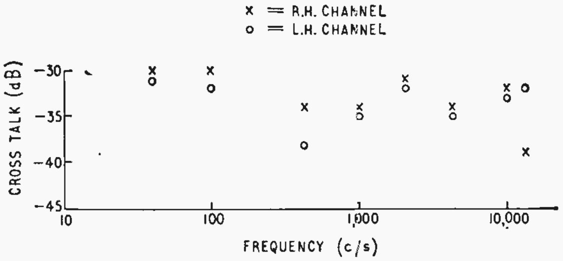


*Fig. 13. Channel separation (experimental results).*

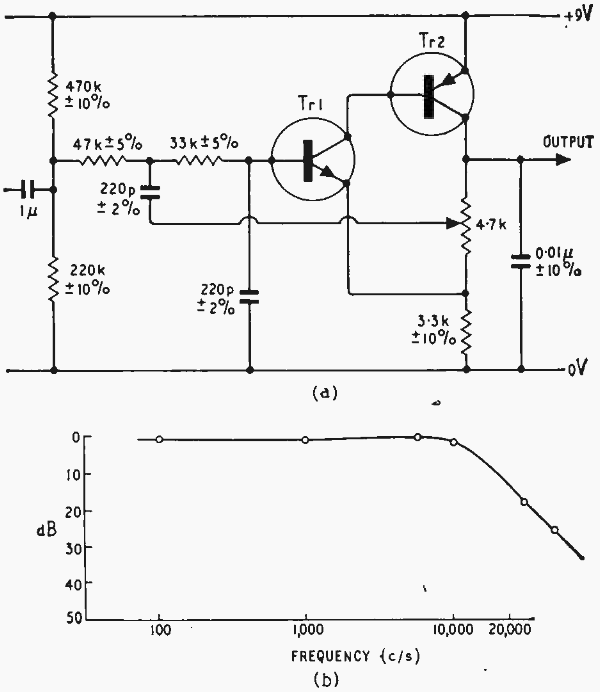


*Fig. 14. (a) Active filter to give attenuation of frequencies liable to beat with tape recorder bias frequency (Tr1: BC108, 2N929, 2N3707 or 2N2926; Tr2: 2N3703, OC201, NKT2044). (b) Response of filter.*

**Acknowledgments.**—The author would like to thank Marconi Instruments Ltd. for permission to publish this article and Mullard Ltd., who supplied the necessary semiconductors.

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# Colour Receiver Techniques

## 1.—THE COLOUR TELEVISION SIGNAL

By T. D. TOWERS*, M.B.E.

At last it looks as though (touch wood!) we will have colour television programmes in the United Kingdom in 1967. Many *Wireless World* readers who have hitherto watched the " battle of the systems " with mild interest and often little understanding now must begin to feel that they cannot any longer put off " finding out what colour television is all about." This article, written with the ordinary mortal in mind, is intended to give some account of the PAL colour television signal currently being put out on a test basis by the B.B.C. (and likely to be what the colour receiver will have to handle when actual programmes start).

### Colour television transmissions on the air

At the time of writing, anyone with a suitable colour television receiver and near enough to London can tune in to the B.B.C. trade test colour transmissions being put out every afternoon, Monday to Friday, from 2 to 5 p.m., with additional evening sessions from 6.10 to 7 p.m., on Wednesdays, Thursdays and Fridays.

These transmissions, on the 625-line, 50 fields/second standard, are radiated primarily on BBC2 from Crystal Palace in South London, but relay stations at Tunbridge Wells and Hertford also put them out. All three transmissions are on u.h.f. in Band V: Crystal Palace on Channel 33 (565.5-573.5Mc/s), Tunbridge Wells on Channel 44 (653.5-661.5Mc/s) and Hertford on Channel 64 (813.5-821.5Mc/s).

How far from these transmitters satisfactory *colour* reception will be possible is yet to be seen from field experience with programme material. In the case of black and white on BBC2, a fairly satisfactory picture *can* in favourable circumstances be obtained in Cambridge, some 60 miles from Crystal Palace. The field strength in Cambridge has been nowhere near the 3,000$\mu$V/metre which some pundits proclaim is necessary in Band V for satisfactory signal/noise ratio in receiving monochrome TV transmissions. Despite this, it has been possible sometimes to use the Crystal Palace BBC2 transmissions for experimental colour receiver work in Cambridge. You can decide for yourself to some extent whether you will be able to receive colour from Crystal Palace now by picking up in black and white on a " normal " BBC2 monochrome receiver the TV colour trade test transmissions mentioned above.

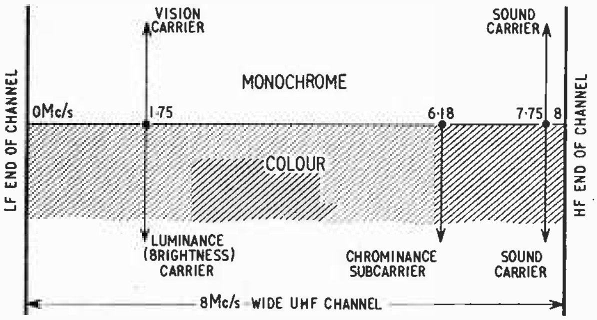

*Fig. 1. Location of information carrier frequencies within u.h.f. channel used for both monochrome and colour transmission. This illustrates how black-and-white and sound information carrier frequencies are the same in both transmissions, while colour information in the colour transmission is on a separate subcarrier not present in the black-and-white transmission.*

### Carrier frequencies in transmission channel

The colour system used has to allow the reproduction of colour transmissions as black-and-white pictures on existing BBC2 monochrome receivers (compatibility). Also, it should reproduce monochrome transmissions on colour receivers as high-quality, black-and-white pictures (recompatibility). To this end, the colour transmissions use the standard, 8-Mc/s-wide, u.h.f. channels with the sound and picture brightness information on the existing black-and-white frequencies within the channel, and with the colour picture information at a new third frequency.

Fig. 1 shows the location of the carrier frequencies within the channel, measured from the low frequency end, with monochrome and colour shown separately for comparison.

In the case of B.B.C. Channel 33, these standard carrier locations resolve into: (1) 567.25 Mc/s = colour luminance and monochrome vision, (2) 571.68 Mc/s = colour-only chrominance, and (3) 573.25 Mc/s = sound. (For the newcomer to the field, " luminance " is the brightness or black-and-white content of the colour signal, while " chrominance " is the colour content in terms of its saturation and hue.)

The carrier frequencies within the channel have been carefully selected in the first instance to ensure the best possible picture from colour transmissions, whether received on monochrome or colour receivers.

From the basic standard specification of 625-lines, 50 fields/second we have:

(a) $f_F$ = *field frequency* = 50 c/s (not locked to mains),

(b) $f_L$ = *line frequency* = 50 × 625 = 15,625 c/s.

For the first actual carrier in the channel, reckoning frequency as from the low-frequency end, we have:

(c) $f_M$ = colour *luminance carrier frequency* at 1.75 Mc/s.

This spacing from the lower end of the channel is to leave room for the lower sidebands of the vestigial-sideband-type transmission used on the carrier. The next carrier up the channel is the " colour subcarrier " specified by:

(d) $f_C$ = colour *chrominance subcarrier frequency* at 6.18 Mc/s.

The actual value of $f_C$ (generated at the transmitter, as distinct from its relative position in the channel) is 4,433,618.75 ± 1 c/s, and since it is a subcarrier superimposed on the main (luminance) carrier, this figure is its spacing from the luminance carrier. The position of $f_C$ in the channel is computed by a formula

$$f_C = f_M + f_F/2 + (284 - \tfrac{1}{4})f_L$$

The detailed basis of this last formula is a little too com-

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*Newmarket Transistors Ltd.

plex for discussion here, but it should be noted that the luminance-to-chrominance inter-carrier spacing includes a " half-field offset " in the term $f_F/2$, and a " quarter-line offset " in $(284-\frac{1}{4})f_L$.

All that remains now in the channel is the sound carrier. Here the spacing from the low-frequency end is

(e) $f_S$ = *sound carrier frequency* at 7.75 Mc/s.

This carrier is set at $f_S = f_M + 6$ Mc/s, i.e., it is precisely 6 Mc/s offset from the luminance carrier. Also, you can see it lies 0.25 Mc/s below the top end of the channel, and thus falls 2 Mc/s (0.25+1.75) below the luminance carrier of the next higher-frequency " adjacent " channel.

## How information is squeezed into the channel

On to the three carrier frequencies (luminance, chrominance and sound) within the passband of the transmission channel, eight vital streams of information are compressed to be sorted out in due course by the colour receiver. These are (1) sound, (2) line sync, (3) field sync, (4) picture brightness (luminance), (5) colour hue, (6) colour saturation, (7) reference colour carrier frequency, and (8) reference colour carrier phase. Each of these will be discussed separately below, but, to give an overall picture of how the information is multiplexed, Fig. 2 shows how the composite carrier amplitude across the channel is made up.

From what has been said already, it will have been gathered that the basic carrier is the luminance one, and that the vision information is conveyed as modulations on this. The luminance video waveform (with line and field sync) is modulated directly on this main carrier. The chrominance is modulated indirectly on to it via a suppressed subcarrier, 4.43 Mc/s from the main carrier (" suppressed " because the subcarrier itself is removed before modulating the main carrier and only the sidebands are transmitted). The a.f. signal sound is modulated onto a sound carrier spaced 6 Mc/s from the main vision carrier.

In the Fig. 2 diagram, (a) shows the band of frequencies resulting from the luminance modulation, the frequency response of the transmission system being nominally flat to 5.5 Mc/s. With double-sideband transmission this would lead to an 11 Mc/s-wide band centred on the luminance carrier at 1.75 Mc/s from the bottom end of the channel. However, in the vestigial sideband transmission method used for channel-width economy, the lower sidebands are attenuated from 1.25 Mc/s below the carrier and the luminance response is kept within the channel as at (d).

The chrominance modulation is narrower-band than the luminance, and nominally extends out to 1 Mc/s only (the system response being flat over this band), as shown at (b) in Fig. 2. Modulated onto the chrominance sub-carrier, this gives a 2 Mc/s wide band of frequencies within the channel as at (e).

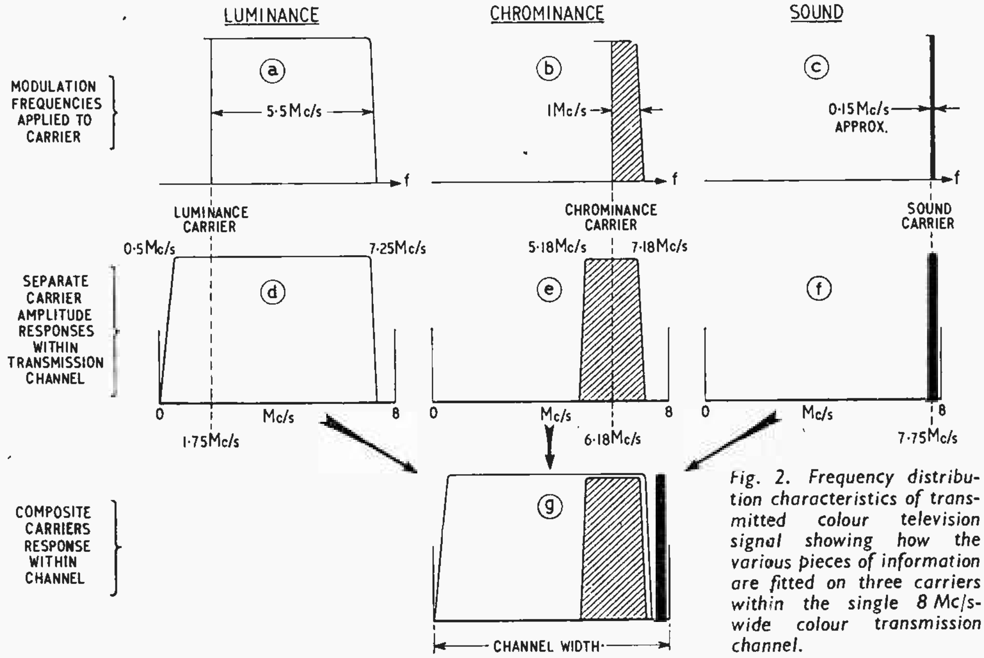

*Fig. 2. Frequency distribution characteristics of transmitted colour television signal showing how the various pieces of information are fitted on three carriers within the single 8 Mc/s-wide colour transmission channel.*

The sound modulation (f.m. with 50 kc/s peak deviation) results in a band of frequencies some 150 kc/s wide as at (c) in Fig. 2. This, modulated on the sound carrier, leads to the response within the channel at (f).

The three modulations are finally combined into the composite channel spectrum shown at (g) in Fig. 2. The immediate thought that springs to mind is: " How is it possible at the receiver to sort out the three lots of information when they fall together in the channel? " This is where the choice of the carrier frequencies is so important. Harking back to the section on carrier frequencies, you will note that the colour subcarrier is spaced from the luminance carrier by a frequency difference which includes a quarter-line frequency and a half-field frequency. As a result of these offsets, the chrominance subcarrier sidebands tend to interleave between the luminance sidebands, and give minimum cross-talk between the two sets of sidebands. Moreover, different modulation methods—amplitude and quadrature amplitude—are used.

As to the sound signals, since these are frequency-modulated with a relatively narrow spread of sidebands, the spacing of the sound carrier at a full 6 Mc/s away from the luminance carrier, and 1.58 Mc/s from the chrominance carrier, reduces interference to acceptable limits.

## Information associated with one picture line

Having considered how the luminance, chrominance and sound information is fitted into the transmission channel, let us now consider how it is distributed in time as it arrives at the receiver aerial. The easiest way is to look at the waveform signal which gives rise to one picture line. Fig. 3 shows, simplified somewhat, a diagram of a single line of the 625/50 colour vision signal. Signal voltages are represented by distances measured vertically,

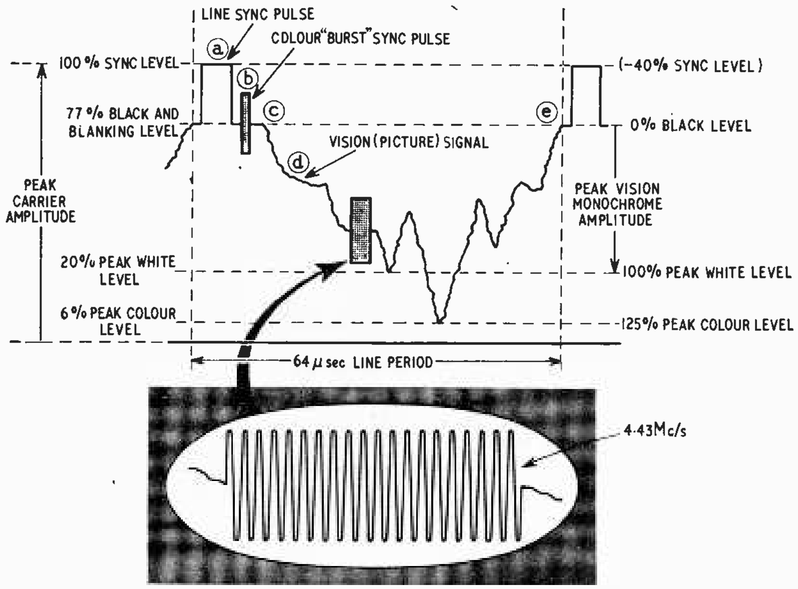

*Fig. 3. Waveform of single line of 625-line, 50 fields per second, colour transmission. Detail below shows how an area of strongly saturated colour appears in the waveform.*

and time horizontally. (Note that this does not include the sound signal.)

The main serial features of the line waveform in Fig. 3 are the line sync pulse at (a), the colour synchronizing " burst " or pulse at (b) and the vision signal (c, d, e). In time, the whole line occupies 64 μs. Within this, the line sync pulse takes up about 5 μs, the colour burst 2.5 μs and the vision signal 52 μs; for the small remaining time, the signal is clamped at black level.

Amplitude-wise, the first significant feature is the inverted, negative modulation of the vision signal. By this, black is represented not as zero carrier, as some might expect, but as 77% of the peak carrier amplitude. Next it will be seen that increasing video amplitude is represented by reducing carrier amplitudes down to a peak colour amplitude of about 6% of the full carrier amplitude.

This picture-information part of the signal is, of course, the voltage resulting from the vectorial addition of the chrominance signal to the luminance (black-and-white) waveform. In Fig. 3 this is illustrated by the short sequence of cycles of subcarrier frequency (magnified below), which would result from a narrow area of strong colour (with luminance, hue and saturation constant across its width) appearing in the picture.

The line sync pulse lies upwards in the " blacker than black " region from the 77% black level to the 100% peak carrier amplitude. The colour burst consists of 10 cycles of sinewave oscillation at the subcarrier frequency, 4.43 Mc/s. It has the same peak-to-peak amplitude as the line sync pulse amplitude, but is located at a lower level, being centred on the black level.

## Line sync pulse details

The line sync pulse, discussed briefly above, is important because it controls the start of the line timebase sweep in the receiver and it is worth looking a little more closely at it. Fig. 4 gives an enlarged diagram with more detail. The sync pulse proper is preceded by a 1.55 μs " front porch," (a)-(b), designed to enable the pulse to start from black level, even when bright patches appear towards the right hand side of the picture, i.e. at the end of the previous line. The 4.7 μs sync pulse itself, (b, c, d, e) has a rapid 0.3 μs rise time, to establish the timebase trigger point precisely, and a fast, 0.3 μs, fall time, returning to set the black level in adequate time to clear the colour burst following.

The 2.5 μs colour burst, (f)-(g), starts 0.8 μs after the end of the line sync pulse, and lies within the 6 μs " back porch," (e)-(h). The vision signal starts at the end of the back porch.

Except for the back-porch colour burst, which is peculiar to colour, the line sync pulse waveshape is the same for monochrome and colour.

To complete the picture of the time distribution of the vision signals, Fig. 5 shows how pulses are provided to synchronize the start of each vertical scan or field. " Field " here is taken as 312½ lines, two interlaced fields sequentially making up a complete 625-line picture. The field from line 1 to 312½ is known as " even " and from line 312½ to 625 as " odd."

Diagram (a) in Fig. 5 shows the frame sync pulses for even fields, i.e., fields in which the vision signal ends on a full line, and which in 625-lines means fields starting at line 1. Up to line 622 of the previous odd field, the regular 4.7 μs line pulses and the vision modulation can be seen. From line 623½ the vision signal is blanked out for 20 lines. As soon as the field blanking starts, there comes a train of five short, half-length, 2.3 μs, equalizing pulses at half-line period of 32 μs. These equalizing pulses are to cut out the vision signal long enough to ensure that the first of the group of five broad, 27.3 μs, pulses that constitute the field sync pulse proper

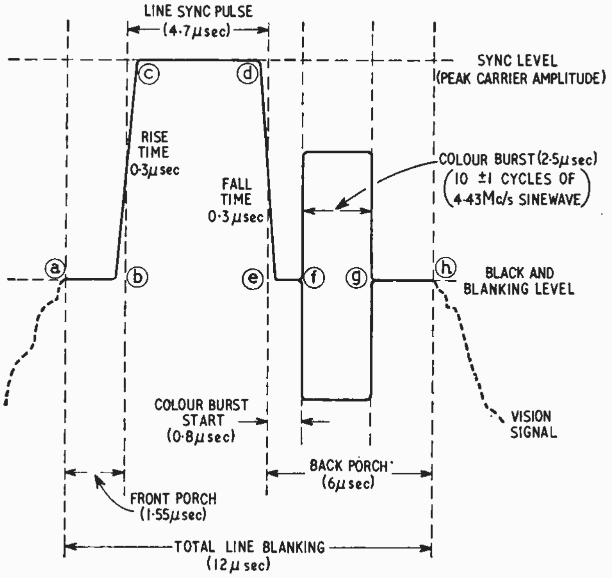

*Fig. 4. Details of line sync and colour burst pulses in 625-line, negative picture modulation colour transmission.*

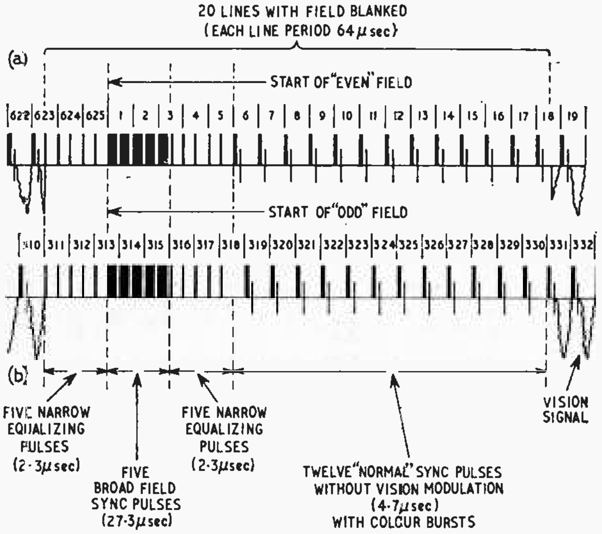

*Fig. 5. General details of field sync pulse composition for (a) "even" and (b) "odd" fields.*

starts from the true black level. This enables the receiver to start line 1 of the even field at a precise regularly spaced interval to ensure satisfactory interlacing of the lines in different fields. The five broad pulses that constitute the field sync pulse are also spaced at half-line period of 32 $\mu$s. They are followed by a further five short, half-line-period-spaced, equalizing pulses to allow the receiver to cut off the field synchronizing pulse at a precisely repeatable point and thus avoid irregularity in the duration of the vertical sweep. From line 6 to the middle of line 18, the normal line sync pulses with colour bursts take up again, but without vision signal. From the middle of line 18 onwards, the vision modulation returns, and we have the full signal again.

To complete the picture (b) in Fig. 5 shows the corresponding field sync pulse provisions for the odd field, i.e., fields with vision information ending on a half line, which on the 625-line system means fields starting on line 312½.

Because 20 lines of vision signal are suppressed out of a total of 312½ per field, 625-line television becomes in reality 625 − 2 × 20 = 585-line only. Similarly, looking back to the line waveform of Fig. 3, we see that vision signal is available for only 52 $\mu$s out of a total of 64 $\mu$s.

Except for the colour bursts appearing during the latter part of the field blanking in lines 6-18, and 319-330 (see Fig. 5), the field sync waveforms for the colour transmission are the same as for standard 625/50 monochrome.

## Colour burst details

So far, we have seen the colour burst in Fig. 4 as a 2.5 $\mu$s train of 10 cycles of 4.43 Mc/s sinewave, following closely after the line sync pulse, symmetrical about the black level, and with a peak-to-peak value equal to the line sync pulse amplitude. We must examine more closely what it actually does.

We noted earlier that the chrominance information is transmitted on a suppressed chrominance subcarrier at 4,433,618.75 c/s from the luminance carrier. This subcarrier is phase-modulated for colour hue and amplitude modulated for colour saturation. When the signal reaches the receiver, the suppressed subcarrier has to be reinserted to enable the hue and saturation information in the sidebands to be extracted for controlling the drives to the colour display tube. To this end, the receiver has a local oscillator (the colour reference oscillator) operating at 4.43 Mc/s. This must be accurately synchronized with the original suppressed subcarrier at the transmitter. The colour burst—a sample of the transmitter subcarrier frequency—is the reference that is used to ensure complete synchronism. The receiver compares the phase of the local carrier reinsertion oscillator with the phase of the colour burst, and produces correcting voltages that bring the local oscillator exactly into phase (and thus frequency) synchronism with the burst waveform and the original subcarrier. Although the colour burst is only sent out for a short period at the beginning of each line, the local oscillator correction circuit works in a sort of flywheel sync arrangement that holds the synchronism throughout the whole line.

It is not the purpose of this article to discuss in detail the PAL system of colour transmission, but it should be noted that the colour picture signal has a composition given by

$$E_M = E_Y + [0.493(E_B - E_Y)\sin 2\pi f_C t \pm 0.877(E_R - E_Y)\cos 2\pi f_C t]$$

where $E_Y = 0.30E_R + 0.59E_G + 0.11E_B$

$f_C$ = chrominance subcarrier frequency, 4.43 Mc/s

$E_Y$ = instantaneous voltage of the luminance signal conveying brightness information

$E_B, E_G, E_R$ = instantaneous voltages corresponding to blue, green and red signals.

For the accurate reproduction of colour, the receiver must be able to reinsert a colour subcarrier with the correct frequency and zero phase reference. In some systems, the same zero phase reference is transmitted on every line colour burst, and in these the reference chosen is at 180° (i.e. in opposite phase to the $E_B - E_Y$ component). In the PAL system, the $E_R - E_Y$ component phase is reversed on every line, as indicated by the ± sign in the formula for $E_M$ above. In earlier versions of the PAL system, the fixed 180° reference was chosen for the colour burst, but in the present version, a "swinging" colour burst is used. In this, the phase reference on alternate lines is 180° ± 45°, the "+" being for lines with $+(E_R - E_Y)$ component and the "−" for lines with $-(E_R - E_Y)$. The phase reference for the $E_M$ equation then becomes the average of the phase excursions of the colour bursts, i.e. the same 180° used in systems with non-swinging colour bursts. As a result, the burst becomes $\sin(2\pi f_C t + 3\pi/4)$ for $+(E_R - E_Y)$ lines, and $\sin(2\pi f_C t + 5\pi/4)$ for $-(E_R - E_Y)$.

To bring together all features of the colour television signal discussed so far, it might pay to consider the colour bar test signal put out by the B.B.C. at present. This takes the form of eight vertical, equal-width stripes filling the television screen, and ranging from white on the left through yellow, cyan, green, magenta, red and blue to black. You will find that the colours are arranged in decreasing order of luminance.

The line waveform for this test signal (all visible lines will be the same) takes the shape of Fig. 6. The by-now-familiar line sync pulse and colour burst will be recognised at the start. The luminance modulation is shown as a thick line, and indicates that with monochrome reception the eight stripes would pass from white to black in progressively darker shades of grey. The chrominance modulation (corresponding to full amplitude 95% saturated primary and complementary colours) "rides on the back" of the luminance and consists of a sequence of equal periods of 4.43 Mc/s oscillation with different

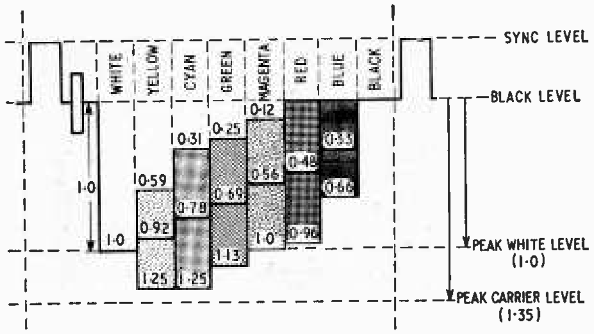

*Fig. 6. Diagram showing colour-bar test waveform (for full amplitude 95% saturated primary and complementary colours). Heavy contour shows how signal would be reproduced ideally on a monochrome receiver in bands of progressively darker shades of grey from white to black.*

phase angles relative to the reference burst. These are shown as shaded bands centred on the corresponding luminance amplitude levels. The mean luminance amplitude level in any coloured band remains virtually unchanged, but the peak total modulation increases. It should be noted that in the yellow, cyan and green bands the peak carrier amplitude extends down beyond the peak white carrier amplitude limit.

For most purposes, the luminance component of the colour signal can be taken as identical with the black and white signal, although strictly speaking, except for white or shades of grey colours, this is not quite true.

### Reception of colour signals in monochrome

Despite the care with which the carrier frequencies for luminance, chrominance and sound are selected to reduce crosstalk between the signals, certain spurious effects can arise when colour signals are reproduced in black and white on a monochrome receiver.

The most significant spurious effect is the presence of a regular pattern of dots caused by the presence of the colour subcarrier signals. This interference pattern is most obvious in areas of strongly saturated colour in the transmitted picture. The subcarrier also produces additional luminance in such areas owing to the non-linear law of the monochrome display tube.

Another effect observed on colour transmissions reproduced on monochrome receivers arises from the colour burst. This burst, occuring during the post-line synchronizing period, usually forms part of the line flyback period of a monochrome receiver, and thus the subcarrier dots due to the burst are stretched out by the relatively fast retrace scan. This may result in vertical lines or bands down the left hand side of the picture.

The sound carrier may also give rise to spurious picture effects. It forms a beat signal of 1.57 Mc/s with the chrominance carrier and this can give rise to further visible dot patterns.

### Further details of B.B.C. colour transmissions

Within the bounds of this article it has been possible only to touch on the main features of the colour television signal. Anyone interested in the more precise technical details should obtain from the Engineering Information Department, B.B.C., Broadcasting House, London, W.1, copies of (a) Information Sheet 4202, "Colour Television," (b) Information Sheet 4002, "625-line Vision Signal Waveform," and (c) Engineering Press Statement 760 "Experimental Colour Television Transmissions."

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# TV Camera with Solid-State Image Sensing

A FIRST step has been taken towards "a new era of personal TV communication systems" according to RCA, who have just announced delivery of an experimental tubeless television camera, smaller than a man's hand, to the U.S. Air-Force Avionics Laboratory at Dayton, Ohio. The camera's solid-state photoconductive image sensing panel and associated scanning generators have been made by thin-film technology and are the latest outcome of a long-term programme of work in this field by an RCA Laboratories team led by Dr. Paul K. Weimer.* The panel has 32,400 photoconductive elements, deposited on a glass slide, which are scanned by pulse signals applied to a matrix of X and Y thin metal conductors—there being an element deposited at each X-Y intersection. Presumably there are 180 X-conductors and 180 Y-conductors.

An image focused on this array causes each photoconductive element to experience a fall in resistance proportional to the intensity of light falling on it. Orthogonal scanning of the resistance pattern, using the X and Y conductors, then results in a sequence of voltages corresponding to the successive values of the video signal produced by a conventional television camera. Since the process of scanning the resistance (light) pattern is similar to the read-out of digital data from a computer matrix store, it would be possible to send pictures from the camera directly to a computer for processing or storage.

The image sensing panel is scanned—60 times per second—by two sets of circuits, each containing 540 thin-film transistors (and other components) deposited on a glass slide. On one side the output transistors are connected to the X-conductors of the image panel and on the other slide the output transistors are connected to the Y-conductors. The actual scanning circuitry used is not disclosed, but in the earlier work it was based on shift registers which generated pulses in sequence along a line of output terminals connected to the X and Y conductors. A fourth glass slide in the camera carries thin-film circuitry performing various control functions.

Pictures produced by the camera can be sent directly to a television receiver by a miniature microwave radio transmitter, also developed by RCA. This uses conventional transistors.

At present the resolution, sensitivity and speed of response of the solid-state camera are inferior to those of a conventional television camera, but Dr. Weimer says that his team expects to overcome these limitations in the future by the use of new circuit techniques and by the development of image sensing arrays with 10 times the number of photoconductive elements used in the experimental model.

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* See, for example, "Integrated Circuits Incorporating Thin-Film Active and passive Elements" By P. K. Weimer, H. Borkan, G. Sadasiv, L. Meray-Horvath, and F. V. Shallcross, *Proc I.E.E.E.* December 1964. Also a note in *W.W.*, July 1965, p. 350.

# CINE FILMING TELEVISION

## MODIFYING A 16-MM PROJECTOR TO RECORD VISION AND SOUND FROM A DOMESTIC TV SET

BY J. M. HALE, Ph.D., B.Sc.(Eng.), Grad. I.E.E.

THERE is little doubt that a machine for recording television programmes would form a worthwhile addition to the present-day range of domestic electronic equipment. The video tape recorder appears to be the most attractive solution, but at present the achievement of acceptable performance from reasonably inexpensive equipment still seems some way ahead.

Meanwhile, the availability of magnetically "striped" film stock enables a satisfactory film telerecorder to be made at a reasonable cost and employing well established techniques. The construction of such a recorder using a modified cine projector is described in this article.

**Choice of film gauge.**—In the interests of low running costs the film gauge should be as small as possible consistent with obtaining acceptable results. To avoid undue loss of picture quality the resolution of the film and optical system should be rather better than that of the television system. If we consider a television picture consisting of horizontal black lines on a white background, the 405-line system is capable of displaying a maximum of about 190 lines. Taking the frame height of 16-mm film as 7·5 mm, the film resolution required is better than 25 lines per mm. It is difficult to be too precise about film and lens resolutions, but this is the sort of figure that one might reasonably hope to achieve quite comfortably in practice.

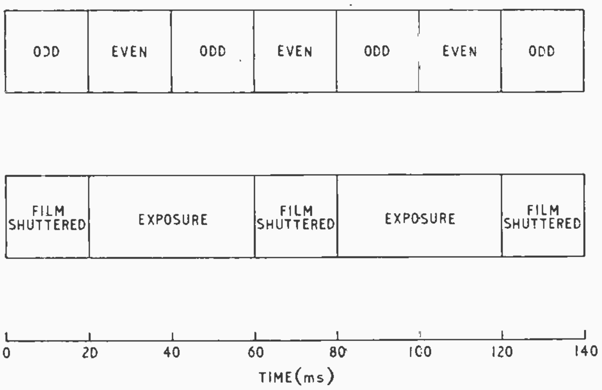
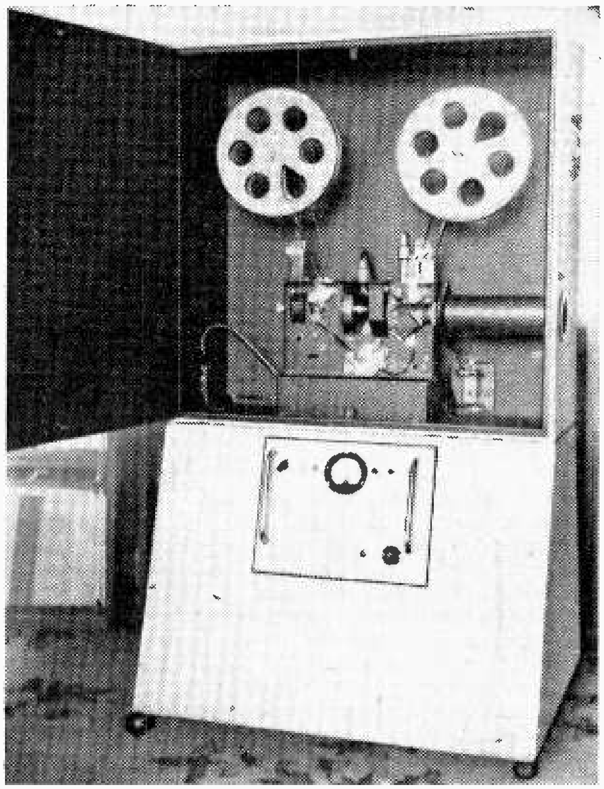


*Fig. 1. Cycle of exposure of film to television fields, to give $16\frac{2}{3}$ film frames (complete television pictures) per second.*



*The complete telerecorder in its light-proof cabinet, showing the amplifier mounted in the trolley.*

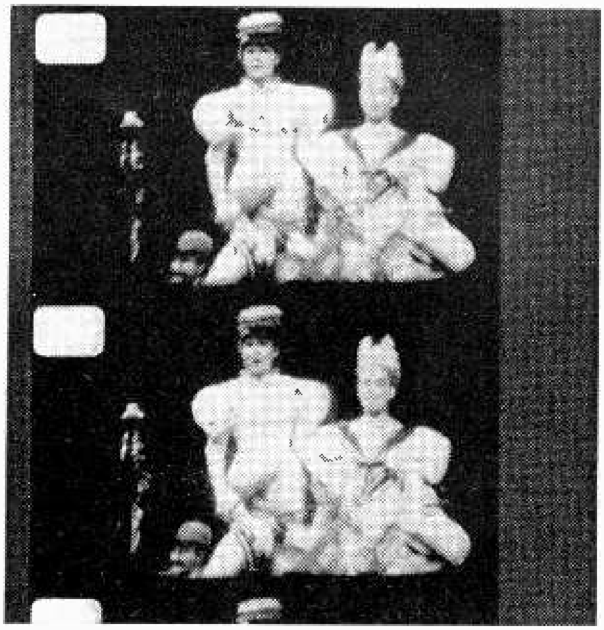
The attractiveness of 8-mm film from the point of view of low running costs and compatibility with other domestic cine equipment is marred by the practice of exposing and processing this gauge in the form of 16-mm (double-8) and slitting it to 8mm before projection. This means that striped single-8 film and facilities for processing it are not normally available.

In addition to the technical difficulties with this gauge, 8-mm projectors with sound are decidedly expensive whereas surplus 16-mm machines are available quite cheaply.

Bearing these factors in mind, it was decided to opt for the 16-mm gauge.

**Choice of exposure system.**—Having decided on the film gauge, it is then necessary to select a suitable exposure system. There are a number of possible systems for recording television on film, but the one which appears most attractive is the $16\frac{2}{3}$ frames per second system. This was developed by the B.B.C. and described in *Wireless World* in 1949.[1] The exposure cycle for this system is shown in Fig. 1. The film is first exposed to an even and an odd field. It is shuttered during the next even field, during which time the film is pulled down. The next odd and even fields are then photographed and the film is shuttered and pulled down during the next odd field and so on. Each exposed frame on the film, therefore, consists of a complete television picture, there being $16\frac{2}{3}$ such pictures per second.

This system has a number of advantages for the present application. First, it is a slow pull-down system, the requirements of which can be met by the claw mechanism



*Frames from a recording, showing sound stripe on the right.*

of a standard projector. The use of 16⅔ frames per second rather than 24 which is usual for sound films results in economical use of the film stock while the film speed of 5 inches per second is sufficiently high for good quality sound recording. The film can be replayed on a standard magnetic sound projector running at 16 frames per second and using a three-bladed shutter.

**Modifications to projector.**—There are two reasons why the recording machine must be based on a projector rather than on a camera. First, the provision of a constant speed sound loop which is required for synchronous sound and vision recording is a feature peculiar to projectors. Also the pull-down must not occupy more than one third of the total exposure cycle. This is a condition which is satisfied in most projectors but is unusual in cameras.

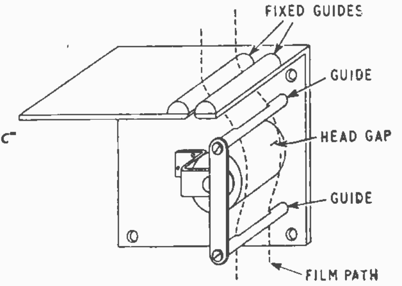
The projector chosen was a Gaumont British L516. This machine is available cheaply on the surplus market and the form of its construction makes it ideal for modification. The author also uses one which has been modified for magnetic sound as the replay machine. The required modifications for the recording machine may be placed under four headings: removal of parts of the machine not required after modification; provision of a new shutter; fitting of a synchronous motor drive; and fitting of record and erase heads.

Only the basic projector mechanism has to be retained. Redundant items include the carrying case, the lamp house, the optical sound focusing unit, the motor-blower and its control gear and all the amplifier wiring.

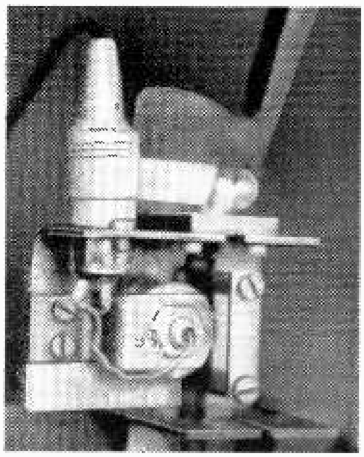
The shutter in the recording machine has to operate between the film and the television screen, whereas originally it is sited between the film and the projector lamp. The main projector shaft has, therefore, to be extended through the front of the machine to take the new shutter, and a hole was drilled in the front plate to allow the shaft to protrude. The machine was dismantled, the clutch mechanism was removed and the original shaft was replaced by a 13-inch length of $\frac{5}{16}$-inch diameter silver steel. To secure additional mechanical smoothing, a flywheel was mounted on the shaft in the position formerly occupied by the lamp house. The shutter assembly was dismantled and put on one side for use with the new shutter. With the 16⅔ frames per second system, the shutter has a single opaque sector of 120° and is transparent for the remaining 240°. Such an unsymmetrical shutter would set up too much vibration if it were made out of metal in the conventional way. For this reason, the shutter was made from a 5-inch diameter Perspex disc with a 120° black painted sector. The disc was bored out to fit the original shutter assembly. In the finished machine, the shutter rotates just in front of the projection lens.

To provide the 1,000 r.p.m. drive to the projector shaft, a 1,500 r.p.m. synchronous motor was bolted to the main chassis and coupled to the projector shaft via a toothed belt drive giving a 3:2 step down ratio. The particular motor used was rated at 1/75 h.p. which was more than adequate for the job.

To preserve the standard 28 frame sound-to-picture separation, the magnetic recording head has to be mounted at the point occupied by the optical sound focusing unit on the original machine. A number of mounting arrangements were tried but the one finally adopted was the simplest. The head was bolted on the main plate of the machine with two screws. A rib of metal on the back of the head enables azimuth adjustment to be made by differentially tightening these screws. Positional adjustment is facilitated by having large clearances between the fixing screws and the holes in the fixing lugs of the head. Correct positioning of the head is critical, because of the unfavourable wrap angle inherent in this arrangement where the magnetic stripe is on the convex side of the film. The flexibility in the system is provided by the film, which can bend under the pressure of the head as it is not supported



*Right: Fig. 2. Construction of erase head.*



*Left: The erase head mounted on the projector.*