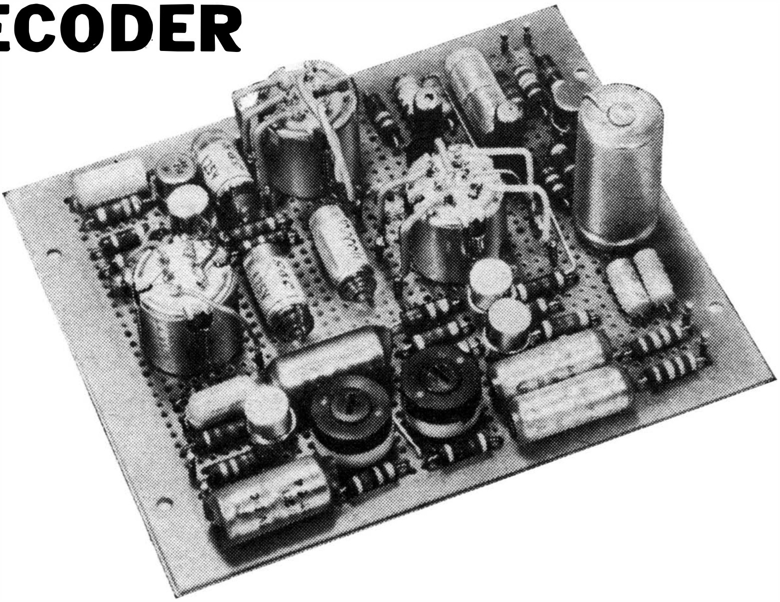
A STEREO DECODER



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 antiphase 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.)

*Marconi Instruments Ltd.

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-

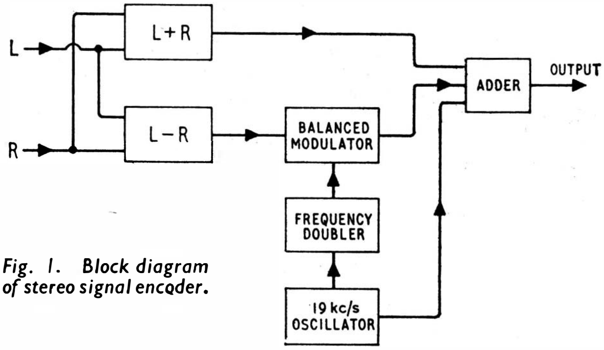


Fig. 1. Block diagram of stereo signal encoder.

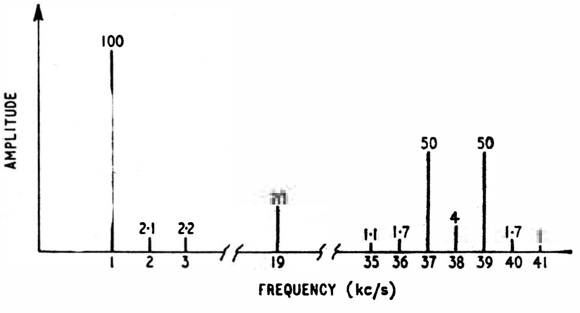


Fig. 2. Frequency spectrum at output of stereo encoder with slightly distorted 1 kc/s signal in one channel.

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 inpuut 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.

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,

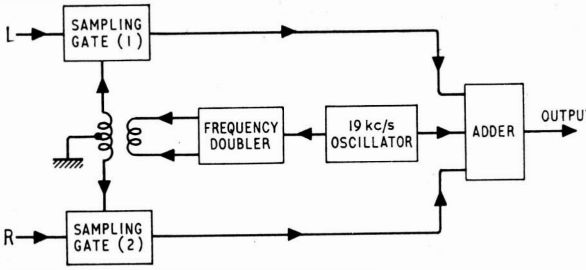


Fig. 3. Sampling method of stereo signal encoding.

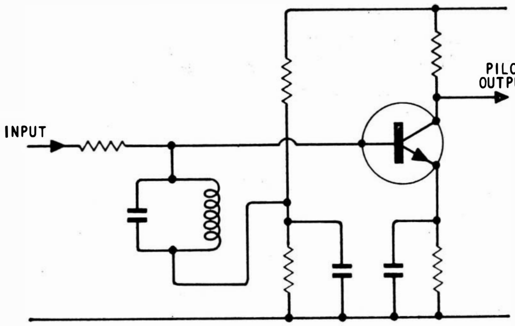


Fig. 4. Simple method of pilot tone extraction.

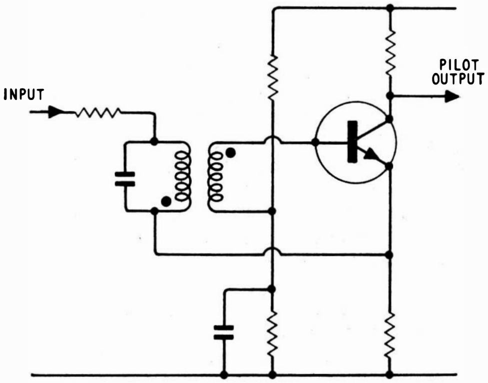


Fig. 5. Q multiplier method of pilot tone extraction.

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.

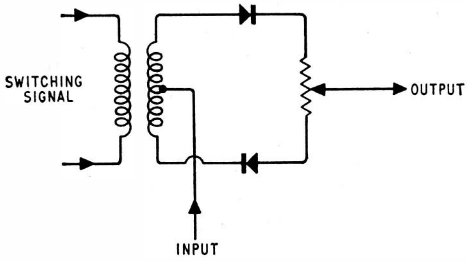


Fig. 6. Balanced diode series gate.

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.

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.

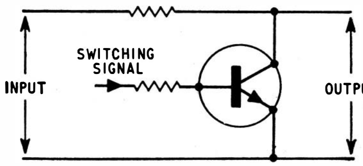
Setting up

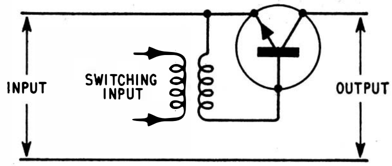
The performance of a decoder, unfortunately, depends very much on the accuracy with which it and the receiver with which it is to be used, have been set up. This setting up consists of three separate parts:—
1. Setting the pilot/sub-carrier phasing.
2. Adjusting the channel separation.
3. Tuning the 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. 7. Transistor shunt gate (right) and series gate (bottom).





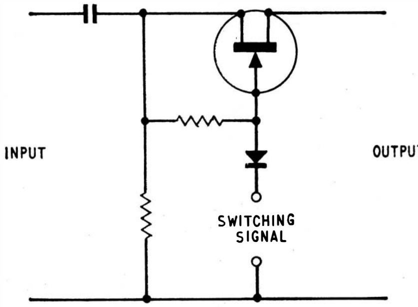


Fig. 8. Series gate using field-effect transistor.

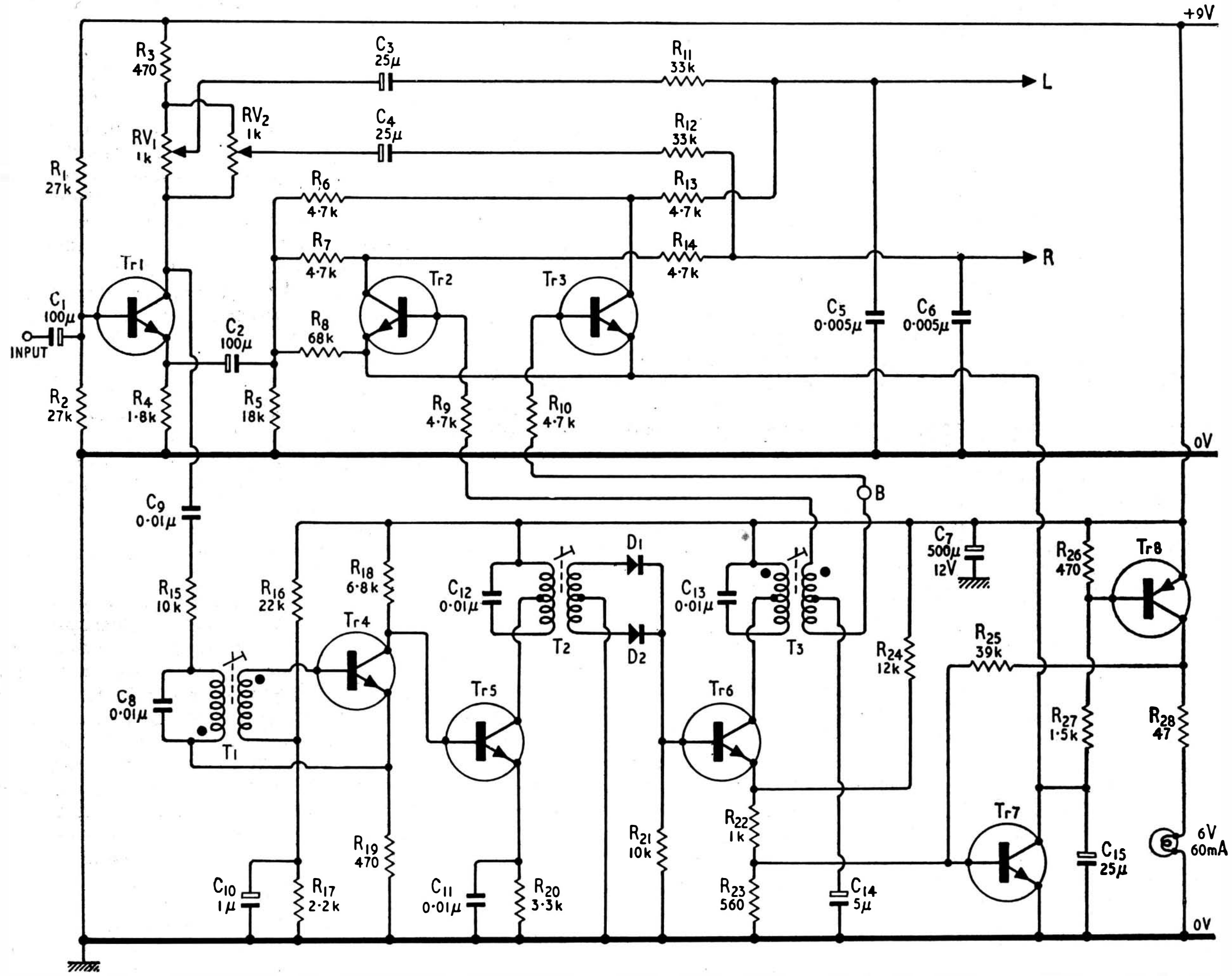


Fig. 9. Stereo decoder circuit (negative earth version). In the positive earth version, polarity of electrolytic capacitors is reversed, resistors R_1, R_{16} and R_{18} altered in value and p-n-p transistors used (apart from Tr8).

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_9	0.01 μF	paper
C_2	100 μF	6 V	C_{10}	1 μF	50 V
C_3	25 μF	15 V	C_{11}	0.01 μF	paper
C_4	25 μF	15 V	C_{12}	0.01 μF ±1%	poly-styrene
C_5	0.005 μF	paper	C_{13}	0.01 μF ±1%	poly-styrene
C_6	0.005 μF	paper	C_{14}	5 μF	15 V
C_7	500 μF	12 V	C_{15}	25 μF	15 V
C_8	0.01 μF ±1%	poly-styrene			

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.

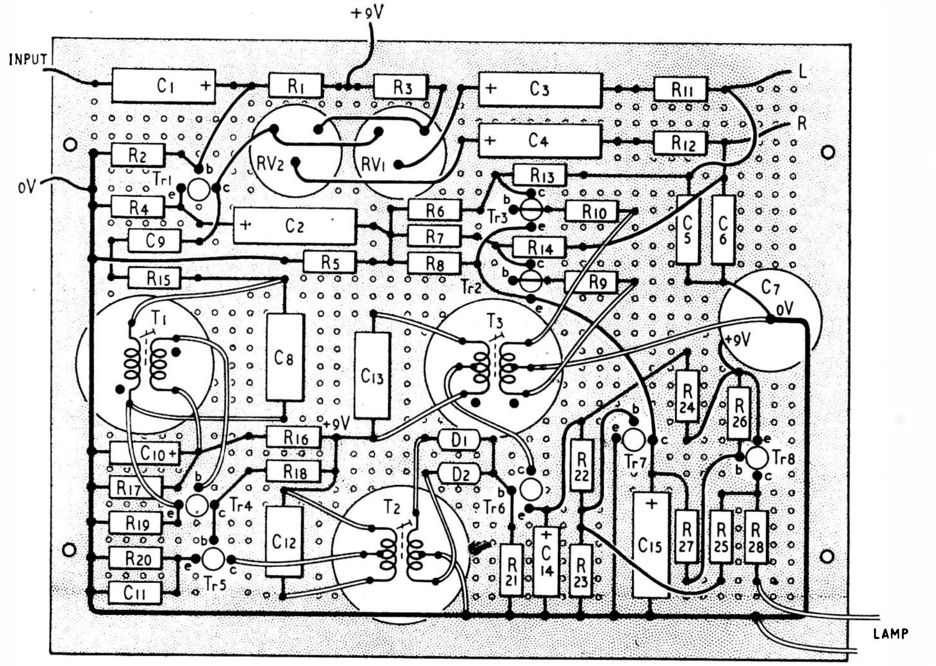
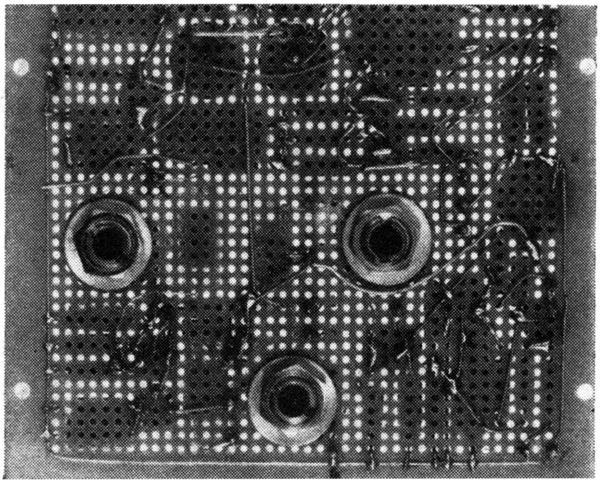


Fig. 10. Diagram to show suggested layout and wiring. The components and wires shown unfilled are on the top side of the board (Lektrokit) and the wires shown solid on the other side, as made clear below ▼



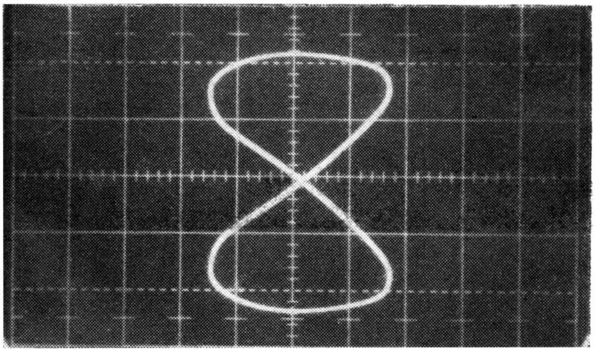


Fig. 11. Pattern obtained when phase relationship between 39 kc/s waveform at B (Fig. 9.) and 19 kc/s input is correct.

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.

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 50μs 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 $\frac{1}{3}$ 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

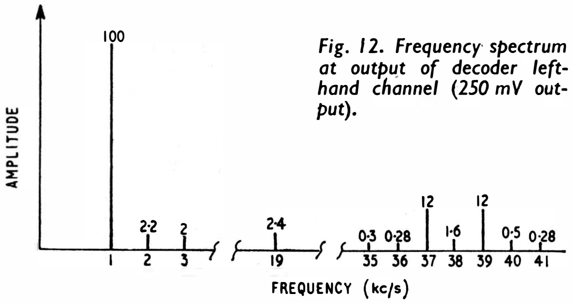


Fig. 12. Frequency spectrum at output of decoder left-hand channel (250 mV output).

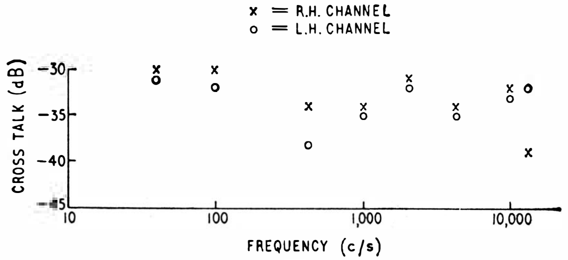


Fig. 13. Channel separation (experimental results).

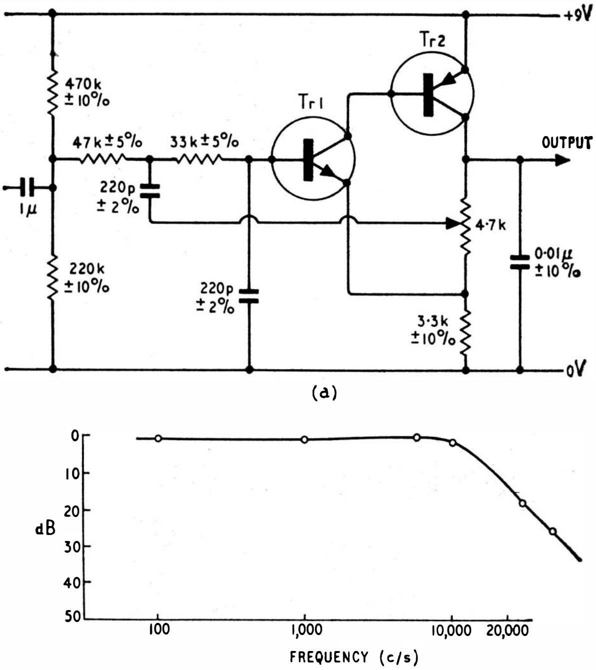


Fig. 14. (a) Active filter to give attenuation of frequencies liable to beat with tape recorder bias frequency (Tr1: BC108, 2N929, 2N3707 or 2N2926; Tr2: 2N3703, OC201, NKT2044). (b) Response of filter.

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.

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

REFERENCES

1. Receiving Stereo Broadcasts. *Wireless World* Sept. 1966.
2. Stereophonic Broadcasting and Reception. G. J. Phillips and J. G. Spencer *Radio and Electronic Engineer* June 1964.
3. Active Impedance Converters, F. Butler *Wireless World* Dec. 1965, p. 601.
4. Radio Laboratory Handbook, M. G. Scroggie 6th Edition p. 277 (Iliffe).
5. Suggestions Concerning Measurement of Stereophonic F.M. Receivers, A. L. R. Limberg *I.R.E. Trans* vol. BTR-10, May 1964.