Colour synthesizer design for the PAL system

Low-cost equipment for amateurs or schools

by N. C. Roberts, B.Sc.

The conventional approach to colour synthesis involves the use of standard colour matrix circuits. The individual components of the colour waveform are generated separately and fed to the matrix circuits. The result is an instrument which, while costing less than a colour television camera, is still outside the scope of any amateur system. The equipment described here generates a resultant colour waveform directly, without the use of matrix circuits, drastically reducing the cost and complexity of the finished instrument. The device is completely compatible with the PAL (Phase Alternating Line) colour system used in Britain.

The article is not intended as detailed constructional notes, but outlines the results of an investigation performed by the author into a new principle. The outcome was a working prototype design which the reader may wish to extend to suit his individual needs.

Before the new method is described, it is necessary to discuss the operation of the PAL system in detail.

The PAL system

A colour television camera will be considered as a convenient source of colour video information.

The incoming light image from the lens is split into three primary colours, red, blue and green, using dichroic mirrors. These three colours are chosen because virtually any colour can be made up by combining these in suitable proportions. It should be noted that these colours are made by a process of addition on the display of a colour television receiver; for example, yellow is made up from a combination of red and green which, due to the spectral sensitivity overlap of the eye, is sensed as yellow.

Each of the three colours is focused onto a camera tube, usually a Plumbicon, which has a maximum spectral response at that colour. The outputs from the tubes are first added in the proportions

30% red + 59% green + 11% blue

to give a component called Y, the luminance or monochrome signal, which is the only signal used by a monochrome receiver. These proportions are chosen to give a good white, called 'luminance C' white, from the camera tubes.

To economize in bandwidth in the final transmitted signal, colour difference signals are used to ensure that no brightness (luminance) information is transmitted in the chrominance channels. Difference signals (R-Y) and (B-Y) are formed by subtracting the brightness signal from the red and blue signals respectively. Only two signals are needed because the third, (G-Y), can be derived in the receiver from the other two.

A monochrome transmission consists of the luminance waveform separated by synchronizing pulses, used to lock the receiver's scan circuits to those of the camera. A colour signal, however, has to convey two additional signals to the receiver. As well as the luminance or Y signal and synchronizing pulses, the (R-Y) and (B-Y) signals must be transmitted, and yet must not interfere with the Y signal, so as to be compatible with monochrome receivers. To this end, a subcarrier is used, and this is added directly onto the luminance signal, as in Fig. 1. The subcarrier is phase modulated for colour hue, and amplitude modulated for saturation, or colour intensity.

The choice of subcarrier frequency is important. It must be within the video range of 0 to 5MHz, and it must not produce an objectionable dot pattern on a monochrome receiver. The chosen frequency is about 4.43MHz, the reasons for which will appear later in the discussion.

It is uneconomic in terms of transmitter power to transmit the subcarrier and its associated sidebands, so the subcarrier is suppressed before transmission and only the sidebands are transmitted. In the receiver, therefore, the subcarrier has to be re-inserted before demodulation, the receiver's local subcarrier oscillator being locked to the transmitter's subcarrier. To this end, a small burst of subcarrier is inserted into the back porch of the video waveform, containing 10 cycles ± 1 cycle of the transmitter's subcarrier. This is known as the colour burst.

The suppressed-carrier modulation technique is used for two subcarriers of the same frequency, but differing in phase by 90°. The (B-Y) signal is modulated on one carrier, and the (R-Y) signal on the other, the basic (R-Y) subcarrier leading the (B-Y) subcarrier by 90°. The two signals are then combined to produce a resultant which varies in amplitude and phase, and this is then added to the video waveform, as seen in Fig. 1.

In some colour systems, for example, the American NTSC system, the phase of the colour burst and the basic phase of the colour subcarrier is the same on every line. This system, however, is prone to differential phase distortion, caused by slight subcarrier phase shifts brought on by different transmission path lengths, and giving rise to incorrect hues. The PAL system helps to overcome this by changing the phase of the colour burst on every other line by ± 45° about 180° to the (B-Y) carrier. The (B-Y) carrier relative phase remains unchanged, but the R-Y) subcarrier is reversed in phase on every other line. As is seen in Fig. 2, the (B-Y) axis is called the U axis and the (R-Y) axis is called the V axis on a vector diagram. Fig. 3 shows the method of reducing differen-

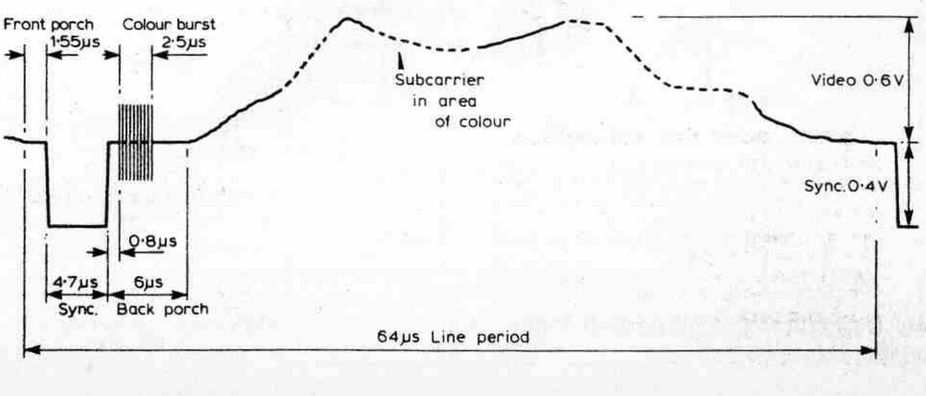


Fig. 1. Colour television waveform, showing colour burst and subcarrier in area of colour.

tial phase distortion — $\phi°$ in the diagram. In the receiver, the signal with −V phase is inverted to bring it into the same phase as lines with +V phase. The resultant vector over two adjacent lines is the original transmitted subcarrier phase. This does give rise to a slight decrease in saturation, but this effect can be minimised in the receiver.

The subcarrier frequency chosen is a multiple of line frequency, plus a quarter of line frequency, to offset the dot pattern produced on a monochrome receiver. In addition, by adding another half cycle per field (25Hz), dot pattern interlacing is achieved, making it even less visible. The final figure for the British system becomes:—

$$\left[\frac{567}{2}+\frac{1}{4}\right]15625+25(\text{Hz})=4.43361875\text{MHz}.$$

The figure of 567/2 times line frequency as the basic subcarrier frequency is chosen so that the chrominance sidebands intermesh with the luminance sidebands, and do not interact.

The dot pattern arises on a monochrome receiver because the subcarrier sine wave modulated on the video waveform is seen by the receiver as a high frequency video component. The effect is only noticed on areas of high saturation. The pattern does not appear on a colour picture because the colour subcarrier is filtered out before the luminance is displayed.

In the receiver, the three difference signals are obtained and added to the brightness component of the waveform in the colour picture tube.

Colour synthesis

The concept of colour synthesis is to use a monochrome video signal, such as one obtained from a monochrome television camera, to produce a colour picture.

The monochrome signal consists of luminance information only, and therefore a colour synthesizer cannot reproduce the actual colours of the viewed scene, but will add colours as desired by the operator. This technique may be considered as painting the colours onto a black and white scene. A synthesizer is of particular use with captions, where a monochrome camera can be used to view the caption, and the caption's video converted to colour using a synthesizer. Furthermore, the colours can be changed at will.

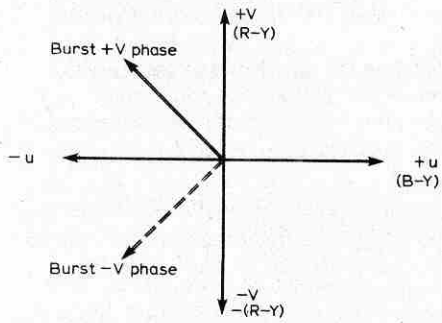


Fig. 2. Colour subcarrier vector diagram.

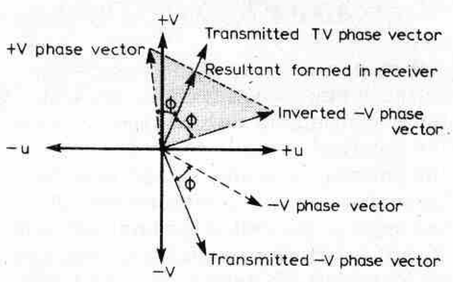


Fig. 3. Resultant formed in receiver from two phase-shift ed vectors is in same phase as transmitted vector.

Colour synthesizers normally have preset red, blue, and green signals, which may be used to colour areas of the picture. These signals, which normally consist of d.c. levels, are fed to a conventional PAL coder, and correspond to areas of constant colour. The expensive colour camera optics, video pre stages, and three camera tubes are therefore dispensed with. However, the PAL coder is still required to process the signals, and convert them into a form suitable for transmission; this constitutes a large proportion of the cost of a colour synthesizer. The author decided to try generating the subcarrier resultant directly, thus obviating the need for a PAL coder, but retaining complete compatibility with colour television equipment.

It was decided that the colour hue determining factor at any point of the picture would be the luminance amplitude at that point; a particular shade of grey would correspond to a particular hue of the electronically generated colour. The range of colours obtainable over a luminance range should be adjustable.

Since the colour saturation is determined by the amplitude of the colour subcarrier, the saturation is controlled via a subcarrier variable-gain amplifier. The generated subcarrier passes through fixed phase-shift networks and gating circuits to generate the colour burst. The colour hue is determined by the phase of the subcarrier; hence, a voltage-controlled phase-shift unit is employed as the colour hue determining network.

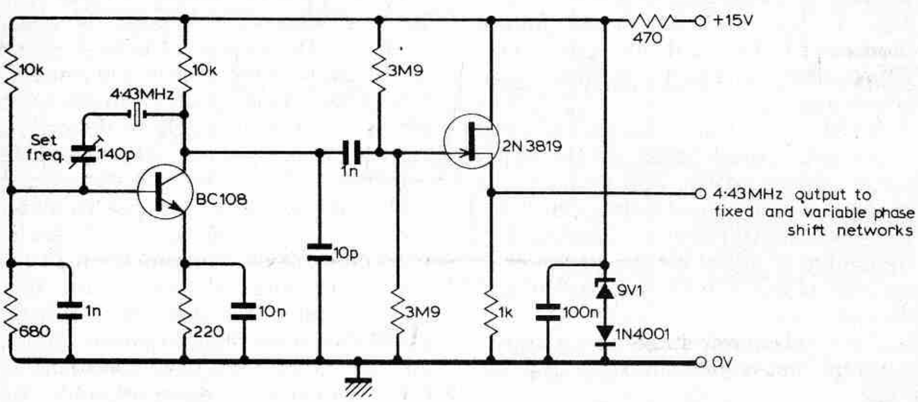


Fig. 4. Colour subcarrier generator circuit.

To be compatible with the PAL system, the phase of the subcarrier has to change on every other line. It has already been stated that with the PAL system, the phase of the (R-Y) subcarrier is inverted on every other line, while the (B-Y) subcarrier remains unchanged. This can be written mathematically as

$$A\sin\omega t + B\sin(\omega t + 90°)$$

where $A\sin\omega t$ represents the (B-Y) subcarrier and $B\sin(\omega t + 90°)$ represents the (R-Y) subcarrier on lines with +V phase. A and B are the relative amplitudes of each. Similarly, we can write

$$A\sin\omega t + B\sin(\omega t + 90°) + 180° \qquad (2)$$

for lines with −V phase.

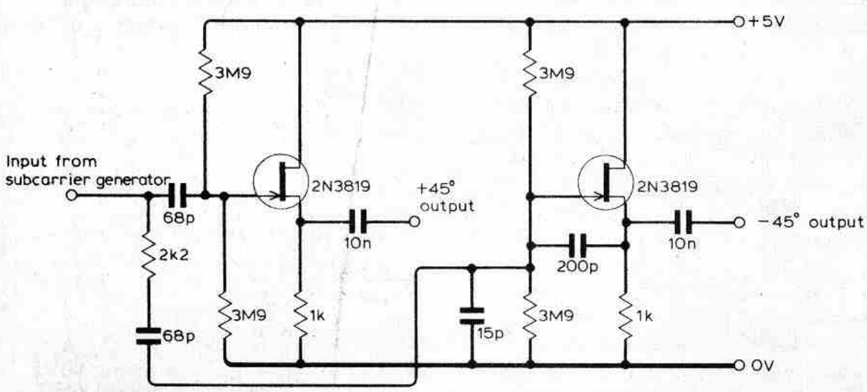


Fig. 5. Circuit to provide outputs leading and lagging by 45° on colour subcarrier to produce colour burst.

Now, since

$$P\sin\Omega + Q\cos\Omega = R\sin(\Omega + \mu)$$

where

$$R = \sqrt{P^2 + Q^2};\ \mu = \tan^{-1}Q/P,$$

(1) becomes

$$A\sin\omega t + B\sin(\omega t + 90°) = A\sin\omega t + B\cos\omega t = C\sin(\omega t + \theta)$$

where

$$C = \sqrt{A^2 + B^2};\ \theta = \tan^{-1}B/A,$$

and (2) becomes:–

$$A\sin\omega t + B\sin(\omega t + 270°) = A\sin\omega t - B\cos\omega t = D\sin(\omega t + \alpha),$$

where

$$D = \sqrt{A^2 + (-B)^2} = C;$$
$$\alpha = \tan^{-1} -A/B = -\tan -^{-1}B/A = -\theta.$$

Hence (2) is

$$A\sin\omega t - B\cos\omega t = C\sin(\omega t - \theta).$$

Therefore, on lines with +V phase, the resultant subcarrier is

$$C\sin(\omega t + \theta),$$

and on lines with –V phase, the resultant is

$$C\sin(\omega t - \theta),$$

where C is a factor controlling colour saturation, and θ controlling the colour hue.

These two expressions show that the resultant subcarrier can be simulated by phase advancing about a mean value on one line, and phase retarding on the next. This is the principle used in this design.

Design

The synthesizer can be considered in eight distinct stages.

Oscillator. The subcarrier master oscillator is crystal-controlled and is designed around a standard colour subcarrier crystal used in domestic colour television receivers. In Fig. 4, the oscillator is of the Pierce type, with a source follower f.e.t. stage to minimize loading effects. The stage is fed from a stabilized power supply to improve stability. The phase of the output subcarrier from this unit is assigned the phase of –(B-Y), the –U axis, and used as the reference phase about which all others are considered.

Fixed phase-shift. The phase of the colour burst alternates by ±45° about the —U axis. Figure 5 shows two networks which use single RC and CR networks to provide the ±45° phase shifts, the resultant being fed to source follower buffer stages. The outputs from the source followers are capacitively coupled to f.e.t. switches in the burst gating unit. The characteristics of the fixed phase shift unit are seen in Fig. 6.

Variable phase shift. At the heart of the system is the voltage-controlled phase-shift unit. In the circuit of Fig. 7, anti-phase signals are fed into the input ports of the network. If resistor *R* is increased from zero to infinity, the phase of the output changes by 180°. If the impedance to both input ports is the same, and low compared with the reactance of capacitor C at the operating frequency, then the resulting output vector amplitude is essentially constant over the entire phase change. This is the basis of the voltage-controlled phase-shift unit. If R is replaced by an f.e.t., controlling the gate voltage controls the source-drain resistance and hence the output phase. Figure 8 shows the circuit of the voltage-controlled phase-shift network.

The input 4.43MHz. from the subcarrier generator is fed into a transformer, which splits the phase of the signal to feed the phase-shift elements. Two f.e.t.s in parallel provide a more linear phase-shift characteristic. The two phase-shift stages in cascade give nearly 360° phase shift over a control-voltage range of zero to –3.5V on the f.e.t.s. Source follower stages are used between the phase shift stages to present the necessary high impedance to the output of the *RC* system, yet provide a low impedance transmitted through the transformer to the input of the *RC* system. The 10kΩ potentiometer on the output controls the amplitude of the subcarrier and hence the colour saturation. Figure 9 shows the characteristics of the unit. The operating range is chosen to be from –2V to –3.5V and this is achieved by adjusting the gain of the control circuits to be considered later.

Sync. separator. In order that the burst may be gated in at the correct position, and to change the phase of the subcarrier at line frequency, it is required to extract the synchronizing pulses from the incoming video waveform. In Fig. 10, the p-n-p transistor is normally

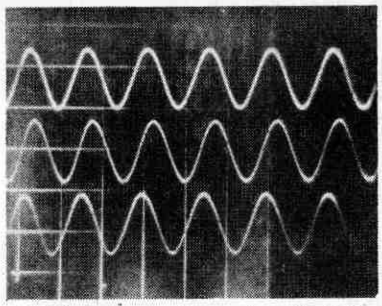


Fig. 6. Waveforms from circuit of Fig. 5. Top trace is input, middle trace leading and bottom output lagging.

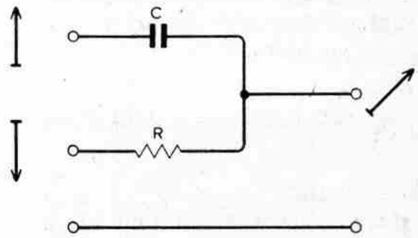


Fig. 7. Basic phase-shift element.

Fig. 8. Voltage-controlled phase-shifter for subcarrier, phase of which determines hue of picture. ▼

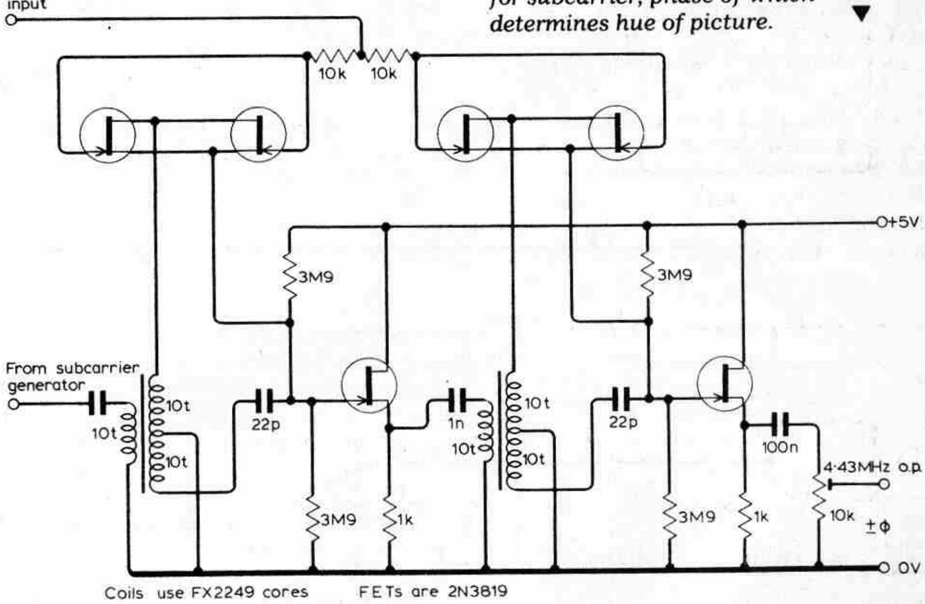
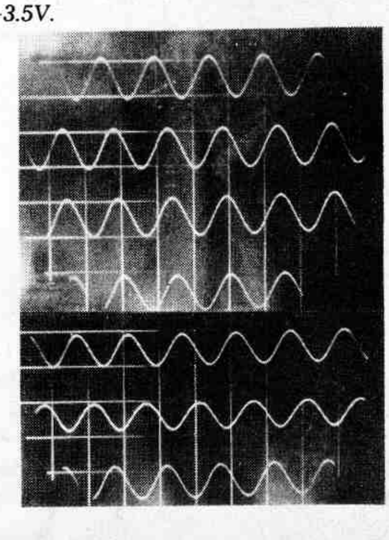


Fig. 9. Characteristics of Fig. 8. circuit. Top trace is input; lower traces show phases when control voltage is set at –0V, –1.5V, –2V, –2.5V, –3V, and –3.5V.



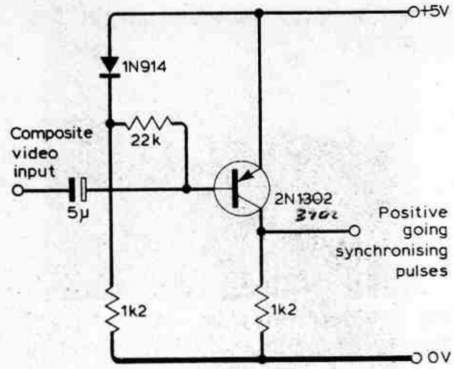
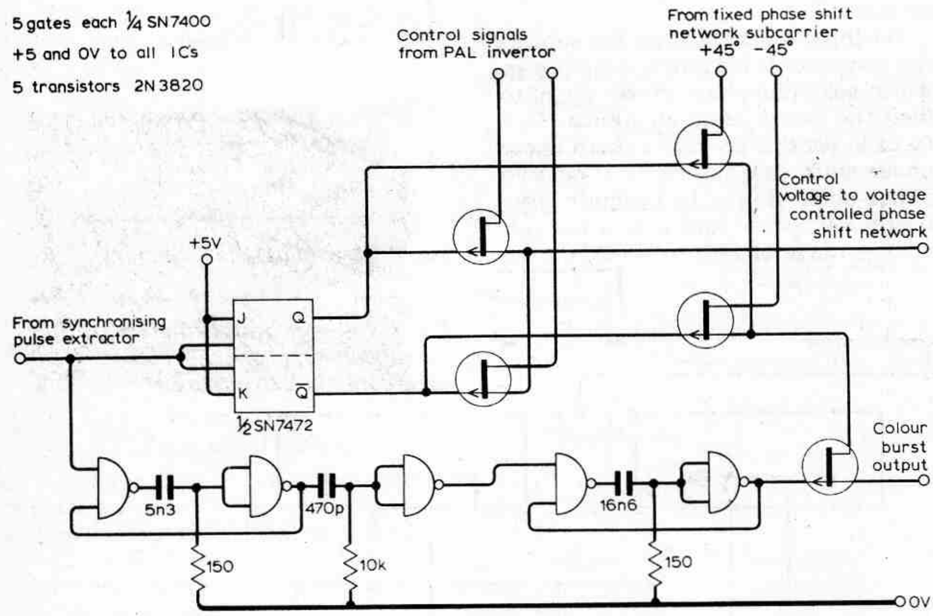


Fig. 10. Circuit to extract sync. pulses from composite video.

Fig. 11. Burst gating and line-frequency divider.



biased into cut-off by setting the base at +4.5V with respect to the collector, using a silicon diode. Therefore, only when the level of the video is low enough does the transistor conduct. This low level is only reached during the negative-going synchronizing pulses. Hence, positive-going synchronizing pulses appear at +5V peak on the collector of the transistor, and are compatible with standard t.t.l. integrated circuits.

Burst gate and line dividers. Synchronizing pulses are fed to the half-line frequency divider and burst gating generator in Fig. 11. The half-line frequency switching-pulse generator is simply a t.t.l. bistable element, the burst gating generator consisting of two monostables. The colour burst is 2.5μs long, occurring 0.8μs after the line synchronizing pulse. The first monostable, triggered on the negative edge of the incoming pulses, provides the 0.8μs delay, its output pulse being inverted and used to trigger the 2.5μs monostable, which produces the burst gating pulse.

The half line frequency pulses select the appropriate burst phase, which is fed to the burst gating f.e.t. to provide the correctly timed and phased colour burst.

Threshold gate. To prevent colour information from entering the black level and synchronizing pulse region, and also the peak white region, a threshold detector is used, as shown in Fig. 12. Composite video is fed to the level detector and the two threshold levels are set on the potentiometers. The output controls an f.e.t. switch which gates-in the subcarrier in the video regions.

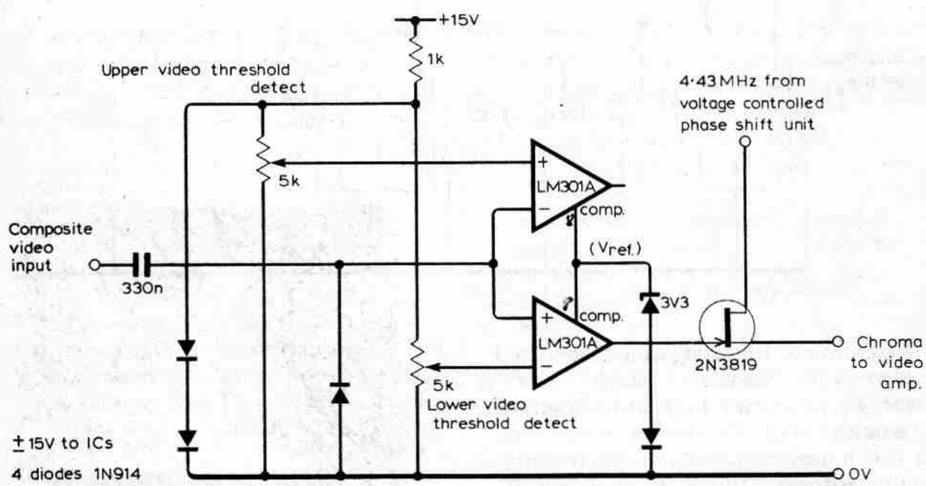


Fig. 12. Chroma threshold gate.

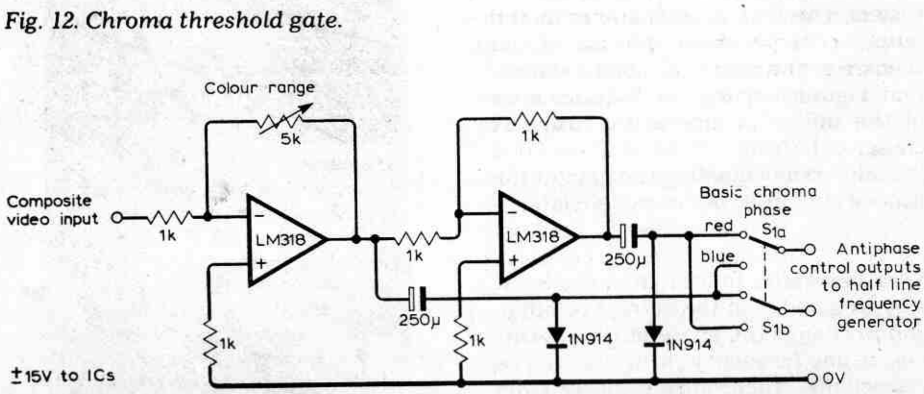


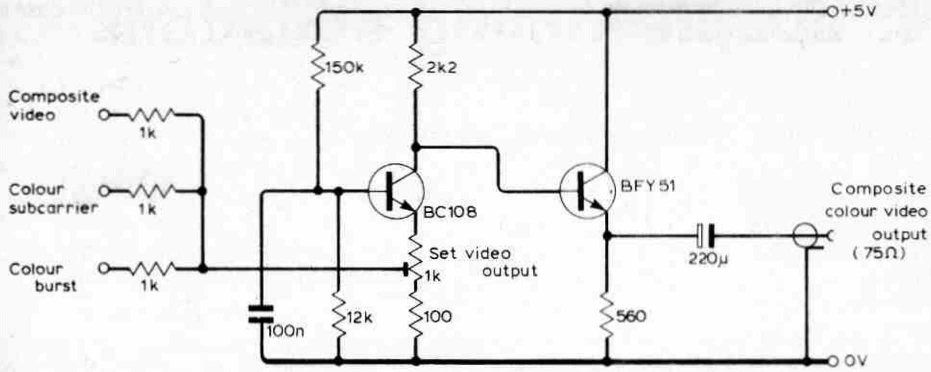
Fig. 13. Colour range amplifier and PAL inverter. Outputs are selected by f.e.t. switches in Fig. 11 to control voltage-controlled phase shifter of Fig. 8.

Amplifier and inverter. The control signal for the voltage-controlled phase-shift network is derived from the video signal in the circuit of Fig. 13. The video signal is amplified in a variable-gain operational amplifier configuration whose gain control determines the range of colours obtained on a picture. Another operational amplifier is used as an invertor and the two signals are fed to f.e.t. switches, which select the direct or inverted signal to control the phase-shift network. The chroma phase switch (Sw_1) selects the phase of the control signal with respect to the colour burst: thus the basic colour of the picture (in the dark regions) can be changed.

Video output. All the signals – the video, colour subcarrier, and colour burst – are combined in the video output amplifier of Fig. 14 The signals are fed to a common base amplifier which supplies drive to the emitter follower stage to present an output impedance of 75Ω.

A block diagram of the synthesizer is shown in Fig. 15.

It should be noted that with this



◀ *Fig. 14. Video mixer and output amplifier.*

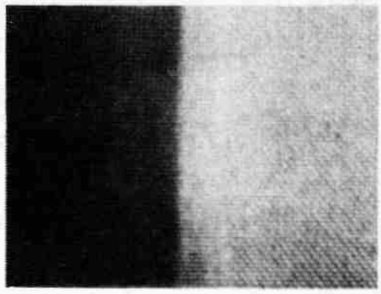


Fig. 16. Subcarrier dot pattern seen on a monochrome receiver.

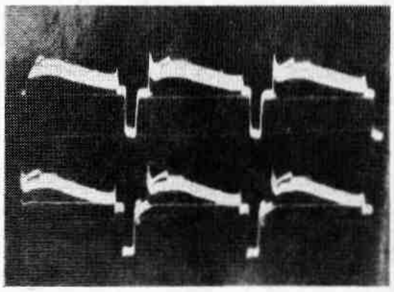
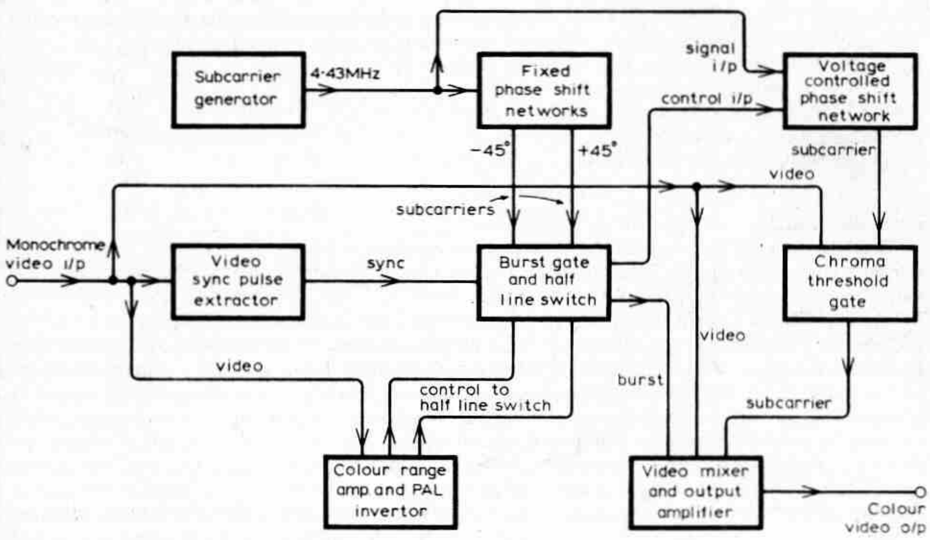


Fig. 17. Monochrome (top) and colour (bottom) video waveforms.



◀ *Fig. 15. Complete block diagram of the equipment.*

system, the subcarrier is not suppressed, but this means that additional information is conveyed to the receiver, where it is filtered out.

Testing

The complete unit may be connected to a monochrome television camera to enable the subcarrier pattern to be viewed.

After switching the unit on, with the camera viewing a scene, the saturation control may be advanced until the subcarrier dot pattern is visible, as in Fig. 16. Adjusting the colour range control changes the dot pattern slightly showing that the phase of the subcarrier has changed.

A comparison of the input and output waveforms of the device can be seen in Fig. 17, in which the colour burst appears after the line synchronizing pulse, and where the video region is slightly more indistinct, showing the presence of the subcarrier.

If the previous tests prove satisfactory, the unit may be connected to a colour television monitor, and the colour range and saturation control adjusted to give a good colour range when viewing the scene. The threshold controls are adjusted so that they just do not clip the chroma at either black or peak white: this is the correct setting of the controls for an all colour picture.

For pictures of high contrast, for example, a black caption with white lettering, two-colour pictures may be obtained. By changing over the chroma phase switch, the dark regions of the picture may be changed from red to blue.

There is a tendency on certain scenes for the colour to flicker at the top of the picture, due to the absence of Bruch blanking. This is the system whereby the burst is blanked off for the first few lines at the beginning of a field to allow the synchronizing circuits to settle down after the field synchronizing pulses.

The unit is capable of generating all the colours obtainable with the PAL system, with an even distribution of the colour, throughout the picture. the phase shift network is quick to respond to a sudden change of luminance with no spurious effects at the transition edge.

The results obtained with these simple circuits were very encouraging, and proved the principle of the design. The unit is intended as a low cost device for providing colour on an amateur system, or for schools. The presence of colour on a caption or diagram greatly increases the clarity and it is here where it would be most useful in an educational establishment.

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Mr Roberts took an honours degree in applied physics at the University of Bath in 1975, subsequently working for two and a half years at Marconi Space and Defence Systems on computers and automatic test equipment. At the present time he is a civil servant. In his spare time, his interests include the design of high-fidelity audio equipment and home computer systems, on which he occasionally lectures to groups of enthusiasts.