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Fountain Press
13–35 Bridge Street, Hemel Hempstead, Hertfordshire,
England

Consultant Editor: Norman Stevens

Model and Allied Publications Limited,
Fountain Press, Book Division,
Station Road, Kings Langley,
Hertfordshire, England

First Published 1974

ISBN 0 85242 371 3

Printed in Great Britain by
Gilmour & Dean Limited, Hamilton, Scotland

PREFACE

COLOUR TELEVISION is probably the most exciting engineering development to have entered the ordinary domestic household since Britain started the world's first television service in 1936. There are now several million colour receivers on the market, bringing the world of colour within reach of the armchair.

The design, production and servicing of these receivers involves a very large number of skilled engineers all over the country, and many amateur enthusiasts build their own models and get great enjoyment from taking part in the new technology.

This book has been written for the benefit of engineers and enthusiasts who are beginning to study colour television. It attempts to explain the principles of the PAL system in simple terms and the way in which they are applied in ordinary domestic receivers. Thus, chapters are included describing the features of a complete receiver together with procedures for aligning colour circuits and carrying out routine servicing. It is hoped that any reader with a reasonable knowledge of monochrome TV practice will have little difficulty in understanding colour techniques.

I would like to express my gratitude to the following companies for generously supplying information about their products: Philips Electrical Ltd, RCA Corporation, Mullard Ltd, Thorn Radio Valves and Tubes Ltd, Pye Ltd, Sony Corporation, Combined Electronic Services Ltd, British Radio Corporation Ltd. The text of this book contains extracts from articles written by the author for *Practical Television* and *Television*. I would like to thank the Editor of these journals for permission to reproduce them.

I am also much indebted to Mr. E. J. Glaisher for reading the manuscript and making many helpful suggestions: to Mr. A. Love for taking the photographs of colour bar waveforms reproduced in the colour plates of Figs. 2-13, and to my wife for her perseverance in typing what at times must have seemed to be a foreign language.

December, 1973 *A. G. Priestley*

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CHAPTER ONE

The Origin of the PAL System

NO BOOK ABOUT THE PRINCIPLES of the PAL colour television system would be complete without at least a passing reference to the debt it owes to NTSC. The first proper colour broadcasting service began in the United States in 1953 using the now well-known system named after the organisation that devised it, the National Television System Committee. It represents a remarkable feat of engineering organisation and expertise on the part of an industrial body set up to choose a system suitable for a national broadcasting service.

It all seems quite straightforward now, but when the television industry in the USA established the new Committee, no satisfactory colour television system existed. Numerous proposals had been put forward, and many demonstrations had been made, but none of them met the requirements of a good system. The NTSC organisation sponsored a lot of research, collated the results of many experiments, and finally came up with a complete new colour broadcasting technique which justly became known as NTSC.

In some ways it was in advance of its time, and early teething troubles caused colour TV to make a poor start in public acceptance. Gradually it gained ground and in the early 1960's it made its breakthrough.

NTSC Variants

At about this time Europe began to get interested in the possibility of starting colour broadcasting, and at first NTSC was the obvious choice, particularly as it offered the opportunity to standardise on one, almost worldwide, system. However, Henri de France proposed a radical modification to NTSC known as SECAM, and political pressures began to influence the choice. Then Herr Bruch of Telefunken experimented with yet another modified version of NTSC which became known as PAL after 'Phase Alternation Line'.

The European Broadcasting Union set up a Committee to compare the merits of the rival systems, in an attempt to get agreement on the best choice, so that it could become the standard for a large number of countries. After many attempts to reach agreement negotiations finally broke down, with the result that France and the Soviet bloc chose SECAM, and most other European countries chose PAL.

In addition to the political issues, there were some sound engineering reasons for trying to develop better systems such as SECAM and PAL. NTSC had proved to be susceptible to distortions caused by defects in signal propagation and transmission, and to drift in receiver circuits. SECAM and PAL both showed better immunity to these effects, although with differing compromises between various factors that influenced the engineering assessment.

Many engineers thought that, overall, PAL was the best system, and this was reflected in its adoption by several countries. Subsequent experience has shown that PAL is a very good system indeed, and later on when discussing decoding we shall see how this comes about.

Fundamental Requirements

Any system for transmitting and receiving colour TV pictures must fulfil certain basic requirements if it is going to be capable of providing a satisfactory national broadcasting service. There are quite a number of factors involved, and these are common to any system—whether NTSC, PAL, SECAM or one of their derivatives—and it is worthwhile considering them before going on to discuss the detailed working of PAL itself.

A good standard of colour performance we take for granted; otherwise there would be no point in starting a colour TV service at all. Note, however, that this performance must be maintained down to very low signal levels, where electrical noise becomes a problem, and also under conditions of poor signal propagation and reception. In other words, the system must be inherently robust and have good immunity to ghosting and other forms of signal distortion caused by reflections from nearby buildings or hills, or by transmission along poor quality cable links.

Another requirement comes under the heading of "compatibility" and "reverse compatibility". It is going to be a very long time indeed before every television receiver in the country is capable of displaying colour programmes. There will be some monochrome (black-and-white only) receivers for as long as one can see into the future. This means that in the interests of common justice the colour TV signal must be compatible with monochrome receivers. Monochrome receivers must be able to display good quality pictures from colour transmissions, although of course the pictures will be displayed in black and white.

Similarly it is reasonable to assume that not all TV programmes will be transmitted in colour, if only because there is a large stock of black and white films that are capable of providing good entertainment. Thus the colour system must have reverse compatibility and permit colour receivers to display good quality monochrome pictures.

These requirements of compatibility arise because we cannot afford to transmit colour on a separate broadcast channel. There are simply not enough channels to go round. There is a worldwide shortage of r.f. signal bandwidth to accommodate all the communications services of modern life. These range from radio and TV to air-sea rescue services; telephony; air and maritime communications; the Services with all their electronic equipment; the humble amateur enthusiast and the astronomers.

Another factor that influences the design of a colour TV system is that no unnecessary limitation must be imposed upon the choice of colour c.r.t. The system must not be designed to work only with one particular type of tube: it must be flexible, so that advantage can be taken of any future improvements in tube design and technology. Colour broadcasting only started in the UK in 1967, and yet already the Japanese Trinitron tube has appeared and others are beginning to loom up over the horizon.

Cost Factor

There is yet another group of factors which has to be taken into account when designing or choosing a colour TV system. Perhaps the first item is cost. Extra cost involved at the transmitting end of the chain is undesirable but is normally only repeated a few times and so may well be acceptable. Extra cost built in to a receiver is multiplied many millions of times and even a small amount added to each receiver may add up to a prohibitive total.

By the same token, a system that allows flexibility in the design of the receiver is likely to yield substantial advantages in the long run. New developments in circuit design and component technology can yield important savings in cost and improvements in performance, as we are already beginning to see in the case of certain all-solidstate PAL receivers.

A good system does not call for a very high degree of electrical stability in the receiver circuitry, nor does it demand great accuracy of circuit alignment. Both of these requirements would have a bad effect on the reliability of receivers and would make manufacture and servicing more difficult.

From what we have just been discussing it is easy to see that there is rather more to designing or choosing a colour TV system than just finding out whether it works. As we learn more about PAL we shall find that it represents a very good example of true system engineering. It meets all the requirements listed above and a good many others as well. For example it takes advantage of the characteristics of coloured light, and the way in which it reacts on the human eye, in order to meet the requirements of the system in the simplest possible way.

The Nature of Light

Light is a form of electromagnetic radiation similar to radio waves, TV, radar, laser energy, infra red, ultra violet, X-rays, cosmic rays and so on. Fig. 1.1 shows where visible light falls in the spectrum of electromagnetic radiation, and it will be seen that light occupies only a very small range of wavelengths. Light which we call red has a wavelength of about 700 milli-microns and violet corresponds to a wavelength of about 400 milli-microns, where one milli-micron = 1·0mu = 1/1,000,000 of a millimetre.

The complete visible spectrum consists of red, orange, yellow, green, blue and violet. These are the colours seen in a rainbow, and they are separated out from white light by refraction. If you pass white light through a prism, as shown in Fig. 1.2, you get this same

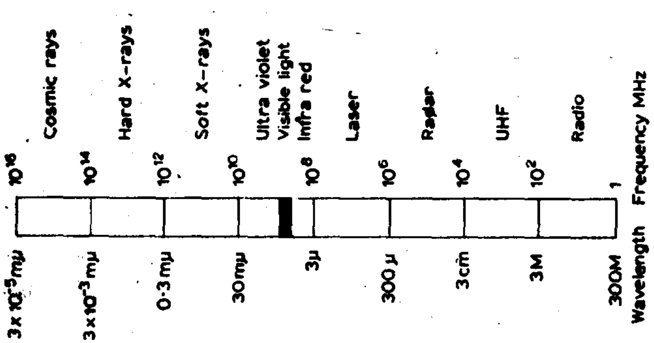

Fig. 1.1 Light forms only a small part of the spectrum of electromagnetic radiation.

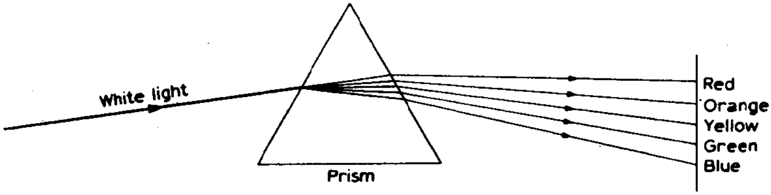

Fig. 1.2 A prism separates white light into its constituent colours by a process of refraction.

separation of colours. It is a standard experiment in Physics and is carried out by nearly all the school children in the country. One of the important things it demonstrates so clearly is that white light is a mixture of coloured lights, and not a simple colour in its own right. If you want white light you can only get it by using a suitable mixture of colours.

How the Eye Sees Colour

The human eye can only see an object when light emitted by it, or reflected off it, passes through the iris of the eye and is focused by the lens on to the retina. (See Fig. 1.3). The retina consists of a very large number of nerve endings, and when these are stimulated by light energy messages are transmitted to the brain which interprets them in terms of colour, brightness and shapes. If no light reaches the eye, the brain gets no messages, and interprets this state of affairs as 'black' or 'darkness'.

The nerve endings in the eye consist of two types called rods and cones. The rods do not react to colour at all and simply register how *bright* the light is. The rods are very sensitive and enable us to see fairly well even when there is not much light. Under these conditions

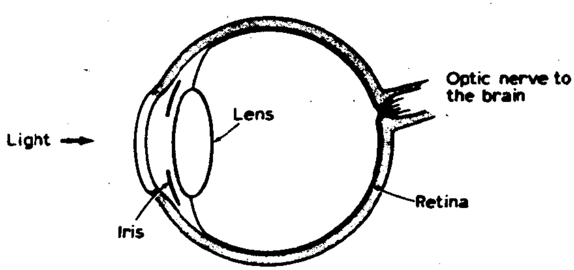

Fig. 1.3 The human eye is only able to 'see' when light falls on the retina.

the cones are hardly registering anything, and this is why we see very little colour even when we can still see objects quite clearly, as on a bright moonlit night.

The cones, however, are not merely lacking in sensitivity: they react to coloured light in a rather unexpected way. In fact, medical scientists still do not fully understand precisely how they work, but the cones behave as though there were three separate types responding to light of different wavelengths. Thus the eye appears to have three-colour vision.

It does not identify each individual colour, but instead analyses all the coloured light reaching it in terms of the red, green and blue constituents. For example if the eye receives a suitable mixture of red, green and blue light the brain interprets this as 'white', and this white light is indistinguishable from ordinary white light containing all the colours of the spectrum.

Another rather striking example of this peculiar characteristic of the human eye is provided by oranges. Oranges reflect light of a very well known colour, and this contains light energy with most of the wavelengths in the visible spectrum except in the region of wavelengths of 589mu. Now if sodium is heated the vapour emits light with a wavelength of 589mu, and the colour of this light is almost indistinguishable from that of the oranges. The eye is unable to see any significant difference.

This fundamental characteristic of three-colour vision is the basis of all present day systems of colour television. It makes it possible to transmit colour in the same channel bandwidth as ordinary monochrome pictures. Without three-colour vision it is doubtful whether it would be practicable to have a national colour television service at all. Certainly it would need a completely different approach and some very complicated electronics with a wide bandwidth signal.

Visual Perception and Bandwidth

There is another characteristic of human vision which plays a very important part in colour television. When the eye is confronted by some very fine detail it is mostly the rods with their high visual acuity that register this detail and transmit the information to the brain. Since the rods are insensitive to colour the brain sees this detail in black and white. There is very little colour perception.

From this simple fact we can derive two useful considerations. Firstly, if the eye is unable to perceive fine detail in colour, there is no point in transmitting and receiving it. This leads to a useful saving of colour bandwidth. Secondly, if we want to obtain a really sharp colour picture with plenty of fine detail we must transmit and receive a wide bandwidth brightness signal carrying the black-and-white information just as we do in good quality monochrome TV practice.

Large area colour information superimposed upon this fine detail monochrome information will give to the eye an impression of a clear, sharp picture. It really does seem to be an extraordinary stroke of good luck that the eye should behave in this way. We could not have designed it better ourselves!

Subtractive Colour Mixing

Anyone beginning to study colour TV must forget all about the paint box mixing of coloured pigments. With a paint brush it is easy to get green by mixing blue and yellow. If you try doing the same thing with coloured lights you will get white, or something near it!

Using coloured pigments is a subtractive process because if white light falls on, say, a red pigment all the constituents of white light are absorbed except for the red light energy. This is reflected instead of being absorbed, and so the eye sees 'red'. If you mix a perfect yellow pigment and a perfect blue one the yellow pigment absorbs all colours except yellow, and the blue absorbs everything except blue. In this instance all the light is absorbed and the mixture of pigments looks black.

In practice, pigments are far from being perfect, and both yellow and blue reflect a certain amount of green. So when these two are mixed all the colours except green get absorbed and we see only the green colour. This state of affairs obviously does not apply when coloured lights are added together instead of being subtracted. However before considering this in detail we must define some simple terms that will serve to describe any coloured light with which we are concerned.

Brightness, Hue and Saturation

A coloured light, or a mixture of colours, can be described in terms of its brightness, hue and saturation. The term *brightness* is self-explanatory. Is the light intense, like sunlight, or is it dim like a torch with a run-down battery? The brightness of a light source, whatever its colour, can be expressed in physical units such as candella per square metre.

The word 'colour' which we have been using so far is rather vague for the purposes of engineering. The correct term is *hue*. We should talk of light having a red hue, or a green hue, etc. We can then describe these hues in physical terms by saying that they correspond to light having wavelengths of 700mu and 520mu respectively. This is a precise description which enables these hues to be reproduced again elsewhere with a high degree of accuracy. Note that a mixture of different hues will appear to the eye as a single hue matching one small part of the visible spectrum. Thus a mixture of light can be described as being equivalent to a light of a particular wavelength.

Saturation tells us whether the hue is pure, or not. Thus a beam of pure red light has 100% saturation. If on the other hand we add an equal quantity of white light to the red, the red light is diluted to 50% saturation, and looks a bright pink. If we add more white light the level of saturation falls still more and we get a pale pink. So a pale pink is a red hue at a low level of saturation.

Mixing Light

We saw earlier that the eye analyses any mixture of hues in terms of its red, green and blue constituents. A suitable mixture of all three gives a sensation of white light. A mixture of red and green gives yellow. We can summarise the more important mixtures as follows:–

	Red	+ Green	= Yellow	
	Red	+ Blue	= Magenta	
	Green	+ Blue	= Cyan (a greenish blue)	
And:–	Yellow	+ Blue	= White	Complementary colours
	Magenta	+ Green	= White	
	Cyan	+ Red	= White	

We say that yellow is the complementary of blue, magenta the complementary of green, and cyan the complementary of red, because all three mixtures give white light.

It is worth going a little further in our description of coloured light, and how it behaves, because it lies at the heart of any colour television system. Many aspects of the working of the PAL system are easier to understand once one has mastered a few simple facts about colour, and this applies particularly to problems of fault-finding. We shall be discussing this later.

The Chromaticity Diagram

Chromaticity means 'pertaining to colour' and the diagram of Fig. 1.4 is a convenient way of showing all the hues visible to the human

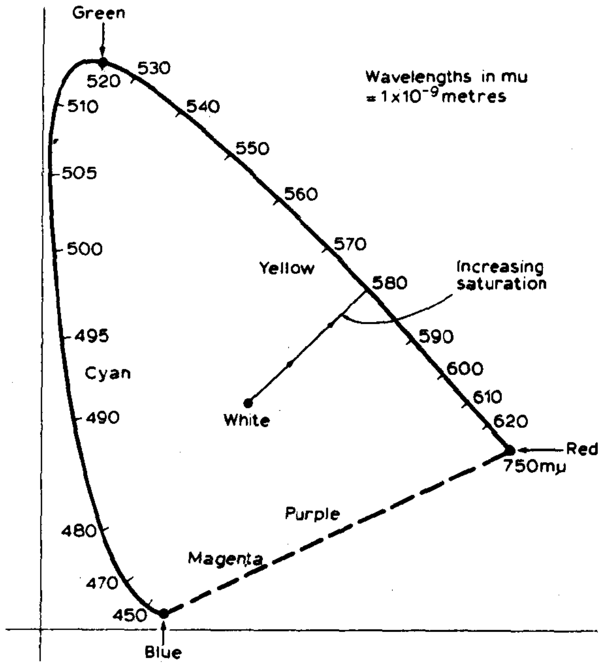

Fig. 1.4 A standard chromacity diagram.

eye together with their wavelengths and levels of saturation. It does not tell us anything about brightness.

All the wavelengths of the visible spectrum are plotted around the arms of the horseshoe from blue at 400mu to red at 700mu. Thus at any point on the periphery we can tell what the hue is by reference to the wavelength. The open arms of the ends of the horseshoe are joined together by a dotted line because the hues along this line are not pure spectral hues. They are obtained by mixtures of red and blue and give mauves, magenta and purple.

The first point to note about this diagram is that it provides us with a means of seeing what happens when we make simple mixtures of different hues. As you add increasing amounts of green to red, you move along the edge of the horseshoe from R to G via orange, yellow, yellowish green to green itself. Similarly adding green to blue takes you through the regions of blue and cyan to green. If you add red, green and blue together you move towards the centre of the horseshoe and the region of white.

This can be seen more clearly on the full colour plate facing page 16. Even the best colour printing cannot quite do justice to all the spectral colours, but you can see how the pure hues lie at the edge of the horseshoe with white near the centre. In other words as you move from the centre white point to the edge of the diagram along a straight line, as shown in Fig. 1.4, the light changes from 0% saturation to 100% saturation but the *hue* remains constant.

Primary Colours

The diagram of Fig. 1.4 is redrawn in Fig. 1.5. The points marked R, G and B represent the hue and saturation of typical light-emitting phosphors used on the screens of present day colour cathode ray tubes. The area enclosed by the lines RG, GB, BR, include all the hues at the levels of saturation indicated which such a c.r.t. is capable of displaying. Any colour outside the triangle cannot be reproduced.

At a first glance it does not look very impressive: it seems as though a large area of colour is being left out. In practice however a very large proportion of the light occurring in nature lies inside the triangle shown and can be reproduced faithfully by the c.r.t. The reason why R, G and B do not lie on the edges of the diagram is simply a matter of chemistry. It is not yet possible to devise phosphors which will emit red, green and blue light at 100% saturation and at an adequate level of brightness. The present situation represents the best available compromise between brightness and faithful colour reproduction.

Of course if it were practicable to use four primary colours as shown in Fig. 1.6 a wider gamut of colours could be reproduced, but the transmitted signal would become more complicated as also

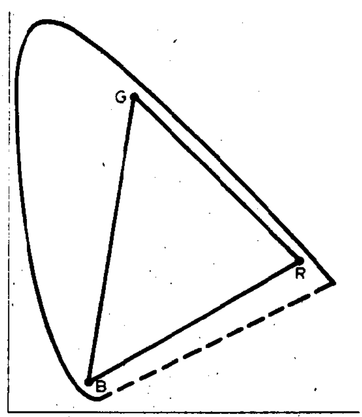

Fig. 1.5 Typical display tube phosphors have hues and saturations as shown above.

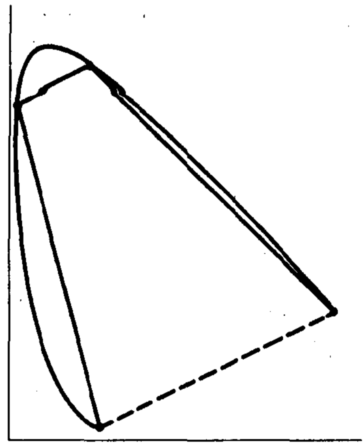

Fig. 1.6 The use of four primary colours would increase the gamut of colours that could be reproduced, but the subjective improvement would not be proportional to the increased area enclosed.

would the receiver circuitry and colour c.r.t. The improvement in colour reproduction would be small in practice and would not justify the increased complexity and cost of the system.

Three-colour Display

A three-colour signal displayed on a three-colour c.r.t. works very well, and is capable of giving a quality of reproduction superior to the best colour films and printing processes. The main limitation in an attempt to get still better colour reproduction is not so much in the colour TV system or the display tube phosphors, as in the accuracy of adjustment of the various preset controls that govern the behaviour of the c.r.t. display.

Ultimately, of course, as receiver circuitry is improved still further and certain critical adjustments are carried out by automatic electronic circuits, it will be the c.r.t. phosphors which will become the limiting factors. The search for better phosphors goes on all the time and there have already been several stages of improvement since the early days of colour television.

The research chemists are trying to achieve two main things. The first is to improve the efficiency of phosphors so that a given amount of electron beam energy in the c.r.t. will give more light output: i.e. a brighter picture for better viewing in daylight. Secondly they are trying to devise red, green and blue phosphors which lie further out