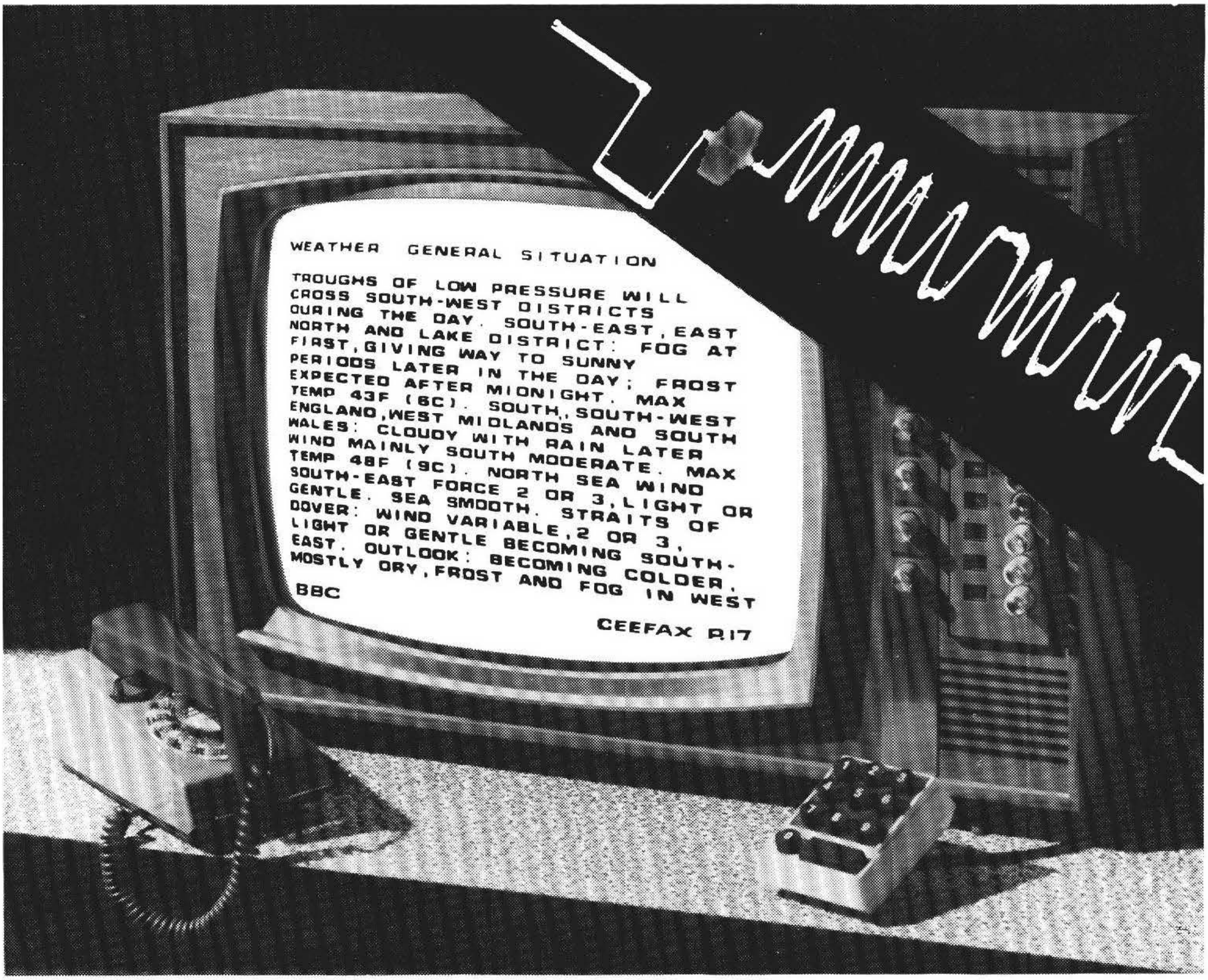
BBC ENGINEERING

Number 93 March 1973



Number 93 March 1973

BBC Engineering

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A record of BBC technical experience and developments in radio and television broadcasting

Contents

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The cover photograph shows a simulation of the Ceefax display and the data pulses which convey the information.

The major contributions are preceded by individual lists of contents.

Ceefax: A New Instant Information Medium

The idea of using the broadcasting system to convey written information into peoples' homes is not new. The Fultograph appeared as far back as 1928, but this was primarily a means of transmitting still pictures in the pre-television era. In the 'thirties a home facsimile system for attachment to a radio receiver was demonstrated in the USA. When loaded with a roll of paper (about the same width as a roll of kitchen tissue) and left connected to a receiver tuned to signals transmitted after the close-down of normal broadcasting, this produced a complete newspaper, including photographs, by the morning. The major stumbling block to this and other proposed home facsimile or printing systems was, however, the cost of the receiving equipment, quite apart from difficulties in operation. Many people find the loading of a camera with film beyond their capabilities, and even more would regard the loading of a machine with a large roll of paper as a daunting prospect; while the need, in some proposed systems, to load the machine with ink would not appeal to many housewives.

The BBC has recently announced that its Research Department is developing a new system called Ceefax in which written information will appear instantly on the screen of a domestic television receiver whenever the viewer presses a button to make his selection from one of about thirty 'pages' covering a variety of subjects of general interest, which may include the latest news headlines, weather reports, market trends, and other topics. When the viewer has read the information he requires, his receiver will immediately revert to displaying the normal broadcast television programme.

The majority of homes in Britain have television sets, and these sets, together with the television broadcasting system, provide an excellent ready-made basis for a new medium of instant information. The existing sound and vision signals occupy the broadcasting channel in such a way as to leave a few gaps into which additional information can be slotted. These gaps may be time-intervals (for example there are still some unused lines within the field-blanking period) or frequency-intervals in which parts of the overall spectrum of the broadcast channel are unoccupied.

To receive Ceefax information the viewer will require an extra unit, housed in a separate box linked by cable to his television receiver. It will not be necessary to buy a new receiver to be able to use the service although manufacturers may eventually incorporate the Ceefax unit within new receiver designs. In the meantime, it is hoped that help from the industry will be obtained in settling the method of connection between the 'black box' and existing receivers. In addition to providing means for enabling the viewer to select the page number that he wishes to see, the Ceefax unit will incorporate a micro-miniaturised alpha-numeric character generator which will respond to the pulses derived from the video signal by producing the letters and figures for display on the picture, in their appropriate positions on the page.

Using two lines of the television field blanking period, it will be possible to transmit all of the data for thirty-two pages, each containing about 750 characters, in fifteen seconds. So the information will be quite literally 'up to the minute'. The television receiver will, of course, be expected to 'write' the whole of any selected page of information in one picture period (1/25 sec) whenever a button is pressed. As the data pulses are coming in at a considerably slower rate, the Ceefax box will have to incorporate data storage corresponding to the total number of characters in all of the pages. The data in this store will be continuously rewritten by the incoming pulses.

The equipment at the transmitting terminal will also include a data store, which will have new information fed into it whenever the content of a page is changed, and will in turn determine the form of the transmitted Ceefax data signal.

The contents of Ceefax messages could, of course, cover any subject; clearly, any application of the system for general use would certainly include the obvious topics such as news, weather, sports results, and so on. Broadcasters would also find it useful to give details of forthcoming programmes and perhaps include public notices, traffic warnings, and other useful data. The Ceefax service might, for example, include the provision of statistics for the serious-minded viewer of programmes on economics, or worked examples for the mathematical student following an educational broadcast.

It may also be possible to use the Ceefax system as a means of providing sub-titles to the television picture to aid people who are deaf, or to provide the story in another language. In this case the Ceefax output would not replace the television picture but would add to it, say in a single line, across the bottom of the picture.

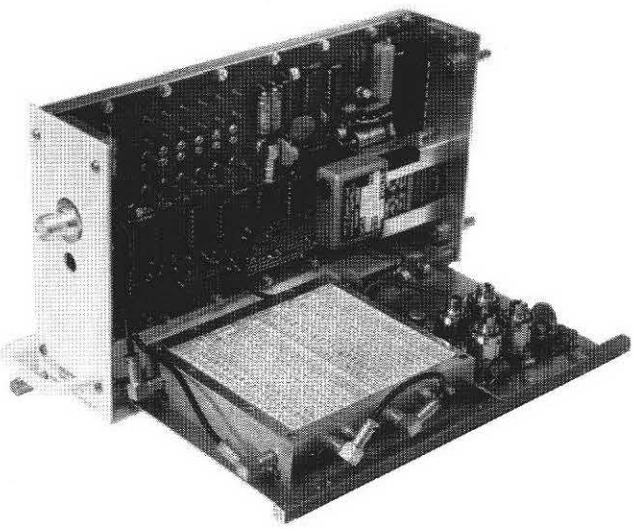
The BBC development programme is aimed at providing an experimental working Ceefax system by late summer 1973. The transmitting terminal will comprise a source of dummy Ceefax data arranged to accompany a television programme. Three receiving terminals will probably be constructed in experimental form and these will be used in field trials to enable the system to be evaluated.

In developing such a system it is necessary to establish standards of operation and during the development work interim (but not necessarily final) standards will be decided upon. Various interrelated aspects will be investigated such as the number of pages, the page format, the data rate, the addressing system, the methods of coding the data, etc., all conditioned by the availability of data channels within the existing vision signal.

The system which has been outlined represents a basis on which greater sophistication could be built. The number of pages available to the viewer could be increased enormously under certain circumstances; for example, the function of one or two of the projected thirty pages could vary during the day when different pages might be transmitted minute-by-minute.

Connection to the telephone system may be possible to obtain information particular to the subscriber. The storage at the domestic terminal could be increased to cope with greater numbers of pages using possibly, disk stores of the computer type or more sophisticated solid-state electronic data-stores when these become cheaper. Some of the new video disk recording processes point to the exciting possibility of recording and replaying whole books via the Ceefax-equipped television receiver.

Frequency Synthesiser



The Designs Department frequency synthesiser OS3/503 produces an output which can be set to any of the forty-two frequencies that lie at 8 MHz intervals in the range 24 MHz to 352 MHz, with a long-term stability better than ±5 parts in 100 million.

The high frequency stability is obtained by phase-locking a voltage-controlled oscillator (VCO) to a high-stability 5 MHz oven-controlled crystal oscillator. The putput of the crystal oscillator is divided by ten to produce the 500 kHz reference frequency for the phase comparator, and the output of the VCO is connected to four divide-by-two stages in cascade and then to a programmable divider, the output of which forms the second input to the phase comparator. The VCO covers the range 176 MHz to 352 MHz and the divide-by-two stage outputs covers 88 MHz to 176 MHz, 44 MHz to 88 MHz, and 22 MHz to 44 MHz respectively.

An internal output amplifier can be connected either to the VCO or to one of three divide-by-two outputs by means of a coaxial plug. This selects the frequency range. The VCO is tuned to approximately the desired frequency by inserting a 'U' link in one of six positions, the exact frequency being selected by six more 'U' links which set the division ratio of the programmable divider. All the 'U' link sockets are mounted on one of the printed boards.

A table pasted inside the unit indicates the position of the coaxial plug and the 'U' links for each of the 42 output frequencies, and a 'phase-lock' lamp on the front panel indicates that the unit is functioning correctly.

The unit is mounted on a standard BBC plug-in chassis and requires supplies of d.c. at +6 V, −6 V, and −24 V. The r.f. output socket is mounted on the front panel; other plugs, sockets, and 'U' links are inside the unit.

General Data

Power supplies	300 mA at +6 V 150 mA at −6 V 150 mA–400 mA at −24 V (400 mA when the unit is cold)
Output power	+7 dBm ±2 dB in a 50 Ω load
Frequency stability	
Long term	Better than ±5 parts in 10^8 for ambient temperature range −10°C to +40°C and supply potentials nominal ±5 per cent.
Short term	Peak frequency deviation better than −60 dB w.r.t. 50 kHz with 50 μs pre-emphasis.
Fine frequency adjustment	More than two parts in 10^5.

Colour Film Transmission in BBC Television

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1 Introduction

Of the total network transmission hours on BBC-1 and BBC-2, about 40 per cent originate on film. Most of this material, about 30 per cent, is transmitted directly as film and the remaining 10 per cent is re-recorded on video tape for transmission, usually because it forms part of a complete recorded television programme.

The proportion of films transmitted in colour has now risen to about 90 per cent; it could rise higher, but sufficient programme material of historical, artistic, and entertainment interest exists on monochrome film to guarantee it a limited but continuing place in television.

Much of the film material transmitted comes from BBC cameramen, sound recordists, editors, and dubbing mixers, who contribute in varying degrees to all types of programme output and provide world-wide coverage of news and current affairs. This is now almost entirely in colour and on 16mm rather than 35mm film for reasons of economy and operational convenience. The transition to 16mm film has been accompanied by extensive investigations and design work[1] to raise the technical quality of the narrower gauge to a satisfactory standard, and some of the resulting developments are described later in this article.

The remaining programme material, produced outside the BBC, consists mainly of feature films, complete films specially produced for television, and news and topical film. Those feature films which are supplied in 35mm wide-screen format present a major problem for broadcasters, and new equipment, which is described later, has been developed to overcome this. The variability in the quality of some early colour feature films, and of much topical material shot under adverse conditions, also poses problems requiring special treatment.

If we now consider the telecine equipment on which the films are transmitted, there are separate machines which service the network news bulletins and these form part of the News complex in the Television Centre Spur.[2] Local contributions to the network news bulletins and other programmes are also provided by the telecines in the non-metropolitan studio centres. All other film transmissions are serviced from the central telecine areas at Television Centre and Lime Grove, which will now be described.

2 Television Centre and Lime Grove Telecine Areas

2.1 Principal Facilities

These areas are equipped with eleven 35mm and thirteen 16mm colour telecines. In addition there is one monochrome 35mm telecine in a special area equipped to handle nitrate film, although this is now a very infrequent requirement.

All are flying-spot continuous motion machines and many of them were bought originally for monochrome use and converted later for colour. The News telecines, which are in a separate News programme complex at the Television Centre, use photo-conductive camera tubes.

The ratio of 35mm to 16mm film to be handled varies from day to day according to programme requirements. The total of twenty-four colour telecines is necessary to provide the flexibility required, but the number scheduled and staffed on any day does not normally exceed twenty-one.

Fig. 1 shows a typical 35mm telecine. The scanning system

Fig. 1 Typical 35mm telecine

is housed in the left-hand cubicle; the door of the adjoining cubicle is opened to reveal the film path and transport arrangements, and the three cubicles on its right incorporate the vision channel, picture and waveform monitors, and control position. To the right is a SEPMAG reproducer which runs in interlock with the telecine.

The 16mm telecines are essentially similar to the 35mm machines although their physical layout is somewhat different. Fig. 2 shows a typical 16mm machine. The door of the left-hand cubicle is opened to reveal the film path and transport; the scanning system is housed in the adjoining cubicle and further to the right are the vision channel cubicles and control desk. The picture monitors are out of sight to the right and the SEPMAG bay is behind the open door of the left-hand cubicle.

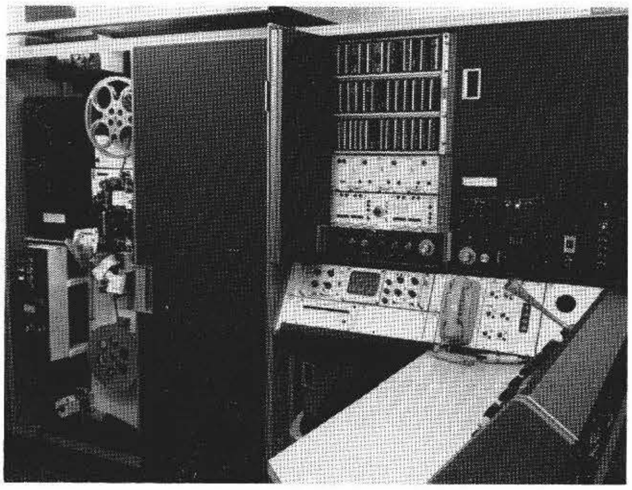


Fig. 2 Typical 16mm telecine

Most of the telecines are of the familiar twin-lens design and can only operate at twenty-five frames per second. This is entirely adequate for most purposes, but there are occasional requirements to run at other speeds. Sometimes films have to be scanned on 525 NTSC at twenty-four frames per second for satellite transmissions; other films may have been produced at twenty-four frames per second and must be run at this speed, although they are transmitted on 625 PAL, to avoid an unacceptable change in musical pitch; on other occasions there is a requirement for variable speed operation in the forward or reverse direction, or for reduced speed to improve the movement on early silent films shot at sixteen frames per second.

These requirements are met by two 35mm and two 16mm polygonal prism flying-spot telecines with variable speed drive. These machines were designed many years ago and are no longer manufactured, but they have been re-equipped with modern colour electronics and produce a very acceptable picture when allowance is made for the complexity and method of operation of the optical system.

2.2 Installation

The advantages which result from centralising all telecine equipment within a studio centre are well-established and this practice is adopted both at Television Centre and at Lime Grove.

The Television Centre equipment is installed on the 1st and 2nd floors of the Main Block Centre Wedge, the 1st floor area being used mainly for film inserts into television studios and the 2nd floor area mainly for transmissions. Fig. 3 shows the 1st floor layout, which includes four 35mm and five 16mm telecines in open-ended cubicles with access from a central corridor. This arrangement is a compromise between an open area, which facilitates supervision, and closed cubicles, which offer the best sound and vision monitoring conditions.

The 1st floor area also includes a studio insert control room, now nearing completion, which will allow more effective deployment of the operational staff, by providing control of several telecines at a central point. Facilities also exist for the remote control of start, stop, and rewind from the studio production control rooms.

The 2nd floor Area, shown in Fig. 4, includes five 35mm and four 16mm telecines, again in open-ended cubicles. The four 35mm telecines grouped at one end of the area are normally used in pairs for the transmission of feature films for both networks, and the remaining 35mm telecine is used for trade test transmissions and as a spare. Three of the four 16mm telecines normally cover complete films for both networks and the fourth, a polygonal prism machine, covers 525 NTSC satellite transmissions and special effects.

The existing control and monitoring facilities are being rationalised and improved by the introduction of the two Transmission Areas, which are now nearing completion. Each Transmission Area serves one network and acts as the co-ordinating and quality control point for all direct telecine contributions to the network.

The Lime Grove Telecine Area contains two 35mm and four 16mm colour telecines, which are used extensively for current affairs programmes. The installation arrangements are largely dictated by the existing building structure, but follow the same general principles as at Television Centre.

2.3 Cleanliness

Cleanliness is of major importance in telecine areas because dust on films is readily visible in the transmitted picture. In this respect 16mm is more critical than 35mm film because of the greater magnification required, and negative is more critical than positive film on transmission because the dust appears white.

To reduce dust in the areas as a whole, the incoming air is filtered down to a particle size of 5 microns and the relative humidity is maintained at 60 per cent. Also, to avoid collecting dust during rewinding, special power-operated rewinders have been developed, of the type shown in Fig. 5. During operation, the lid is closed and clean air is blown in through filters. The film runs through two pairs of static discharge heads, each of which consists of four spikes recessed in a nylon block and capacitively coupled to a 7kV a.c. source. These remove any charge from the film and thus prevent the attraction of dust particles. Similar discharge heads are fitted to all 16mm telecines which handle negative film, together with suction cleaners which operate on both sides of the film before it enters the gate.

The effectiveness of these arrangements has been established during a quantitative study of dust on film. The method used is to take a number of film loops, all exposed

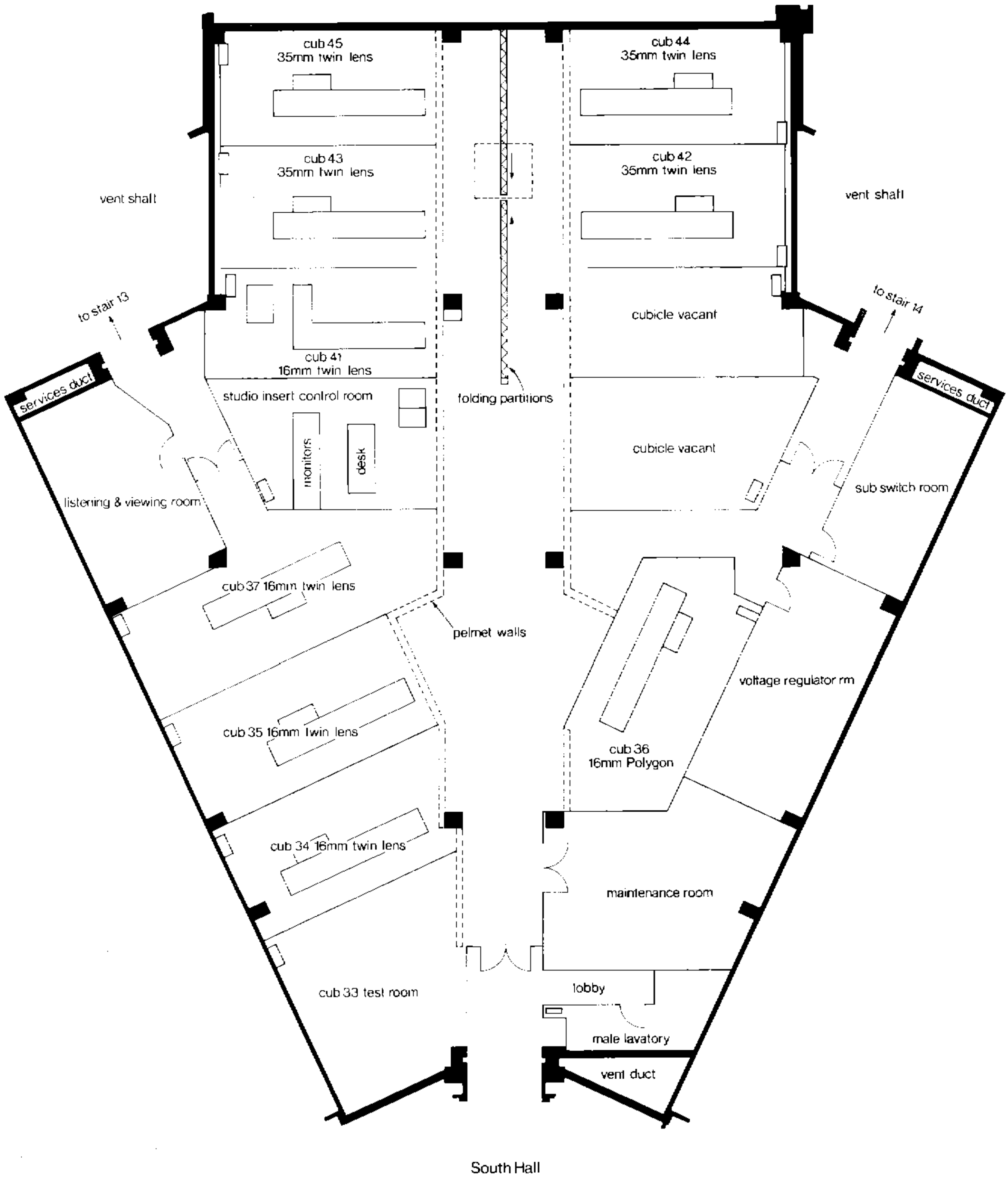


Fig. 3 Television Centre 1st Floor Telecine Area

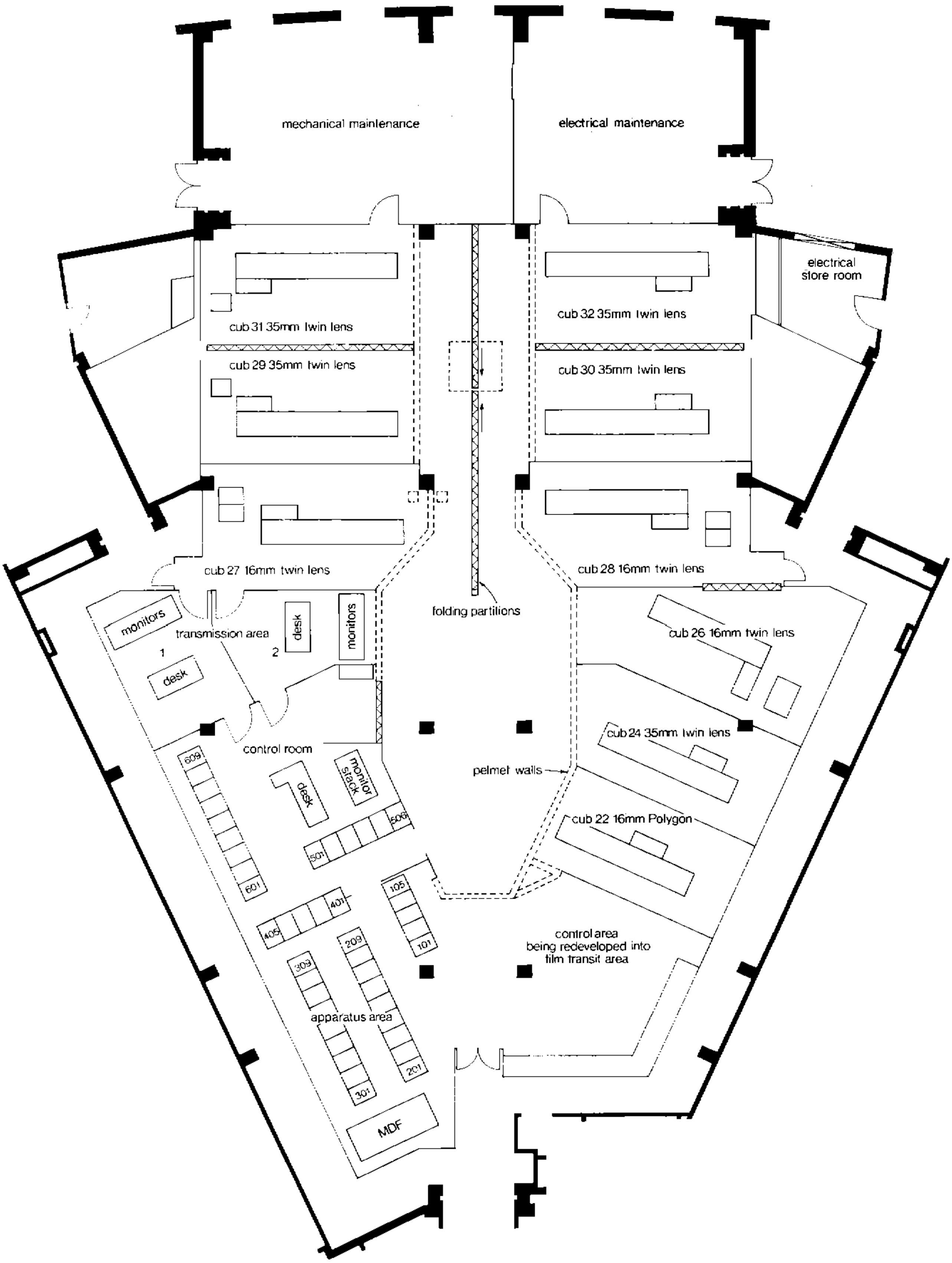


Fig. 4 Television Centre 2nd Floor Telecine Area

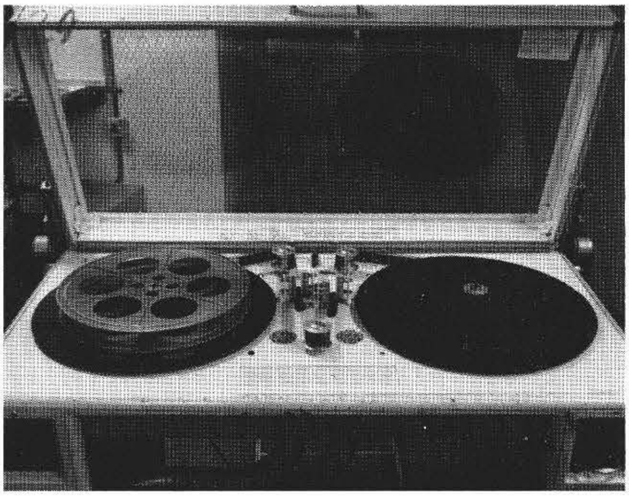


Fig. 5 Power-operated rewinder

and processed to a uniform mid-grey level, run them in a telecine and examine the vision output signal with a special detector. This counts all signal excursions of a specified duration and amplitude, previously chosen as being characteristic of dust particles. The change in the particle count rate occurring at each stage of the film handling process provides an objective measure of the dust contributed by that stage, and a ready means of evaluating any improvements.

3 Problems and Opportunities in Colour Telecine

3.1 Cinemascope Films

Many 35mm feature films are supplied in the Cinemascope wide-screen format. When projected in the cinema these films have an aspect ratio of about 8×3, and their presentation on television at an aspect ratio of 4×3 requires special treatment.

The 35 mm film frame size is slightly larger for Cinemascope than for normal films and it is 'squeezed' laterally by about 2:1, the picture being 'unsqueezed' on cinema projection by an anamorphic lens. When these films are transmitted from a flying-spot telecine, the simplest solution is to arrange that the raster scans the full picture width with its height adjusted for correct geometry. The television receiver then shows the full wide-screen format with blank areas at the top and bottom of the picture; the visual effect is unpleasant however and the impression is not one of dramatic breadth but sub-standard height.

A much preferable arrangement is to scan the full height of the film frame and reduce the horizontal scan for correct geometry. The television receiver then shows a normal picture, but only about 54 per cent of the original picture width is visible at any time, and it is then necessary to move the raster laterally to follow the action. If the dramatic effect of the film is to be preserved, the movements of the raster must be selected with great precision and they will often occur in quick succession; it is essential therefore to use an automated control system.

The process begins with the examination of the film by Purchased Programmes Department using a modified editing machine. Nine equally-spaced horizontal positions are defined across the width of the film; these are identified by the code letters A to J and marked on the viewing screen. There is a further position T which allows the complete film frame to be displayed for title sequences, the horizontal squeeze being accepted as less objectionable on titles than losing part of the lettering.

A film editor decides which area of the picture he wishes to be presented, the precise frame at which the change to the new position is to occur, and the required panning rate. This rate is defined in terms of the time, in seconds, required for a complete pan from A to J, and the choices are 0 (a cut), 2, 4, 6, 8, and 10. The editor produces a cue sheet giving the required shot positions, their timings on the film, and the panning rates. Also, at present, he marks the shot positions on the edge of the film with a metallic foil cue dot. These cue dots are used extensively for automatic telecine control and they are picked-up in the telecine by a detector head and oscillator unit. When the cue dot is close to the head it causes the oscillator current to fall and produces a timing pulse. This type of detector has proved reliable in service but it is planned to change over in the future to a frame counting and coincidence detection system which will avoid the need to mark the film.

The Cinemascope cue sheet is transferred manually to punched paper tape and this is loaded in a console-mounted tape reader. The console also contains a logic control system, which automatically changes the telecine scan position in accordance with the cue sheet instructions and cue dot timings. Fig. 6 shows two consoles being used to control a duplexed pair of telecines.

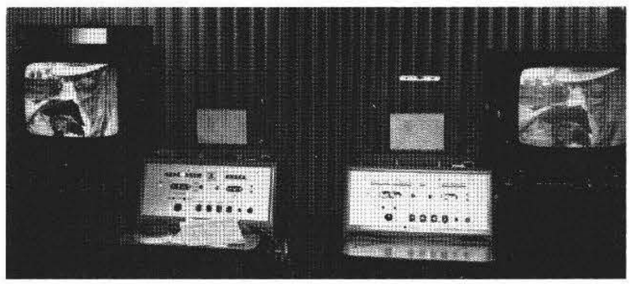


Fig. 6 Cinemascope control consoles

This equipment is extensively used and has become an important programme facility. More detailed information on the system, and the production considerations which have to be taken into account when preparing the cue sheet, was published in the B.K.S.T.S. Film 69 papers[3].

3.2 Colour Error Correction

Ideally no further colour corrections should be necessary on a telecine which is adjusted to produce a truly monochrome grey scale from a visually-neutral stepwedge in the gate. In practice some correction is generally necessary, because the acceptable margin for colour errors in television is very small. Film has to match the excellent colour reproduction of the television camera and it is seen on a television receiver surrounded by familar objects.

The sources of error are numerous. The colour temperature of the scene illumination may be unsatisfactory or variable, the camera filter may not be ideal, the negative exposure or processing may be wrong, there may be errors in the colour balance, exposure, or processing of the positive and the dyes may fade differentially with age. Some of the older colour films were never produced to the tolerances required by television.

To correct these errors the BBC developed an electronic compensation unit named TARIF,[4] shown in Fig. 7. Units of this type, in one form or another, are standard equipment on all BBC colour telecines.

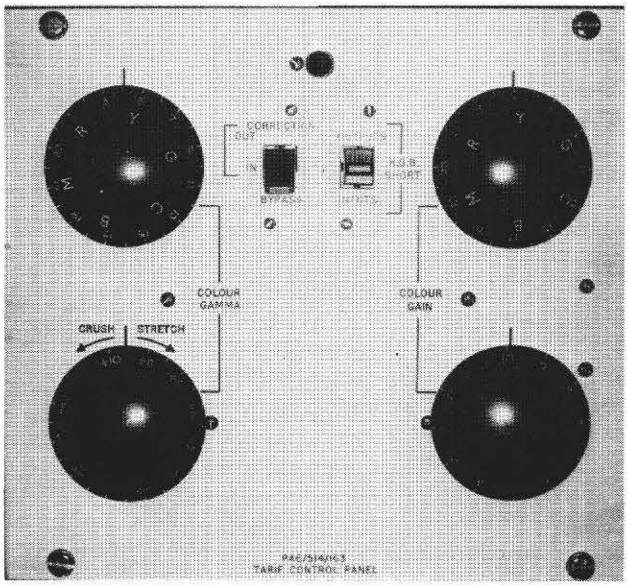


Fig. 7 TARIF Control Panel

The TARIF unit provides master lift and master gain controls (not shown in the figure), which function similarly to the lift and gain controls on a monochrome telecine; it also incorporates a colour gain section to correct for colour casts in the picture highlights and a colour gamma section to correct for colour casts in the shadow areas. With these controls it is possible to make all the adjustments normally needed for the transmission of colour films.

The most valuable feature of the TARIF concept is the operational simplicity with which this wide range of powerful colour corrections can be made. The colour gain and colour gamma sections both have two controls; one determines the amount of the correction and the other the colour axis along which it operates. To make the same corrections with separate R, G, and B controls could require six interdependent adjustments.

This type of TARIF unit is still most widely used. A later alternative version is preferred however for news and current affairs films, when the corrections must be changed quickly and frequently. This uses two joysticks, one controlling master lift and colour gamma and the other master gain and colour gain. Rotation of the joystick knobs adjusts the master controls; the direction of movement of the joystick determines the colour axis and the distance moved determines the amount of the correction. A typical TARIF unit of this type is incorporated in the colour correction programming equipment shown in Fig. 8. The main advantages are first that with one joystick in each hand the operator has immediate control of all the corrections, and secondly that he does not need to remember what corrections are already applied, as in the case of rotary

Fig. 8 Colour Correction Programmer

controls, because movement of the joystick in a given direction always produces the same type of correction. On the other hand, when films only require a fixed correction throughout, the rotary control TARIF is preferable.

Although the joystick TARIF offers sufficient speed and degree of control for most requirements, some early colour feature films and news material involve so many large and rapid changes in correction that it is impossible for the operator to keep pace with them. Two new systems have been developed to meet this problem.

The first is an automatic TARIF unit, which can be used either independently or to supplement a manual TARIF. It operates on the telecine R, G, and B signals, equalising the black levels of all three signals to a preset master black level and adjusting their gains automatically to achieve a predetermined peak signal level; it also includes, as an optional facility, automatic frame-by-frame control of the R and B gains to make the sum of the R, G, and B signals integrate to grey, a condition fulfilled in practice by many natural scenes.

The main application of this unit, with the integration to grey operative, is correction of variable news-type film for which little or no rehearsal time is available. It removes much of the variability and avoids the more objectionable effects; some of the better scenes are not handled as well as with manual TARIF, but the average quality of the film is considerably improved, and if manual TARIF is used additionally the demands made on the operator are greatly reduced. It can be used alternatively without the integration to grey facility, to relieve the operator of the need to adjust master gain and master lift and, to a large extent, colour gamma also. This arrangement is most suitable for films of moderate variability and it enables the operator to achieve a much better standard of colour correction than would otherwise be possible.

The system so far described is essentially an aid to colour correction during transmission; it does not allow the prerecording of corrections determined during rehearsal. This facility, for which there are several important applications, is provided by the second system previously mentioned. The equipment used, which is shown in Fig. 8, combines a joystick TARIF with a programmer which records the corrections on punched paper tape. A detailed description is given in BBC Engineering Number 91,[5] but the method of operation is briefly as follows.

The film is rehearsed normally, without stopping; the TARIF joysticks are adjusted by the operator in the usual way and the control voltages from the joysticks are continuously quantized to facilitate recording. Experience shows that changes in the TARIF corrections are generally only required at shot changes and should occur coincidently with them. The programmer achieves this by recording the instantaneous TARIF settings at each shot change and back-dating them so that they become effective, on replay, at the previous shot-change.

The position of each shot change is defined either by a metallic foil cue dot on the film, or by a frame-cue paper tape or by an automatic shot change detector.[5] Whichever system is used, however, the shot-change frame numbers are always recorded on the same paper tape as the TARIF settings, the changes in the TARIF settings being initiated during replay when the next stored frame number and the telecine frame counter reading coincide.

This equipment has been used with considerable success during transmission of negative colour film and a number of feature films involving difficult colour corrections. It has produced a substantial improvement in the colour consistency of transmitted film without significantly affecting rehearsal time.

There is a further aspect of colour film reproduction which is of special importance in television, where direct comparison occurs with electronic camera pictures; this is the failure of the film to reproduce saturated colours at high luminance levels. There are several contributory causes, including the colour analysis characteristics of the film and telecine and, more significantly, the spectral transmission characteristics of the film dyes. This limitation can be largely eliminated by the use of electronic masking, which introduces a compensating inter-coupling between the telecine R, G, and B signals.

Ideally compensation should be applied to both the linear and logarithmic R, G, and B signals, but it can be restricted in practice, without serious error, to the logarithmic signals only, and these are readily available in the standard telecine channel. All the telecines incorporate masking and different degrees of it can be introduced to suit particular films.

3.3 Transmission from the Colour Negative

As the use of 16mm colour film has grown in BBC Television, the need for improved 16mm quality, closely matching television camera performance, has also grown. Much work has been done in the obvious fields of film camera and lens maintenance and re-equipment, and in improving the accuracy of exposure, processing, and printing. Better film stocks, continuing improvements to telecine equipment, new vertical aperture correctors, and the colour correction facilities already described all helped to raise the standard. Considerable losses were still occurring, however, in the production of the 16mm print, affecting resolution, linearity, colour accuracy, and steadiness, and there was clearly scope for substantial improvement if the print could be eliminated.[6]

One immediate possibility was to use reversal original film. This was already used for News coverage and had the advantages of high speed and fine grain. It had the important disadvantages, however, of limited exposure latitude and a tendency to colour errors; also if copies had to be made later they would be inferior in quality to normal prints made from a negative. It was decided therefore to develop, for applications other than News, the facility of transmitting directly from 16mm colour negative. This required some re-design of the telecine channel to invert the colour signals, and a new scanning tube with increased light output to offset the density of the negative orange-coloured mask; special electronic masking coefficients were also required. The development was successful and negative transmission has been in regular use since September 1971.

The system benefits greatly from vertical aperture correction and this is invariably included. Also, because it is necessary to handle the variations in negative exposure which would normally be compensated during printing, programmed TARIF is generally used, supported by automatic shot change detection, which is especially successful with negative film.

The most significant improvements in the transmitted picture are the large contrast range, freedom from colour errors, high saturation, and excellent steadiness. The operational problems encountered are mainly the increased visibility of dust and occasional disturbances due to film splices.

Cleaning of the film and the various dust-reduction techniques already described are largely effective, but dust and blemishes are still sometimes visible. In video tape recording occasional drop-outs are considered a sufficient reason for introducing drop-out compensators, and there is no justification for applying a different standard to film transmissions, except for the technical difficulty of developing suitable equipment. A recent BBC investigation has resulted in considerable progress towards the design of such a unit which could, in time, become a standard telecine accessory. If this is successful, negative film could eventually be transmitted with less impairment from dust than a print made from it.

The presence of picture splices, though unwelcome, cannot be avoided when transmitting from the original film instead of a print. It could be eliminated by transferring the programme to video tape for editing, but this would be costly in time and facilities and has been proved to be unnecessary provided that the splices are made with care. Various splicing methods have been tried, and at present narrow cement joins are preferred because they are reliable and relatively unobtrusive.

Negative transmission has not yet been extended to A and B roll operation and fades and dissolves between scenes are consequently not available. This technique, in which the edited negative is made up into two rolls containing alternate scenes with an overlap for mixing, is commonly used during printing, and may be developed later in the form of a dual-telecine installation.

So far negative transmission has proved most valuable for studio inserts requiring close matching to television cameras, and for topical programmes where time for editing and sound dubbing is limited. When the negative is transmitted it is only necessary to make black-and-white copies for editing and dubbing, the negative being cut subsequently to match the edited black-and-white copy. This is both quicker and cheaper than obtaining colour prints of all the original material for editing and transmission.

3.4 Special Facilities

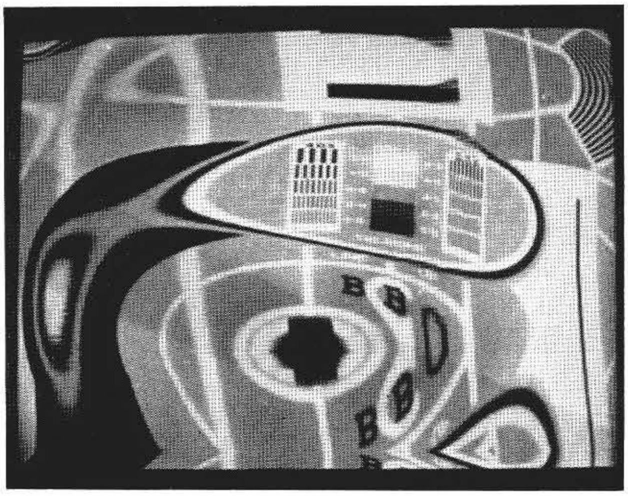
The role of telecine is not restricted to the simple reproduction of film for television; it also offers a variety of creative production options. One example is the GEM (geometric electronic modulation) system which was developed originally for the 'Restless Earth' programme. The producer wished to show the contours of the North Atlantic sea bed as the sea was gradually drained away; for this purpose a large flat model was constructed into which water could be introduced or drained away, as required. For realism, however, the television picture had to portray a spherical rather than a flat surface.

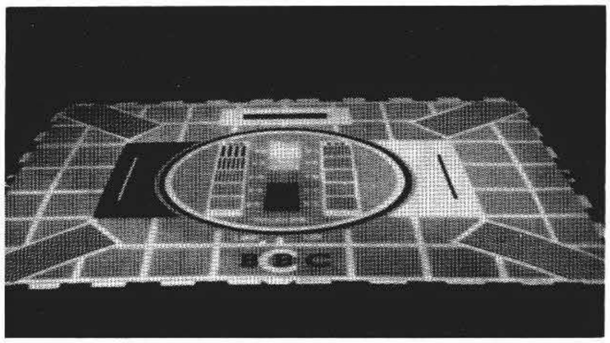
The solution adopted was to film the model and to distort the telecine scanning raster to achieve the desired effect. Fig. 9 on page 12 shows two typical examples of the effect achieved.

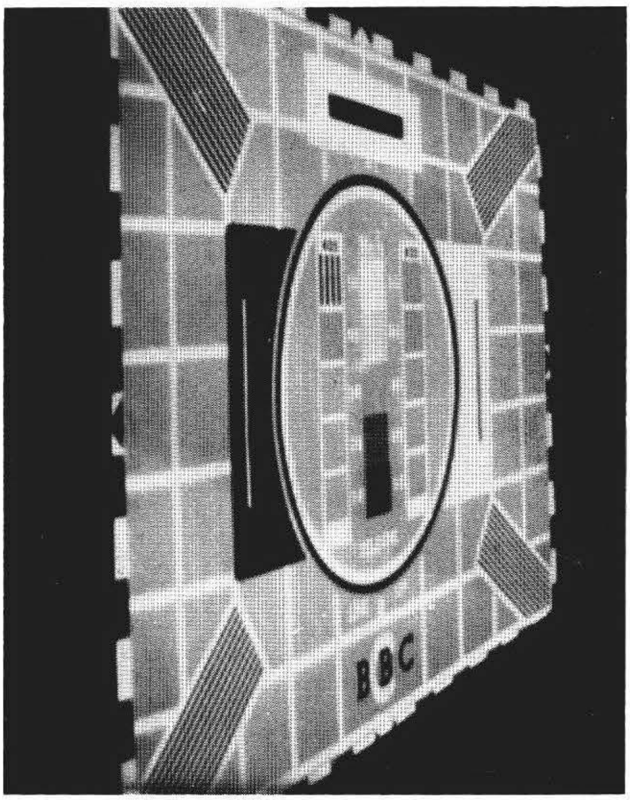
The potential of the GEM system is much wider, however, since it offers a choice of many perspectives and distortions. Fig. 10 illustrates some of the effects which can be produced from a line-up test film in the telecine gate.

A further option is the use of colour separation overlay between different film sources or between film and the studio. The development of 16mm negative replay on telecine has been particularly useful for this purpose because of its excellent steadiness and well-defined B–Y signal, which is required for switching. Both colour separation overlay and GEM were used in 'Parade', a programme which dealt in highly imaginative pictorial terms with the work of the composer Erik Satie. Some of the more interesting pictures appeared in the dream sequence, some examples being shown in Fig. 11.

The basic room scene was defined by a photograph set up







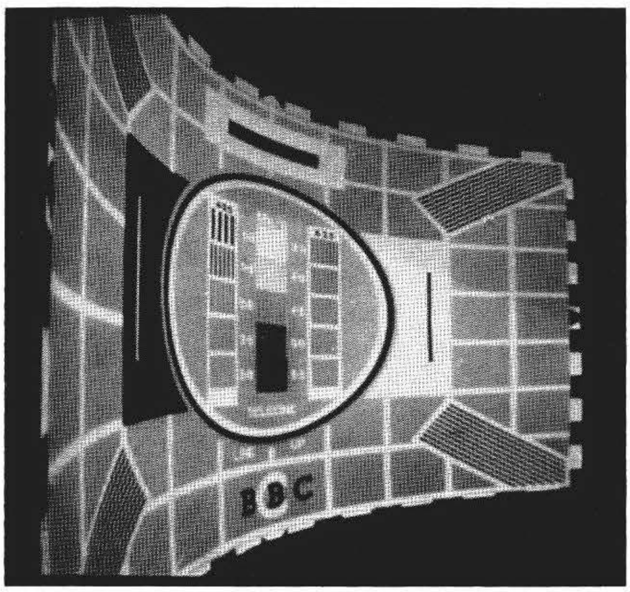


Fig. 10 Perspectives and distortions produced by GEM

in the studio, over which a number of blue cards could be registered accurately to generate switch signals for overlaying the walls, floor, and ceiling. By recording and replaying from video tape, various film scenes were overlaid one at a time until the full composite picture was complete.

Some of the films were geometrically distorted by the GEM

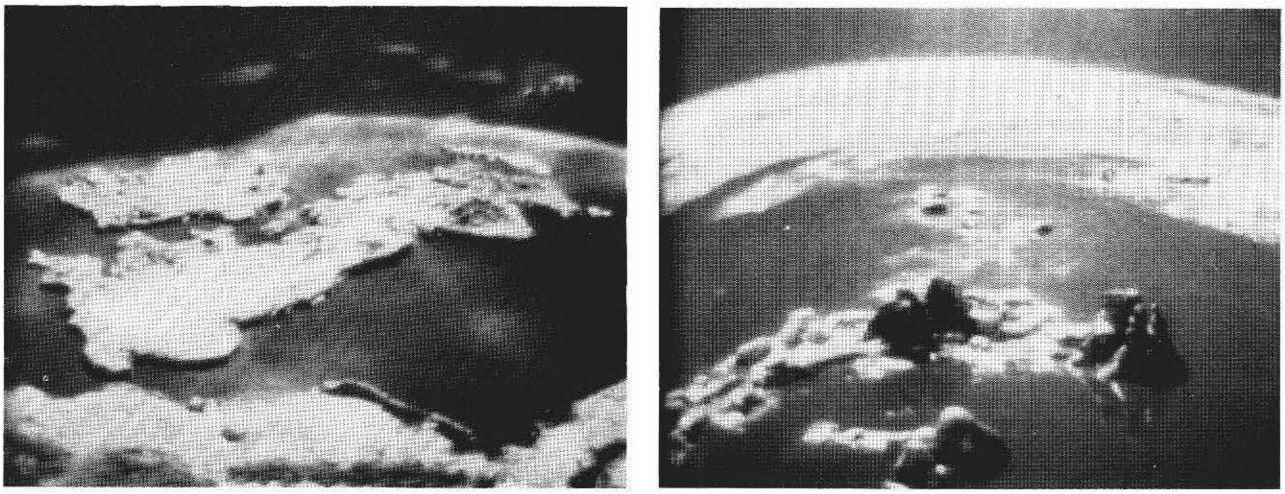


Fig. 9 Simulated earth curvature produced by GEM from a flat model for the 'Restless Earth' programme

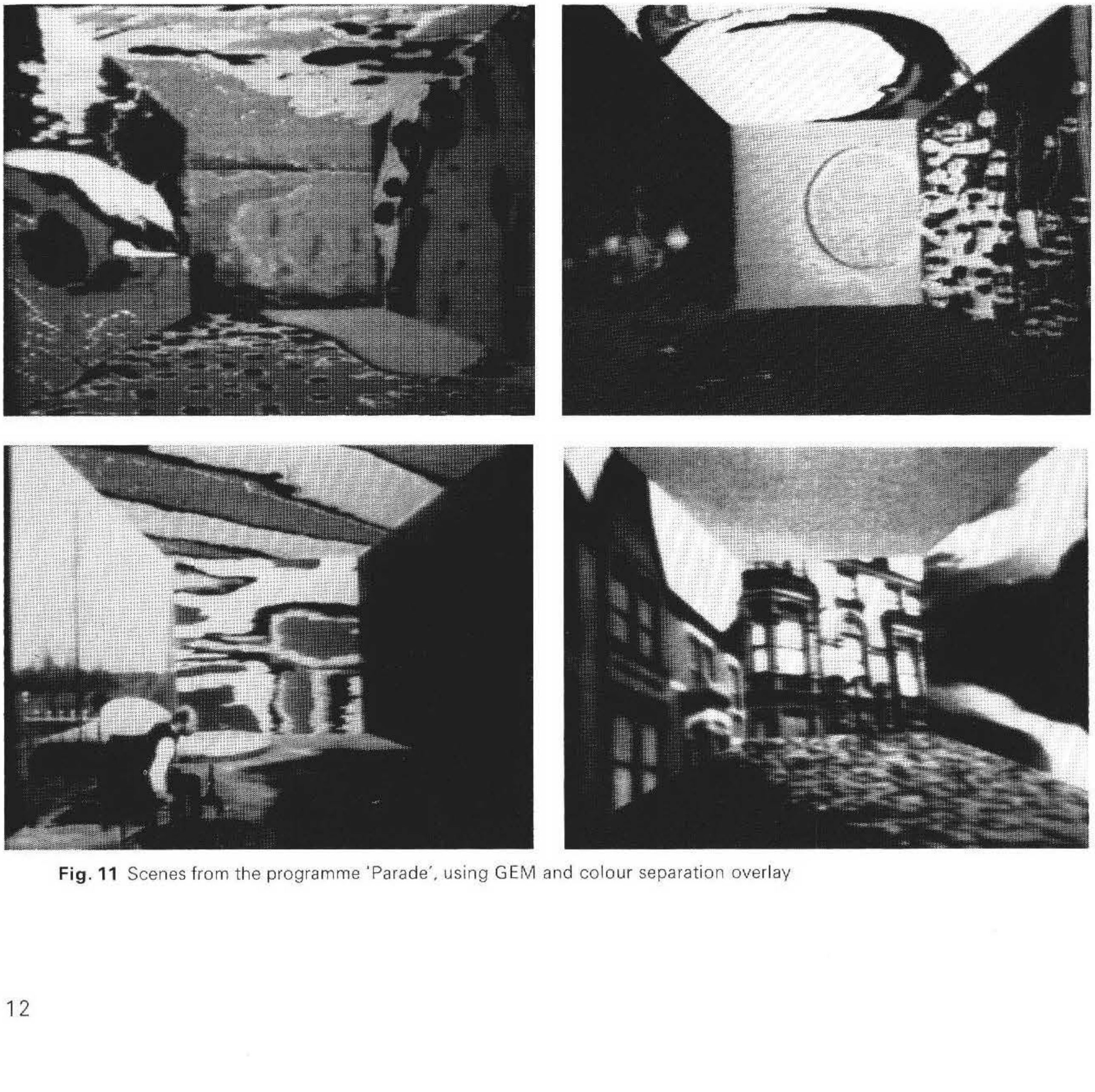


Fig. 11 Scenes from the programme 'Parade', using GEM and colour separation overlay

system to produce the required perspective; others were fed through a colour quantiser which quantised the luminance into four levels, which were made to create a variety of R, G, and B outputs. Although produced by well-defined engineering techniques, the visual effect of moving coloured images on walls, floor, and ceiling is perhaps the ultimate in abstract pictorial art.

Looking to the future there is every reason to expect further technical improvements from better film and equipment and continuing development in the production uses of the versatile combination of film, telecine, studio, and video tape recorder.

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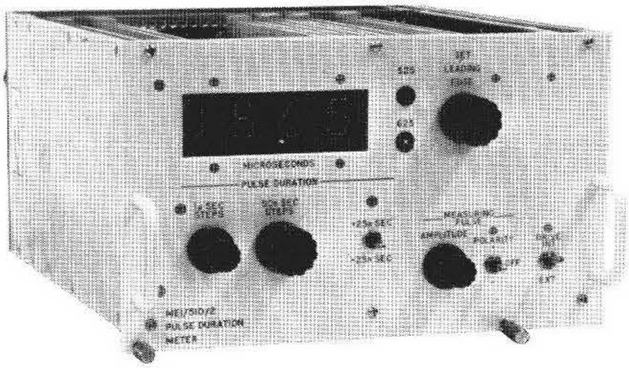
Pulse Duration Meter



The durations of the various component pulses of the television synchronising-waveforms are specified to within close limits (one part in 10^3) and it is necessary to measure these to ensure that this part of the waveform of the radiated signal is within limits. The measurements are difficult using standard equipment (such as an oscilloscope, which may be accurate only to within 3 per cent) and, consequently, errors are likely to occur.

The pulse-duration meter ME1/510 offers a highly accurate and convenient means of measuring these durations (periods up to 60 μs can be measured to an accuracy of a few nanoseconds) but the indication given is normally only to the nearest fifty nanoseconds, because this is the degree of accuracy to which the durations are specified. Measurement can be made of 625- and 525-line systems, the changeover being effected automatically.

The instrument generates a sequence of rectangular pulses, synchronised with the signal to be measured, and added linearly to the signal internally. The basis of the measurement depends upon a precise coincidence being achieved between the 50 per cent points of the transitions and the waveform component to be measured. For this purpose the measuring-pulses are adjustable by means of front-panel controls for timing, amplitude, and duration. Coincidence is indicated by a unique appearance of the display, the sensitivity of which is such that coincidence between the 50 per cent points of the transitions can readily be set to within a few nanoseconds.

The duration of the measuring-pulses (and hence of the waveform component to be measured) is indicated by a digital display on the front-panel of the instrument in microseconds and decimal fractions of a microsecond. Normally, the last digit of the display is either 0 or 5, but a facility for further discrimination of ±25 ns can be brought into use by manual switching, if required.

The meter requires a supply of a.c. mains and must be used in conjunction with a cathode-ray oscilloscope having suitable triggering-facilities.

General Data

Power requirement	220 V–260 V a.c. mains, 50/60 Hz
Input signals	Video: up to 2 V p-p Drive: video or mixed syncs
Input impedances	Video: >10 kΩ Drive: 75 Ω
Output impedances	Video: 75 Ω Trigger: 75 Ω

Performance Data

Measuring-pulse amplitude	0–2 V, positive-going or negative-going
Measuring-pulse duration	250 ns–60 μs in 1 μs steps (0–59 μs) and 50 ns steps (0–1 μs). ±25 ns by centre-off biased switch.
Measuring-pulse leading-edge phase-adjustment	80 μs (nominal)
Measuring-pulse rise-time	35 ns

Interpolation in Digital Line-Store Standards Conversion: A Theoretical Study

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Summary: The experimental Digital Line-Store Standards Converter[1] built in Research Department served to demonstrate the good picture quality obtainable with digital techniques, even when using a comparatively simple linear interpolation aperture utilising information from only two lines of the input picture. The work described in this report was a study, mainly theoretical, into the requirements for a more sophisticated interpolation system involving the use of signal contributions from more than two lines. Computer optimisation techniques were used in determining the most suitable aperture shape using contributions from different numbers of successive field lines, and a block schematic diagram was derived for a proposed experimental interpolator to be used with the experimental digital line-store converter. This has since led to further work involving subjective tests designed to establish the basic interpolation parameters of a converter for service use.

1 Introduction

The use of digital techniques in standards conversion offers the potential advantages of high reliability, small size, reduced cost, and, provided that the arithmetical operations involved in signal processing are correctly carried out, optimum picture quality from the output signal, however complex the signal processing. This last advantage is of particular importance when considering the requirements for interpolation, since, as a rule, the more lines which are available simultaneously, the more accurate will be the estimate that can be made of the picture information that would have been produced had the signal been originally scanned using the output standard.

Information from a block of lines can be made available simultaneously by using the signals appearing at the inputs and outputs of a number of one-line delays in series; analogue signal delays of this duration produce small but perceptible picture defects. However, shift registers provide a means of delaying digital signals with no degradation and it is possible to achieve fairly sophisticated interpolation without involving undue cost and complexity.

The equipment proposed in this report is not intended as a design prototype for future digital line-store converters, but rather as a research tool to enable subjective tests to be carried out with the purpose of determining the practical limitations which can be imposed on the complexity of the interpolation whilst achieving a high standard of output picture quality.

2 Theoretical Considerations

2.1 A Definition of Interpolation Aperture

Interpolation is necessary in standards conversion because the scanning of the original scene samples the picture vertically at a rate (in terms of spatial frequency) which depends on the number of lines per field. If a television picture is to be obtained as if generated on another standard, the original scene must first be recovered from the input samples to effectively give a continuous function which can then be resampled, and hence rescanned.

According to Nyquist's sampling theorem, if a signal is sampled at a rate greater than twice the highest frequency it contains, it can, in theory, be recovered perfectly from the samples using a suitable filter. However, it can, in practice, be recovered with various degrees of accuracy by replacing each sample, represented as an impulse, by an aperture function whose origin coincides with the impulse position and whose magnitude is scaled in proportion to the strength of the impulse. The value of the recovered signal at any point is then the sum of the various aperture functions corresponding to the train of samples. A representation of this process is shown in Fig. 1 where the original signal has been recovered by interpolation from the samples. It will be observed that the aperture function used here as an example resembles $(\sin x)/x$ over a limited range. The choice of a suitable practical aperture will be discussed in Section 2.5.

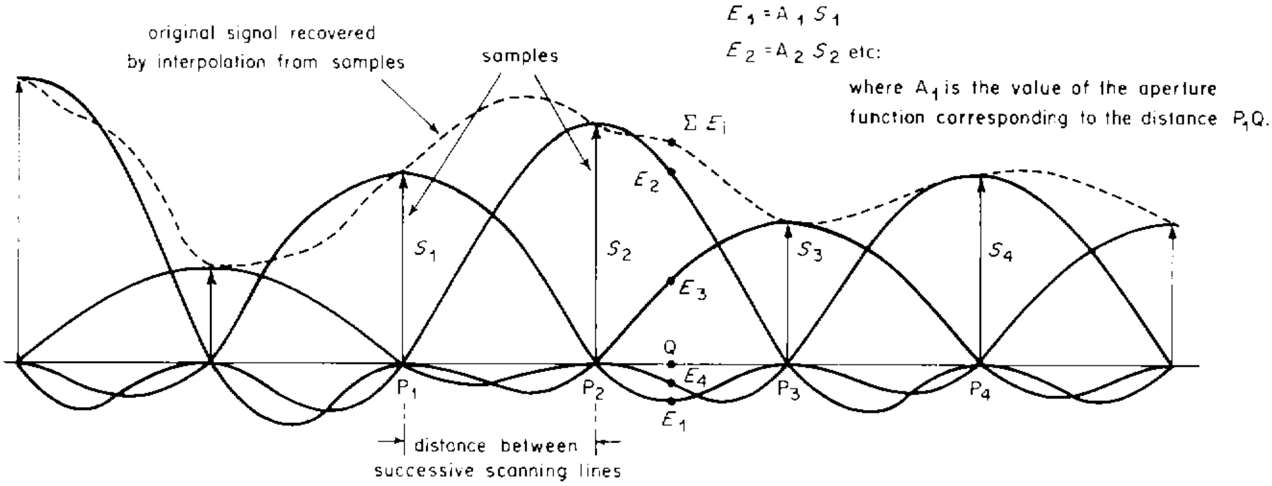

Fig. 1 Interpolation as a summation of displaced aperture functions. The recovered signal at Q is the sum of E_1, E_2, E_3, and E_4

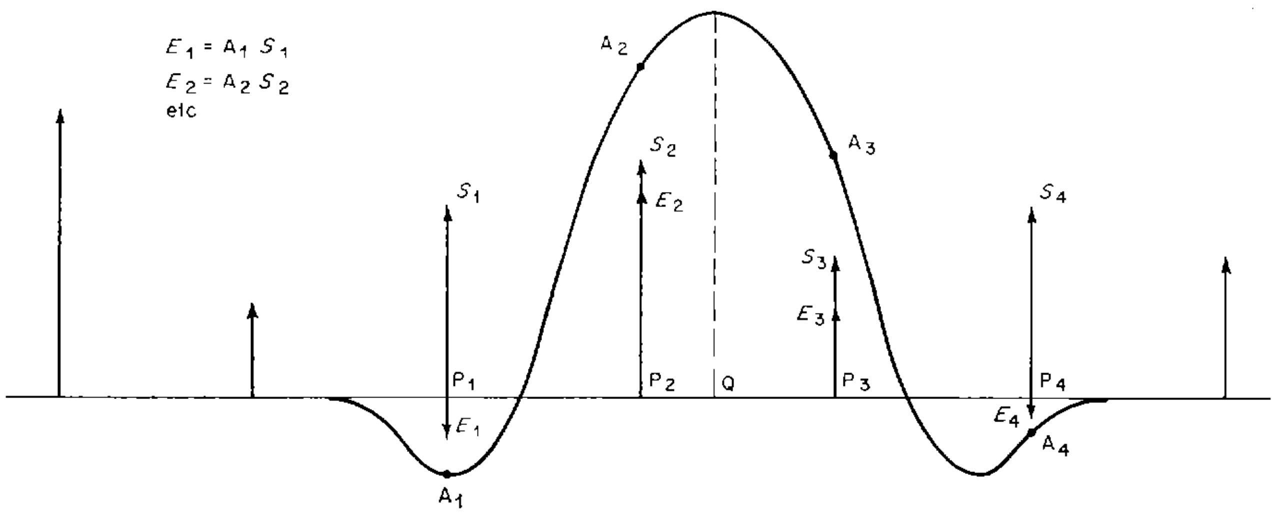

Fig. 2 Interpolation as a summation of weighted samples. The disturbance at Q is equal to the sum of E_1, E_2, E_3, and E_4

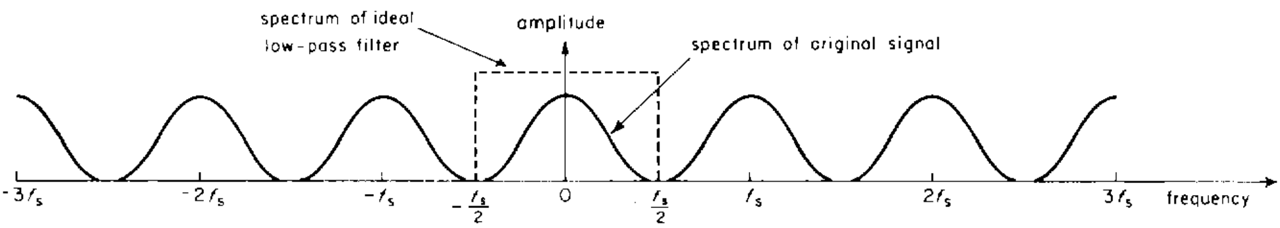

Fig. 3 Spectrum of signal sampled at a frequency f_s

The aperture function need not be symmetrical about its origin; but if it is, an alternative approach is to consider it centred on the point at which the interpolated value is required. The magnitudes of the neighbouring impulses are then scaled by the relative value of the aperture at the various impulse positions and the scaled values summed to produce the required interpolated value as shown in Fig. 2.

The process of displacing and weighting a function is a convolution operation and thus interpolation can also be described as multiplication in the frequency domain where the spectrum of the sampled signal is simply multiplied by the spectrum of the interpolation aperture. The action of sampling a signal causes its spectrum to appear as sidebands centred on multiples of the sampling frequency as in Fig. 3. The spectra centred on the sampling frequency and its harmonics can, however, be almost completely rejected if the spectrum of the interpolation aperture approximates the passband of a low-pass filter that would transmit only the zero-order spectrum representing the original signal.

2.2 Space-time Duality

The signal representing the brightness down a vertical line in the scene has spatial frequency components and is spatially sampled. Thus distance can be measured in terms of picture height (p.h.) or line height (l.h.) and frequency in cycles/p.h. or cycles/l.h. However, there is a complete analogy with the time domain in that, for a particular element position along a scanning line, the samples occur at regular intervals of time (line period) and the interpolation aperture becomes the temporal impulse response of a low-pass filter. This is the approach used in the design of analogue line-store converters[2] now in service.

2.3 The Ideal Aperture

From Fig. 3 the ideal interpolation aperture would seem to be that which has the rectangular spectrum of an ideal low-pass filter cutting at half the sampling frequency, but other factors may influence the choice.

1. The original scene may contain spectral components at frequencies greater than half the sampling frequency, and these components will be accentuated if excessive vertical aperture correction has been employed. The process illustrated in Fig. 3 will then produce overlapping of the repeated spectra, an effect known as 'aliasing' since the spectral components overlaid are not distinguishable from the signal components. In such cases it may be desirable to reduce the cut-off frequency of the aperture spectrum to eliminate the alias components as in Fig. 4.
2. The vertical bandwidth will be too high if interpolation is followed by down-conversion. In this case it may be desirable that the cut-off should be reduced below half the input sampling frequency.
3. The effect of interlace.

This third factor is by far the most important and is discussed further.

The following argument applies to down-conversion when both input and output standards are interlaced.

Suppose that the spatial spectrum of the brightness signal down a vertical line in the original scene is as shown in (*a*) of Fig. 5. If the scanning action of the source at the input standard takes place with a spatial frequency f_i c/p.h. assuming that the source aperture is infinitely small the spectrum of the sampled signal is shown in (*b*); as can be seen, higher order spectra are produced. The spectrum of the second, interlaced, field has inverted components (as explained in Reference 4) for odd orders as shown in (*c*). If spectra (*b*) and (*c*) are combined to form a complete picture at the input standard the even orders reinforce each other and the odd orders partially cancel each other out to an extent which depends on the temporal response of the display phosphor. Hence, integrated over a complete picture the effective value of f_i is doubled. However, because the eye is able to resolve temporally the individual fields, the partial cancellation of the odd orders gives rise to the familiar phenomenon of 'strobing' at low input frequencies (e.g. a plain raster) and 'twittering' at high frequencies (e.g. edges).

Suppose, however, that spectra (*b*) and (*c*) are interpolated and resampled in an interlaced manner before being combined. If the interpolation aperture has a rectangular spectrum cutting at f_c where $f_c < f_i/2$ the spectra of the interpolated fields are shown in (*d*) and (*e*).

If the interpolated signals are now resampled with a spatial frequency f_o, the spectra of the two fields are shown in (*f*) and (*g*). When spectra (*f*) and (*g*) are combined to form the complete output picture as in (*h*) steady and alternating components are produced as outlined above.

Finally, a limit must be imposed on the range of displayed frequencies because of visual acuity or the existence of line broadening[3] caused by the finite display spot size. A reasonable assumption is that these effects restrict the spectral content of the displayed picture to an upper frequency of f_o as shown in (*i*).

The final result can be illustrated by examining the output for a sinusoidal input whose frequency varies from zero to f_i. This can be done by tracing through the products derived from a particular spectral component in Fig. 5(*a*). For an input frequency f in the range zero to f_c indicated by F_1 in Fig. 5(*a*) an alternating component at $f_o - f$ is produced in addition to the steady component at f. If f lies between f_c and $f_i - f_c$ no output is possible but if f lies beyond $f_i - f_c$ as indicated by F_2 in Fig. 5(*a*) a steady and an alternating spurious component are again produced. As the dotted lower curves in Fig. 5(*i*) are parts of the curve of Fig. 5(*a*) translated by an amount f_i and the solid lower curves are parts of the same curve translated by an amount $(f_i - f_o)$ the alternating component is at a frequency $f_i - f$ and the steady component is at a frequency $f - (f_i - f_o)$. This behaviour is summarised in Fig. 6. The alternating component at $f_o - f$ in region (1) would be present in a signal generated at the output standard and is therefore inherent. If, in region 3, the steady spurious component is the more objectionable and its visibility decreases with increasing frequency then there might be an advantage in lowering f_c, thereby narrowing region 3 and delaying the onset of the steady component. This would be paid for by a loss in definition. On balance there does not seem to be any strong reason for not putting f_c equal to $f_i/2$. It must be emphasised, however, that although it is possibly the best solution it is not ideal because of the spurious products in region 3 and therefore the result of the conversion process field by field can never

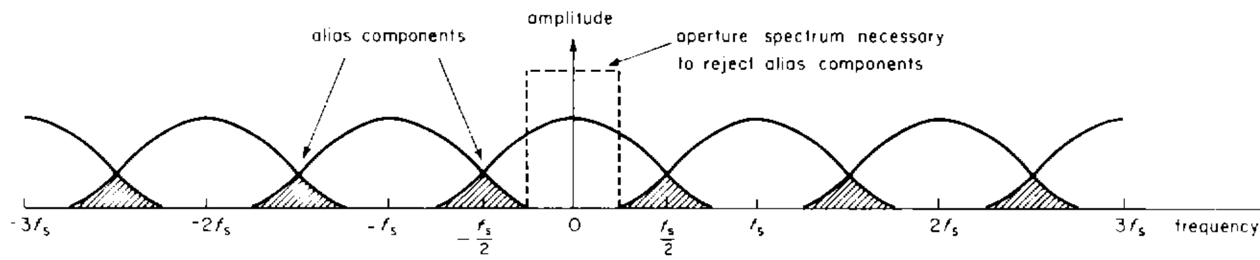

Fig. 4 Alias components generated when original signal contains spectral components at frequencies greater than $f_s/2$

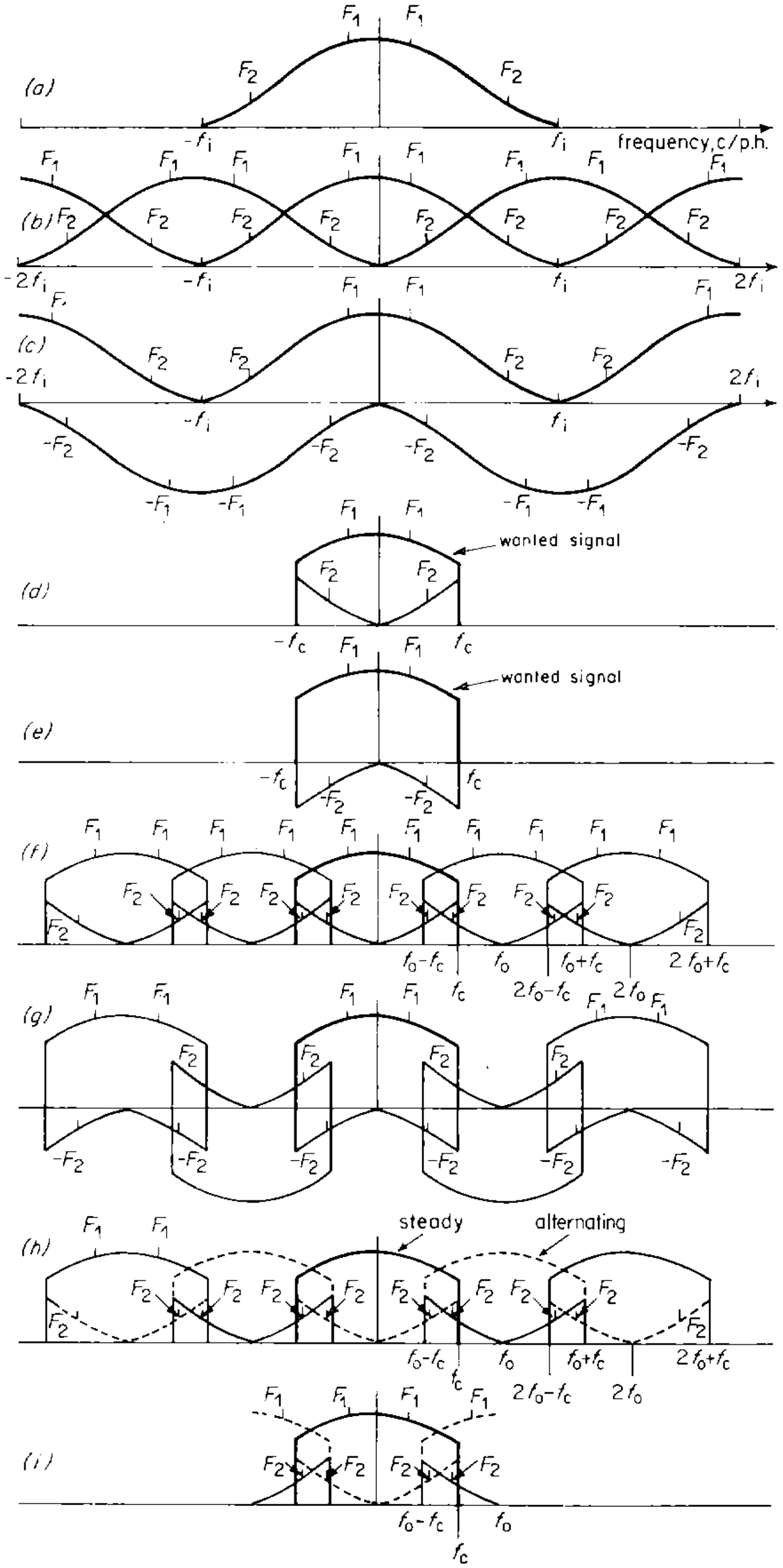

Fig. 5 The spectral behaviour of sampled, interpolated, and re-sampled signals

(*a*) Original signal

(*b*) Sampled signal

(*c*) Interlace-sampled signal

(*d*) and (*e*) Result of interpolating (*b*) and (*c*) with an 'ideal' aperture

(*f*) and (*g*) Resampled and interlace-resampled interpolated signals

(*h*) Addition of resampled and interlace-resampled signals

(*i*) Resampled signal subjected to restricted bandwidth be the same between interlaced systems as that obtained by generation at the output standard at the source. The aperture profile having this flat spectrum cutting off at $f_i/2$ is of $(\sin x)/x$ form, having zeros spaced at the distance between successive lines of an input field.

2.4 Limitations on the Practical Aperture

If the best aperture is of $(\sin x)/x$ form it is clear that a practical aperture of limited width and having an imperfect spectrum approaches the 'ideal' as its width increases. There are, however, certain conditions of varying importance which should preferably be satisfied by any aperture of limited width. These conditions are discussed below.

(i) The aperture spectrum must have zeros at integer multiples of the input sampling frequency f_i. If this is so the higher orders of a sampled constant signal (corresponding to a picture having uniform vertical brightness) are completely rejected and no spurious components are produced. Failure to meet this condition would, after resampling, give rise to horizontal striations on a uniform background. This condition is also equivalent to the requirement that values of the aperture profile spaced apart a distance of one field line should sum to a constant regardless of their position, an extension of Equation 2 in Reference 4.

(ii) The value of the constant in condition (i) should be unity if the interpolation process has unity gain.

(iii) The spectrum of the aperture should have zeros at integral multiples of the output sampling frequency so that no spurious product is formed at zero frequency except when the input frequency is f_i. In general, a spurious component at zero frequency can only occur by the translation in the resampling process after interpolation of a frequency at an integral multiple of f_o. Thus if the aperture spectrum has zeros at these frequencies, no spurious d.c. component can result.

(iv) The value of the normalised spectrum at half the input sampling frequency should approximate to 0·5, corresponding to the ideal case.

(v) The aperture profile should have no discontinuity at the ends. See, for example, Fig. 2. Failure to meet this condition with apertures having a width not equal to an integral number of lines implies a discontinuity in output signal as the position of the output line varies, assuming a uniform d.c. input signal. With apertures having a width equal to an integral number of lines no discontinuity of output signal occurs, but an extra sample is needed to produce the output when an output line coincides with an input line.

(vi) The gradient of the profile should be zero at the ends (except for any discontinuity) if it is continuous elsewhere (Fig. 2). Failure to meet this condition with apertures of both integral and non-integral line widths implies a discontinuity of gradient at points on the profile spaced at integral line widths from the ends.

2.5 The Derivation of a Practical Aperture

There are several possible approaches to the problem of deciding on the profile of a practical aperture. The approach described here is a limited Fourier series method, an extension of a method already described elsewhere.[4]

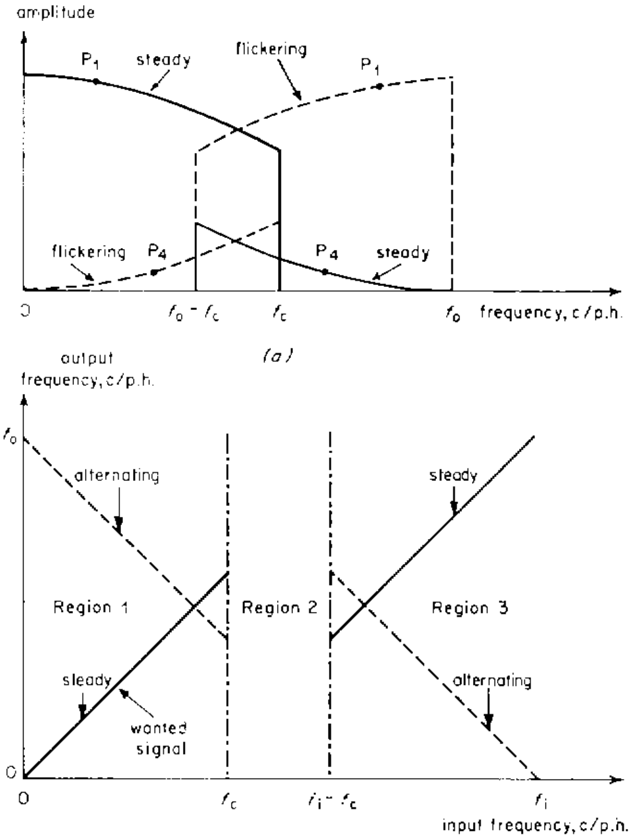

Fig. 6 The spectral behaviour of the converted display using an aperture having a rectangular spectrum cutting at f_c where $f_c < f_i/2$

The starting point is a theorem[5] which states that an aperture of width w units has a spectrum the value of which can only be independently specified at discrete frequencies which are multiples of $1/w$ cycles/unit. The spectrum in between these frequencies is derived by the superposition of appropriately scaled $(\sin x)/x$ functions centred on each frequency, and having zeros $1/w$ cycles/unit apart. This follows because the aperture can be expressed as the product of a repetitive waveform having a period of w units and a rectangular pulse of width w units and the spectrum of the aperture is the convolution of the spectra of these two functions. This process is illustrated in Fig. 7 for an aperture width w equal to $6/f_i$ p.h. where $1/f_i$ is the input sampling spatial period. The spectra of the repetitive waveform and the pulse are shown in (*a*) and (*b*) respectively and the spectrum of the aperture in (*d*). As can be seen the spectrum parameters A_0, A_1 etc. are the amplitudes of the Fourier components of the repetitive waveform, at the frequencies 0, $1/w$ etc. Thus the aperture profile can be expressed as the Fourier series

$$S(\theta) = A_0 + A_1 \cos\theta + A_2 \cos 2\theta \ldots, \quad |\theta| < \pi \qquad (1)$$

In Equation (1) θ is an angular coordinate which varies from $-\pi$ to $+\pi$ across the aperture and is given by

$$\theta = 2\pi\, d/w \qquad (2)$$

where w is the aperture width in p.h. and d is the distance coordinate in p.h. measured relative to the centre of the aperture.

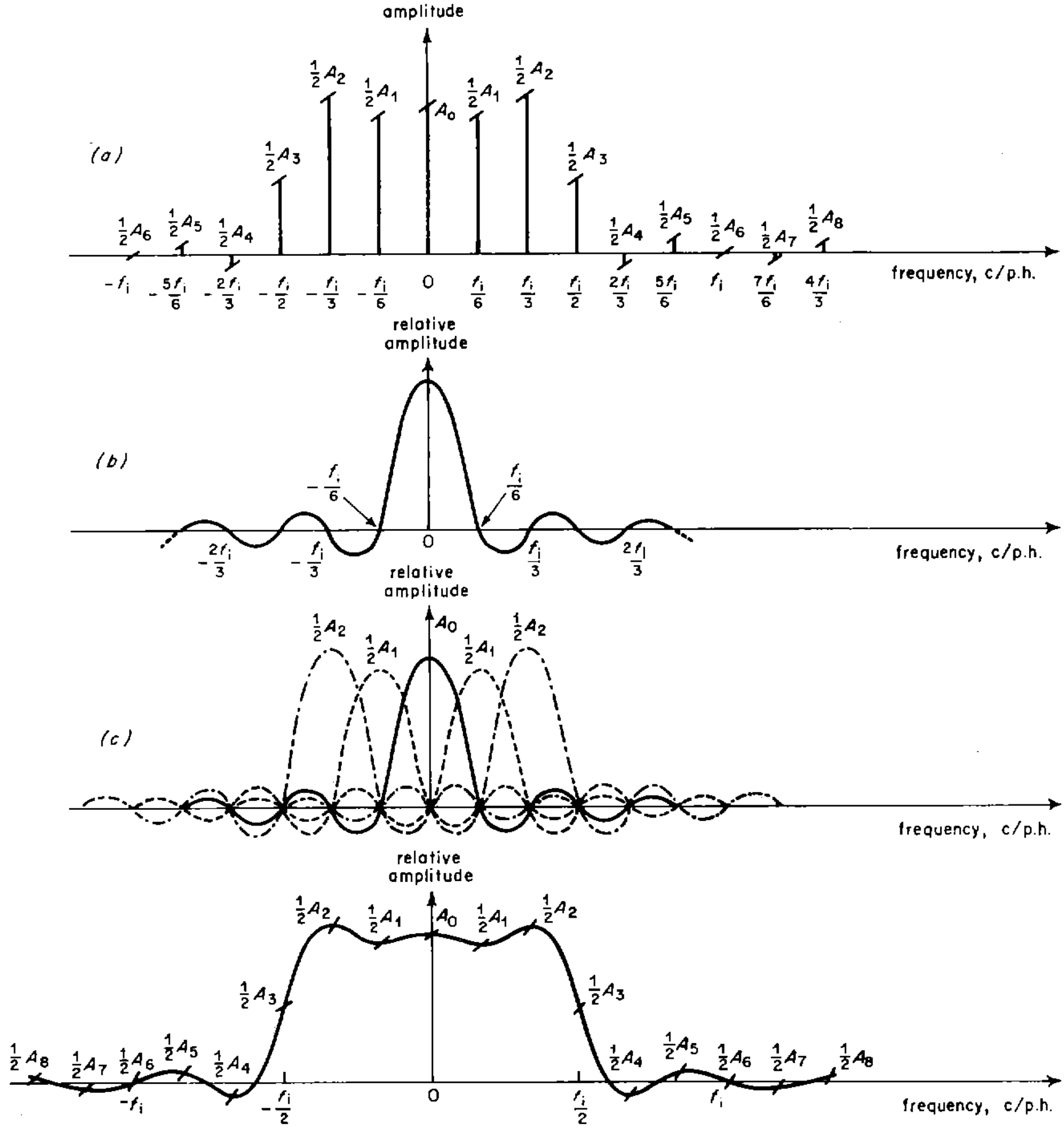

Fig. 7 Derivation of aperture spectrum of width $6/f_i$ p.h.
(*a*) Spectrum of repetitive waveform
(*b*) Spectrum of single square pulse of width $6/f_i$
(*c*) Some components of aperture spectrum
(*d*) Aperture spectrum obtained by summation of all components

Fig. 7 is drawn for an aperture width equal to an integral number of lines but the method of building up the spectrum applies equally well to non-integral line widths. When the width is an integral number of lines, so that

$$w=(n+1)/f_i \tag{3}$$

where n is the order of interpolation, then the spectrum has the value $A_{n+1}/2$ at the frequency f_i which can thus be specified as zero thereby satisfying condition (i) of Section 2.4.

Moreover, to simplify the mathematics, the values of A_r for $r>n+1$ can also be set to zero thereby ensuring that the spectrum passes through zero at the points $rf_i/(n+1)$ for $|r|\geqslant n+1$. Thus the aperture profile becomes a limited Fourier series given by

$$S(\theta)=A_0+A_1\cos\theta+A_2\cos 2\theta\ldots.+A_n\cos n\theta$$

$$=\sum_{r=0}^{n}A_r\cos r\theta,\ |\theta|<\pi \tag{4}$$

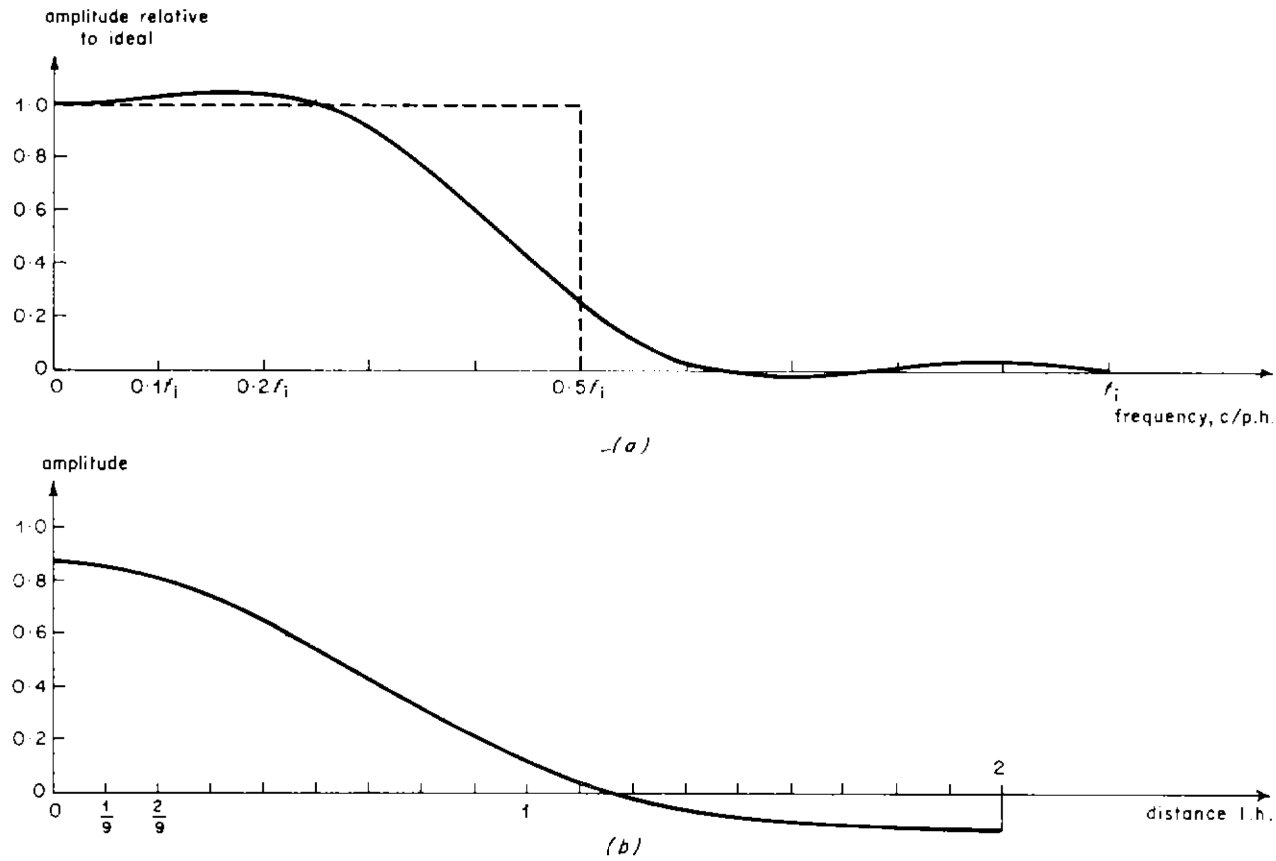

Fig. 8 Typical aperture spectrum and profile obtained by optimisation process
(*a*) Spectrum (*b*) Profile

and the aperture spectrum $F(v)$ is given by

$$F(v)=A_0 \operatorname{sinc} vw+\frac{A_1}{2}\Big[\operatorname{sinc}(v-{}^1/w)w+\operatorname{sinc}(v+{}^1/w)w\Big]-\dots$$
$$+\frac{A_n}{2}\Big[\operatorname{sinc}(v-{}^n/w)w+\operatorname{sinc}(v+{}^n/w)w\Big]$$
$$=\sum_{r=0}^{n}\frac{A_r}{2}\Big[\operatorname{sinc}(vw-r)+\operatorname{sinc}(vw+r)\Big] \qquad (5)$$

where $\operatorname{sinc} vw=\sin(\pi vw)/(\pi vw)$ is the spectrum of a rectangular pulse of width w.

2.6 Optimisation of the Aperture

The profile defined by Equation (4) satisfies condition (i) of Section 2.4 because A_{n-1} is zero and condition (vi) because it is a finite series. However it does not necessarily satisfy the remaining four conditions as can be seen by referring to Fig. 8 which shows an aperture of width 4 lines and the problem of optimisation is to decide on the importance of the various conditions consistent with obtaining a spectrum as close as possible to the 'ideal' rectangular form of cutting at $f_i/2$. If there are insufficient degrees of freedom because n is too small it will be impossible to impose all the conditions simultaneously.

Assuming $n>2$ so that all the conditions can be accommodated there are four linear equations relating $A_0 \dots A_n$ and the spectrum is optimised as a function of the remaining independent parameters.

The optimisation can be performed by minimising an error function which represents the deviation of the actual spectrum from the ideal spectrum. An error function which has been used in theoretical work was formed by summing values of the spectrum expressed in decibels at regular frequency intervals within the passband (i.e. up to $f_i/2$) and adding to this a similar contribution from the stopband but expressed as a deviation from a desired value of -40dB.

Alternatively the parameters $A_0 \dots A_n$ can be given arbitrary values and the spectrum and profile inspected to see how closely the four conditions are obeyed. If necessary the parameters can then be adjusted. This second approach was found to be more successful particularly as it was found in practical work that some of the conditions could be relaxed.

2.7 Spatial Quantisation of the Aperture

The ratio of 625 to 405 line frequencies is such that 81 output lines occur in the same time interval as 125 input lines. This relationship can also be assumed to hold for the spatial positions of the lines. This means that only 81 discrete values of the interpolation aperture profile per line of each input field need be known. If, however, the aperture is several lines wide the number of values that needs to be stored may become prohibitively large and, moreover, if the values are to be set independently as part of a subjective experimental arrangement the complexity of the apparatus reaches impractical proportions.

The required number of stored values can be reduced if certain restrictions are imposed on the interpolation aperture. Firstly the aperture can be assumed symmetrical so that the number of required values is halved. Secondly, the apertures can be spatially quantised into less than 81 discrete values although impairments in interpolation will then result in addition to those caused by the finite width of the aperture. The form of these impairments can easily be analysed in the frequency domain.

The quantising can be expressed as a sampling action followed by a boxcar operation (Fig. 9). Thus, if the aperture is quantised into k quanta per input line height it is equivalent to sampling with a frequency $f_q = kf_i$ c/p.h. and forming each sample into a rectangular pulse of width $1/kf_i$ p.h. In spectral terms if the original aperture spectrum is $F(\nu)$ the quantisation produces a spectrum

$$F_q(\nu) = \text{sinc } \nu/kf_i \sum_{t=-\infty}^{\infty} F(\nu - tkf_i) \qquad (6)$$

where sinc $u = \sin(\pi u)/(\pi u)$.

The summation term results from the sampling and the sinc term from the boxcar operation. The derivation of a typical form of $F_q(\nu)$ is shown in Fig. 10. As can be seen the effect of quantisation is to introduce additional spectral lobes at the frequencies $\pm kf_i$, $\pm 2kf_i$, etc.

Now the first scanning process (at the input frequency f_i) produces components centred on 0, $\pm f_i$, $\pm 2f_i$ etc. (Fig. 5) and thus significant energy exists near the frequencies $\pm kf_i$, $2kf_i$ .... after interpolation. The effective resampling process described in Section 2.3 (at the output frequency f_o) translates all components through integral multiples of f_o and thus the

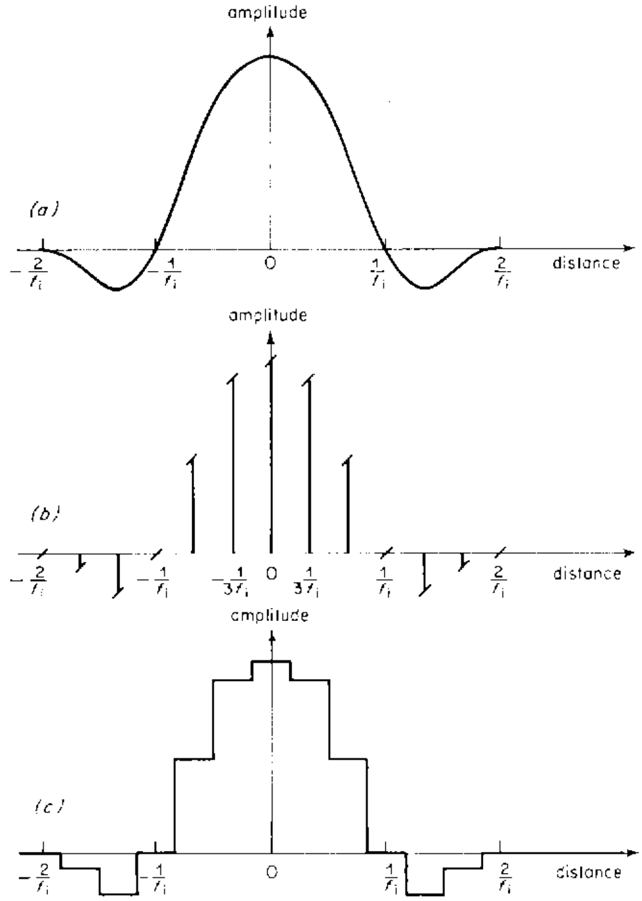

Fig. 9 Derivation of spatially quantised aperture for k = 3
(a) Original aperture
(b) Sampled aperture
(c) Quantised aperture

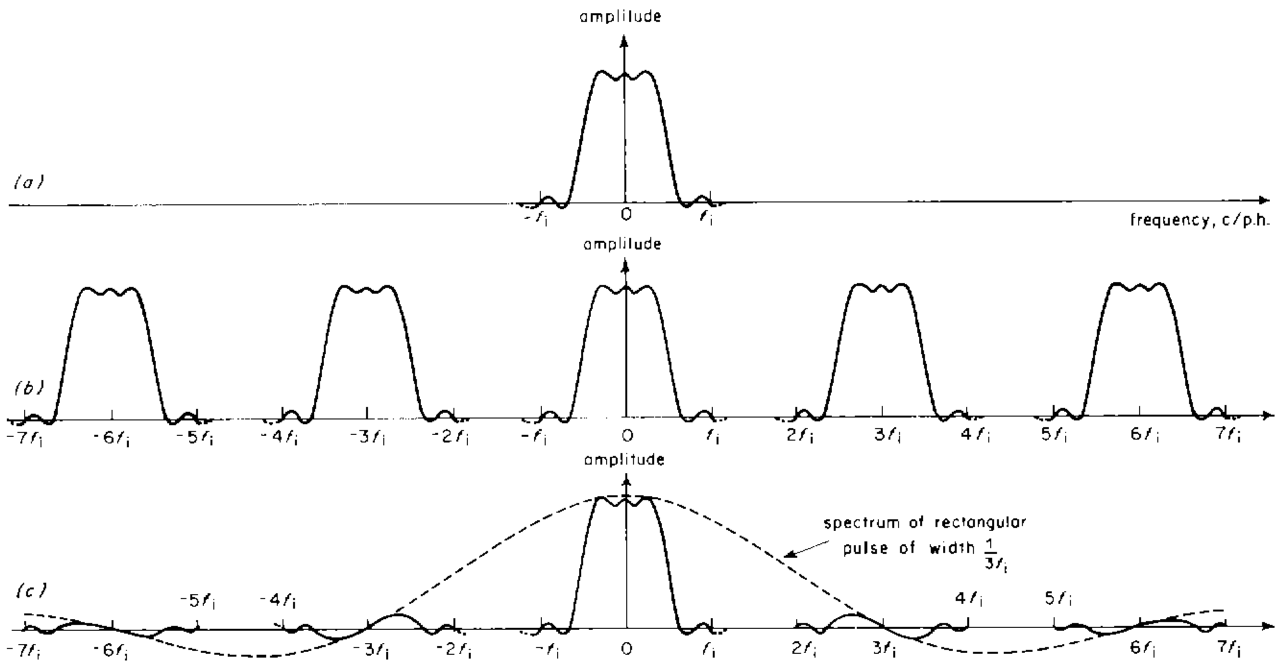

Fig. 10 Derivation of the spectrum of a spatially quantised aperture for k = 3
(a) Original spectrum (b) Spectrum of sampled aperture (c) Spectrum of quantised aperture

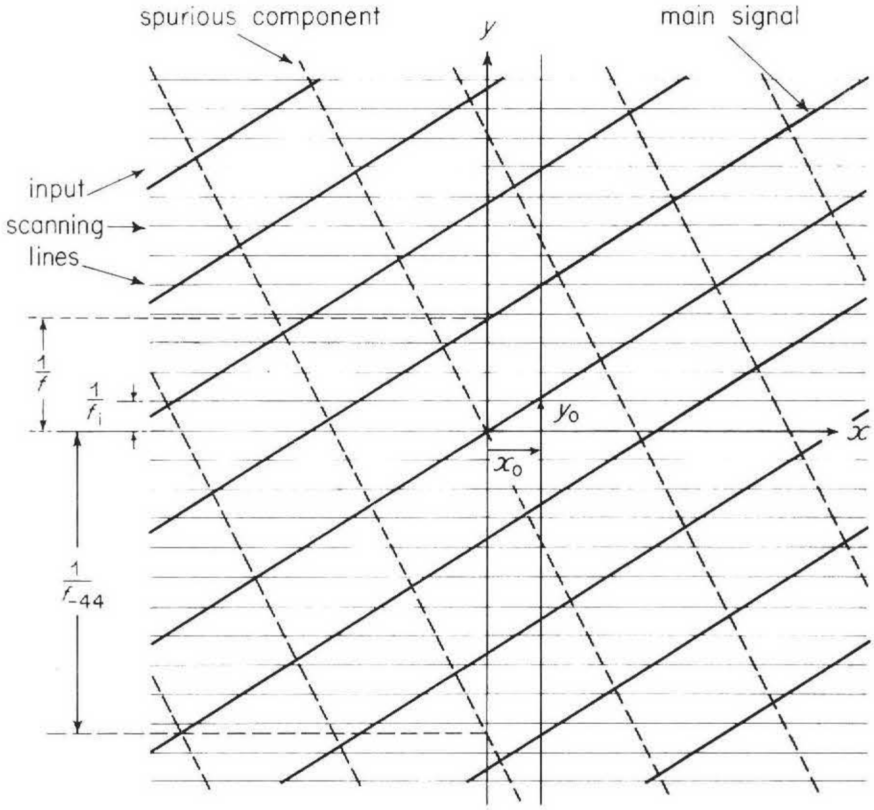

Fig. 11 Postitions of maximum brightness on the display for an input of sloping bars showing the −44th order spurious component. The output scanning lines are not shown

energy in the additional lobes may eventually produce substantial components near the origin. It can be shown that the result of the two sampling processes, with or without intervening interpolation, produces additional spurious components at spatial frequencies separated from the input frequency by integral multiples of $f_i/125(=f_o/81)$. If the component at $f_i(=f+rf_i/125)$ is termed the rth resultant order the amplitude of this component, ef_r), is given by

$$e(f_r)=\sum_{s=-\infty}^{\infty} F_q(f+[35r+81s]f_i) \qquad (7)$$

This equation also holds for unquantised apertures when F_q becomes F but because of the absence of the additional lobes, the level of the spurious products is much lower. It can also be shown that Equation (7) reduces to the unquantised case when $k=81$. This must be so if interpolation requires values of the aperture only at the centre of each quantum. This argument can be extended to cover the case when k is any multiple of 81.

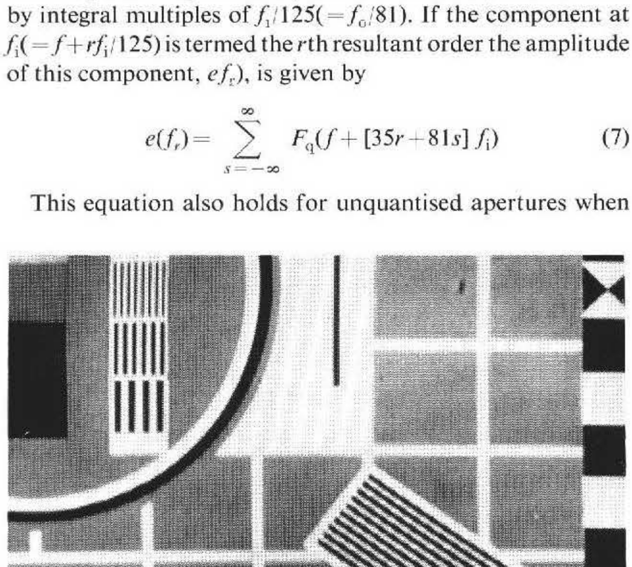

Fig. 12 Photograph illustrating interpolation errors in the corner bars of Test Card C

The energy pattern of resultant orders repeats every 81 so that the 81 orders nearest the origin contain all the information about the levels of the spurious products. The effect of quantisation can now be assessed by comparing the level of these 81 products with and without quantisation.

The physical significance of the resultant orders is best appreciated by considering an input signal in the form of sloping bars of sinusoidal cross-section for example the corner bars of a Test Card. The spurious components can be shown to appear as sloping bars as shown in Fig. 11.

The interaction of the spurious bars with the input bars gives rise to the familiar phenomenon known as 'knotting'.

For example, when linear interpolation is used the level of the relevant resultant order causing the strongest spurious component is about −20 dB and this is visible on the corner bars of a Test Card as can be seen in Fig. 12.

2.8 Theoretical Results Obtained

Aperture spectra have been optimised according to the criterion mentioned in Section 2.6 for various integral values of n up to 7, that is for aperture profiles up to eight lines wide. In general, increasing the value of n gives a sharper cut, as might be expected. For example, with $n=7$ the spectrum falls from 90 per cent to 10 per cent of the value at the origin in

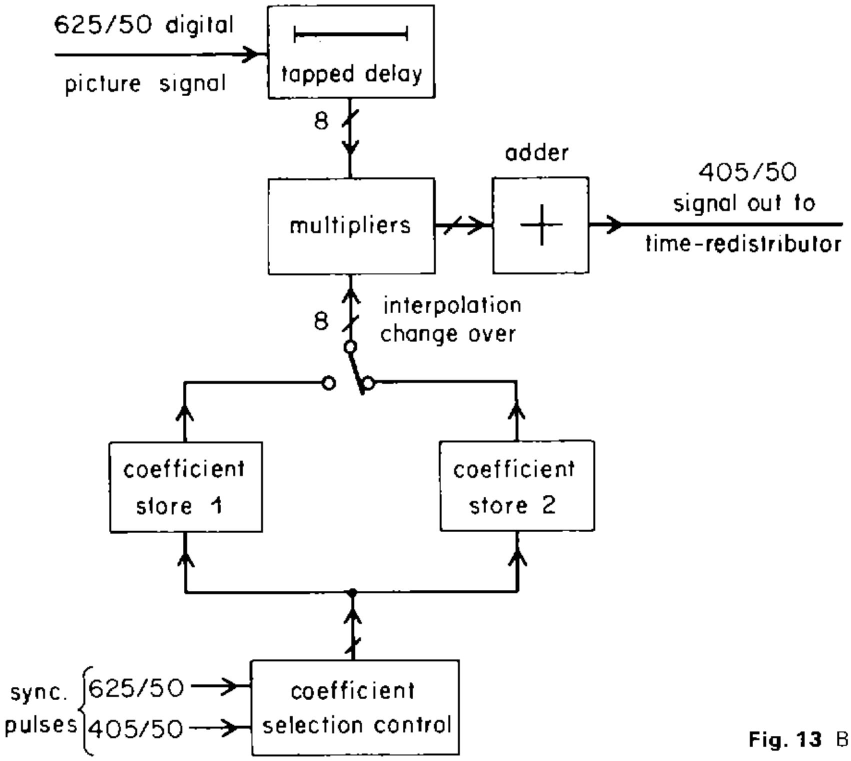

Fig. 13 Basic block diagram of proposed interpolator

a frequency range of $0{\cdot}11f_i$ compared with $0{\cdot}32f_i$ for the present analogue converters.*

To obtain theoretically satisfactory rejection of unwanted signals it was found necessary to relax condition (iv) of Section 2.4, allowing the spectrum to take on values much lower than 0·5 at the frequency $f_i/2$. In the absence of condition (iv) however, the optimisation resulted in spectra having a very good stopband response but a poor passband response.

The second approach of setting arbitrary parameter values was then tried. The imposition of condition (v) was found to be most restricting and when this was removed spectra were produced which were theoretically and experimentally acceptable and which generally satisfied condition (iii) quite closely. Finally condition (ii) was relaxed very slightly to allow for the fact that the aperture values were quantised in amplitude and therefore did not always sum to unity. Fig. 8 shows a typical aperture spectrum and profile obtained.

As a subsidiary investigation certain profiles were quantised into nine and three quanta per line and the resulting spurious products calculated and compared with those from the unquantised aperture and the quantised ideal aperture.

It was calculated that the behaviour of an aperture having a width of eight lines is virtually identical to that of an infinite-width aperture. Moreover, it can be shown that for nine quanta per line the spurious products for an infinite-width aperture are at least 29dB down. As products at −20dB caused an impairment of about grade 3 (see Section 2.7) it is considered that an aperture profile having nine quanta per line should be acceptable.

2.9 The Effect of Contrast Law on Interpolation

The above theoretical treatment is based upon one important assumption which is not necessarily upheld, namely that the chosen interpolation aperture will operate upon signals having a linear relationship to brightness. In practice, standards converters are located at transmitter stations, and so receive an input composite signal which has been gamma-corrected.

Standards conversion of gamma-corrected signals will generally result in an incorrect summation of aperture samples, these errors being greatest when the difference in brightness from line to line is greatest.

A series of exploratory tests was carried out using the digital converter with a linear interpolation aperture and suitable switching arrangements were provided whereby conversion could take place before or after gamma correction, and the pictures produced by the two processing paths were viewed alternately. Slides covering a good cross section of subjects were selected (including those known to show up interpolation errors), and a suitable high quality slide scanner was used as a source of signals. However, very little or no improvement could be detected when converting signals before gamma correction.

It was concluded that for the majority of subjects, the line to line differences in picture content were restricted by the vertical resolution of the system, and were consequently never large enough to show up the inaccuracies caused by operating on gamma-corrected signals. It was provisionally concluded, therefore, that gamma correction was unlikely to influence the design of the interpolation system, although more sophisticated interpolation methods would enable further confirmatory tests to be carried out.

3 Practical Proposals

To assess the practical importance of the theoretical conclusions reached above, subjective tests must be performed on the visible impairments to the television picture caused both

* This information was communicated to the authors by Mr R. E. Davies.

by simple and by more refined interpolation methods. For this work, (not the subject of this present article) a flexible and comprehensive interpolator was developed to provide immediate comparison of the same programme material interpolated in various ways.

Fig. 13 shows the basic block diagram of the interpolator. The tapped delay consists of seven one-line digital delays so that signals from eight adjacent field lines of the picture may be simultaneously available for processing. The eight video signals are multiplied by appropriate coefficients in eight multipliers and the resulting products added, with due regard to sign, in the adder.

The complexity of the equipment increases rapidly as the width of the aperture, the number of bits in the coefficients, and the fineness of the spatial quantising of the aperture are increased. For example, an aperture eight lines wide, with eight bits per coefficient and nine quantised positions, requires an interpolator using nearly 1500 simple integrated circuits with correspondingly high cost. For an experimental interpolator this degree of complexity was therefore taken as the upper limit.

Immediate comparison between two chosen sets of interpolation parameters is provided by the interpolation changeover switch which selected coefficients from one or other of two coefficient stores in use. A number of plug-in store boards are available by means of which comparisons can be quickly made.

By suitable choice of the coefficients loaded into a store, the width, shape, amplitude resolution, and to some extent the spatial quantisation of the aperture may be varied.

4 Conclusions

The best aperture spectrum for standards conversion between interlaced television systems is probably rectangular, cutting at half the input standard field spatial frequency. The corresponding aperture profile is of $(\sin x)/x$ form having zeros one field line apart. A practical aperture can approach this ideal as closely as desired as its width increases. If the aperture is expressed as one cycle of a limited Fourier series the resulting spectrum is a function of a limited number of variables and can be optimised subject to certain constraints. These constraints are that the spatial spectrum should have zeros at integral multiples of the input and output spatial scanning frequencies and fall to half amplitude at half the input spatial scanning frequency. In addition the aperture profile and its gradient should both fall to zero at the ends of the aperture. If the aperture is spatially quantised to save storage of information the smallest number of quanta per input-field line that gives acceptable degradation probably decreases with increasing aperture width. For a width of eight input lines nine quanta is probably acceptable. The determination of the minimum width of aperture, amplitude resolution, and number of spatial quanta per line which are acceptable is the subject of further work (not covered in this article) involving subjective tests, and using the equipment described in Section 3.

5 References

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The Calculation of Electronic Masking for use in Telecine

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Summary: The technique of electronic masking[1] is a means of controlling the colour reproduction of a telecine by suitably combining the red, green, and blue signals so as to introduce a degree of cross-coupling to compensate for deficiencies of the colour film, the telecine, and the colour display. This article describes a method of theoretically determining the required cross-coupling for the reproduction of both positive and negative colour films. As a result of electronic masking, the picture quality is much improved and differences of reproduction between telecines having very different colour-analysis characteristics may be eliminated.

The improvement in colour quality achieved by using calculated electronic masking is a particularly important contribution towards obtaining a satisfactory match between pictures from television cameras and those from film.

1 Introduction

Two quite different approaches may be made towards the generation of television pictures from colour motion-picture film. The first, and perhaps the most obvious, is to attempt to reproduce, on the television screen, the picture which would be obtained by optically projecting the film; this result could be obtained by using, in the telecine, colour analysis characteristics broadly similar to those used in a colour camera. The second approach is to regard the colour film simply as a recording medium in which the scene information is already resolved into superimposed colour-separation images (e.g. red, green, and blue) by the analysis characteristics of the negative film, and to generate corresponding colour-separation signals which are suitable for the colour display and are as free as possible from unwanted cross-coupling.

By adopting the second approach, and by employing electronic masking in the process of obtaining the colour-separation signals relating to the colour-separation dye images, certain advantages may be gained with regard to the final reproduced picture.

2 The Picture Presented by Optical Projection

2.1 The Subtractive Colour Process

Colour film presented by optical projection is a subtractive colour process; the dyes in the positive film absorb light from the projector, over certain regions of the visible spectrum, allowing the remaining light to pass to the projection screen. In practice this process causes distortions to the reproduction in respect of saturation and luminance. The reasons may be found from a study of the dye characteristics. Three coloured dyes are employed, which together control the whole spectrum of light reaching the projection screen; separately they are intended to control those sections of the spectrum corresponding to the primary colours, red, green, and blue. From a glance at the spectral density characteristics of typical dyes, shown in Fig. 1, it can be seen that each dye has some absorption over most, if not the whole, of the visible region, and it is these characteristics which cause errors in the projected picture. This can be explained in the following way.

Suppose it is required to reproduce a very bright and saturated blue on the projection screen. In order to obtain high saturation, all the red and green light from the projector must be absorbed, which calls for high cyan and magenta dye-

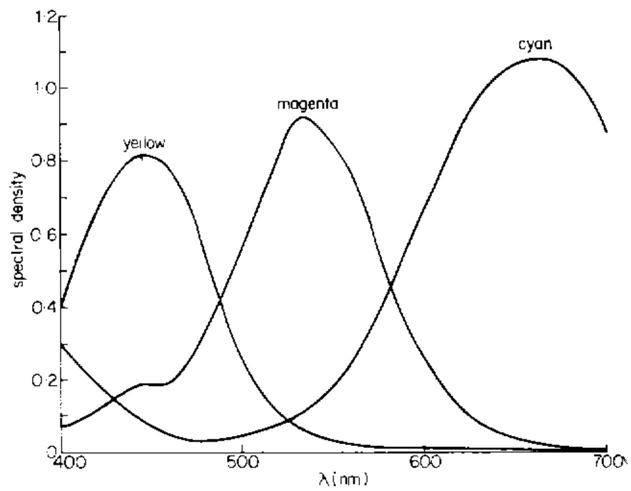

Fig. 1 Typical 'neutral set' of film dye characteristics

densities in the film. From examination of the spectral characteristics of the film dyes (Fig. 1) it will be seen that, under these conditions, absorption of blue light also takes place and, in consequence, the intensity of the blue light reaching the screen is reduced. This causes a reduction in both the luminance and saturation of the reproduced blue.

2.2 Corrections in the Film Process for Film-dye Deficiencies

The film manufacturer attempts to offset the dye deficiencies by raising gamma, that is, by shaping the transfer characteristic of the film so as to expand the contrast. This enhances saturation but the consequent distortion of the brightness scale results in a reduced amount of the scene contrast-range being displayed since there is limited contrast attainable in the film, which is further restricted by projection. The overall result in the cinema is, however, acceptable as is evident by the success of colour film in the motion-picture industry. Other measures employed to offset the film deficiencies, such as dye making techniques – which also enhance saturation, may be used in some special films such as colour negative film.

3 An Alternative Approach to the Reproduction of Film in Television

Motion-picture colour film may be regarded as a three-colour channel recording of the original scene; the fact that the subject of the recording is visible as a colour picture is, in this context, incidental. Knowing the parameters of the film record it is possible to scan the film in a telecine and produce separation signals which, in principle, are proportional to the original light stimuli from the scene, which exposed the negative film in the film camera. By this means it is possible to obtain a television reproduction of the original scene which is more accurate than that achieved with optical presentation.

3.1 The Film 'Recording' Process

The production of a colour photograph of a scene is initiated in the film camera in the same way as the production of television pictures in a colour television camera. The light from the scene enters the camera lens and produces an image of the scene on the three sensitive layers of the negative film; the image is separated by filters into red, green, and blue separation images and these are separately recorded; at this point the similarity between a colour camera and a colour film ends. After processing, three dyes are produced in the film whose densities are related to the intensities of the red, green, and blue components of the light falling on the film. These dyes are cyan, magenta, and yellow in colour and their densities may be considered as records of the red, green, and blue separation images of the scene.

When the film is subsequently printed, the red component of the light reaching the print film is controlled in brightness by the concentration of the cyan dye (since it absorbs red light), the green light is controlled by the magenta dye, and the blue light is controlled by the yellow dye. The picture formed after processing the print film is therefore a positive picture in which the extent to which cyan dye is absent represents the positive red separation-image of the scene; corresponding arguments apply for the magenta dye (green separation-image) and the yellow dye (blue separation-image).

If a telecine machine were able to produce three electrical signals each independently controlled according to the extent to which each film dye is absent in the print, these signals would then be similar to those from a colour camera viewing the original scene. The remainder of this report is mainly devoted to the application of electrical matrixing techniques in the telecine process, as a means for achieving these requirements.

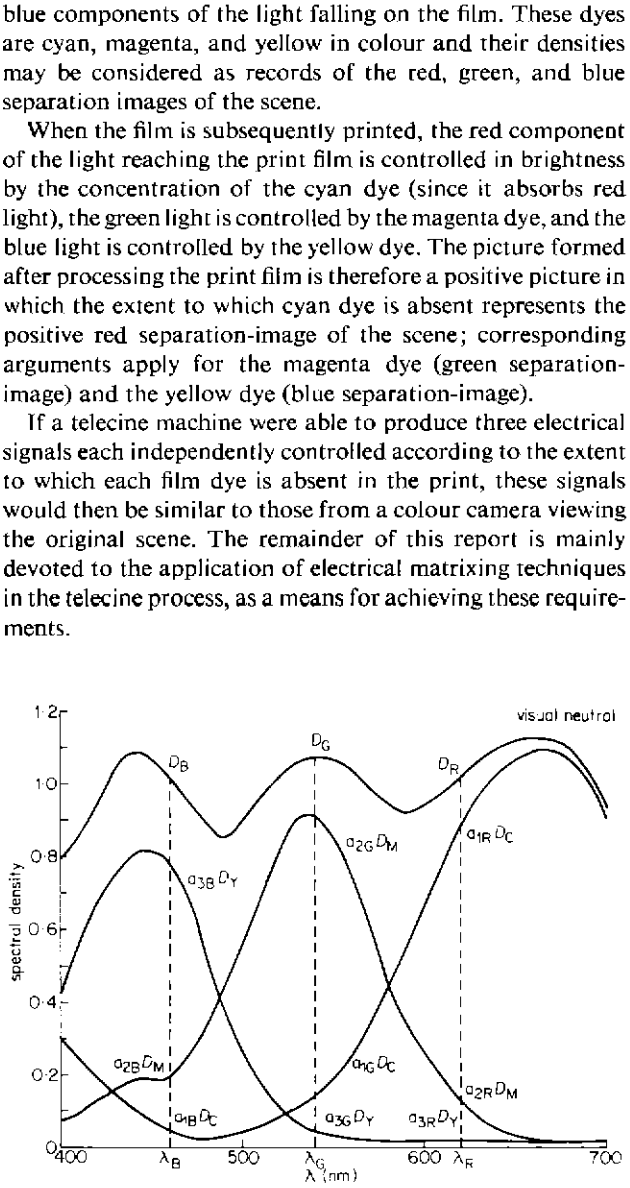

Fig. 2 Typical 'neutral set' of film dyes with spectral line analysis

4 Film Scanning by Telecine

4.1 The Photomultiplier Output Signals

The photomultipliers in a telecine provide signal currents in proportion to the total light energy received. The light from the flying-spot tube is focused on to the film plane, and light passing through the film is split into red, green, and blue components which are collected by separate photomultipliers.

With no film in the telecine gate the gain of each photomultiplier is adjusted so that white level produces a unit signal level

p.e.c. white-level signal (open gate):

$$E_{OG}=\mathrm{K}\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\,d\lambda \qquad (1)$$

λ_1 and λ_2 are the limits of the spectrum of light received by the photomultiplier and $T_S(\lambda)$ is the effective transmission of the telecine analysis at wavelength (λ) for the particular channel (red, green, or blue) under consideration. The telecine analysis characteristic is derived by multiplying together the spectral characteristics of all optical components in the particular light path, including filters, the spectrum of the light emitted from the flying-spot tube, and the spectral response of the photomultiplier.

The constant K is related to the photomultiplier gain and permits the normalisation to unit signal level for white so that

for $E_{OG}=1$

$$\mathrm{K}=\frac{1}{\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\,d\lambda} \qquad (2)$$

When a film is placed in the telecine gate it absorbs some of the light falling on it and the photomultiplier signal is reduced from the open-gate level to a level linearly dependent upon the spectral transmission of the film over the relevant wavelength range.

The relative p.e.c. signal with film in the gate is therefore

$$E_f=\frac{\mathrm{K}\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\,.\,T_f(\lambda)\,d\lambda}{\mathrm{K}\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\,d\lambda} \qquad (3)$$

where $T_f(\lambda)$ is the transmission of the film at wavelength λ.

4.2 Narrow Band Analysis

If the band of wavelength from λ_1 to λ_2 is very narrow and approximates to a spectral line then

$$E_f=\frac{\mathrm{K}T_S(\lambda)\,T_f(\lambda)}{\mathrm{K}T_S(\lambda)}=T_f(\lambda) \qquad (4)$$

The spectral transmission characteristic of a film $T_f(\lambda)$ is the product of the individual spectral transmission characteristics of the cyan, magenta, and yellow dyes ($T_C(\lambda)$, $T_M(\lambda)$, $T_Y(\lambda)$).

Hence for a narrow band of wavelengths, from (4)

$$E_f=T_C(\lambda)\,.\,T_M(\lambda)\,.\,T_Y(\lambda) \qquad (5)$$

Now the density of a film D is related to its transmission T by the formula

$$D=\log_{10}\frac{1}{T}$$

so that Equation (5) can be rewritten

$$E_f=10^{-[D_C(\lambda)+D_M(\lambda)+D_Y(\lambda)]} \qquad (6)$$

where $D_C(\lambda)$, $D_M(\lambda)$, and $D_Y(\lambda)$ are the spectral dye densities at wavelength λ.

Thus by taking the logarithm of the p.e.c. output signal a further signal related to the effective dye densities may be obtained.

$$-\log_{10}E_f=[D_C(\lambda)+D_M(\lambda)+D_Y(\lambda)] \qquad (7)$$

The density of each dye, at wavelength λ, ($D_C(\lambda)$, $D_M(\lambda)$, $D_Y(\lambda)$) may be related by a coefficient to its equivalent neutral density*

$$D_C(\lambda)=a_1D_C$$
$$D_M(\lambda)=a_2D_M$$
$$D_Y(\lambda)=a_3D_Y$$

Coefficients a_1, a_2, a_3 are constant for a given wavelength λ and for given spectral characteristics of dye densities.

Equation (7) now becomes

$$-\log_{10}E_f=a_1D_C+a_2D_M+a_3D_Y \qquad (8)$$

In a telecine three such signals are obtained, one for each primary colour, and the three corresponding expressions for the signals from the red, green, and blue channels may be written in the form of a matrix equation

$$\begin{bmatrix}-\log R\\-\log G\\-\log B\end{bmatrix}=\begin{bmatrix}a_{1R} & a_{2R} & a_{3R}\\a_{1G} & a_{2G} & a_{3G}\\a_{1B} & a_{2B} & a_{3B}\end{bmatrix}\begin{bmatrix}D_C\\D_M\\D_Y\end{bmatrix} \qquad (9)$$

a_{1R}, a_{2R}, a_{3R} are coefficients relating density at wavelength λ_R to equivalent neutral densities D_C, D_M, D_Y.

a_{1G}, a_{2G}, a_{3G} are coefficients relating density at wavelength λ_G to equivalent neutral densities D_C, D_M, D_Y.

a_{1B}, a_{2B}, a_{3B} are coefficients relating density at wavelength λ_B to equivalent neutral densities D_C, D_M, D_Y.

λ_R, λ_G, λ_B are the analysis wavelengths for the red, green, and blue channels of the telecine.

Once this matrix is known the inverse matrix can be calculated and used to form primary analysis signals (proportional to D_C, D_M, and D_Y) from the signals representing the logarithms of the photomultiplier signals.

A graphical interpretation of Equation (9) is shown in Fig. 2 for a spectral line analysis in each channel of the telecine.

4.3 Non-narrow Band Analysis

In a practical telecine each channel may, for signal-to-noise reasons, have an analysis-wavelength range ($\lambda_1 \rightarrow \lambda_2$) which is relatively large and the theory for narrow band analysis then no longer applies. In order to achieve a solution, certain approximations have to be made, and it will be shown that for practical purposes a treatment similar to that for narrow band analysis may be adopted. (The accuracy of the approximations can be verified by computer calculations on a typical practical system; see Section 5.)

As already stated, the spectral transmission characteristic of a film $T_f(\lambda)$ is the product of the individual spectral transmission characteristics of the cyan, magenta, and yellow dyes.

* The density of the neutral image that could be formed by adding to the dye deposit under consideration sufficient quantities of the other two dyes.

From Equation (3):

$$E_f = \frac{\int_{\lambda_1}^{\lambda_2} T_S(\lambda) \,.\, T_C(\lambda) \,.\, T_M(\lambda) \,.\, T_Y(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda} \qquad (10)$$

Consider also another expression

$$E_f = \frac{\int_{\lambda_1}^{\lambda_2} T_C(\lambda) T_S(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda} \cdot \frac{\int_{\lambda_1}^{\lambda_2} T_M(\lambda) T_S(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda} \cdot \frac{\int_{\lambda_1}^{\lambda_2} T_Y(\lambda) T_S(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda} \qquad (11)$$

In order to achieve the required result (an approximation to narrow band analysis) it is necessary to show that these two expressions for E_f give approximately the same answer. We can do this by showing that both expressions are approximately equal to a third expression.

If we assume that the transmission of each film dye (T_C, T_M, T_Y) is constant across the analysis passband ($\lambda_1 \rightarrow \lambda_2$) (or varies only slowly), the transmission of each dye as a function of wavelength can be replaced in the above equations by a 'mean' value. Let these 'mean' values be $\overline{T}_C$, $\overline{T}_M$, and $\overline{T}_Y$ for the cyan, magenta, and yellow dyes respectively. Since these values are now constants they may be taken outside the integral and further simplifications become possible.

Equation (10) becomes:

$$E_f = \frac{\overline{T}_C \,.\, \overline{T}_M \,.\, \overline{T}_Y \int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda} = \overline{T}_C \,.\, \overline{T}_M \,.\, \overline{T}_Y \qquad (12)$$

and Equation (11) becomes:

$$E_f = \frac{\overline{T}_C \int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda} \cdot \frac{\overline{T}_M \int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda} \cdot \frac{\overline{T}_Y \int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda}$$

$$= \overline{T}_C \,.\, \overline{T}_M \,.\, \overline{T}_Y$$

Since this result is identical to Equation (12), Equations (10) and (11) are equivalent if the transmission of each dye varies sufficiently slowly over the analysis passband (i.e. is effectively a constant value); this is approximately true for practical telecine analyses. Moreover, the performance of the final dye density analysis, using masking matrix values calculated on this assumption, can be checked for accuracy; the primary analysis signals which result for various combinations of film dyes can be calculated and compared with the ideal values. The results of such a calculation appear in Section 6.

Comparison of Equations (11) and (12) indicates the method which is used to evaluate the 'mean' values $\overline{T}_C$, $\overline{T}_M$, and $\overline{T}_Y$.

$$\overline{T}_C = \frac{\int_{\lambda_1}^{\lambda_2} T_C(\lambda) \,.\, T_S(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda} \qquad (13)$$

$$\overline{T}_M = \frac{\int_{\lambda_1}^{\lambda_2} T_M(\lambda) \,.\, T_S(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda} \qquad (14)$$

$$\overline{T}_Y = \frac{\int_{\lambda_1}^{\lambda_2} T_Y(\lambda) \,.\, T_S(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_S(\lambda)\, d\lambda} \qquad (15)$$

This method takes the analysis passband into account within the integral and the limits of the integral (λ_1 and λ_2) may therefore be extended to the limits of the visible spectrum.

Since Equation (12) is equivalent to Equation (5), once the values of $\overline{T}_C$, $\overline{T}_M$ and $\overline{T}_Y$ are known the remainder of the calculation is similar to that for narrow band analysis.

Since $$D = \log_{10}\frac{1}{T}$$

from Equation (12)

$$E_f = 10^{-[\overline{D}_C + \overline{D}_M + \overline{D}_Y]} \qquad (16)$$

where $\overline{D}_C$, $\overline{D}_M$, and $\overline{D}_Y$ are densities equivalent to transmission values $\overline{T}_C$, $\overline{T}_M$, and $\overline{T}_Y$.

$$-\log_{10}E_f = \overline{D}_C + \overline{D}_M + \overline{D}_Y \qquad (17)$$

and if coefficients a_1, a_2, a_3 relate the mean density values $\overline{D}_C$, $\overline{D}_M$, and $\overline{D}_Y$ to the equivalent neutral density of the appropriate dye

$$\overline{D}_C = a_1 D_C$$
$$\overline{D}_M = a_2 D_M$$
$$\overline{D}_Y = a_3 D_Y$$

Then we have Equation (8)

$$-\log_{10}E_f = a_1 D_C + a_2 D_M + a_3 D_Y$$

with coefficient values given by:

$$a_1 = \frac{D_C}{\bar{D}_C} = \frac{D_C}{\log_{10}\frac{1}{T_C}} = \frac{D_C}{\log_{10}\left[\frac{\int_{\lambda_1}^{\lambda_2} T_s(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_C(\lambda)\,.\,T_s(\lambda)\, d\lambda}\right]} \quad (18)$$

$$a_2 = \frac{D_M}{\log_{10}\left[\frac{\int_{\lambda_1}^{\lambda_2} T_s(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_M(\lambda)\,.\,T_s(\lambda)\, d\lambda}\right]} \quad (19)$$

$$a_3 = \frac{D_Y}{\log_{10}\left[\frac{\int_{\lambda_1}^{\lambda_2} T_s(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} T_Y(\lambda)\,.\,T_s(\lambda)\, d\lambda}\right]} \quad (20)$$

Evaluating values of a_1, a_2, and a_3 for each channel of the telecine in turn will give the complete matrix relationship which, when the matrix is inverted, will give masking matrix values to provide the required primary analysis signals.

As in Equation (9)

$$\begin{bmatrix} -\log R \\ -\log G \\ -\log B \end{bmatrix} = \begin{bmatrix} a_{1R} & a_{2R} & a_{3R} \\ a_{1G} & a_{2G} & a_{3G} \\ a_{1B} & a_{2B} & a_{3B} \end{bmatrix} \begin{bmatrix} D_C \\ D_M \\ D_Y \end{bmatrix} = A \begin{bmatrix} D_C \\ D_M \\ D_Y \end{bmatrix} \quad (21)$$

$$\begin{bmatrix} D_C \\ D_M \\ D_Y \end{bmatrix} = A^{-1} \begin{bmatrix} -\log R \\ -\log G \\ -\log B \end{bmatrix} \quad (22)$$

4.4 Equivalent Neutral Density

In order for a film to produce a neutral grey a certain relative combination of film dyes is required. The quantity of each dye may not be the same since the controlling factor is that, over the visible band, equal or near equal absorption must take place. As can be seen from Fig. 1 the amount of yellow and the amount of cyan dyes required is very different, due to the unwanted absorption by the dyes. If electrical signals are produced, proportional to the quantity of dye, then, for a visually neutral scene, they would not be equal. In television, equal electrical signals are required for neutral colours and some normalisation is required:

If R_1, G_1, and B_1 are the required television linear signals then

$$-\log R_1 = x_1 D_C$$
$$-\log G_1 = x_2 D_M$$
$$-\log B_1 = x_3 D_Y$$

where x_1, x_2, and x_3 are normalising constants. From Equation (21) substituting for D_C, D_M, and D_Y

$$\begin{bmatrix} -\log R \\ -\log G \\ -\log B \end{bmatrix} = A \begin{bmatrix} -\frac{\log R_1}{x_1} \\ -\frac{\log G_1}{x_2} \\ -\frac{\log B_1}{x_3} \end{bmatrix}$$

Incorporating coefficients x_1, x_2, and x_3 into the matrix and then inverting we have

$$\begin{bmatrix} -\log R_1 \\ -\log G_1 \\ -\log B_1 \end{bmatrix} = B \begin{bmatrix} -\log R \\ -\log G \\ -\log B \end{bmatrix} \quad (23)$$

4.5 Masking for Negative Colour Film

There are two types of colour negative film which are likely to be used in telecine operation. One is a negative film which contains photographic masking employing further coloured dyes in addition to the three dyes normally encountered, and the other is a film in which only the three basic colouring dyes are present. For negative films which do not employ photographic masking, the process of calculating the masking matrix is similar to that employed for positive film already described, with one exception. The gammas of the three dyes in the negative film may not be identical, in which case the normalising coefficients cannot be calculated from the dye spectral characteristics. The coefficients may be found by measurement of the linear telecine photomultiplier signals when a grey-scale, photographed on the negative film in question, is placed in the telecine. Graphs are drawn of $\log_{10}$ (scene brightness) and $\log_{10}$ (photomultiplier signal) whose slopes are measured. The normalising coefficient is then found by dividing the slope of the graphs into the nominal gamma of the film.

$$\text{slope} = \frac{\text{log scene brightness)}}{\text{log (p.e.c. output)}} = \gamma$$

$$\text{Normalising coefficient} = \frac{\gamma_n}{\gamma}$$

where γ_n = nominal gamma of the colour negative.

Figures are found for the red, green, and blue channels of the telecine and are used in the calculation of the masking matrix to effect the correct reproduction of a grey-scale in respect of gamma and gamma tracking.

Photographic masking often employed in colour negative films provides some degree of compensation for unwanted dye absorptions in the process of printing the negative on to the positive print stock. It is designed solely for this purpose and it would be most unlikely also to provide the necessary masking when the film is used in a telecine. It is usual to employ two extra dyes in the film for the purpose of masking, one being yellow and coupled to the magenta dye, the other being orange and coupled to the cyan dye. The yellow main dye does not usually have an associated mask dye.

The photographic process is such that, as the quantity of cyan and magenta dyes are varied, the amount of yellow and orange mask dye varies in an inverse proportion. It is possible to combine the spectral characteristics of the main coloured dyes with their associated mask dyes to produce a set of three dye characteristics referred to as the Equivalent Dyes.[2]

These spectral characteristics contain regions of 'negative density' which are attributable to the operation of the masking dyes. A typical set of equivalent dyes is shown in Fig. 3.

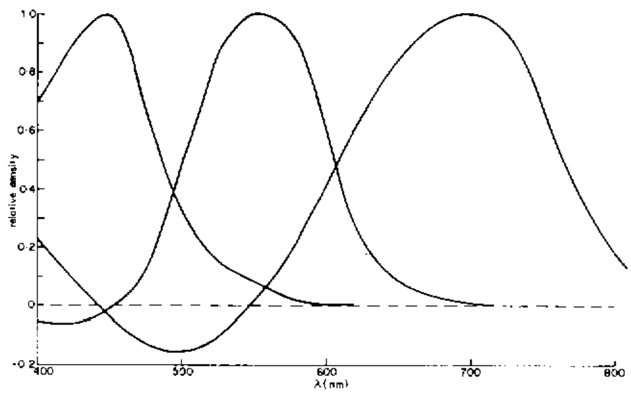

Fig. 3 The equivalent dyes of a colour negative film incorporating photographic masking

The masking coefficients may be found using these spectral characteristics together with grey-scale correction, as described previously for non-masked negative films.

4.6 Correction for Film Analysis Errors

Since films are not designed with television reproduction in mind, the analysis of the film is not exactly that required to suit television phosphors. In television cameras electrical correction for non-ideal analysis has been in use for some time in the form of a 3×3 matrix of the linear television signals relating to the light stimuli. It can be shown that, given reasonable camera analysis, the matrix is a major factor controlling the overall colorimetry. In telecine reproduction of film a linear matrix may also be used. However, the required signals (R_1, G_1, and B_1) occur only in the logarithmic or gamma-corrected form after masking correction for the unwanted dye cross coupling. It has been found that a matrix operating on the logarithmic signals produces very nearly as good a result as the linear matrix and, since a matrix already exists for the film dyes, the analysis correction matrix is usually combined with the dye-masking matrix to produce a single matrix for the whole correction process. The calculation of the analysis matrix involves utilising an optimisation computer programme which has been described[3] and will not be

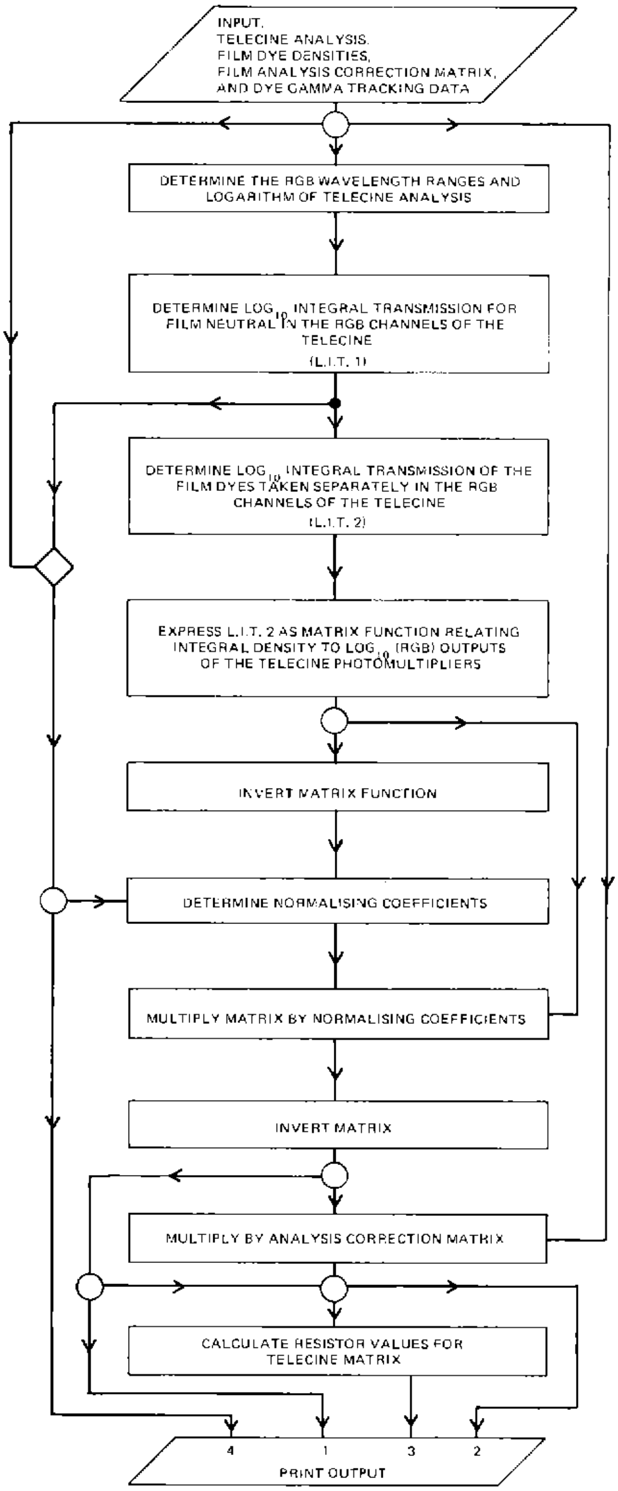

Fig. 4 A computer programme flow diagram for the calculation of electronic masking
Output consists of:
(1) The matrix for film dyes
(2) The matrix for film dyes together with analysis correction
(3) Resistor values for the telecine matrix
(4) The film gammas when viewed by telecine before masking

repeated in this report except to say that the matrix must be designed for use with logarithmic signals instead of linear ones.

5 The Calculation of Masking Matrices with the Aid of a Computer

Calculation of the masking matrixes so far described becomes a lengthy process unless a computer is used. A considerable amount of arithmetic is involved since it is necessary to carry out calculations for each of a set of wavelengths spaced at ten-nanometre intervals throughout the visible spectrum.

The operation of the computer calculation is best explained with reference to a flow diagram (Fig. 4).

5.1 Input Data

The input data for the calculations consists of several parts, as listed below:

1. Telecine analysis characteristics at ten nanometre intervals over the range 380 to 750 nm.
2. The film-dye spectral-densities, if possible for an equivalent neutral density of 1·0, at each ten nanometre interval.
3. A matrix, previously calculated by an optimisation process, which by operating upon the telecine signals produces a 'best fit' condition between the original film analysis and the television display phosphors.
4. If required, the normalising coefficients for the film which have been determined by practical measurement. This is usually only required for negative colour films or where the individual dye densities which form an equivalent neutral density of 1·0 are not known.

5.2 Calculation

The first section of the programme calculates the telecine signals which are produced when a film with an equivalent neutral density of 1·0 is scanned. Since, for a density of 1·0, a signal representing 10 per cent (transmission) would be expected, the ratio of the expected and calculated signal expressed in density form gives a normalising coefficient which is later used to modify the masking matrix to maintain accurate reproduction of neutral brightness levels. If the quantities of the separate dyes, which together form a neutral density of 1·0 are not known, then the normalising coefficients may be found as described previously, from measurements of photomultiplier signals when a film grey-scale is scanned and these values substituted for the calculated values.

The telecine signal, expressed as a density, is the logarithm of the integral of the reciprocal of transmitted light over its sensitive wavelengths,

$$\text{i.e.}\quad D_{(\text{telecine signal})} = \log_{10}\int_{\lambda_1}^{\lambda_2}\frac{1}{T(\lambda)}\mathrm{d}\lambda = -\log_{10}\int_{\lambda_1}^{\lambda_2}T(\lambda)\mathrm{d}\lambda$$

The abbreviation L.I.T. will be used to represent log integral transmission from this point in the description.

In order to produce a matrix function relating the film dyes to the telecine signals, the L.I.T. for each dye taken separately is now calculated. This enables the expression below to be used.

$$-D_{(\text{telecine signal})} = \log_{10}\int_{\lambda_1}^{\lambda_2}T_c(\lambda)T_s(\lambda)\mathrm{d}\lambda + \log_{10}\int_{\lambda_1}^{\lambda_2}T_m(\lambda)T_s(\lambda)\mathrm{d}\lambda + \log_{10}\int_{\lambda_1}^{\lambda_2}T_y(\lambda)T_s(\lambda)\mathrm{d}\lambda$$

where T_c, T_m, T_y are the film dyes transmission and T_s the telecine sensitivity.

Three such equations are calculated, one for each of the telecine signals and a matrix is derived.

$$\begin{bmatrix}\log R\\ \log G\\ \log B\end{bmatrix} = \mathrm{M}\begin{bmatrix}D_c\\ D_m\\ D_y\end{bmatrix}$$

The matrix is inverted and then the coefficients x_1, x_2, x_3 are calculated using the normalising coefficients calculated previously as data for log R, log G, and log B.

$$\begin{bmatrix}x_1\\ x_2\\ x_3\end{bmatrix} = \mathrm{M}^{-1}\begin{bmatrix}\log R\\ \log G\\ \log B\end{bmatrix}$$

The values of $x_{1,2,3}$ are used to multiply the original matrix which is then inverted. This is now the mask matrix which will balance out all unwanted effects of dye absorptions in the electrical signals.

This matrix is now combined with the analysis matrix to give the final masking matrix and this is printed out as part of the results of the calculation.

The calculation is repeated for a range of equivalent neutral densities of dye scanned by the telecine from a density of 0·1 to 3·0. By comparing the values of these matrices for various densities the accuracy of the approximation used to establish the theory of the method (Section 4.2) may be checked. If large discrepancies occur it suggests the analysis bandwidths of the telecine are too wide.

Since the approximation used is most appropriate for low quantities of dye then the matrix for a density of 0·1 is the one used in practice.

6 Checking of the Calculated Masking System

A second computer programme has been written in which the film and telecine spectral characteristics together with the matrix calculated to remove the effects of unwanted absorptions of the film dyes were used as data. The programme set up a model telecine in which the quantity of one of the film dyes could be made to vary whilst maintaining constant density of the remaining two dyes. The telecine output signals were derived (a) for conditions of no masking matrix correction and then (b) for conditions including correction. Figs. 5, 6, and 7 show graphically the results obtained when one dye density is varied from 0·2 to 2·0 whilst maintaining the remaining dyes at density 1·0.

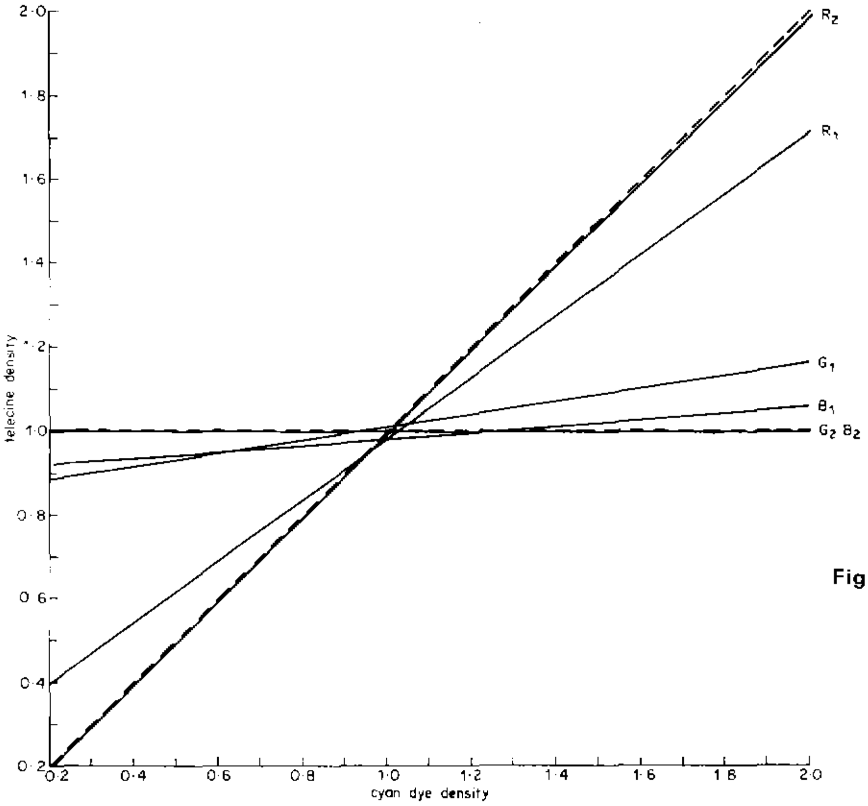

Fig. 5 The effect of masking upon unwanted dye absorptions
The density of Cyan dye is varied from 0·2 to 2·0
The density of Magenta dye = 1·0
The density of Yellow dye = 1·0
$R_1G_1B_1$ are unmasked results
$R_2G_2B_2$ are masked results
------- Ideal system with no crosscouplings

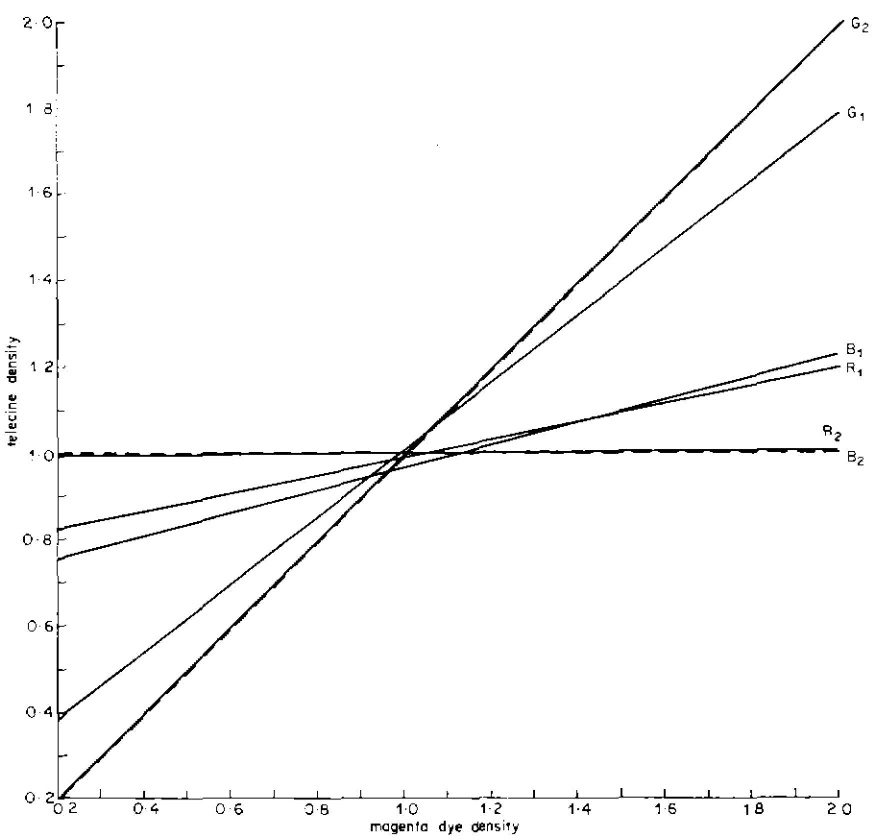

Fig. 6 The effect of masking upon unwanted dye absorptions
The density of Magenta dye is varied from 0·2 to 2·0
The density of Yellow dye = 1·0
The density of Cyan dye = 1·0
$R_1G_1B_1$ are unmasked results
$R_2G_2B_2$ are masked results
------- Ideal system with no crosscouplings

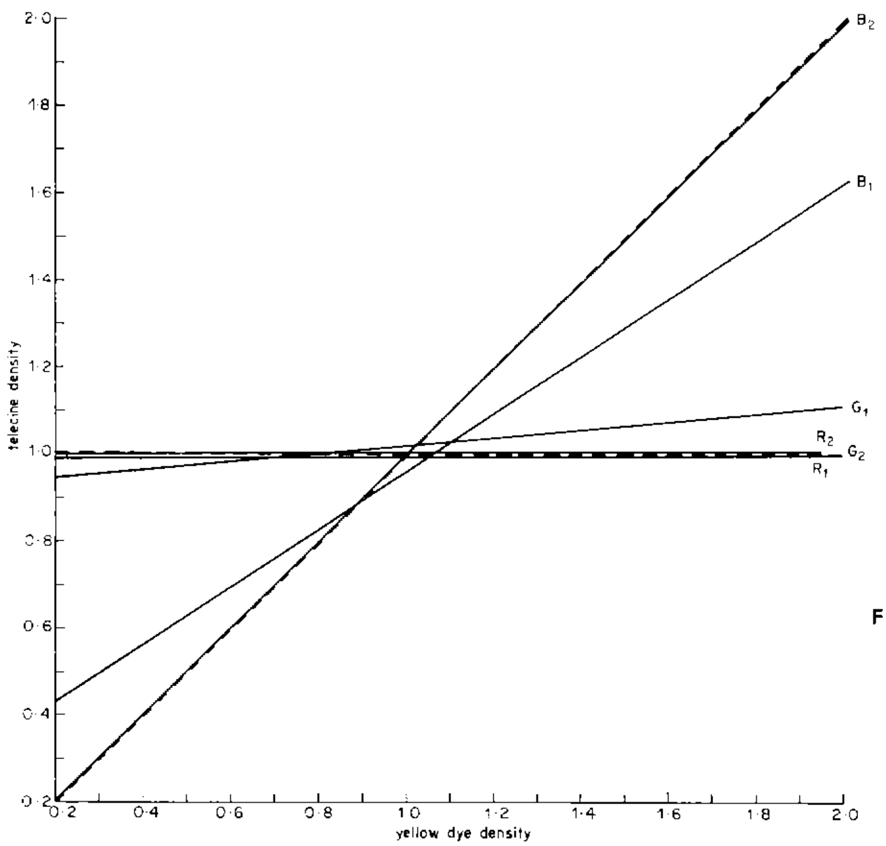

Fig. 7 The effect of masking upon unwanted dye absorptions
The density of Yellow dye is varied from 0·2 to 2·0
The density of Cyan dye = 1·0
The density of Magenta dye = 1·0
$R_1G_1B_1$ are unmasked results
$R_2G_2B_2$ are masked results
------- Ideal system with no crosscouplings

It can be seen that even with wide band analysis the masking matrix provides almost complete correction for the effects of unwanted absorptions by the film dyes.

It has been found, in practice, that variations in performance with various film stocks may be reduced to small proportions, the residual errors being due to internal differences of film stocks as yet uncompensated for. Over ranges of luminance which do not suffer great distortion, the colour performance using positive print film is very similar to that obtained from negative film.

7 Conclusions

The method of calculating masking matrices as described provides a reliable means of obtaining a high performance from a colour telecine. Using this method different telecine analysis characteristics may be used, yet the colour performance may be made the same. Indeed at one time, there were two different sets of analyses in use by the BBC Television Service, each with appropriate matrices, and yet nominally identical pictures were produced from a given film.

8 References

1. Burr, R. P. 1953. The use of electronic masking in colour television. *Proc. Inst. Radio Engrs.*, **42,** 1, pp. 192–200.
2. Sant, A. J. 1961. Equivalent dyes for films with incorporated coloured couplers. *Photogr. Sci. Engng*, 1961, **5,** 3.
3. Use of a linear matrix to modify the colour analysis of a colour camera. BBC Research Department Report No. T-157, Serial No. 1965/50.

Transportable Radio Presenter's Desk and Disk Reproducer

The DK4/16 transporable desk is designed for use by the presenter in OB programmes such as Radio One Club. Normally it is used with two disk reproducers (BBC type RP2/8, described below) and three tape cartridge machines such as the Plessey CT80 or equivalent stereo cartridge reproducer.

Particular attention has been paid to making the presenter's desk compact and easily transportable. Part of the desk folds during transportation and the hinged desk top provides a protective cover over the operating panels. The tape-cartridge machines are removable. Hinge-back doors at the end protect the left-hand panel, which provides all the mains connections, and for the right-hand panel, which provides the external programme connections. A detachable rear panel, covered on both sides with black plastic laminate, enable publicity material to be displayed while also providing a protective cover to the rear of the desk and the tape cartridge machines.

The desk has three monophonic and six stereophonic channels and provides the following facilities:

(*a*) Three tape cartridge channels, which can accept either mono or stereo inputs, with remote start and stop controls.

(*b*) Two stereo disk reproducing channels.

(*c*) Three mono microphone channels with coarse pre-set gain controls to suit microphones of differing sensitivities. Microphone 1 is normally a Beyer M160 mounted on an adjustable arm; this microphone is used also for talkback or for the public-address system directly.

(*d*) One miscellaneous stereo channel which can be switched for use with either low-level microphone or high-level inputs. A coarse pre-set gain control is provided, similar to that on the microphone channels.

(*e*) Pre-hear keys on all channels; these cause the normal studio-output or cue-fee connection to the presenter's stereo headphones to be replaced by the relevant channel input. A volume control is provided for the headphones, which may be switched also to a cue feed sent from the OB engineer's desk.

(*f*) Low-impedance stereophonic outputs available from all channels in addition to grouped stereophonic disk and grouped stereophonic cartridge outputs. Up to 100 m of multi-pair connecting cable may be used.

(*g*) A panel-mounted synchronous clock with sweep second hand. By hinging up the clock the minute and hour hands can be adjusted, while a non-locking push-button beneath the clock can be used to stop the clock temporarily and so synchronise the second hand.

(*h*) A lamp on an adjustable mounting for illuminating the desk.

The desk has been designed to give outputs at a nominal −30 dB level with the inputs to the channels as follows:

Tape cartridge and Gram channels	10 dB
Microphone channels	−70, −60, −50, −40 dB
Miscellaneous channel (low level)	−70, −60, −50, −40 dB
(high level)	−20, −10, 0, +10 dB

The channels will each give an output 28 dB above line-up, (i.e. 20 dB above peak volume) with low distortion and, therefore, will be able to handle a wide range of programme volumes satisfactorily.

The desk is designed for use with its outputs fed to a remote OB engineer's desk providing facilities for balance, control, monitoring, and inserts, etc., and the presenter's desk outputs are therefore at low impedance (30–40 Ω) to enable cables up to 100 m long to be used without cable-capacitance affecting the frequency response.

The desk requires two input power feeds from separate fused plugs; the equipment is divided between the supplies so that if one supply should fail at least half the facilities of the desk will remain working.

Disk Reproducer RP2/8

This transportable stereo reproducer is normally used with the presenter's desk, DK4/16, and comprises a Gates turntable type CB-77 fitted with a 12 in. Gray arm and Goldring-800 pickup. The turntable has three speeds, 33⅓, 45, and 78 r.p.m., though the latter speed is unlikely to be used frequently as it involves a change of stylus.

The associated electronics are very simple, there being no operational controls at all. The normal output level on each channel is −10 dB. An adjustable mono output for headphone monitoring is provided on the front of the reproducer.

The cabinet is designed to be complementary in appearance to the presenter's desk. It comprises a wooden frame with inset black plastic-laminate panels on the sides and rear. A detachable lid clamps the turntable chassis, the turntable, and the pickup arm during transportation. The electronics and all internal electrical connections are accessible behind a panel at the front of the reproducer, while the lower part of the cabinet is also fitted with a removable panel, providing storage space for electrical leads, etc. The cabinet is fitted with a spirit-level and adjustable feet.

Overall dimensions for the reproducer (with lid fitted) are 550 mm wide × 520 mm deep × 850 mm high. Weight is 45 kg approximately.

Biographical Notes

George Le Couteur joined the BBC Research Department as a graduate trainee in 1965 after graduating in physics at King's College, London. He worked for a time on problems relating to the registration capabilities of colour television cameras. After transferring to the Special Projects section, he worked on the BBC Advanced Field-Store Standards Converters. More recently he has been concerned with the application of digital techniques to standards conversion. He has also been involved in work concerned with the possible modification of television field synchronising signals, and is now investigating laser beam deflection techniques.

Jeffrey Chew, who is forty-six, graduated in Electrical Engineering at Bristol University in 1948 and the same year joined the BBC. He was, for a short time, in Designs Department but transferred to Research Department where he has remained.

He has worked on electro-acoustics, instrumentation of electro-acoustic measurement, and after a period of two years in Aerial Section, more recently upon pulse-code-modulation and other digital systems.

Tony Griffiths joined the BBC in 1959 in Manchester where he worked in the Television Studios with image orthicon cameras and vidicon telecine equipment.

He transferred to Research Department after eighteen months to join the Aerial Section, and assisted with the investigations into television reception interference at relay stations caused by precipitation static. With the start of work on colour television transmission systems in 1962, he transferred to Image Scanning Section where he participated in the PAL, SECAM and NTSC tests and has since worked on problems connected with the reproduction of film on television, developing many of the techniques now employed in modern telecine signal processing.

He left the BBC in September 1972 to join the Decca Record Company as Chief Engineer (Video) and is now concerned with developments in Television Disc recording.

J. O. Drewery graduated at Cambridge and afterwards took a Ph.D. in Electronic Engineering at the same university. He entered the BBC Research Department in 1968 and has been involved with various projects, notably field-store standards conversion and digital line-store standards conversion. He is at present working on the application of digital techniques to picture signal generation and processing.

Leslie Griffiths was a classical scolar at Oxford during 1940–1 and 1946–7, graduating in 1947. During the war he held a technical commission in the Army from 1941 to 1946, working on radar and communications equipment, and in 1951 obtained a London external degree in Mathematics and Physics. After three years with the Marconi Company, he joined the BBC in 1951 and held a number of appointments with the Planning and Installation Department, concerned with television studios and recording, becoming Senior Television Planning Engineer in 1966. In 1969 he was appointed Head of Engineering, Television Recording, with the Television Operations and Maintenance Group.

Books by BBC Authors

The following books, written by BBC authors, can be obtained from technical bookshops or by direct application to the publisher.

BBC Publications, 35 Marylebone High Street, London W1M 4AA.

BBC Engineering 1922–72 (£7) by Edward Pawley

Focal Press Ltd, 31 Fitzroy Square, London, W1

Motion Picture and Television Film Image Control and Processing Techniques (£4·50) by D. J. Corbett

Butterworth & Co., 88 Kingsway, London, WC2

Sound with Vision (£6) by E. G. M. Alkin

Principles of Transistor Circuits (case-bound £3; limp £1·50) by S. W. Amos

Sound and Television Broadcasting: General Principles (£2·25) edited by K. R. Sturley

Television Engineering: Principles and Practice by D. C. Birkinshaw, S. W. Amos, and K. H. Green

Volume 2: Video-frequency amplification (£3·50)

Volume 3: Waveform Generation (£3·50)

High-quality Sound Production and Reproduction (case-bound £2·10; limp 75p) by H. Burrell Hadden

Microphones by A. E. Robertson (£3·75)

Principles of PAL Colour Television and Related Systems (case-bound £1·75; limp £1·05) by H. V. Sims

The following Engineering Training Supplements, also written by BBC authors for engineering training purposes, can be obtained by application to Head of Technical Publications Section, BBC, Broadcasting House, London W1A 1AA:

No. 6 Programme Meters (15p)
No. 11 Lighting for Television Outside Broadcasts (30p)
No. 13 Monitoring and Relaying of Short-wave Broadcast Signals (62½p)
No. 14 Colormetry (22½p)

Publications available from Engineering Information Department

Information Sheets on the following subjects can be obtained from Head of Engineering Information Department, Broadcasting House, London W1A 1AA, and are available free of charge, except where otherwise indicated.

General

9002 Wavebands and Frequencies Allocated to Broadcasting in the United Kingdom

Television

4006 UHF Television Reception
9003 Television Channels and Nominal Carrier Frequencies
2701 Television Interference from Distant Transmitting Stations
4101 Television Receiving Aerials
4306 Test Card F
2001 Transmitting Stations, 405-line Services (BBC-1 and BBC Wales): Channels, Polarisation, and Powers
2901 Transmitting Stations, 405-line Services (BBC-1 and BBC Wales): Map of Locations
4003 Transmitting Stations, 625-line Services: Channels, Polarisation, and Powers
4919 Main Transmitting Stations, 625-line Services: Map of Locations
2020 405-line Television: Nominal Specification of Transmitted Waveform
4202 625-line Television (Colour and Monochrome): Brief Specification of Transmitted Waveform
How to receive BBC TV – 625 lines and colour

Radio

1042 BBC Local Radio Transmitting Stations (MF 2 VHF): Frequencies and powers.
1701 Medium-wave Radio Services: Interference
1603 Stereophonic Broadcasting: Brief Description
1604 Stereophonic Broadcasting: Technical Details of Pilot-tone System
1605 Stereophonic Broadcasting: Test Tone Transmissions
1034 VHF Radio Transmitting Stations: Frequencies and Powers
1919 VHF Radio Transmitting Stations: Map of Locations

Service Area Maps

Individual maps showing the service areas for many radio and television transmitters are also available.

Specification of Television Standards for 625-Line System I Transmissions

A detailed specification of the 625-line PAL colour-television signal transmitted in the United Kingdom is published jointly by the British Broadcasting Corporation and the Independent Broadcasting Authority, and can be obtained for 50p post free from Head of Engineering Information Department, Broadcasting House, London W1A 1AA.