COLOUR TELECINES
METHODS OF MEASUREMENT AND SPECIFICATIONS

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Introduction

Many of the characteristics of motion-picture film have been standardized, both formally and informally, with the result that there are few technical impediments to the international exchange of film programmes for the cinema. Sub-group 03 of the EBU has drafted standard requirements for colour motion-picture film materials intended for colour television [1] - as distinct from cinema projection - and also specified the optical projection conditions [2] which should be used when assessing the technical quality of films intended for television broadcasting. The present document continues the work of standardization by specifying the more general characteristics of a modern colour telecine. The intention is to assist makers of film programmes who wish to carry out a more detailed assessment of the suitability of their film print for television by viewing it on a telecine and who need guidance as to what kind of telecine may be taken as representative of broadcasting practice. In addition, in this document the problems are approached in such a way as to provide information to the manufacturers on the relative importance that the broadcasters attach to the principal characteristics of these machines. Finally, it is thought that this document may be of value to broadcasters who are contemplating the purchase of new colour telecine equipment.

Since the second edition of this document was issued in 1979, a new type of telecine has become available using solid-state charge-coupled device (CCD) sensors. This third edition takes into account this new development and contains additional information covering this type of film scanner.

The concept of a standard broadcast telecine is far from being novel, yet no European broadcaster has put such an ideal into practice. Indeed, telecine machines show a greater divergence of mechanical designs, of methods of image analysis, and of the types of electronic processing which they employ, than either electronic cameras or video tape-machines. Nevertheless, Sub-group G3 has been impressed with the advantages, which some broadcasters have found to accrue from adopting a particular telecine machine as a standard reference telecine.

However, in one sense at least, all telecine machines used for broadcasting satisfy certain basic requirements, such as accepting a standard-perforation film and producing television signals which conform to CCIR scanning and waveform standards. On the other hand, it would be possible, though hardly desirable, to stipulate that the only telecine to be used in broadcasting is a certain model made by a particular manufacturer. Between these two extremes, there may be a compromise position which would be helpful to broadcasters in general and which, rather than inhibiting the future development of the art and science of television films, instead serves to point the way forward.

Telecines may be used for transmitting complete film programmes, and such programmes may have been shot or processed specifically for television; on the other hand, the film may have been prepared for the cinema. Telecines may also be used to insert filmed sequences into a programme produced by electronic cameras. In the case of a drama production, the " insert " may have been shot on film purely as a matter of expediency, and its quality must be comparable with that of the electronic camera shots which precede and follow it.

In the case of those broadcasting services which carry advertisements, the telecine used for commercials may be required to handle - in rapid succession - a number of short, spliced, advertising films which have been shot and printed on different stocks and processed by various laboratories. Finally, some broadcasters may demand a very special application, in that they require to transmit not only positive film, but also negative film; the telecine must then be able to give a normal positive picture output although the input film is a masked colour negative.

These various types of film usage lead to print images of different characteristics and different relationships to the real scene and to the television reproduction which is required of them.

An essential requirement of a telecine is to reproduce the original scene. It is obvious that such a requirement leads to the adoption of criteria that are at once delicate, numerous and difficult to standardize. At the final stage of transmission it is in fact the viewer who will judge the pictures as seen on his receiver, where they will be in competition with pictures from other sources. Accordingly, it is necessary to have access to an arsenal of varied means so that the reconstitution of the original scene as derived from the film image may be of the best possible quality.

On the other hand, it should be noted that it is often standard practice to review films made for television under the projection conditions which are recommended in EBU document Tech. 3091. This technique enables sufficiently uniform results to be obtained, no matter which organization carries out this viewing, and serves, consequently, as a standard for the international exchange of programmes recorded on fIlm. It is important that an artistic effect approved when seen by direct projection should be preserved when the film is televised.

It will be seen from the foregoing that the role of the telecine in contributing to television programmes cannot be embraced by a single, standard, mode of operation. The elementary telecine which makes a simple transcription from the visual image to primary electrical signals can only fulfil a limited number of the desired functions.

The telecine must be sufficiently flexible to reproduce, at one extreme, a film of first class quality when viewed by optical projection. At the other extreme, it must achieve the best possible reproduction of ungraded film shot and processed in the minimum time, or, for example, an archive colour film print which has faded so much that it could not enjoyably be viewed by optical projection. In the case of the good quality film, the opportunity may be taken in the signal processing of the telecine to improve the colour rendering of the scene by techniques such as logarithmic masking, which can provide a good compensation for the known deficiences of the combined film and telecine process. In the case of poor quality film, the film image is such an inaccurate description of the original scene that the telecine signal processing must be able to be adjusted over a wide range of parameters to produce the best visual production of the scene as judged by an operator. In this case, adjustment of logarithmic masking, grey scale correction, resolution (aperture correction) etc. which can be made easily while the film is being viewed are all desirable features. Where the film is very variable in quality, the most satisfactory procedure is to record the correction settings for each scene during a review of the film, and to use this recording to change the operating condition of the telecine automatically; this is known as pre-programmed operation. Pre-programmed operation is, however, time consuming and expensive and the importance a broadcaster attaches to picture quality, considering the cost of achieving it, must be an individual judgment. In view of this, it may be therefore necessary to provide remote control of such an operation. It is also a requirement that a telecine should be able to be switched to monochrome operation so that it reproduces a black-and-white silver image as neutral, even if the base of the film is tinted.

The above description assumes that the intention of the broadcaster is to reproduce, as closely as possible, the colour characteristics of the original studio scene. An alternative mode of operation would be to attempt to reproduce on the television monitor the same colours as would result from optical projection of the film, in the hope that the film manufacturer has reduced any colorimetric errors to a low enough level to be acceptable. These two ways in which a telecine can be used are identified in this document by the phrases " as exposed " and " as projected " reproduction respectively. The " as exposed " approach is more relevant in cases where good matching between insert material shot on film and material shot by electronic cameras is desired; the " as projected" approach can yield some simplifications in the electronic signal processing required by telecines.

Chapter 1
Fundamental characteristics

It may be considered that in essence the telecine performs two physical processes: in the first, the cinematographic images are analysed into their trichromatic components, thereby producing "analysis signals" which are proportional to the transmission coefficients of the film being scanned: in the second, the analysis signals may be processed so as to produce a " video signal " that conforms to the television standards [3] .The characteristics of telecines that correspond to each of the two processes will be discussed in the following two sections.

It is not always possible to isolate the analysis signals at a given point in the machine and thus it is not always possible to isolate their characteristics from the overall characteristics of the telecine, which can only be measured with the output signals. Account has been taken of this restriction in the discussions in each section.

1. Scanning and analysis characteristics

1.1. Trichromatic analysis curves

The aim of the colour analysis, for most types of film-scanning operation and bearing in mind the contemporary level of our technology, is a colorimetric one-to-one correspondence between the chromaticities in the original scene and those of the reproduction on a display tube using the EBU phosphor chromaticities, with the analysis system correcting for the colour temperature of the scene illumination to give signals corresponding to those that would have been produced with a standard white D6s illumination. Since, in general, the display tube will not allow an objective reproduction of luminance, other considerations apply to the brightness tone scale (e.g. " Gamma ").

In the present state of the art, any subjectively desirable variations away from objective colorimetric fidelity in the reproduction are left to the production crew. It will be seen later, however, that it is desirable that provision should be made on the telecine for varying certain colorimetric characteristics of the picture, but the function of the analysis section is to translate light into electrical signals with the best colorimetric fidelity.

The film stands between the original scene and the telecine. It is only possible therefore to define the telecine characteristics that will provide a faithful reproduction of the scanned film. To achieve this fidelity, the spectral characteristics of each analysis signal channel must be related to the colour-matching functions that correspond to the picture tube primaries. Fig. 1 shows these colour-matching functions for the television reproduction stimuli as defined by the EBU [4], taking account of the visual sensitivity of the CIE 1931 standard observer.

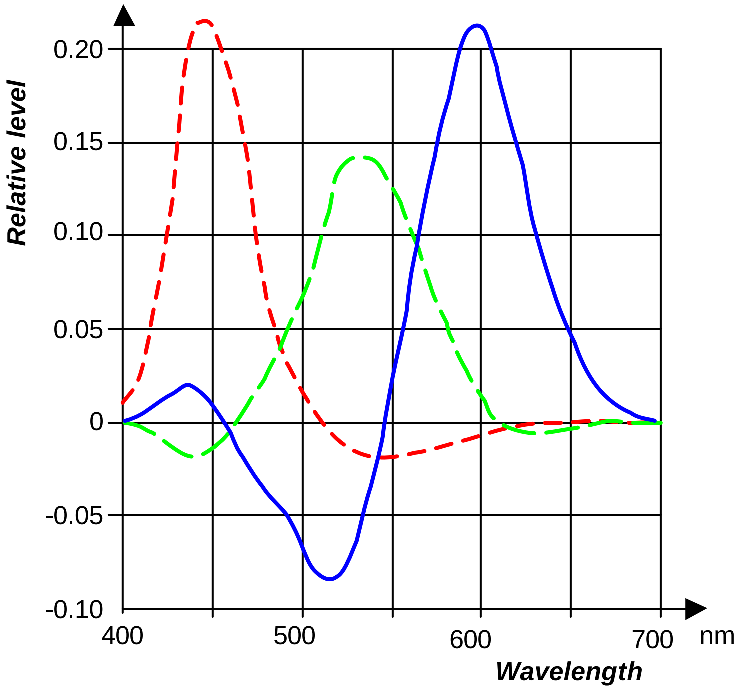

Fig.* 1 -*Colour-matching functions for phosphors conforming to the EBU recommendations.

It will be seen that the colour-matching curves for the phosphors recommended by the EBU each contain parts where the required sensitivity is negative. Thus, the ideal analysis curves cannot be realised in practice since negative light does not exist and since the physical colour analysis of a telecine can only be in terms of positive lobes of sensitivity. It is, however, a relatively simple matter to obtain the equivalent of negative lobes by means of a matrix operation upon the colour-separation signals. In telecines using the " as projected " approach this matrixing may be applied to signals that are linearly related to the light transmitted by the film; in the case of camera-tube telecines, however, the relationship may be a power law making it more difficult to obtain the desired characteristic. In telecines using the " as exposed " approach on the other hand, in order that the colour analysis in the telecine may be as accurate as possible, this matrixing of the colour separation signals is complemented by a similar operation on signals that are logarithmically related to the light transmitted by the film.

These are not the only important considerations however and the overall performance of the telecine depends also upon the signal processing which follows.

For this reason the EBU does not specify optimum curves for the trichromatic analysis at the present time and stipulates only that the colour rendering of a certain number of samples should fall within well-defined limits, in accordance with the method of measurement which is detailed in Chapter 3 (§ 5 - Colorimetric fidelity}.

1.2. Contrast handling

Colour films may carry picture information extending over a contrast range of 200 : l or more. Optical flare should be compensated or reduced to such a degree that this information remains substantially undistorted over a range of at least 100 : 1 in all picture areas greater in extent than 1 '¥o of the whole frame.

1.3. Signal-to-noise ratio

In theory, the signal-to-noise ratio of the analysis system should be measured at the output of the analysis section, but for practical reasons it may be necessary to measure it at the telecine output. Its value is dependent upon a number of factors related to the design of the telecine.

Primary sensitivity, which depends upon the type of device used to provide the electrical signals as a result of light stimulus, has a most important bearing on the final noise level.

Signal matrixing processes inevitably worsen the signal-to-noise ratio in cases where one signal is subtracted from another. The noise accompanying the two signals can only be added statistically: sophisticated signal processing therefore requires a higher initial signal-to-noise ratio than that needed in an elementary telecine.

Aperture correction and, in a flying-spot machine, afterglow correction will increase the apparent noise, which, at the output, will not be uniformly distributed throughout the grey-scale.

Details of the method of measurement of noise that may be effected on the telecine output signals will be given in Chapter 3, § 4. The principle of the method is to produce an analysis signal of such a level that, at normal settings of the gamma correctors, the input/output characteristic is unaffected; consequently, the signal-to-noise ratio measured at the output of the telecine will be equal to that at the output of the analysis section and the factors that have been mentioned above will have a minimal effect. This signal is obtained by placing a neutral-density filter in the telecine gate. Under the conditions specified in Chapter 3, with gamma-correctors set to an exponent of 0.4, for a bandwidth of 5 MHz, the matrixed luminance peak signal-to-unweighted RMS noise ratio should be greater than 100 : I, or 40 dB. This is the minimum acceptable value and it is expected that the values obtained in practice will be better than 45 dB.

Typical values for a high standard of performance are given in Appendix 1, both for the three colour channels and for the luminance channel.

1.4. Fixed pattern noise

When measured as in point 1.3, fixed pattern granularity of the scanning system (whether CCD element sensitivity variations, flying-spot tube phosphor grain or camera-tube target structure) in the matrixed luminance signal shall give an unweighted RMS noise component more than 45 dB below the peak-white signal.

In the case of a CCD telecine using a line-array sensor, compensation for element-to-element sensitivity variations should in principle be perfect; in practice, because of instrumental limitations, some errors will probably arise but these need to be very small since their effect is to produce stationary vertical stripes on the picture.

It is also common practice in certain types of flying-spot machines to carry out some signal processing, such as sequential-to-interlace scanning conversion using digital frame storage. In the case of CCD machines it is a fundamental requirement. This can also produce fixed pattern noise due to breakthrough of the digital clock and its sub-harmonics into analogue circuits. Both these forms of fixed pattern noise must be at a very low level estimated to be more than 55 dB when expressed as a peak signal-to-unweighted noise ratio. In practice this is a difficult measurement to make due to the presence of other non-f1Xed pattern noise and must be judged visually in relation to the contrast handling ability required of the telecine.

2. Video signal processing characteristics

2.1. Transfer characteristic

The transfer characteristic of a telecine is only one link in the overall transfer characteristic of the film and television chain which connects the illumination of the original scene and the luminance of the receiver screen. Its gamma will depend in particular on the power laws that characterise the receiver, on the one hand, and the film, on the other.

Television display tubes have a gamma of around 2.5, depending upon the method of modulation, and this power-law response is maintained, in the absence of significant ambient light and small-area face-plate scatter, down to very low signal levels. Most cinematograph film processes have a print-through gamma greater than unity (typically 1.6) and are designed for projection in a dark cinema. The print-through transfer characteristic of film does not have a single-valued exponent throughout the whole tone range so that the overall characteristic of the combined film-television system is rarely that of a simple power-law function.

There is no ideal curve for the overall transfer characteristic; the viewer's subjective preferences undoubtedly playa part in its determination and different types of scene may require a different optimisation. The viewing conditions of the display screen also affect this choice. Furthermore, since the average real-life outdoor scene has a contrast range which is higher than can be reproduced in domestic viewing situations, some compression of the luminance scale is often desirable. The setting of black-level at the telecine -not to mention that of the viewer's receiver -can make marked changes to the value of effective gamma in the shadow areas.

The desired transfer law for the telecine may be obtained by acting on the electrical signals produced in the machine. If the signals at the output of the analysis section are proportional to the transmission coefficients of the film being analysed, then the transfer law is defined as the relation between the amplitudes of the analysis signals and the amplitudes of the signals at the output of the telecine.

Ideally, transfer laws should be provided in which the gamma may be varied between 0.3 and 0.7, but if it is preferred to provide a single, fixed gamma curve the optimum value is probably in the region of 0.4. The non-linear amplifiers used should maintain the various transfer laws provided and specified by the manufacturer over an input-signal range of about 46 dB, with a tolerance of ± 5 % of the correct value, but the laws of the individual ROB channels must be such that for equal input the outputs are also equal, to an accuracy of I 670 at white and 0.25670 at black (approx. 10 670 output).

2.2. Definition

Loss of resolution in the final television picture may be due to the telecine, to the film or to both. Loss of resolution will, in general, be in both the horizontal and vertical directions and in the case of the film will be uniform in all directions. In a properly-adjusted flying-spot or CCD telecine the aperture losses due to the optics and the scanning should be small and should be a good deal less than those caused by 16-mm film. In the case of a camera-tube telecine the losses in the camera tubes themselves will be rather greater and are certainly not negligible compared with the film.

Horizontal aperture equalisation is a well-known technique and correction of vertical aperture losses using one-line delays is universal among television cameras. Even in a flying-spot telecine with its negligible vertical aperture losses, correction of the vertical losses in the film produces a very worthwhile improvement in picture quality.

If it is assumed that the losses are all in the film then two things follow: firstly, the correction must be easily adjustable from one film to another and, secondly, the correction should preferably take place at the same gamma as did the original loss. This means that the corrector should be in a part of the telecine channel where the signals are in logarithmic form, although experience has shown that the subjective effects are also satisfactory if the corrector is fitted after the gamma corrector. It is simpler, instrumentally, if correction is applied to the luminance component rather than separately to the red, green and blue signals. But, if a y signal is matrixed from R, G and B, one-line delays must also be included in the R- Y and B- Y paths so that the re-matrixed R, G and B maintain correct registration.

Horizontal as well as vertical aperture correction can be applied in this way. The suggested range for each of these corrections is O to 6 dB.

The spatial frequency at which the correction peak occurs is also of importance. Horizontally the normal peaking frequency is 3 MHz; this is a compromise giving a reasonable subjective impression of sharpness without incurring excessive levels of cross-colour and grain in the final picture. However, if the film has a significant response at higher frequencies a more pleasing final result can sometimes be obtained by employing a peaking frequency of 6 MHz; this will be further enhanced by the use of transmission methods that are not liable to the failings of the present PAL and SECAM systems; such as the MAC/packet family of standards recommended by the EBU for direct satellite broadcasting and cable distribution in EBU document Tech. 3258. Similar considerations apply to the choice of peaking frequency for the vertical aperture correction, where lines of both interlaced fields may be used in order to increase the spatial frequency of the peak correction. If resolution on the original film is limited, the high levels of boost needed by this " picture-Iine " aperture correction may merely enhance the visibility of film grain; however if there is a significant content at these higher spatial frequencies (as, for example, with good 35-mm print material) benefits can be obtained by the use of " picture-line " correction rather than by the use of only the lines of a single field.

It is recommended that means be provided for optionally making the correction signal level-dependent. Such a procedure, known as " coring ", allows high-contrast detail to be increased in level without at the same time enhancing the visibility of film grain in large uniform areas.

3. Essential mechanical characteristics

3.1. Film formats

The European television organizations require telecines capable of reproducing l6-mm and 35-mm films. The 35-mm format is still widely used but the 16-mm format is the predominant requirement; multigauge machines will be preferred. The Super-S format is not accepted for the international exchange of programmes but in certain organizations it is, nevertheless, used to a limited extent for special applications.

The normal television format is 4: 3, but it should be possible to reproduce wide-screen film formats. There are several ways of solving this problem.

It should be possible to make the change from normal format or " letter-box " reproduction to wide-screen format reproduction during the field-blanking interval to allow this change to be made inconspicuous at the start and finish of title sequences.

Where the television raster height is filled with the film frame, horizontal panning of the scene should be possible.

3.2. Film base

Telecines should be able to handle films on both acetate and polyester bases.

3.3. Capacity

1200 metres for 16-mm, and not less than 910 metres for 35-mm, on either base.

3.4. Splices

The telecine should be able to pass up to ten conventional splices per metre (cement, tape or thermal) without seriously affecting picture quality, steadiness, or sound quality.

3.5. Tension

The maximum tension which is admissible within a snort period of time (e.g. start or stop) should not exceed 7 N for l6-mm and 9 N for 35-mm format.

When film is left laced to the machine in the standstill mode for 24 hours the tension should not be so high as to cause in the case of two-sided tape-splicing a perforation pitch error of more than 0.5 % of picture height. For 16-mm film this can be achieved by a tension of less than 2 N.

3.6. Closed loop

There should be facilities for running a closed loop.

3.7. Film speed

The nominal running speed of the film should be 25 frames per second, with a lock to the television waveform. The lock of the traction mechanism should be such that a new film frame is always effectively first scanned by television field l or field 2. The choice as to which field should constitute the first scan of a film frame should be selectable. This requirement is essential for facilitating subsequent transfer of the output of the telecine back to film and other operations which require the relationship between the picture image and the scanned sequence to be known.

3.8. Frame count

The output of a frame count system (frame count, time, etc.) should be available.

3.9. Picture unsteadiness

Picture unsteadiness in the vertical direction should be less than 0.1 % of the picture height and in the horizontal direction should be less than 0.1 % of the picture width.

3.10. Shrinkage

The correction for film shrinkage should be automatic and the machine should be capable of operating satisfactorily with short-pitch film.

3.11. Film path and control of dirt

Film path design, and in particular the action of rollers, flanges and sprockets, should be such as to minimise the redistribution of loose particles already on the film (particularly dust particles on the edges and sprocket-hole areas of the film). It should be possible to fit cleaning or similar devices to the film path to remove dirt and conceal film scratches before the picture gate. More generally, the telecine should be designed in such a way that dust is not allowed to fall on the film.

3.12. Loading

Loading should be as simple as possible and should require the minimum of operator skill. Automatic loading systems that would enable this objective to be achieved would be welcomed. The machine should be able to handle film on spools or cores alone, in both A and B windings.

For capstan-driven telecines, it should be possible to loosen the brakes of the film reel shafts during threading of the film.

3.13. Acoustic noise

The ISO has established standards for permissible noise in working areas. The combined noise level due to a working machine should not exceed the values given by curve NR40 in ISO Recommendation R 1996 [5].

3.14. Sound reproduction

16-mm telecines must be capable of reproducing both COMMAG and COMOPT sound tracks and machines require a remote-controlled change between the two. In a multiplexed installation consisting of telecine channels combined with slide scanners the sound output, if appropriate, should be selectable from each of the sources.

Interlock with SEPMAG reproducers should be effective during start, stop, inching and forward and reverse operations, so that a separate sound track remains in synchronism with the picture on the film under all conditions, including at the end of fast winding, if provided.

3.15. Remote control

Remote control of the general operation of a telecine is considered to be an essential characteristic; it must be possible for start, stop, inch and rewind operations to be controlled remotely from the studio using the ESbus remote-control system for broadcasting production equipment [6]. Within the telecine, each of these functions should be initiated by the momentary closing of a pair of contacts.

3.16. Safety

Interlocks should safeguard the operator, the programme and the machinery. An emergency stop button should be fitted.

4. Audio signal characteristics

The sound channel of the telecine machine must conform to CCIR Recommendation 265 (Standards for the. international exchange of monochrome and colour television programmes on film) and be capable of COMOPT, COMMAG and SEPMAG operation.

The EBU draws particular attention to the desirability of making " film " sound indistinguishable from " television studio " sound, and stresses that equalization appropriate to large theatre reproduction is not suitable for television. A switchable correction for prints originally intended for large theatre reproduction should be provided.

It is current practice to replay some optical sound tracks with hlgh-frequency de-emphasis. All 35-mm telecines should provide either a 00 flat " replay characteristic or one condition of de-emphasis. The same type of facilities would be very useful also on 16-mm telecines.

In the " flat " condition, the telecine should be aligned to produce a uniform response (% 1 dB) between 50 Hz and 7 kHz for 16 mm and between 60 Hz and 8 kHz for 35 mm using the Pl6 MF and P35 MF SMPTE test films.

Replay of these films with an appropriate de-emphasis network produces the response characteristics shown in Fig. 2 which also shows the alignment tolerances. The response shown for 35-mm films has about half the attenuation at high frequencies of the original " Academy " characteristic, and has been judged to be a better compromise between noise and high-frequency response.

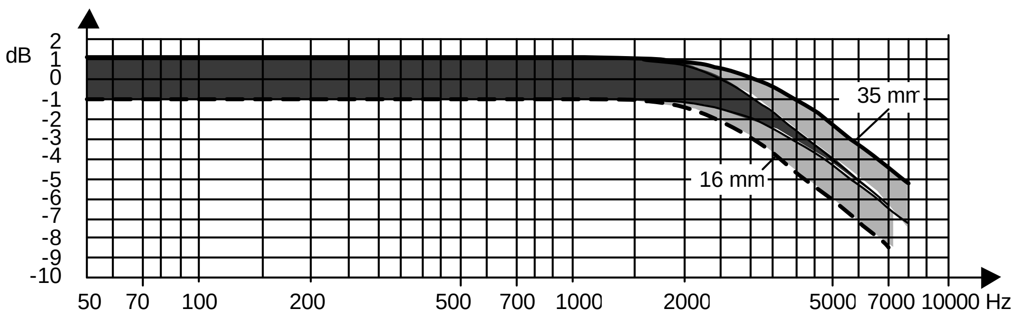

Fig. 2. - Optical sound reproduction characteristic

It will be seen in Fig. 2 that no modification to the response is made at low frequencies. It is generally found that this produces a satisfactory balance between high-frequency and low-frequency response.

A survey of day-to-day practice has shown that the majority of films can be replayed with the fixed de-emphasis shown in Fig. 2. However, for very old or damaged sound tracks, further correction may be applied with variable external correction units which have a range of low-pass, band-pass and notch filters which are adjusted subjectively for optimum sound reproduction.

The dimensions and locations of the sound records normally comply with ISO standards, but it must be kept in mind that the physical dimensions of the film material may change due to ageing and improper climatic conditions during storage thus influencing the quality of the recorded sound.

Chapter 2
Optional facilities

Chapter 1 describes those characteristics of a television film-scanner that might be considered to be the minimum requirements for a modern machine. Many telecines also offer a series of options that allow the broadcasting organization to improve picture quality, to increase the versatility of their film making or to improve the efficiency of their telecine operations. The EBU hopes that these possibilities will be retained, or even extended, but emphasises nevertheless, that it is not essential that all the telecines offered on the market should be equipped with these options. The necessity for them will depend on the operational conditions within the organization concerned. It is considered, however, that they constitute means of obtaining the optimum use of film in television.

1. Correction of exposure and colour errors

Films are normally a compilation of scenes shot on different occasions under different conditions of lighting. These scenes are then edited together to make the final film. It is the function of the grader in the printing laboratory to adjust the printer light to compensate for the differences from scene to scene but there are many occasions when perfect correction is not achieved. This may be, in the case of television films, because of the speed with which the final print is required or, in the case of cinema films, because of an ageing process which has affected some parts of the film more than others. Television viewing is, in any case, more critical than viewing in the cinema and the film as seen by the television viewer can contain unacceptable variations of density and colour.

When the picture content of the film has been converted by the telecine into electrical signals it is possible to manipulate those signals in a way which will compensate for the errors. The term " electrical grading' , is sometimes used to describe all the corrections of colour and density that are introduced by modifying the telecine signals for the various sequences in a programme. Thus, a variation of gain of all three colour channels simultaneously will reduce the effect of variations of exposure, while differential alteration of one channel with respect to the other two will correct for an overall colour cast [7] . Unfortunately, this approach is an oversimplification and a closer examination of the problem reveals that the causes of error are much more complicated than simple changes of exposure. Variation of film stock and processing must also be taken into account and the problems are compounded by duplication and printing processes.

In fact, the problem appears to be insoluble as one non-linear relationship (characteristic curve of the original fIlm) has already been superimposed on another non-linear relationship (characteristic curve of the print). If, however, it is wished to achieved results as close to perfection as possible, experience has shown that it is necessary to provide three variables per channel so as to be able to modify, independently of each other, the picture whites, the mid-greys (regions of interest such as faces) and the blacks.

The provisions for adjusting these variables generally take the form of colour-gain controls (before gamma) for the whites, colour-gamma controls for the grey-levels and colour black-level controls for the picture blacks. The manipulation of nine controls by the operator, who must also adjust the master variables for the three channels, is often considered too difficult to constitute a systematic method of operation. Some organizations therefore turn to the idea of a less-complex grading in which three of the nine variables above are omitted and for which two possibilities can be distinguished :

- we can proceed as in the case of original film material and not concern ourselves with the picture-blacks. In fact, we can accept, given the shape of the characteristic curves, that the contrast-correction applied to the picture grey-levels will improve the blacks and that the residual colour casts will, in most cases, be negligible;
- we can limit ourselves to correcting the picture-whites and blacks, but, in this case, the action on an individual colour black-level automatically results in an overall variation in the input/output response and, hence, a distortion of the grey-levels in the picture.

In the second possibility the necessary corrections can easily be separately identified and the operator is accordingly provided with controls which affect the lighter areas of the picture without affecting the darker ones (master gain and individual control of red, green and blue gains) and controls which operate on the darker areas without affecting the lighter tones (master and individual black-level control or gain-compensated lift). Although the latter procedure is in theory less satisfactory than the former, since it does not take the most interesting parts of the picture into consideration, that is to say the grey-levels, it must be admitted that, in most cases, it gives satisfactory results.

In the case of original films, the telecine must deal with a succession of ungraded shots; it must therefore provide means of correction giving an end-result at least as good as that given by a good photographic grading.

In the case where the telecine uses input/output response-curves with a constant gamma, the ability to vary the gamma of this response results in an artificial change in the contrast of the film. being transmitted, that is to say, the slope of its characteristic curve in the average, virtually straight-line, region in the neighbourhood of its point of inflection. As it is also possible to adjust the amplitude of the analysis signals to correct the densities of the three layers of the film, it is possible in theory to introduce perfect correction over a whole range of densities including, in general, the interesting portions of the picture to be graded.

It is obvious that, like photographic grading, electronic grading has its limits and can only be effective when applied to normally-exposed and normally-developed films. If the major portion of the information which they contain lies either in the toe or the shoulder of the characteristic curve of the film, they cannot be correctly graded and it does not even seem desirable that they should be, since this grading would, to an unacceptable degree, emphasise defects due to the image structure, including in particular , grain and loss of definition.

In general, the specification of grading parameters and the method of control do not fall within the scope of this document, since they depend directly on the construction of the telecine. The control may be direct manual, automatic or pre-programmed. In most cases it will operate on the ROB signals but in certain machines the adjustment of colour takes place on the coded signal.

It is worth making one observation, however. The gamma-correction circuits in a telecine have a limited range, both in the sense of the range over which they provide the correct theoretical gamma and also of the range over which they maintain full bandwidth. An unusually dense film may therefore expect to suffer in two ways; firstly the amount of black stretch applied to its darkest areas may be inadequate and, secondly, the resolution will be limited by the restricted frequency response of the high-gain portion of the gamma amplifier characteristic. For both these reasons, it is desirable that the gain control should take place before the gamma amplifier to make sure that the signal excursion falls within the optimum range of the amplifier.

It is thought that, whatever the system of grading adopted, the following specifications should be applied:

a) provision should be made for differential variation of the amplitude of the analysis signals by about 12 dB (this represents a density shift of about 0.60 or ~~ printer lights);
b) it should be possible to provide for differential variations of about :i: 20% in the gamma value of the signal processing.

2. Electronic masking

Neither the spectral sensitivity' curves nor the dye-absorption curves of colour film stocks are ideal; as a consequence, unwanted cross-talk between the three tristimulus signals is introduced by the film and this causes a loss of saturation in the final television signals and some hue errors.

This defect may be corrected by an electronic process analogous to film dye masking so that the appropriate amount of negative cross-coupling is introduced between the red, green and blue channels to cancel out the unwanted components. For those colour errors that are logarithmically proportional to the intensity of light, the correction should preferably take: place at a point in the channel where the electrical signal is logarithmically related to the light transmitted through the film.

Although the telecine channel is complicated by the need for logarithmic and subsequent anti-logarithmic or exponential amplification, a gamma law can be conveniently introduced at this point by suitable attenuation of the signal between the log and anti-log amplifiers. Electronic masking can also be used to correct for errors due to the non-ideal spectral analysis curves of the telecine.

The masking matrix will vary from one film stock to another and it is advisable to have a selection of masking characteristics available on a switch. Precise values will, in any case, be dependent on the analysis characteristics of the telecine.

3. Operation with negative film

Although the normal practice is to use positive films, either prints or reversal films, there are advantages to be gained from using a negative [8] .The economic arguments are outside the scope of this document and will be largely determined by the particular circumstances of a broadcaster's film operations. The arguments in terms of picture quality will also not be discussed in detail, since much depends upon the film stocks that are available and the conditions under which the film is exposed. What is of more immediate concern is the way in which the requirement to use negative film affects the telecine itself.

The most obvious way in which the telecine channel must be altered is concerned with the transfer characteristic. As with positive films, the input/output characteristic may be related to the traditional concept of gamma but this necessarily involves the manipulation of negative gammas and thus of power functions, the extremities of which are at infinity. This leads to difficulties in both picture whites and picture blacks. Extreme care must be taken in the design in order to provide a gain of about 20 dB at a level corresponding to white-level in the scene (small analysis signals) and a gain of about -20 dB at a level corresponding to 1 % of white-level (large analysis signals).

The required transfer law may most easily be obtained by the use of logarithmic amplification, inversion and anti-logarithmic or exponential amplification. The required gamma correction is achieved by suitable attenuation of the signals before exponential amplification, this point also being the correct place for introducing electronic masking.

A typical negative film stock has a transfer characteristic which allows the recording of a scene brightness contrast of more than 100:1 without departing from a constant gamma. Although the scene may not have such a wide range in practice, variations in exposure can result in film densities covering this span and the telecine channel must be able to apply the same value of gamma over the whole of the range if distortion is not to occur. If no control of signal amplitude is included before logarithmic amplification, the amplifiers must also be able to handle this wide range without error (the effects of the orange mask may be compensated by altering the colour of the light in a photoconductive or CCD telecine or by altering the photo-multiplier gains in a flying-spot machine). In practice, the channel gain may most conveniently be altered to compensate for exposure changes by adding a DC " lift " to the signal after the logarithmic amplifier, this being equivalent to multiplication of a linear signal. Control of the signal in this way has the added advantage of limiting the excursion of the signal in the exponential amplifier.

In practice, it has been found that for negative film it is necessary to provide both master and differential control of gain as well as master and differential control of black-level. The range of control that is required is comparable with that necessary for positive films. Since no grading can be applied to the negative, the changes of the controls from scene to scene which are required can be very large and some form of pre-programming is virtually essential if satisfactory pictures are to be obtained.

4. Pre-programming

The pre-programming of telecine controls means the storing of control settings arrived at during rehearsal and the subsequent automatic reproduction of these: settings during transmission. The most frequent use of this technique is for the storage of the corrections for exposure and colour errors so that, on transmission, the corrections may be applied at the same: instant that the error occurs [9] .Changes of the control settings shall occur during the vertical-blanking immediately preceding the first picture concerned. In this case the information stored must be the setting of the control, together with the film frame-number at which the change occurs, usually coincident 'with a shot change. While such a system is virtually essential for negative film, pre-programming of the controls for prints can provide better reproduction as well as reducing the number of prints which may be required before an acceptable result can be achieved.

Pre-programming may also be applied to other processes 'where a human operator can only produce acceptable results with the greatest difficulty. one example of this being the presentation of films with wide screen formats by the method of filling the height of the screen and panning the picture to follow the significant action. Another example is the synchronization of sub-titles from a caption generator with foreign-language films.

Provision for an instantaneous overriding of the pre-programming system should be provided.

5. Other desirable characteristics

5.1. Speeds other than nominal speed

The possibility of running the film at speeds other than 25 frames/second is desirable.

Films produced for the cinema are shot at 24 frames/second and it is also useful to be able to transmit old film shot at slower speeds. When running film at speeds other than 25 frames/second, however, it is possible to generate judder on moving objects; this judder has a frequency equal to the beat frequency between the television field-frequency, 50 Hz, and the nearest harmonic of the film frame rate. It can be attenuated to acceptable levels by incorporating a degree of movement interpolation or lap-dissolve, either optically in the telecine analysis system, or electronically using additional field storage.

Slow motion is also desirable. From the point of view of operational convenience, it would be advantageous to be able to run the film backwards and forwards at high speed, say up to ten times normal, preferably with a recognisable picture even if it is not suitable for transmission.

5.2. Run-up time

Stable reproduction of both picture and sound should be achieved without damage to the film in less than 1 second; ideally it should be effectively instantaneous.

5.3. Stop marks

For the rehearsal of film inserts it is advantageous if means can be used which will cause the machine to stop and, if required, rewind back to the start of the section.

5.4. Still frame

It is desirable that the telecine should be capable of showing a still frame, if possible without deformation. Frame-by-frame forward and reverse movement is also desirable.

5.5. Picture framing

It should be possible to control picture framing remotely as well as locally.

5.6. Optical focusing

It should be possible to adjust the optical focus both locally and remotely, together with changeover from one emulsion position to the othelr .

5.7. Horizontal panning movemer1lt

When a wide-screen format is being shown by filling the television raster with the full height of the film frame, it is desirable to be able to pre-program the required horizontal panning movement.

5.8. Film breakage

Breakages occurring after the film gate should not cause the machine to stop but should trigger an alarm. This paragraph only applies to machines using sprocket drive; it obviously cannot be applied to capstan-drive machines with servo-controlled feed and take-up spools.

5.9. Magazines

Where the film can be handled in magazines, these should be designed so as to accept the standard film centres.

5.10. Changeover time in multiplex systems

Where projectors are multiplexed, the changeover time between projector outputs should be such as to make it possible to perform .an on-air optical wipe or mix between any two sources. Spurious movement should cease within 60 milliseconds.

5.11. Automatic operation

It is desirable that the machine should be able to operate in an automatic mode, with cue location and search facilities.

5.12. A/B roll operation

The capability of operating t1NO telecines in A/B configuration is desirable.

5.13. Checking the sound channel

It is desirable to be able to check the sound channel of the telecine by aid of a suitable sound signal inserted before the pre-amplifier.

5.14. Audio facilities

It is desirable to be able to replay in stereo a 35-mm COMOPT Dolby A stereo sound track, and to have a high quality mono mix of the Dolby output available.

5.15. Time code

Provision should be. made to read a time code on the film as will be specified later.

Chapter 3
Methods of measurement

Measurements may be made on telecine channels for a variety of different reasons, but principally either to establish that a particular machine meets a given specification or to make sure that the telecine is working as well as it should from day to day. For the latter purpose, it is often sufficient to use a test-waveform which may be peculiar to a given channel because the object is to measure the small changes which occur from day to day so that they may be corrected. In the former case, the overall performance of the machine must be measured and there is usually no substitute for using calibrated film material to generate the necessary signals. It is with this type of meas11rement that this section is concerned.

1. Luminance transfer characteristic

In practice, the effective transfer characteristic of a telecine is generally expressed by the relation that exists between the densities of a grey-scale film and the corresponding levels of output signal from the telecine.

This overall measurement has the disadvantage that it combines the two fundamental characteristics of a telecine, these being :

- its trichromatic analysis curves;
- its electrical transfer characteristics.

In fact, to be .completely comprehensive, two types of measurement must be carried out; the first to determine how the telecine translates optical film densities into analysis signals, and the second to determine how the telecine transforms these analysis signals into output signals.

To determine how the telecine responds to optical densities, it is necessary to have a test film containing uniform grey levels and produced on the type of emulsion to be transmitted. The film used for this measurement should preferably be made up of whole frames of a given density so as to avoid difficulties due to shading, flare, etc. These grey levels are characterised by their blue, green and red densities measured under standard conditions by means of a densitometer. The telecine may be considered to be a densitometer, the response of which is to be evaluated in relation to the reference densitometer , since it also measures, in its own way, the blue, green and red densities of the various grey levels. If the analysis signals are measured, these are, in general, representative of the transmission coefficients of the film and if the telecine employs a logarithmic amplifier for the analysis signals it is possible, in effect, to measure signals at the output that represent the densities of the various levels.

To measure the transfer characteristic considered as an electrical parameter, it would seem to be preferable to use measurement signals derived from a test-signal generator and used in place of the above-mentioned analysis signals. This may be considered as the measurement of the amplitude/amplitude characteristic of an electrical four-terminal network and for this it is possible, as a measurement signal, to use a white line at the usual nominal level (700 mV for example) which may be attenuated by means of a calibrated attenuator. If the attenuation A_s of the output signal is measured in decibels with respect to the nominal value for an attenuation A_a of the analysis signal, the curves $As = f(A_a)$ corresponding to the various possible adjustments of the telecine may be drawn. In the particular case where the gamma is adjusted to be constant, this would obviously give $A_s = A_a$ over a certain range of contrast. If it is considered that the adjustment should give " variable gamma " curves, it is still possible to define the equivalent " gamma" at a given input level by the ratio A_s/A_a.

Although this appears to be the optimum procedure for the more-modern telecines in which there is access to intermediate signals at the output of the logarithmic amplifier, it must be recognised that it cannot be applied to other machines. For these, it is necessary to measure the overall transfer characteristic and this may be determined by drawing a graph of the logarithm of the output voltage from the telecine channel against the film density. If the non-linear correctors of the telecine under consideration are true gamma correctors, this characteristic will, in theory , be a straight line when drawn on a logarithmic graph. The slope of this straight line represents the gamma of the pre-distortion which is introduced mainly to compensate for the non-linearity of the transfer characteristic of the picture tube but which may also include a factor intended to take account of the differences between the optimum characteristics for direct projection and for television reproduction.

The practical problems which arise in this measurement are, in the main, caused by the contrast range that must be taken into account. In normal operation the gamma would probably be of the order of 0.4 and, consequently, it is necessary to introduce very considerable gain in the region of the black-level if this value is to be maintained over the whole operating range of the telecine. There is, however, a limit to the amount of gain that can be used in practice and even if only those values that would normally be met are considered, the errors of measurement that are likely to occur in the region of black-level are often very large, due to the considerable amplification of small interfering signals.

The channel gain should be adjusted to give 100 % output when a film of minimum density is placed in the gate; a minimum density of 0.35 would be suitable for this measurement. The telecine channel should not be adjusted so that zero illumination (that is to say, in the absence of scanning or with the projector lamp extinguished) gives zero output from the channel. On the contrary, the channel should be adjusted so as to give a 10 % output signal for a film density of 2.05, this corresponding to a contrast range of 50:1.

The black level should therefore be adjusted at a density of 2.05, although the transfer characteristic should be measured over the whole range of contrast normally encountered, that is to say, to a density of at least 2.35. In practice, a grey scale containing a number of density steps is used for the measurement of the transfer characteristic and, if it is impossible to measure the analysis signals in isolation, the telecine is adjusted so that this grey scale gives :

- an output voltage of 10 OJo for a density of 2.05;
- an output voltage of 100 OJo for a density of 0.35,

2. Horizontal definition

It was seen in Chapter 1 that loss of definition of the television picture may be caused by the film or by the telecine. So as to isolate the losses due to the telecine, a calibrated test-film should be used, particular care being taken to ensure that the latter is of such a form that the results are not affected by shading. The gamma of the channel should be set to unity so that the measurement conditions are identical to those under which the film was calibrated, and the aperture correction should be set to zero.

The film should contain several cycles at a number of different frequencies in the range of 0.5 to 5 MHz.

3. Flare

Black-level variations which depend on the mean picture content can be caused by optical flare as well as by faulty circuitry (clamp errors, defective or maladjusted flare compensators). As this effect impairs the rendering of both tone and colour, it should be minimised in any picture area of significant size. Whereas black-level errors caused by the circuitry are usually measured with test signals fed into the preamplifiers, special test-charts are required for the determination of the optical flare performance.

For the measurement of the DC portion of optical flare, which causes a uniform veiling in the picture, the use of a test-chart with a black (D > 3) rectangular patch on a white (D = 0.35) background is recommended. The area of the black patch should be 50 % of the total picture area (Fig. 3).

In order to measure only that part of the flare that can be compensated electronically, this total picture area should correspond to the area transmitted by the telecine, as standardized by the ISO (R 1223, see Appendix 2) *. The surround of the white background should be black.

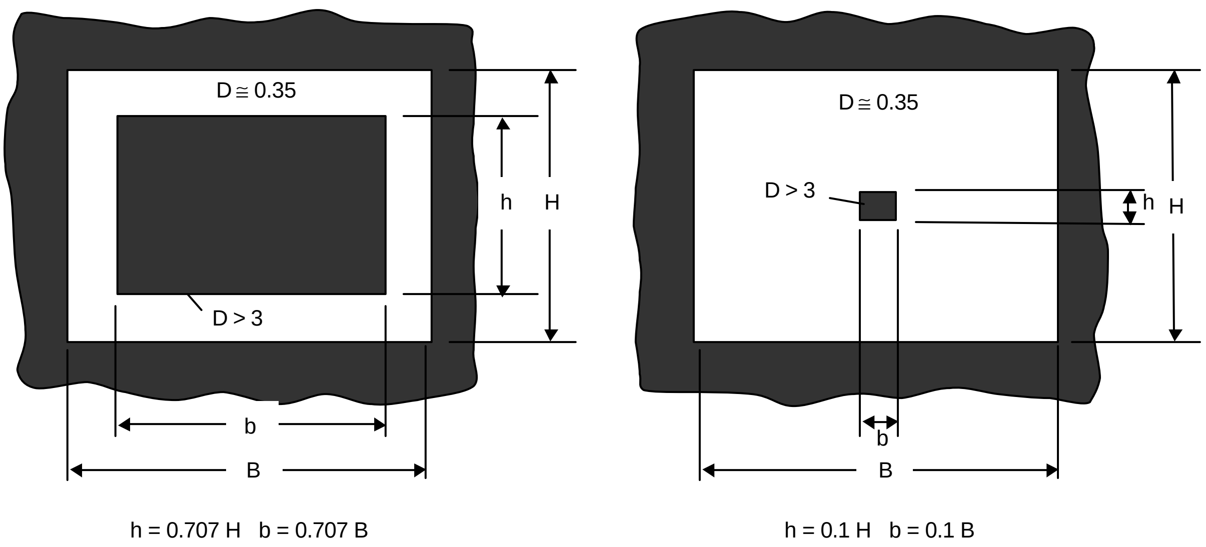

Fig. 3. -Test-chart for the measurement of the DC flare component
Fig. 4. -Test-chart for the measurement of the AC flare component

In order to take account of the effect of the content of adjacent frames, and so as to be able to apply the method to telecines that do not offer a still-frame facility, it is suggested that a series of identical test frames recorded on a loop of film be used.

* In certain types of telecines with a picture gate larger than the scanned area, additional flare may be caused if the area corresponding to the difference between the exposed and the transmitted areas is transparent. This defect can be assessed by using a similar test-chart, but this time with the total test-picture area corresponding to the area usually exposed by film camera aperture [10].

Before beginning the measurements in all channels, the raster size, focus, afterglow correction (for flying-spot telecines) and uniformity of white level, must be adjusted with care and all optical surfaces must be cleaned. The black-level should be measured at unity, gamma at the centre of the opaque area with an oscilloscope in the line-strobe mode or with a suitable video-level meter. In order to avoid clipping or crushing, the lift should be set to 5 % with the gate closed. Any black-level correctors must not be in operation during the measurements.

Before processing the results, the measured black-level must be corrected to allow for the 5 % lift and for possible clamp errors. As the relationship between the average picture level (APL) and the amount of the black-level variation (ΔBL) due to DC flare has been found to be linear up to an APL of about 60 %, the slope of this straight-line portion can be regarded as being typical of the DC flare performance of a telecine. On this basis, we may define the DC flare factor (ff_{DC}) as being :

$$ff_{DC} = \frac{\Delta BL}{APL}$$

where ΔBL and APL are expressed as percentages.

For the test-chart of Fig. 3,

$$ff_{DC} = \frac{\Delta BL_{50\%}}{APL}$$

To determine AC or edge-flare, the main effect of which is to brighten transitions from a white area to a black area, it is recommended that a test-chart (as shown in Fig. 4) with an APL of 99 % be used. The measurement shall be carried out in a similar way to that of the DC flare and in all channels. As indicated by the non-linear portion of the curve in Fig. 5, the additional AC flare component (f_{AC}) can be specified with good approximation as :

$$f_{AC} = \Delta BL_{99\%} - 2\Delta BL_{50\%}$$

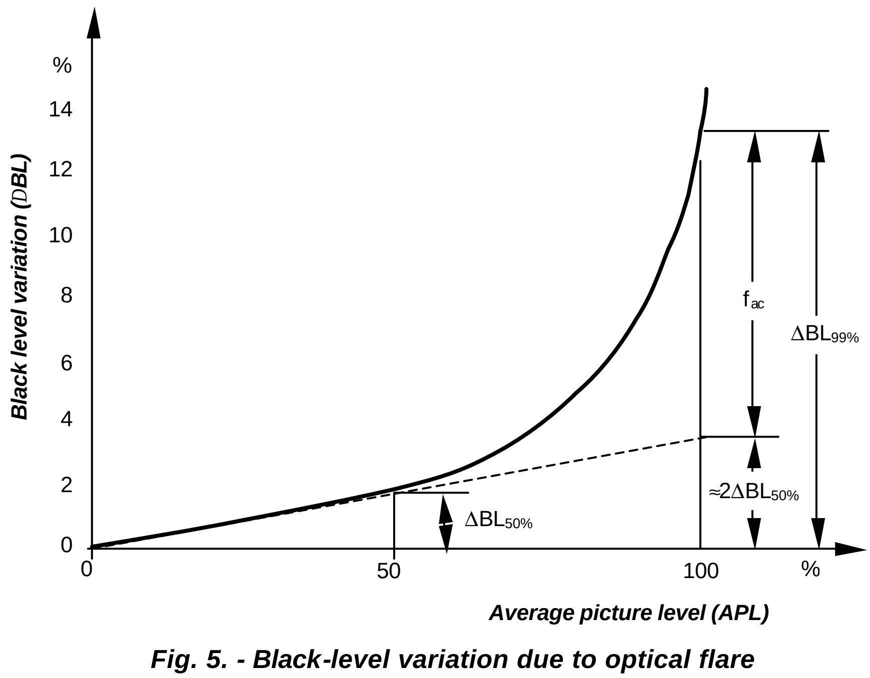

Fig. 5. - Black-level variation due to optical flare

4. Signal-to-noise ratio

Noise in a telecine depends on numerous factors and, in particular, on variable factors such as the gamma correction or the arrangements for matrixing the signals. The minimum noise level of which a telecine is capable is set by the operating characteristics of the analysis section and it is this value that should be determined with the best accuracy.

Gamma correction should therefore be switched off when measuring signal-to-noise ratios, but if this is not possible, another technique can be used.

If m is the slope of the input/output characteristic, the signal-to-noise ratio of the analysis signals (corrected for the effects of aperture and streaking) is obtained from the signal-to-noise ratio measured at the output of the telecine by the relation :

$$S / N_{analysis} = S / N_{output} + 20 \lg m$$

In order to eliminate the lg m term, a point on the curve must be chosen at which the slope is unity and if, for example, the value of gamma is 0.4, the measurement can be made on an open-gate signal which has been attenuated by placing a neutral filter of density 0.66 in the gate. Even in those cases where the linear condition can be obtained, the signal-to-noise ratio should still be measured with a neutral density filter of 0.66 in the gate.

In practice, a neutral filter of density equal to 1 is used and this implies that the nominal level of the analysis signal corresponds to the analysis of a density equal to 0.35.

The measurement procedure thus consists of:

1) adjusting the gamma to 0.4;
2) adjusting the gain of the channel to give 100 % output with a filter of density 0.35;
3) placing a grainless neutral filter of density 1.0 in the gate;
4) measuring the signal-to-noise ratio (peak-to-peak/RMS) in the red, green and blue channels.

The value of this ratio for the luminance signal is then obtained by calculation.

Unweighted values are generally given, although it might be useful also to give values weighted according to the CCIR formula (see CCIR Recommendation 567, Part C, Annex II).

It is obvious that the signal-to-noise ratio will be considerably affected by the frequency response of the channel. In theory, the measurements should be made with the channel response correctors adjusted to compensate for losses in the telecine only. In some cases this may not be possible and due allowances must be made when assessing any measurement made when this condition is not fulfilled.

5. Colorimetric fidelity

5.1. Criteria for a standardized test procedure

To be of practical value, a standardized test procedure for the examination of the colour-reproduction properties of telecines should enable both simple and comparable measurements to be made by different broadcasting organizations. Furthermore, if it is to be meaningful, the recommended evaluation method should provide results which correlate well with the subjective impression of the difference observed when appraising film pictures in optical projection on the one hand and on a colour monitor, after having been transmitted by the telecine under test, on the other .

The way in which the evaluation of the colorimetric performance of a telecine is carried out depends to some extent upon the philosophy underlying the design and use of the telecine. One can either take the view that the film-scanner should enable high fidelity to be achieved with respect to the original scene or, alternatively, that it should reproduce faithfully the image which exists upon the film as seen under standard review-room conditions [2, 11]. These are known as the ..as exposed " and ..as projected " approaches, respectively. The first philosophy arises when it is important for the telecine to produce a quality image which can be intercut with pictures from a television camera. In order to obtain representative results for this use of a telecine, the assessment must take account of the performance of both the film and the telecine. The second approach, which is still more widely used by broadcasters, aims to give a good rendering of any film. In this case, only the colorimetric performance of the telecine in isolation need be assessed. For the evaluation of a telecine in its function of reproducing the projected picture, the "colorimetric colour reproduction" criterion [12] is both valid and useful (a perfect "colorimetric colour reproduction" is achieved when the tristimulus values of the reproduced and the object colours are in proportion).

The EBU recognises that at present the Member Organizations use their film-scanners in these different ways and that, as a result, it is not easy to specify a unique colorimetry test and evaluation procedure for both applications. Nevertheless, whilst an assessment of the colorimetric performance of the complete "film plus telecine" system is really only of internal interest to each organization, an exact knowledge of the performance of the telecine as a device for the reproduction of films made outside the control of the broadcasting organization is of general interest. This is the case, for example, in the exchange of programmes on film and the following recommendation for the evaluation of the colorimetric characteristics has therefore been restricted to this latter application of a telecine.

5.2. General principles of the applied colour-rendering concept

The following sections describe a measurement and evaluation procedure which is an extension of a colour-shift method that was originally recommended by the CIE for the determination of the colour rendering properties of light sources [13] and that was subsequently standardized by the Deutsche Industrie-Norm (DIN) for specifying colour reproduction in the field of colour photography, printing and television [14]. This procedure is based upon a test colour method in which the perception of the reproduced colours is compared with the perception of the original colours, both being viewed under identical reference illuminants. The resultant colour difference *DE* between object and reproduced colours for any of a number of suitably-selected colour samples is determined in an approximately uniform colour space. The colorimetric deviation can be illustrated graphically in the 1976 CIE chromaticity diagram. From the actual colour difference for each test sample a number of " mean " differences can be determined for different sets of test colours.

5.3. Nature of the test-colours

In order to measure the colour-rendering properties of light sources, the CIE has standardized 14 reflective test-colour samples, which constitute a selection of practical colours. These colours can be used for telecine assessment together with six other more-saturated colours also based, like the original CIE set, on Munsell colours (these six additional colours aim at extending the range of test colours to cover as far as possible the whole gamut of colours met with in prac1tice). At this stage, it may also be noted that CIE colour 12 is outside the gamut covered by the EBU phosphors and so is excluded from further consideration. Fig. 6 shows the complete set of colours (in relation to the EBU phosphor gamut) in the 1976 CIE-UCS diagram and Table 1 shows the correspondence between the numbering of these colours in the set and their Munsell notation.

Tableau 1- Munsell notations of the test colours for telecines

Colour number	Munsel/ notation			Colour number	Munse1l notation		
EBU/TC 1	7.5	R	6/4	EBU/TC 11	4.5	G	5/8
EBU/TC 2	5	Y	6/4	EBU/TC 12*	3	PB	3/11
EBU/TC 3	5	GY	6/8	EBU/TC 13	5	YR	8/4
EBU/TC 4	2.5	G	6/6	EBU/TC 14	5	GY	4/4
EBU/TC 5	10	BG	6/4	EBUITC 21	5	R	5/10
EBU/TC 6	5	PB	6/8	EBU/'TC 22	5	YR	7/10
EBU/TC 7	2.5	P	6/8	EBU/TC 23	10	GY	6/10
EBU/TC 8	10	P	6/8	EBU/TC 24	2.5	B	5/6
EBU/TC 9	4.5	R	4/13	EBU/TC 25	7.5	PB	3/10
EBU/TC 10	5	Y	8/10	EBU/TC 26	7.5	P	4/10

* Not used in the calculation of colour rendering indices.

For the operational assessment of telecines, however, the test colours are in the form of transmission filters. They are supplied in the form of sets of calibrated test-filter samples.

Under illuminant D_{65} these filters {Nos. 1 to 14) give a good metameric match to the corresponding CIE test-colours, reduced in luminance factor by 45/60 = 0.75. This lightness reduction takes into account that for colour films intended for colour television the resultant density corresponding to a fully-lit object in the scene having a reflectance of 60 % should be D = 0.35 (or T = 45 %). Unlike the CIE test-colours, however, the filter samples are composed of three basic colour dyes, the spectral characteristics of which are closely related to the spectral absorptions of actual dyes used in colour film emulsions. In this way it is intended to imitate the effects of the selectivity of those film materials that are currently used in television. In contrast to real film dyes, however, the filter samples have a high degree of stability as regards fading. (Filters 21 to 26 would similarly be metameric: matches to the Munsell colours shown in Table 1.)

To permit a neutral pre-alignment of the telecine and to enable an assessment of its grey-scale rendering, a set of 5 neutral filters is also available (Nos. 15 to 19), which use the same basic colour dyes as the colour filter samples.

At present, a complete set of calibrated test-filter samples thus contains 24 filters. For each filter the spectral transmission factors and the colorimetric values under i1luminant D6s are indicated.

To avoid confusion, the type of test-filter set that has been used should in any case be indicated in the report of the measurement results.

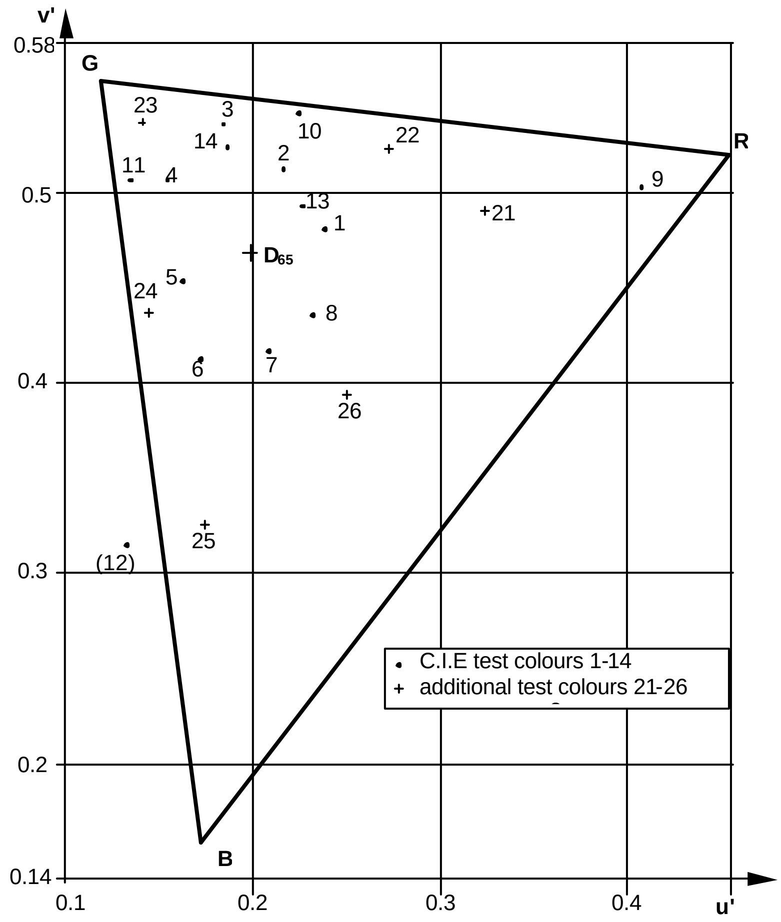

Fig. 6. - Position of the EBU test colours in the 1976 CIE. UCS diagram

5.4. Methods of measurement

At first sight, it seems obvious that the practical assessment of the colorimetric performance of a telecine should be applied to the complete transmission chain, from the test pattern in the picture gate through to its reproduction on the television screen. However, as it is difficult to make sufficiently-accurate colorimetric measurements on the screen, it is advisable to make measurements at the output of the film-scanner and then to continue the evaluation by calculation. It is recommended that an ideal transmission and reproduction chain be assumed in this theoretical processing of the output signals since, although some associated effects such as the actual adjustment of the transfer characteristics of both the telecine and the monitor, the neutral balance of the monitor screen etc. may be partly neglected in this assumption, the most substantial variations found in telecines of different design are, nevertheless, taken into account. These arise particularly in that part of the opto-electric conversion chain which is characterised by the spectral-analysis functions.

For the measurement of the telecine outputs the preferred method is to use a video analyser employing a "sample-and-hold" method which integrates over a number of short periods on successive lines. Neutral pre-alignments and all the measurements should be carried out in turn at the same sampling area in the centre. A standard maintenance oscilloscope can be used if this special equipment is not available. To minimise the influence of noise, shading, etc., a line strobe, a roll-off or 1-MHz low-pass filter and a small test area (5 µs duration at the centre of the field) should be used when reading the waveforms. In order to obtain representative results, the colour-separation signals should be read to an accuracy of at least 1 % of peak white.

5.5. Measurement procedure

Before beginning the measurements, the standard line-up procedure of the telecine in the " as projected " mode must be carried out with care. As such a standardized specification for the basic alignment of telecines does not yet exist within the EBU Member Organizations, the evaluation of the colorimetric characteristic of a telecine should be carried out with the machine in its usual operating condition at the broadcasting organization concerned. To enable the results to be compared, however, this basic alignment should be described in detail in the report. Likewise, the point at which the output signals have been measured should be indicated (e.g. after the preamplifiers, after masking, matrixing, gamma-correction or before encoding). The pre-alignment and the measurements should be made with the utmost possible precision.

The test-colour filters should fill the gate area of the film-scanner and the measurements should be carried out in the following way:

1. Linear signal processing should be selected *.
2. With the gate closed (light obscured), the lift should be set to 5 % in all channels, so as to avoid clipping or crushing.
3. With neutral density filter No.15 inserted in the gate, the gain for peak output should be set in all channels to 60 + 5 = 65 % of peak white.
4. The coloured and neutral test-filter samples (Nos. 1 to 18, excluding No.12, together with Nos. 21 to 26) are then successively inserted in the gate and all channel outputs are measured for each sample.

5.6. Correction of measured telecine outputs

Before determining the colorimetric errors, the measured (Y), R, G, B, channel outputs for each test-filter sample must be corrected theoretically to allow for :

1. Measurements with non-unity gamma (where applicable)*.
2. The 5 % lift, so that zero light input is made to correspond to zero signal output.
3. The deviations caused by setting the actual peak outputs which neutral-density filter No.15 to 60 + 5 = 65 % instead of the actual transmission factor of this filter (normalization of the output signals).
4. The difference in the grey-level output in each channel as actually measured with neutral-density filter No.18. These differences, which are caused by the interaction between the non-achromatic absorption of the neutral-density filter (as also occurs with neutral film) and the non-ideal spectral-response curves of the telecine, can be corrected by subsequently equalizing the grey-level outputs of the red and the blue channels to that of the green channel. As the basic alignment of item 3 in point 5.5 has to be taken into account, this can only be achieved by altering the gamma setting. This correction of the telecine outputs mayor may not be necessary, depending on the neutral pre-alignment procedure of the telecine under test in usual operation, either with real colour film materials or with non-selective test-patterns. It should be indicated in the report whether this grey-scale correction was carried out or not.
5. In the case of measurements on a 4-channel telecine, the R, G, B signals must be derived from the Y, R, G, B outputs by calculation, assuming standard matrixing coefficients in the coder and the decoder.

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* If it is impossible to find a unity-gamma output point at which to monitor, the actual light-to-electrical signal transfer characteristic for each channel should be determined and plotted, so that the corresponding linear signal values can be derived by inspection of the curve.
In cases where the effects of the actual shape of the transfer characteristics on the colorimetric performance are of particular interest, or where masking or matrixing is employed after gamma-correction, the output signals can be measured immediately before encoding and converted theoretically to linear values, assuming a true power law of 2.5 for the gamma of the reference picture tube. In any case, however, this procedure should be described in the report.

The formulae for the correction of the measured telecine outputs are as follows:

Correction for the inserted lift and normalization of the output signals

The value of the signal in the red channel to be used in the calculations is related to the measured values as follows :

$$R_{no} = \frac{R_M - L}{65 - L} \bullet Y_{015}$$

where: R_{no} = $R_{nonnalised}$ in %
Rm = $R_{measured}$ in %
L = 5 % = inserted lift in %
Y_{015} = transmission factor of neutral-density filter No. 15, in %.

Similar' equations apply to the green and blue channels.

Differences in grey-level outputs

The value of the signal in the red channel to be used in the calculations relating to neutral density filters is given by:

$$R_{greycorrected} = a_R \bullet R^{gR}$$

R = OR. R'YR

where: γR = lg (GN 15/GN 18) / lg (RN 15/RN 18)
a = GN 15 x (RN 15)$^{-\gamma R}$

where RN 15, RN 18, GN 15 and GN 18 are the red and green outputs for neutral-density filters No.15 and 18 respectively.

Similar equations apply to the blue channel.

Derivation of RGB signals from YRGB outputs

If Y, R, G and B are the output levels of the four telecine channels and γ is the gamma to which the transfer characteristic has been adjusted, we calculate successively:

$Y' = Y^{\gamma}$
$R' = R^{\gamma}$
$G' = G^{\gamma}$
$B' = B^{\gamma}$

Y'' = 0.299 R' + 0.587 G' + 0.114 B'
R'_c = R' -Y'' + Y'
G'_c = Y' -0.509 (R' -Y'') -0.194 (B' -Y'')
B'_c = B' -Y'' + Y'

R_c = R' 1/''Y c
G_c = G' 1/''Y c
B_c = B' 1/''Y c

5.7. Analysis of results

5.7.1. Tabulation and graphical presentation of colorimetric errors

Although, in general, the resultant overall transfer characteristic has a direct effect on the appearance of the displayed picture, for calculation purposes a linear overall gamma (telecine plus display plus observer) can be assumed because, as has already been stated, the colorimetric evaluation is restricted to the telecine in its function of accurately reproducing the picture which would be obtained using straight-forward optical projection. In these cases, the pictures obtained from optical projection and as reproduced on the monitor (both with a dim surround luminance) are both appraised under similar viewing conditions [2, 11]. Furthermore, as the determination of the performance of the telecine in isolation is of particular interest, an ideal television receiver with EBU display primaries [4] and with the neutral balance of the screen set to match illuminant D_{65} can be also assumed in the mathematical derivation of the colour errors.

In a meaningful evaluation of a colour transmission and reproduction system it is some value to determine the direction of the individual colour error since the visual importance of the error -for example its degree of acceptability -can depend on both the magnitude and the direction of the shift. This is always particularly important where the colorimetric equalization of telecines of different types is intended.

It is therefore essential to indicate the magnitude and direction of the shift in colour reproduction for each neutral and coloured test-filter sample. This should be done :

- by tabulating, as in Table 2, the original chromaticities and luminances of the test colours and the corresponding values as reproduced by the telecine outputs using the EBU phosphors. (The use of the CIELUV 1976 u'v' coordinates is preferred.)
- by plotting the chromaticity coordinates (original and reproduced).

This process will enable any worker to apply his own method of assessing the colorimetric performance of the equipment.

Table 2 - Presentation of results

Colour number	*CEI Coordinates of original colour*			*CEI Coordinates of reproduced colour*		
	u'_o	v'_o	L^*_o	u'_r	v'_r	L^*_r
1						
2						
3						
..						
..						

5.7.2. Numerical determination of colour errors

A proposed method for the numerical assessment of colorimetric errors is the use of the CIE colour-difference formulae of 1976, which are shown below.

The colour difference ΔE^*_i is calculated for each of the test colours, using the CIELUV 1976 nearly-uniform colour space. The ΔE^*_i values can then be averaged arithmetically in various ways to find a number of " mean " values. Among these, a mean neutral colour difference can be computed for neutral density filters Nos. 15 to 18, to enable also an assessment of the grey-scale rendering performance of the telecine under test.

The calculation details are as follows:

It is assumed that for the i^{th} test colour the telecine outputs obtained as given in points 5.5 and 5.6 are R_{ri} G_{ri} and B_{ri}. The subscript r refers to quantities as reproduced by the telecine. The CIE 1931 tristimulus values X_{ri} Y_{ri} and Z_{ri} are now calculated, for EBU primaries and D_{65} display white point, using the following equations:

$$X_{ri} = 0.4306\, R_{ri} + 0.3416\, G_{ri} + 0.1782\, B_{ri} \qquad (1)$$

$$Y_{ri} = 0.2220\, R_{ri} + 0.7067\, G_{ri} + 0.0713\, B_{ri} \qquad (2)$$

$$Z_{ri} = 0.0202\, R_{ri} + 0.1296\, G_{ri} + 0.9392\, B_{ri} \qquad (3)$$

The CIE 1976 chromaticity coordinates u'_{ri}. v'_{ri} are then calculated from the tristimulus values using the following equations :

$$u'_{ri} = \frac{4X_{ri}}{X_{ri} + 15Y_{ri} + 3Z_{ri}} \qquad (4)$$

$$v'_{ri} = \frac{9Y_{ri}}{X_{ri} + 15Y_{ri} + 3Z_{ri}} \qquad (5)$$

Coordinate values on the CIELUV 1976 colour space [4, 15] are now derived referring to the reproduction of the i^{th} colour by the telecine (note that u' = 0.1978, v' = 0.4683 is the chromaticity of illuminant D_{65}).

$$L*_{ri} = 116\left(\frac{Y_{ri}}{100}\right)^{1/3} - 16 \qquad (100 \geq Y_{ri} \geq 1) \qquad (6)$$

$$u*_{ri} = 13L*_{ri}\,(u'_{ri} - 0.1978) \qquad (7)$$

$$v*_{ri} = 13L*_{ri}\,(v'_{ri} - 0.4683) \qquad (8)$$

In a similar manner, coordinate values in the CIELUV 1976 colour space $L*_{o}i$, $U*_{oi}$ et $V*_{oi}$ are derived, referring to the original chromaticity and luminance (u'_{oi} v'_{oi}, Y_{oi};) of the i^{th} colour when illuminated with illuminant D_{65} as provided in the data accompanying the test filters. These coordinate values are formulated as in equations (6), (7) and (8) with the substitution of the subscript o for the subscript r.

The magnitude of the colour difference is then calculated using the CIELUV 1976 colour difference formula.

$$\Delta E*_{i} = \sqrt{(L*_{oi} - L*_{ri})^2 + (u*_{ro} - u*_{ri})^2 + (v*_{oi} - v*_{ri})^2} \qquad (9)$$

with i = 1 to 11, 13 to 18, and 21 to 26.

Five average colour difference values are now defined :

1) the average of the ΔE^*_i values over colours 1-8 inclusive (ΔE^*_a).
2) the average of the ΔE^*_i values over colours 9-11 and 21-26 (ΔE^*_b).
3) the average of the ΔE^*_i values over the neutral colours 15-18 (ΔE^*_n).
4) the ΔE^*_i value for colour 13 (skin tone) (ΔE^*_s).
5) the worst (numerically highest) ΔE^*_i value obtained (ΔE^*_w) and the colour giving this worst value.

Ideal transmission and reproduction of a test-colour would give the colour difference $\Delta E^*_i = 0$. Departures from this value indicate corresponding errors in colour reproduction. In practical colour transmission and reproduction systems such as colour television, colour errors are not restricted to one colour range only but normally occur, to a greater or lesser extent, in all parts of the reproducible colour range. The deviations that may then be tolerated by a viewer are probably smaller than those for one single colour error only. To take account of this mutual dependence, therefore, it is meaningful to calculate a number of colour differences based on different groups of test colours using the CIELUV 1976 formulation. Experience gained in the interpretation of these values has shown that reasonable minimum values are as follows :

ΔE^*_a = 7 (average of ΔE^*_i , i = 1-8)
ΔE^*_b = 13 (average of ΔE^*_i , i = 9-11 and 21-26)
ΔE^*_n = 3 (average of ΔE^*_i , i = 15-18)
ΔE^*_s = 5 (skin tone)
ΔE^*_w = 20 with value of w indicating the colour giving the worst (numerically highest) value of ΔE^*_i .

6. Picture steadiness

Television pictures derived from film generally show a greater picture instability than those produced by electronic cameras, These errors can be caused by the film-stock itself as well as by drive-mechanism faults of the record-replay equipment (film camera, printer, telecine). Errors due to the film itself are likely to be reduced by a tightening of the tolerances on perforation dimensions and the EBU has made its opinion known on this in the second edition of document Tech. 3087 [1]. Studies are still to be made for cameras and printers.

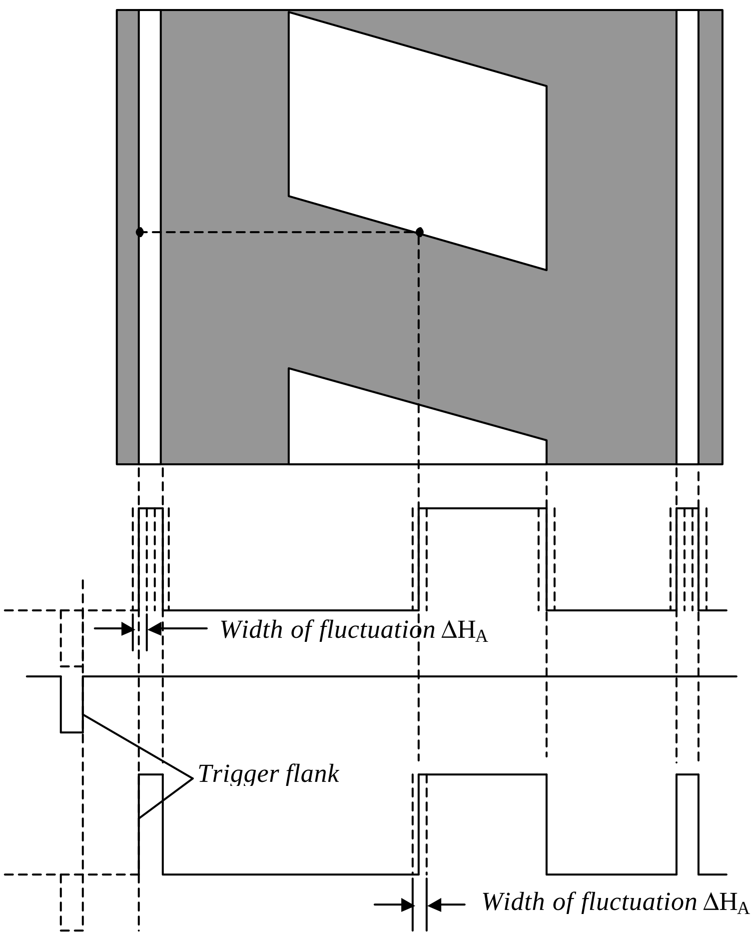
In order to measure the horizontal and vertical contribution of a telecine to the overall picture jitter, it is recommended that a film with a test picture according to Fig. 7 * be used. On a black background with an optical density D > 2, two continuous vertical white stripes (D ≈ 0.35) are provided near to the edge for determining the horizontal component of picture jitter. Between these stripes two white areas (D ≈ 0:35) are arranged with three transitions tilted at 15° to the horizontal, whose purpose is to translate vertical picture jitter into horizontal timing fluctuations.

In order to keep the picture stability errors originating from the test-film itself as small as possible, it is necessary to use a film-stock whose inherent defects and mechanical deformation through processing and ageing are small (e.g. a polyester stock). For optimum stability the test picture has to be exposed on the film by use of an optical effects printer with negligible faults. The test film should not be used too often, because the film-dependent picture steadiness can rapidly deteriorate with frequent use.

* Such a test film can be obtained from the Bavaria Atelier GmbH, Abt. Trickfilm, Bavariafilmplatz 7, 8 Munich 80, West Germany.

For the measurement of the *horizontal* picture jitter the vertical transition at point A (Fig. 7a) in the blanked picture signal (or in the composite signal) should be observed with external triggering of the delayed time-base of the oscilloscope in the line-selection mode, with a time scale of about 100 ns/cm (or with 50-fold stretching of a line) and the maximum fluctuation width (Fig. 7b) should be read. In order to increase the reading accuracy, it is recommended, that the signals in the scanner should be limited by overmodulating and reducing the black level. The relative horizontal picture jitter is given by:

$$\frac{\Delta H}{H} = \frac{\Delta H_A}{520}\% \quad (\Delta H_A \text{ in ns})$$



a) Test pattern on the film

b) Signal with line selection A-B and triggered by external sync. signal

c) Signal with line selection A-B and internal triggering on the first narrow pulse

Fig. 7. -Measurement of the horizontal and vertical fluctuations of the frame steadiness.

For determining the *vertical* picture jitter, the diagonal transition in the blanked picture signal (or in the composite signal) should be, observed, for example at point B (Fig. 7a) in the line-selection mode with internal triggering of the delayed time-base on the narrow pulse of the picture signal (see Fig. 7c). Then the maximum fluctuation ΔH_B of the leading edge of the wide pulse should be read. By means of the internal triggering, the influence of any horizontal picture jitter is eliminated. One then obtains for the relative vertical picture jitter:

$$\frac{\Delta V}{V} = \frac{\Delta H_B}{1450}\% \quad (\Delta H_B \text{ in ns})$$

The components of the test-pattern are arranged in such a manner that the horizontal and vertical picture jitter can also be measured in other parts of the picture. It is recommended that the vertical picture steadiness at the upper and lower edges of the picture should also be measured. The biggest error is to be indicated.

If the measured values lie within the order of magnitude of the inherent error of the test-film (it may attain values up to 0.1 %), then the measurement result, for example for the vertical picture jitter, must be corrected according to the formula:

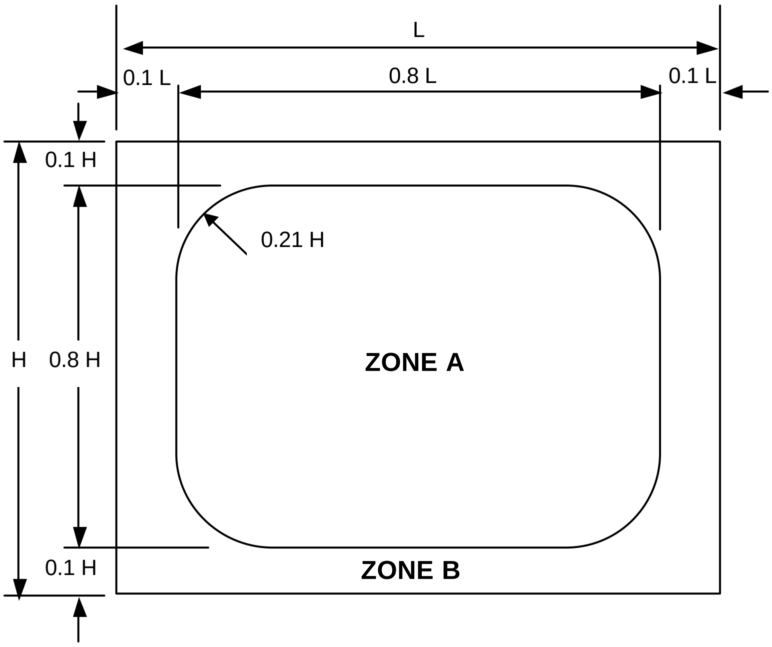
$$\left|\frac{\Delta V}{V}\right|_{corrected} = \left|\frac{\Delta V}{V}\right|_{measured} - \left|\frac{\Delta V}{V}\right|_{testfilm}$$

An analogous formula applies to the correction of the horizontal jitter.

Appendix 1
Outline performance requirements

In this document, an attempt has been made to define design principles rather than to give a detailed specification of the construction of a standard telecine. It may, however, be useful to indicate the level of performance which is attainable with modem telecine machines. The values shown here may be considered to be representative of a high standard of performance and should be examined in conjunction with those shown in the preceding text. Nevertheless, it is accepted that, based on these figures, the manufacturers could offer a wide range of equipment offering several possibilities of compromise between quality and price.

The television systems used by the Members of the EBU are based on an aspect ratio of 4:3. For the definition and measurement of the specifications, the picture area is divided into two zones as shown below. The inner area is known as Zone A and the outer area as Zone B.



Picture

Length of test loop required should be standardized and capable of adjustment with variation of ± 10 frames.

Film shrinkage accommodation	:	+ 1 % / -3 % of picture height.
Maximum run-up and run-down time	:	less than 1 second
Picture stability	:	horizontal (weave) ± % 0.1 % (peak-to-peak of picture width) vertical (hop) : % 0.1 % (peak-to-peak of picture height) The hop and weave shall not exceed these limits more than 3 times per minute and shall never exceed twice the limit.
Picture geometry (correspondence between a test film and electronic grille)	:	Zone A: 0.5 % of picture height Zone B : 1 % of picture height
Video outputs (minimum two)	:	Output impedance: 75 Q (return loss from 50 Hz to 5.5 MHz better than 45 dB) Peak white signal : 0.7 V with less than 0.1 dB difference between similar outputs
Gain stability (after specified warm-up time)	:	± 0.2 dB on test-signal Black level variation: ± 1 % of peak white Differential variation between channels at white: ± 0.5 % Differential variation at black: ± 0.2 %
Resolution (of a calibrated test film with optimum aperture correction)	:	Zone A : flat to 4 MHz :!: 1.0 dB Zone B : flat to 3 MHz + 0 dB, -3 dB
White shading (with gamma correction)	:	Zone A : 3 % in each channel 2 % difference between channels Zone B : 5 % in each channel 2 % difference between channels Any high frequency white-level fluctuations that are coherent from line to line, such as might be produced for example by a CCD telecine with inadequate correction for element-to-element sensitivity variations, should be significantly smaller than this if they are not to be visible. Peak-to-peak values of 0.5 -1.0 % should be regarded as maximum values in each channel

Black shading (with gamma correction)	:	Zones A and B	0.5 % in each channel 0.5 % difference between channels
Colour registration (between any two channels)	:	Zone A:	5 nanoseconds (0.014% of picture height)
		Zone B:	25 nanoseconds (0.07 % of picture height)
Positional hum	:	0.05 % of picture width. Difference between channels: negligible	
Latent and spurious signals	:	At least 50 dB below peak white. Any coherent components, such as might be caused by breakthrough of digital noise from sequential-to-interlace converters, or in the element-to-element sensitivity variation in correction circuits of a CCD telecine, should be significantly lower than this. A target figure of 55 dB may be assumed initially, but the final acceptability or otherwise will usually be judged visually in relation to the contrast-handling ability required of the telecine	
Noise (RMS unweighted value referred to peak signal, with aperture correction necessary to provide the required resolution)	:	Red channel Green channel Blue channel Matrixed luminance	-52 dB -49dB -52 dB -52 dB
Flicker (maximum field-to-field video amplitude difference)	:	Luminance	Zone A: 0.75 % Zone B: 1.5 %
		Colour separation signals (Zones A and B)	Red: 3% Green : 2% Blue: 7 %
		Interlace (worst ratio)	45 % : 55 %

Sound

Audio outputs (minimum two)	:	Level adjusted to 0 dBu for 40%o modulation (optical) or 160 nWb/m (magnetic). Variable control to allow increase of gain by 10 dB.
Output impendence	:	50 Ω or less
Maximum output level	:	+ 22 dBu.
Amplifier distortion	:	When the audio gain has been adjusted such that 40 % optical modulation or 160 nWb/m magnetic modulation produces an output of 0 dBu, an increase of head output level by 14 dB shall not produce total harmonic distortion exceeding 0.5 % for all frequencies.

Frequency response (to calibrated test film) (wrt output at 1 kHz) :

35 mm	COMOPT	± 2 dB from 40 Hz to 9 kHz
35 mm	COMMAG & SEPMAG	± 1 dB from 40 Hz to 12 kHz
16 mm	COMOPT	± 2 dB from 40 Hz to 8 kHz
16 mm	COMMAG& SEPMAG	+1/-3 dB from 40 Hz to 10 kHz

Signal-to-noise ratio (amplifiers only) : All the following values are given in dB relative to 0 dBu. The parameters shall be measured using a quasi-peak meter and, where appropriate, a low-pass filter or a weighting network conforming to CCIR Recommendation 468-4.

	COMOPT	COMMAG
Weighted random	52 dB	45 dB
Unweighted random	57 dB	50 dB
Buzz track	32 dB	

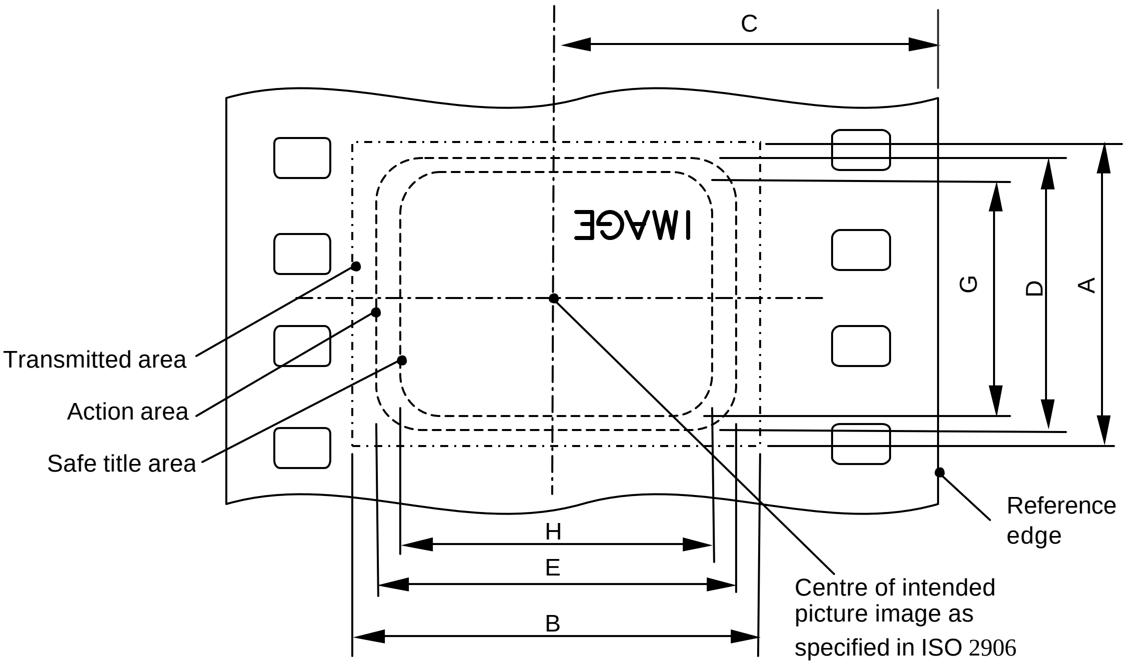
Wow and flutter (peak weighted, according to IEC Publication 386) : 0.1% (35 mm) or 0.15% (16 mm).

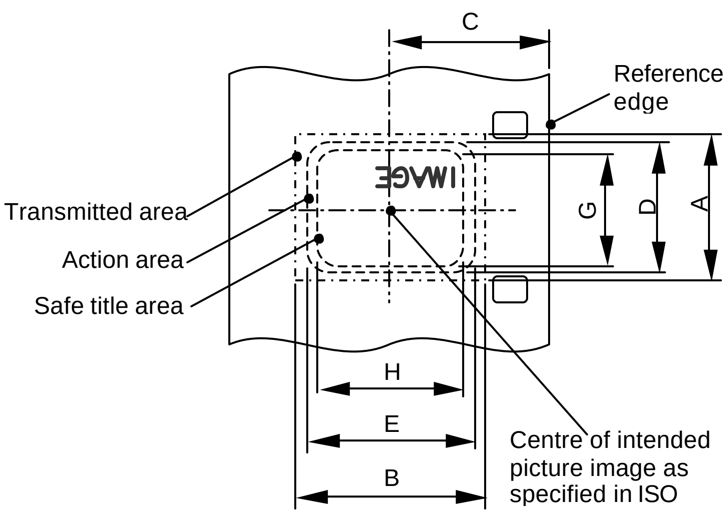
Appendix 2
Picture areas on cinematographic films and slides

The picture areas on cinematographic films and slides for television are the subject of ISO Standard 1223-1985: " Cinematography - Picture areas for motion-picture films and slides for television - Position and dimensions ". The table below in conjunction with the figure on p. 42 gives these values.

For the international exchange of films and slides, it is recommended that all important information should be contained within the "action areas" shown, although telecines and slide scanners will normally be adjusted to scan the whole of the "transmitted area".

	Millimetres		
	35-mm film	***16-mm film***	***5x5 cm slides***
A. Transmitted area height	15.10 ± 0.10	7.00 ± 0.05	21.50 ± 0.20
B. Transmitted area width	20.12 ± 0.10	9.35 ± 0.05	28.60 ± 0.20
C. Centreline position	18.75 ± 0.05	7.98 ± 0.05	25.40 ± 0.20
D. Action field height (maximum)	13.6	6.3	19.3
E. Action field width (maximum)	18.1	8.4	25.7
F. Action field corner radius (minimum)	3.6	1.7	5.1
G. Safe title area height (maximum)	12.1		17.2
H. Safe title area width (maximum)	16.1	5.6	22.8
J. Safe title area radius (minimum)	3.2	7.5	4.6


C
IMAGE
G
D
A
Transmitted area
Action area
Safe title area
Reference edge
H
E
B
Centre of intended picture image as specified in ISO 2906


C
Reference edge
IMAGE
G
D
A
Transmitted area
Action area
Safe title area
H
E
B
Centre of intended picture image as specified in ISO

Appendix 3
Colorimetric characteristics of receiver primaries

If the colorimetry of telecine and slide scanners is to be studied, the characteristics of the primaries used in the receiver must be known. The EBU has recommended to the manufacturers that the following values should be adopted for the phosphors used in monitors.

EBU phosphors	***CIE (UCS, 1960)***		***CIE (1931)***	
	u	***v***	***x***	***y***
Red	0.451	0.349	0.64	0.33
Green	0.121	0.374	0.29	0.60
Blue	0.175	0.105	0.15	0.06

The EBU has also established the tolerances to be respected in relation to these values of chromaticity. They are given in EBU document Tech. 3213 [4].

The reference white is illuminant D_{65} as standardized by the CIE. Its coordinates, in the 1960 CIE system, are: u := 0.1978 and v = 0.3122; in the CIE 1931 system they are: x = 0.313 and y = 0.329.

The colour-analysis characteristics of telecines and slide scanners should thus be optimised on the assumption that the phosphors have the coordinates shown above and the receiver white is illuminant D_{65}.

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