Library Copy

BBC

ENGINEERING DIVISION

MONOGRAPH

NUMBER 33: DECEMBER 1960

Sensitometric Control in Film Making

by

L. J. WHEELER, F.R.P.S.

BRITISH BROADCASTING CORPORATION

PRICE FIVE SHILLINGS

BBC ENGINEERING MONOGRAPH

No. 33

SENSITOMETRIC CONTROL IN FILM MAKING

by

L. J. Wheeler, F.R.P.S.

DECEMBER 1960

BRITISH BROADCASTING CORPORATION

FOREWORD

THIS is one of a series of Engineering Monographs *published by the British Broadcasting Corporation.* About six are produced every year, each dealing with a technical subject within the field of television and sound broadcasting. Each Monograph describes work that has been done by the Engineering Division of the BBC and includes, where appropriate, a survey of earlier work on the same subject. From time to time the series may include selected reprints of articles by BBC authors that have appeared in technical journals. Papers dealing with general engineering developments in broadcasting may also be included occasionally.

This series should be of interest and value to engineers engaged in the fields of broadcasting and of telecommunications generally.

Individual copies cost 5s. post free, while the annual subscription is £1 post free. Orders can be placed with newsagents and booksellers, or BBC PUBLICATIONS, 35 MARYLEBONE HIGH STREET, LONDON, W.1.

CONTENTS

PREVIOUS ISSUES IN THIS SERIES

SENSITOMETRIC CONTROL IN FILM MAKING

SUMMARY

This Monograph describes the calibration and operation of the Type X6 Sensitometer and the Type MND Line Densitometer installed at Alexandra Palace, together with a detailed description of the system of sensitometry established to control the continuous processing of films used in the BBC television news programmes.

It also discusses the subsidiary factors which must be controlled when any form of sensitometry is employed and the working tolerances which apply to each variable.

The success of this work is demonstrated by the close agreement achieved between films processed at Alexandra Palace and at commercial film-processing laboratories.

1. General Introduction

The system of sensitometric control described herein is similar in principle to that employed by most commercial film-processing laboratories. However, it is specifically applied in this instance to the control of the BBC film-processing laboratory situated at Alexandra Palace.

This laboratory is employed continuously to process films used in all the television news programmes, 'Town and Around', and similar material originating from Alexandra Palace.

The current output from the laboratory is approximately 3,000 ft of film per day. By commercial laboratory standards this is not a large footage but, because of the nature of the work, it can create 'peak rush periods' much heavier than the steady hourly output in other laboratories.

Compiling several news-film bulletins every day is somewhat similar to the production of a newspaper in that the material must be rapidly collected, processed, edited, and scripted to meet a 'deadline'. Because of this, the bulk of each day's news stories arrives for processing between 2 and 5 p.m. (for inclusion in the early evening bulletins) and again between 7 and 9 p.m. for inclusion in the final evening bulletin.

All this work is handled by three Lawley Junior continuous film-processing machines. A detailed description of this equipment is given in BBC Monograph No. 30, 'Film Processing and After-processing Treatment of 16-mm Films'. All the film currently processed at Alexandra Palace is manufactured by either Ilford Ltd or Kodak Ltd, and approximately 90 per cent of the work is carried out on 16-mm negative stocks of which 75 per cent is coated with a magnetic edge-stripe on which the accompanying sound is recorded.

Selection of a particular film stock is governed by the wide range of lighting conditions encountered in news photography and, because of this, it must be possible to process any one of the following films immediately: Ilford F.P.3, H.P.3, and H.P.S.; Kodak Plus-X, Tri-X, and Type 8374 telerecording film. Under these conditions it was essential that a rigid system of sensitometric control should be adopted and, preferably, should be simple and rapid in operation.

Although most of the film processed at Alexandra Palace remains in negative form (tonal inversion so as to transmit a positive image being accomplished in the telecine equipment), it sometimes happens that positive prints are also needed. This usually occurs when a news item is of wide interest and copies are required abroad. Under such circumstances it is current practice to send the exposed material directly to commercial film-processing laboratories both for original development and for printing.

Because of this it was essential that any system of sensitometry applied at Alexandra Palace should yield negatives which, for all practical purposes, are identical to those produced at commercial laboratories. Throughout this Monograph references are made to duplicate tests carried out at both Alexandra Palace and a selected commercial laboratory which demonstrate the very close agreement which has been achieved in this respect.

2. Definition of Terms

Several terms used throughout this Monograph are employed to describe certain photographic characteristics rarely encountered beyond the field of photographic science; these are briefly described as follows:

Sensitometry. This term is used to describe the precise measurement of the reaction of a photographic emulsion to light as revealed by the density created when the exposed film is processed under controlled conditions in any given developing solution.

Sensitometric Control. This is the system of sensitometry carried into effect by first creating a known series of exposures on the film by means of a 'Sensitometer' (such a series usually takes the form of twenty-one exposures made along the film and in such a manner that each succeeding exposure is $\sqrt{2}$ greater than the one preceding it). After processing the film in a chosen solution for an accurately controlled time, and at a given temperature, a series of densities will be achieved which bear a direct relationship to the initial series of exposures. These densities are measured on a 'Densitometer' and their relationship to the logarithm of exposure is then plotted graphically. The curve which results from this operation is known as the 'characteristic curve' of that emulsion under those processing conditions.

Gamma. Emulsions are so constructed that the major portion of the characteristic curve remains substantially straight over the useful range of densities achieved with recommended developing solutions and so that known increments in exposure result in proportional increments in density. Because of this it is possible to express the relationship in terms of the tangent of the angle formed between the 'straight-line portion' of the characteristic curve and the log-exposure axis of the graph. This measurement is known as the 'gamma' of the emulsion and is, in effect, a measure of the degree of contrast created in the final image on the film.

Thus a 'gamma of 0·4' means that the angle between the straight-line portion of the characteristic curve and the log-exposure axis is 22° (tan 22° = 0·4) and that the photographic image is of low contrast, whereas a 'gamma of 1·0' means that the angle between the straight-line portion of the characteristic curve and the log-exposure axis is 45° (tan 45° = 1·00) and, therefore, the increments in density are equal to the increments in log-exposure—thus the contrast in the image is equal to the contrast in the original subject.

Normal motion picture negatives are processed to a gamma value of the order of 0·5–0·7; telerecordings are processed to a gamma value of the order of 1·0–1·5 (depending on whether a negative or positive image has been recorded) and normal motion picture positive prints are processed to a gamma value of the order of 2·3–2·7.

The relationship between the gamma values chosen for the various types of films used throughout the whole process of cinematography is somewhat complex. It is governed by the gamma or contrast values of all the various lens systems and electrical transducing circuits which exist between the original subject and the final image as seen by the viewer. It is also largely controlled by the types of emulsions which can be manufactured to respond equally well to all colours (as must be the case in negative emulsions) or need only respond mainly to one colour (as can be permitted in positive printing emulsions).

In the theoretically ideal case it should be possible to multiply together all the gamma values of all the links in the chain and arrive at a final product of unity—thus implying that the contrast range of the final image as seen by the viewer is equal to that of the original subject. For several reasons this is not achieved and, in practice, certain compromises and working tolerances have to be permitted.

Density. This is the term used to describe the blackness of a photographic image. If light is directed on to a processed film surface, that proportion which is passed through the film is called the 'transmission' (τ), and the reciprocal of transmission is known as the 'opacity'. Density is defined as the logarithm of the opacity of the film. This may be expressed as follows:

$$D = \log O = \log \frac{1}{\tau}$$

Reciprocity Law Failure. This term is used in the Monograph when discussing the sensitometer and refers to the condition under which a film is exposed to light. Exposure is defined as the product of the Intensity of the light and the Time it is allowed to act on the emulsion, thus:

$$E = I \times T$$

However, it has been shown that photographic emulsions fail to react equally to an exposure consisting of a low intensity operating for a long time and a high intensity operating for a relatively short time although, in both cases, the product $I \times T$ is identical. Because of this it is essential that the sensitometer chosen to measure the reaction of film emulsions to given processing conditions shall create a series of exposures having times comparable to those which will be given by the camera or sound recording equipment used in practice.

3. The Factors Governing Image Formation

Film processing can be unsatisfactory if any of the following variables fluctuate beyond established working tolerances:

(*a*) Camera exposure
(*b*) Developer concentration
(*c*) Developer temperature
(*d*) Developer exhaustion
(*e*) Developing time
(*f*) Fixing solution concentration and hardening
(*g*) Washing time and efficiency.

The control of each of these factors as they are applied to the Lawley machines used at Alexandra Palace is described below.

3.1 *Camera Exposure*

Film processing control by sensitometry is basically to guarantee to the cameraman that the degree of development will always be maintained at a chosen level. Because of this it implies that processing cannot be varied either to suit individual cameramen or to compensate for over or under exposure.

Once the processing conditions have been established, it is important that the cameramen become acquainted with the exposure latitude and emulsion speed of the various films under these conditions. It is not unknown for a cameraman to report that his exposure was incorrect and for him to request processing compensation by varying the established machine speed.

Whilst this practice was very common some years ago, it is not at all possible under present-day conditions of precise laboratory control. The only acceptable system is to guarantee the processing conditions by developing sensitometric control exposures for a known time at a known temperature so as to achieve standard gamma and density values. The photographic speed of the emulsion is then firmly related to these conditions. This data assures the cameraman that, providing his exposures have been calculated by applying this knowledge, his results will always be maintained at the optimum condition.

Naturally, under the unpredictable lighting conditions associated with news photography, it is not always possible to give the desired exposure but, providing the relationship between camera exposure and sensitometric processing is understood, the major part of all such work will be maintained within very close limits.

3.2 *Developer Concentration*

The developing solution used in the Lawley machines is diluted so that 1 gallon of developer is added to 6 gallons of water. The concentrated liquid is supplied from the manufacturers in 1-gallon bottles and, for some time, it was assumed that these bottles contained precisely 1 gallon.

However, spurious fluctuations in densities resulting from sensitometric test exposures led to an investigation of the exact volume contained in each bottle. It was found that random samples varied by as much as 8 oz. in excess of the nominal gallon.

Because of this, the operators now measure precisely 1 gallon of concentrated solution into a graduated container before diluting with water. Dilution and mixing is carried out in the processing tank itself and adequate mixing is immediately ensured by using the developer circulating pump attached to the processing tank.

Sensitometric tests have revealed slight differences between the activity of one batch of developer and the next. Batches of developer are designated by a code number printed on the bottle label. Developer is ordered in bulk, usually 50 gallons at a time and, in general, the suppliers ensure that all the bottles in one delivery are from the same batch.

Whilst the machine speeds quoted in this Monograph are the average speeds found over a number of batches of developer, it must be remembered that, for precise work, the actual speed will vary slightly and depend upon the activity of the particular batch of developer in use at the time.

This variation will only be of the order of ± 2 ft per minute on a nominal machine speed of 30 ft per minute. Put another way, if the machine speed is always held at 30 ft per minute for a particular type of film, developer batch-to-batch variations can cause a swing of $\pm 0{\cdot}02$ in gamma on a nominal gamma of $0{\cdot}65$. This factor must be recognized in assessing daily sensitometric tests and in establishing a precise speed for very accurate work.

3.3 *Developer Temperature*

The built-in immersion heater and refrigeration plant in the Lawley machine is capable of holding the developer temperature to within $\pm\frac{1}{2}$°F at all temperatures between 60 and 90°F and when the ambient temperature varies between 50 and 100°F.

In practice the developer is held at 73°F ($\pm\frac{1}{2}$°F) and this control is applied automatically once the machine is in operation. Naturally, operators often require this temperature to be obtained very quickly and, under certain conditions, they can do much to assist the machine in this connection.

For example, in periods of heat-wave (such as the summer of 1959) the temperature of the incoming water was often above 73°F first thing in the morning at Alexandra Palace. Whilst the refrigerator will hold a given temperature very successfully, it may take quite an appreciable time to attain this condition from a 'standing start' and, therefore, to mix the developer with water above the desired temperature of 73°F is unwise when work is to be processed quickly.

The correct procedure is either to run off all the water which has been held in the storage tank overnight or, preferably, to supplement this with iced water. It must be remembered that, initially, the immersion heaters in the Lawley machine always raise the temperature more quickly than the refrigerator will lower it and, therefore, it is unlikely that 'over-cooled' water will cause any undue delay in starting a day's work.

3.4 *Developer Exhaustion*

In large commercial laboratories the supply of developer to the continuous processing machines is constantly replenished with a concentrated solution. The rate of replenishment is controlled by 'bath analysis' in conjunction with a knowledge of the footage of film processed per hour. Chemical analysis, constant replenishment systems, and automatic bleeding of surplus liquid is a complicated process requiring the attention of a fully trained chemist.

Clearly this system was not practical in the present circumstances and alternative simple methods had to be employed. The developing tank in the Lawley machine contains 7 gallons of solution and it was necessary to establish the maximum quantity of film this basic volume could process before the results varied beyond acceptable tolerances. In other words, a 'developer exhaustion test' had to be made.

This was done by using the dual gauge Lawley machine available at Alexandra Palace in which 35-mm film may be processed. The developing tank in this machine has a capacity equivalent to those in the 16-mm machines and, by using 35-mm film, a greater degree of exhaustion was created with an equal length of film. The film was intentionally over-exposed so that the developer had more than average work to perform. Between each 1,000-ft length of film a sensitometric exposure was processed so that any changes in the activity of the bath would be revealed.

It was found that whereas the initial gamma value was 0·66 before any work was processed, this only dropped to 0·64 after 5,000 ft of film had been through the developer. Similarly, the 13th step on the sensitometric density wedge (selected because it approximated 'face tones' in a practical image) only varied between 0·74 and 0·69 over this test. The density of the film base—known as the 'fog density' and created by spurious chemical reaction and not by intentional exposure—only rose from 0·27 up to 0·31. Because of these results on 5,000 ft of over-exposed 35-mm film, and also because only approximately 3,000 ft of 16-mm film is the average daily output from Alexandra Palace, it was obvious that one basic tank of developing solution would more than serve this requirement without any need for complicated chemical replacement or bath analysis.

The system employed is therefore to mix a fresh developing solution each morning and, regardless of the footage which has been processed during the day, to discard that solution at the conclusion of each day's work. Naturally, should several 1,000-ft telerecordings also be added to the work, the operators refer to their 'developer log sheet' on which all film processing is recorded and, if the total footage approaches 5,000 ft, a new developer is mixed before proceeding with any further work on that day.

However, when this occurs, the second developer is still discarded at the conclusion of that day's work. In this manner a new developer is always mixed each morning and remembering that, under these circumstances, the cost of development is only approximately one shilling per 100 ft (1 gallon of concentrated solution, thirty shillings) this system is far more economical and simple than one employing continuous replenishment.

3.5 *Developing Time*

The accurate control of developing time is a fundamental requirement of any system of sensitometry. In the Lawley machine this factor may be varied in three ways. Firstly, by changing the number of film loops in the developing solution. Secondly, by changing the length of the loops in that solution. Thirdly, by changing the speed at which film passes through the bath.

When dealing with a wide variety of film emulsions, each requiring a different developing time, it is clearly not practical to rethread the machine and so change the loop formation each time a different type of film is to be processed. Similarly, the length of the loops in the developing tank can only be changed by clearing the machine of work, bringing it to rest and, with leader film in position, adjusting the loop length and then absorbing any slackness thus created—a long operation which is quite impossible when different types of film are continually arriving for immediate attention.

Because of this, a film loop-length had to be selected which would provide all the variations in developing time by adjusting the overall machine speed.

Nominally the developing tank in the 16-mm Lawley machine can accommodate sixteen complete loops of film in two banks of rollers. When all these loops are threaded it is found that they must be raised by approximately one-third of the tank depth in order to achieve all required machine speeds without further adjustment. If this system is adopted it creates a very low ratio between that portion of a film loop which is immersed in solution and that portion which is exposed to air. In consequence 'aerial fog' is inclined to occur and image density variations take place.

To overcome this condition several loops were omitted from each bank of rollers and the loop-length was increased to the maximum. Calibrations are provided on the rods controlling the depth of the lower banks of rollers in the solution and, therefore, it was preferable to select a position at which such calibrations could be easily set by the operators. The selected position was such that the control rods are maintained 1 in. above their lowest position.

Under these conditions it was found necessary to maintain eight complete loops in the developing tank, four on each bank of rollers. With this arrangement, machine speed can be varied between 15 and 70 ft per minute—thus providing any developing time between 0·68 and 3·20 minutes.

In practice all films currently used can be processed to achieve the desired gamma and density values at developing times ranging between 0·80 and 2·40 minutes. The arrangement is therefore more than adequate for present requirements and calls for the minimum of adjustment by the operator.

Initially motor speed control was by means of a wire-wound variable series resistance. This proved to be unstable and the operators found it necessary to continually 'ride' the resistance control to maintain constant machine speed. Motor speed is now controlled by means of a Variac and, once the speedometer has been brought up to the required setting, no further adjustment is necessary although, of course, the operator will continually check the machine speed whilst film is being processed.

A wide-scale speedometer calibrated in film feet per minute is employed. In practice machine speed always remains within ± 1 ft per minute at a nominal setting of 30 ft per minute.

3.6 *Fixing Solution Concentration and Hardening*

The purpose of the fixing solution is to dissolve all the unexposed silver halide remaining in the emulsion after development and so to render the image permanent. When a hardening agent is added to this solution it also makes the emulsion less susceptible to scratching and similar damage but, of necessity, it makes the final washing operation more difficult.

The fixing solution used at Alexandra Palace is made up as follows:

5 gallons of Rapid 'Amfix'
160 fluid oz. of Amfix special hardener
Water to make 17 gallons.

This solution is held in 30-gallon rubber-lined storage vats and is thoroughly mixed by an electrical stirrer during manufacture. The Lawley machine has a fixing tank capacity of 7 gallons and this quantity is drawn from the storage vat daily and transported to the machine in polythene buckets.

It is important to realize that Amfix solution is heavier than water and, unless thorough mixing is ensured, this factor may result in only partially fixed film. The Lawley machine is not fitted with a fixer circulating pump and, unless the solution has been well mixed, the actual fixing time will be inadequate.

Tests similar to those carried out to establish the rate of developer exhaustion were also made with the fixing solution. However, in order to create the most severe conditions, the film was not previously exposed—and so the fixing solution was required to dissolve the entire emulsion. These tests showed that 4,000 ft of 35-mm film could be completely 'cleared' before the solution became exhausted.

Here again the capacity of the bath was greater than the daily footage of 16-mm film and, therefore, this solution is also used on a daily basis—a new bath being introduced each morning and discarded each evening.

3.7 *Washing Time and Efficiency*

In the 16-mm Lawley machine the film passes from the fixing tank into two washing tanks before entering the drying cabinet. The total footage in these tanks is 107 ft, thus providing a washing time of between 1·78 and 5·35 minutes at film speeds between 20 and 60 ft per minute.

Of this footage, 38 ft is contained in a 3½-gallon tank of continuously changing water and 69 ft is passing through a tank in which high pressure water spray jets impinge on both sides of the film.

Washing efficiency is measured in terms of the residual hypo content left in the dried film. Originally the machine was supplied so that the spray washing tank immediately followed the fixing tank and the tank containing continuously running water acted as the final wash. Under these conditions the residual hypo content was found to be 340 micrograms per square inch.

By reversing the order of these tanks, and increasing the water-flow rate to 90 gallons per hour, the residual hypo content was reduced to 150 micrograms per square inch. This value is somewhat better than that required in commercially processed film.

4. The Sensitometer

4.1 *General*

Sensitometers are precision instruments by which a series of known exposures may be made on to any photographic material. The exposure range is made sufficiently large to cover all exposure conditions met with in practice, and is so arranged that each successive exposure is substantially $\sqrt{2}$ greater than the preceding exposure. The logarithms of these exposures are plotted graphically against the densities created on the film and since by definition density is also a logarithm, with an ideal emulsion a linear relationship will result.

The conditions under which these precise exposures are made can vary from one type of sensitometer to another. For many years the only precision instrument available for general commercial laboratory control was the Kodak Type IIb sensitometer. In this machine the factors Intensity and Time, which together create a known Exposure, were related so that the intensity of the light source always remained constant and the time of the exposure increased in $\sqrt{2}$ steps and over a range of twenty-one exposures. Hence this instrument was known as a 'time-scale sensitometer'. The actual exposure times provided ranged from 0·005 seconds up to 4·990 seconds and, therefore, only a small portion of this range is comparable to practical exposure conditions used in present-day motion picture cameras and sound recording equipment.

Because of this, Kodak Ltd have recently introduced a new sensitometer in which the time of the exposure remains constant throughout the whole range whilst the intensity of the light is varied—this is done by passing a constant narrow beam of light behind a carbon deposit of increasing opacity. By this

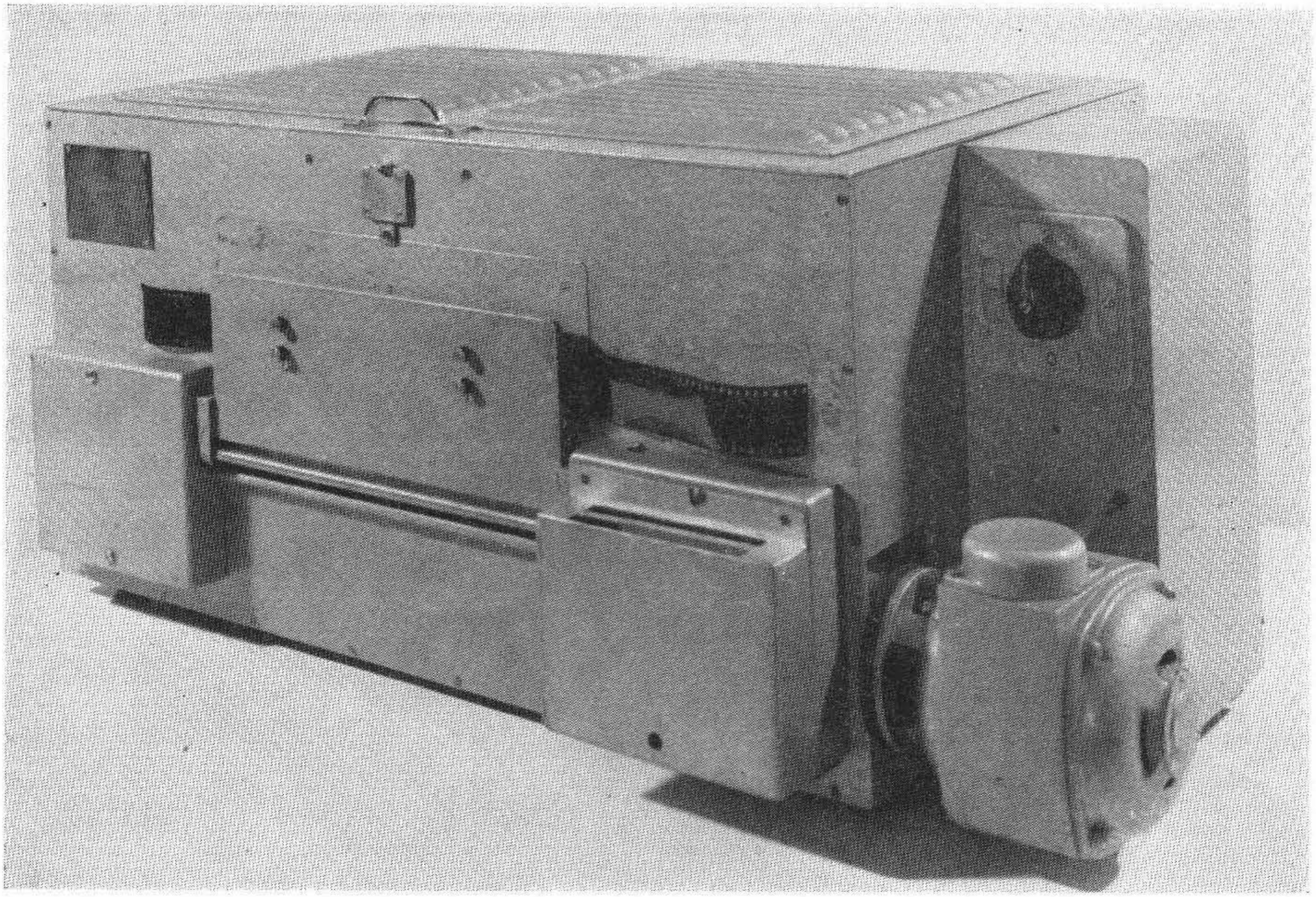

Fig. 1 — The Type X6 Intensity-Scale Sensitometer

technique the intensity of the light may be varied whilst its colour temperature remains constant. This new sensitometer is known as 'The Type X6 Intensity-Scale Sensitometer' and is the machine installed at Alexandra Palace.

It is important to realize that many commercial laboratories still use the Type IIb sensitometer and, whilst equivalent gamma values can be obtained at laboratories using different types of instruments, it is not possible for the densities of individual steps from each instrument to agree precisely. Since some film is sent from Alexandra Palace to a commercial film-processing laboratory (where a Type IIb sensitometer is still in use) this factor must be remembered when comparing results from that laboratory with similar work processed on the Lawley machines and controlled by a Type X6 sensitometer.

4.2 *The Type X6 Sensitometer*

A general view of this instrument is shown in Fig. 1. The sensitometer consists essentially of a carriage carrying a lamp at a constant speed behind a sensitometric wedge. A sensitometric wedge is a series of accurately made small areas of known density arranged in a predetermined series of equal increments. The film to receive a sensitometric test exposure is held in front of and in contact with this wedge and, in effect, an accurately controlled 'contact print' is made of the density increments on the wedge.

On the lamp carriage, between the lamp and the wedge, two filter-holders are mounted to accommodate 3-in. by 3-in. or 2-in. by 2-in. filters by which the colour temperature or intensity of the light source may be modified. In addition, a four-position filter wheel bearing colour filters, and a four-position wheel carrying aperture slits to provide 1/10th, 1/25th, 1/50th, and 1/100th-second exposures are also mounted on the carriage. By these combinations it is possible to create representative exposure ranges on fast negative film or, for example, slow blue-sensitive positive printing film, merely by adjusting the combination of filters and exposing apertures provided.

The lamp-carriage is driven by an accurately machined horizontal lead-screw powered by a 220-volt, three-phase motor, revolving at 1,500 revs per minute. This drives the carriage at a rate of 20 cm per second. It is most important that the lead-screw, and the associated 'lathe-bed' on which the carriage rides, shall be regularly lubricated with a thin machine oil—thick oil or grease may not on any account be used for this purpose.

The optical axis is directly perpendicular to the vertical front side of the instrument and the movement of the carriage is from right to left and left to right alternately. The exposure apertures are arranged at less than 1 mm from the sensitometric wedge so as to reduce light diffusion to a minimum. The lamp is enclosed in a light-tight housing which is cooled by two 220-volt single-phase helical fans. A baffle plate between the lamp and filter holders serves as a shutter to prevent the filters becoming overheated when no exposure is being made.

The distance d from the lamp filament to the exposing plane can be varied between 10 and 28 cm. This variable enables lamps of different light output to be calibrated so as to provide equal illumination at the plane of exposure. The precise setting of each lamp is selected by means of a metal scale engraved in 0·5-mm increments and built into the lamp house base. When the lamp-holder has been adjusted on its guide rails (to a position giving the correct light intensity at the exposing plane) it may be locked in that position by means of a quick-set cam-operated clamp attached to the lamp-holder. The exposure plane is vertical and the light beam is horizontal—without any lenses—thus permitting direct calibration of the illumination into lux:

$$I = \frac{\text{candle-power}}{d^2}$$

The maximum illumination at a colour temperature of 3,000°K is approximately 100,000 lux.

The sensitometric wedge covers an exposure range of approximately 3·0 log E in twenty-one steps and with step increments of approximately 0·15 log E. The film to be exposed is held in position by a spring-loaded pressure pad which is automatically released at the completion of each exposure.

Naturally, it is essential to know the precise log E increments from one step to the next on the sensitometric wedge in order to plot the resultant data. An accurate calibration of each wedge is made by the manufacturers and sent out with the machine. Should the wedge become damaged or broken a replacement, together with its own calibration, is readily obtainable. The calibration of the wedge in use at Alexandra Palace is reproduced below.

Step No.	*Wedge Density*	*Log E Increment*
1	3·27	0·00
2	3·12	0·15
3	2·96	0·16
4	2·80	0·16
5	2·66	0·14
6	2·50	0·16
7	2·34	0·16
8	2·17	0·17
9	2·01	0·16
10	1·88	0·13
11	1·73	0·15
12	1·58	0·15
13	1·42	0·16
14	1·27	0·15
15	1·10	0·17
16	0·95	0·15
17	0·80	0·15
18	0·65	0·15
19	0·50	0·15
20	0·35	0·15
21	0·20	0·15

It should be noticed that step 1 carries the highest density whereas, on a sensitometric strip obtained from a processing machine, step 1 carries the lowest density. This is because the densities of the wedge are printed through on to the test film and, therefore, the highest density on the wedge will produce the lowest density on the test strip. Since several of the lower densities are usually masked by the fog-level on negative film exposures, the eleventh or centre step on the wedge is marked with an arrow to assist in locating individual steps when plotting the resultant data.

When plotting characteristic curves of exposures made on this sensitometer it is necessary to make the successive increments along the log E axis of the graph in the actual increments shown in the above table—rather than to make twenty-one equal increments of 0·15 as would be the case with tests made on the Type IIb sensitometer. To simplify this operation a permanent scale of increments has been made on graph-paper and, covered with celluloid, it forms a convenient rule from which to rapidly transfer these increments whilst plotting the graphs.

The exposure cycle in the Type X6 sensitometer is started by a momentary-contact push-button switch. This switch operates a relay causing the carriage to move across the exposure plane and automatically closing the pressure pad on to the film as it starts from rest. The scanning cycle is ended and a reversing relay is actuated by the carriage making contact with a limiting microswitch located near to the end of its travel.

The pressure pad holding the test film in register with the carbon wedge is closed and opened automatically during the scanning cycle by a mechanical linkage operated by a cam attached to the lamphouse. This linkage also damps the motion of the carriage at the end of the scanning cycle after the motor has been stopped.

The movement of the carriage can also be controlled manually by rotating a knurled knob on the left-hand side of the instrument. Before an exposure cycle can be started the carriage must be at one end of the lead-screw and with the pressure pad in the open position. If this is not so then the carriage should be moved to this position by manually rotating the knurled knob.

4.2.1 *Electrical Supplies to the Type X6 Sensitometer*

The motor driving the lead-screw used to traverse the lamp-house across the carbon wedge is operated by 220-volt, three-phase alternating current. At Alexandra Palace this supply is derived from a step-down three-phase transformer fed with 415 volts input.

The exposing lamp is a 500-watt Class A1 projector lamp under-run at approximately 76 volts single-phase a.c. This supply must be well regulated and is derived via a Sorensen model LT–1,000–25 voltage regulator. Since this instrument operates on single-phase 240-volt a.c. supply, the output from the regulator is fed into a step-down transformer to provide 100-volt single-phase regulated current. This is then fed via a 6-ohm 5-amp rheostat to provide a regulated voltage capable of adjustment to between 70 and 80 volts. The precise voltage employed is measured on a meter having an expanded scale over the range 15–120 volts on a 6-in. dial.

4.2.2 *The Sorensen Voltage Regulator*

The following brief description of this instrument is supplied by the manufacturers, Messrs J. Langham Thompson.

The regulator depends for its operation upon the control exercised by a saturable reactor in series with an auto-transformer in the main power circuit. A change in the direct current flowing in the control winding causes a variation of the reactor impedance, thus affecting the output voltage of the auto-transformer. Precautions are taken to ensure that the output does not rise excessively if the control circuit fails.

The voltage reference stage consists of a bridge in which one element takes the form of a special diode operating in a temperature-limited condition. Thus, an increase in the temperature of the filament causes a decrease in the impedance of the diode, and vice versa. It is mainly this feature which introduces a time constant into the process of regulation.

The filament is supplied with current derived from the output of the regulator so that changes in the output voltage and load directly affect the impedance of the diode, and consequently the balance of the bridge. The differential voltage from the bridge is applied to an a.c. amplifier which supplies current to the control winding of the saturable reactor.

The high forward gain of this closed electrical feedback loop ensures good regulation accuracy. Two transformers are used to obtain the voltages which combine to supply the diode filament, and the proportion of voltage due to the load current is adjusted to give the required load characteristic.

Harmonic distortion, due to the non-linear impedance of the saturable reactor, is reduced by the introduction of filters to by-pass third and fifth harmonic currents from the primary of the auto-transformer.

4.2.3 *Calibration of the Sensitometer Lamp*

The Type X6 sensitometer depends upon accurate knowledge of the precise exposure caused by the chosen lamp. The calibration of this lamp and sub-standard lamps is not carried out by the manufacturers but must be done by the user. The general formula used to establish this condition is given below:

$$\log E = \log C + \log T - 2 \log d - D$$

where E = the exposure ($I \times T$)
C = the candle-power of the lamp
T = the exposure time in seconds
d = the distance from the lamp filament to the exposing plane in metres
D = the density of any filters inserted in the system

The lamp supplied with the instrument had been previously measured by the suppliers for colour temperature and candle-power at a range of voltages. This was therefore only used as a standard lamp with which to calibrate the instrument and, thereafter, against which to calibrate sub-standard lamps for general use. The standard lamp was measured by the suppliers as follows:

Temperature (°K)	*Voltage*	*Candle-power*
3,000	96·2	904·5
2,850	84·4	574·5
2,700	72·7	343
2,660	70·1	298·5
2,360	50·8	83·4

It is recommended that the maximum log E when no density in the carbon wedge is obstructing the light should be approximately 0·5 when testing negative films and 2·0 when testing positive films. The sensitometer had therefore to be so arranged that the insertion of a single density in the filter on the lamp carriage would modify the exposure from that suitable for slow positive films to that suitable for fast negative films. The calculations which follow assume the instrument is being set up with the density in position and to suit negative films.

The variables available for this purpose were as follows:

(*a*) the distance between the lamp and the exposing plane
(*b*) the size of the aperture used in the exposure-time control
(*c*) the insertion of a fixed neutral density in the light path.

The candle-power of the lamp was fixed because the colour temperature was required to be 2,700°K. After several trial settings and—of importance at Alexandra Palace—comparison of the results with those obtained at a commercial laboratory on their Type IIb sensitometer, the following conditions were selected:

$$\text{Lamp voltage} = 73$$
$$\text{Exposure time} = 1/10\text{th second}$$
$$\text{Distance } d = 22\cdot 4 \text{ cm}$$
$$\text{Neutral density } D = 2\cdot 18$$

It was found that the carbon wedge retained a small minimum density (0·20) even at the lowest point in the system and, therefore, provision had to be made for this in the formula. It is designated below as D_1 in the amended formula:

$$\begin{aligned}\log E &= \log C + \log T - 2 \log d - D - D_1 \\ &= \log 350 + \log 0\cdot 1 - 2 \log 0\cdot 224 - 2\cdot 18 - 0\cdot 20 \\ &= 0\cdot 46\end{aligned}$$

This condition was adopted and tests were made to check the reproducibility of the exposures as, for example, when the lamp carriage was either travelling to the left or to the right. Once these conditions were established it was then possible to calibrate a series of sub-standard lamps.

4.2.4 *Calibration of Sub-standard Lamps*

The standard lamp is only used for the initial calibration of the instrument and, thereafter, as a master against which to calibrate sub-standard lamps.

In practice the sensitometer is rotated by hand until the lamp is mid-way along the lathe-bed, the carbon wedge is removed, and a colour temperature meter is placed in line with the optical axis. The lamp to be calibrated is then energized and the voltage supply is adjusted until the colour temperature of 2,700°K is reached. This now determines the voltage at which the lamp must be used.

The lamp under calibration is then replaced by the standard lamp and the colour temperature meter is replaced with an incident-light foot-candle meter. The voltage is re-set to that required by the standard lamp and the light meter reading is noted. The standard lamp is then replaced by the lamp under calibration and the voltage supply is adjusted to that previously found to produce the required colour temperature with this lamp.

It is then only necessary to adjust the distance between the lamp and the meter until the foot-candle reading is equal to that measured previously with the standard lamp.

Each sub-standard lamp is designated with individual labels indicating the correct operating voltage and the distance at which the lamp-carriage should be set from the exposing plane.

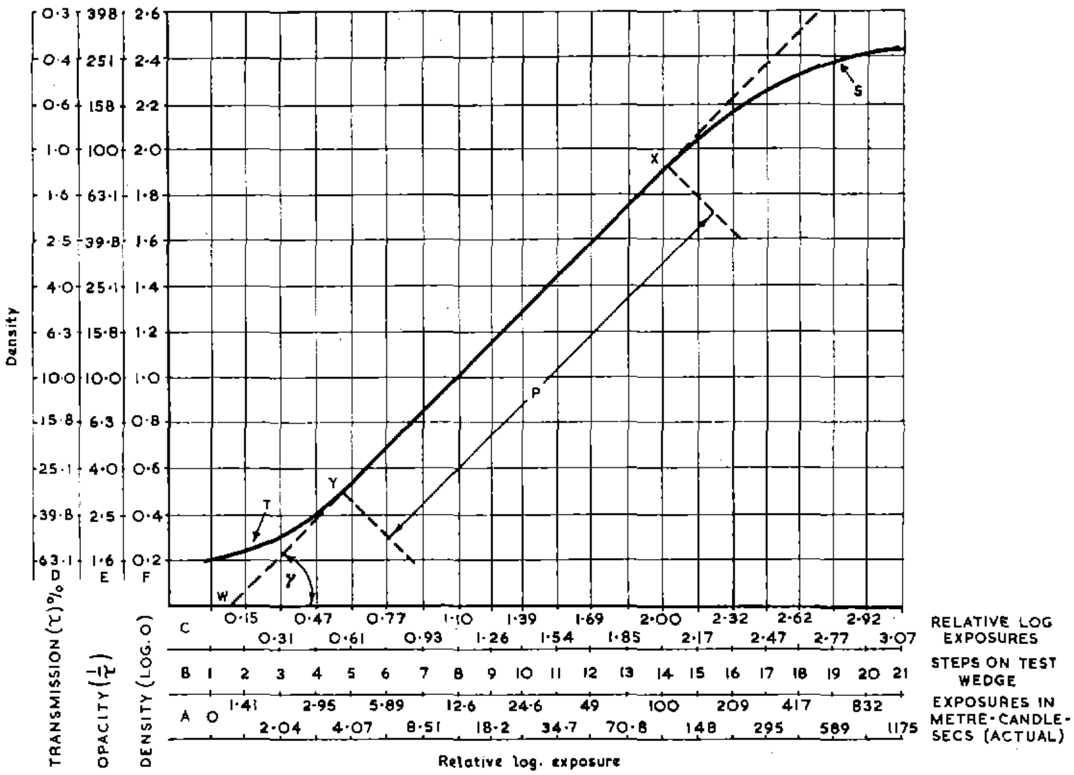

Fig. 2 — Typical Exposure/Density curve, with comparative scales for different methods of measurement of exposure and density

5. The Densitometer

Density measurements are made at Alexandra Palace by employing a line densitometer in conjunction with a Type M.N.D. photometer.

The line densitometer measures diffuse transmission density over an aperture 0·10 in. in length and 0·02 in. in width—the film-carrying platen being oriented so that the maximum dimension of this aperture is parallel with the film edge. The dimensions of the aperture are important—particularly in the measurement of 'ten-step wedges' generated in telerecording equipment. A ten-step telerecording wedge covers the full width of a 16-mm film frame—that is, 0·410 in. One step in the wedge is therefore approximately 0·04 in. wide—that is, twice the width of the aperture in the line densitometer. However, since this aperture is a mechanical slit exposed to the work table of the instrument, it is liable to become obstructed with dirt particles. When this happens it may become impossible to zero the instrument during calibration. If this occurs the aperture is best cleaned by using a compressed-air gun rather than attempting to dislodge dirt with any metal instrument.

The principle of the densitometer is to project the image of the lamp filament through a series of limiting aperture plates, through the film sample and then on to a photocell. The M.N.D. photometer amplifies this signal to produce a reading of density or percentage illumination directly on a calibrated 'dead beat' milliammeter.

The instrument has a full-scale deflection of 1·0 density, subdivided into units of 0·02. By means of a range-change switch any density between 0 and 3 can be read and, within this range, an accuracy of ±0·02 is claimed by the manufacturers. The electrical supply to the densitometer should be 220–240 volt a.c. single-phase.

The densitometer must be calibrated each time it is put into service and, if a great number of readings are to be made, it is advisable to check the calibration occasionally to guard against the possibility of drift.

6. Plotting Characteristic Curves

The characteristic behaviour of a photographic emulsion is depicted by plotting a series of densities against the log E exposures which created them in combination with certain developing conditions.

Fig. 2 shows the relationship between actual exposure, log-exposure, transmission, opacity, and density. The actual exposure made in any sensitometer is in units of 'metre-candle-seconds', that is, a light of known candle-power operating at a known distance and for a known time. Scale 'A' shows the actual exposures made in the Type X6 sensitometer installed at Alexandra Palace (naturally, because these exposures depend upon the individual carbon wedge supplied, they will be slightly different in each model of this type but, since the precise densities are known, all models will be equally accurate).

Scale 'B' shows the steps on the carbon wedge corresponding to these exposures.

Scale 'C' shows the units of exposure converted into logarithms and, therefore, represents the conventional 'log E' scale used in plotting these curves.

Scale 'D' shows units of percentage transmission—that is, the percentage of incident light transmitted through the film when measuring its ability to stop the passage of light. Scale 'E' shows the reciprocal of transmission—that is, the opacity of the film. Scale 'F' shows the opacity converted to logarithms which, of course, are units of density and, therefore, represent the conventional scale plotted in this axis of the graph.

A typical curve is shown in Fig. 2 to illustrate the five main characteristics recorded by this system. These are as follows:

(*a*) The range of proportional working
(*b*) The range of under-exposure
(*c*) The range of over-exposure
(*d*) The contrast of the film
(*e*) The relative speed of the film.

6.1 *The Range of Proportional Working*

This is the main part of the characteristic curve and is shown in Fig. 2 as the length 'P', bounded by the limits 'X' and 'Y'. Within this area increases in log E will cause proportional increases in density and, therefore, tone distribution in the original subject corresponding to these exposures will not suffer distortion in the negative image. This is usually known as the 'straight-line' portion of the characteristic curve.

6.2 *The Range of Under-exposure*

This is the 'toe' of the characteristic curve indicated at 'T', Fig. 2, and is due to the inability of a photographic emulsion to respond in a linear manner to exposures below a certain level. Any part of an original scene reflecting only enough light to correspond to an exposure in this part of the curve (such as detail in dark shadow) will not be truly recorded in the film image but, in fact, will be compressed.

6.3 *The Range of Over-exposure*

This is the 'shoulder' of the characteristic curve indicated at 'S', Fig. 2, and is due to the inability of the photographic emulsion to continue to respond in a linear manner to exposures above a certain level. Any part of an original scene reflecting so much light that it corresponds to exposures in this region (such as high-lights in close-up pictures of a face) will again be compressed and detail will be lost.

6.4 *The Contrast of a Film*

The contrast of a film is the rate at which resultant density is created in relationship to proportional increases in exposure. Because of this, the contrast of a film is only measured over the 'straight-line' portion 'P' in the curve shown in Fig. 2.

Contrast is measured by producing the straight line 'X–Y' until it cuts the log-exposure axis, as at 'W'. The tangent of the angle thus formed is known as 'gamma' and is the unit used to represent this characteristic of an emulsion.

6.5 *The Relative Speed of a Film*

Several methods have been devised for measuring the speed with which a film will react to light. One basic approach is to compare the position along the log-exposure axis at which point 'W' makes contact with that axis. Clearly, if several emulsions are all processed to equal gamma values (that is, so that the straight-line portion of each characteristic curve is parallel to the others) the one which lies farthest to the left will be the fastest emulsion, whilst that farthest to the right will be the slowest emulsion for that particular condition.

6.6 *Time-gamma Curves*

It is a constant requirement in any film-processing laboratory to be able to establish a machine speed necessary to achieve a desired gamma value. This is done firstly by processing several sensitometric strips to a range of machine speeds. Fig. 3 shows a family of curves produced in this manner, each curve indicating a different gamma value produced by a different machine speed.

These gamma values are then plotted against the machine speeds which produced them—resulting in the 'time-gamma curve', or the 'machine speed-gamma curve', shown in Fig. 4. From this curve it is then possible to select the precise machine speed necessary to produce any gamma value within the range covered by the tests.

6.7 *Temperature-gamma Curves*

In a similar manner, it may be necessary to maintain the machine speed at some fixed condition in order to meet work commitments, and yet to be able to vary the gamma to which the film is processed. This can be done by exposing a family of sensitometric strips and processing each one to a different developer temperature whilst the machine speed remains fixed. From this family it is then possible to plot a 'temperature-gamma' curve which will indicate the precise temperature necessary to realize any required gamma value within the range covered by the test.

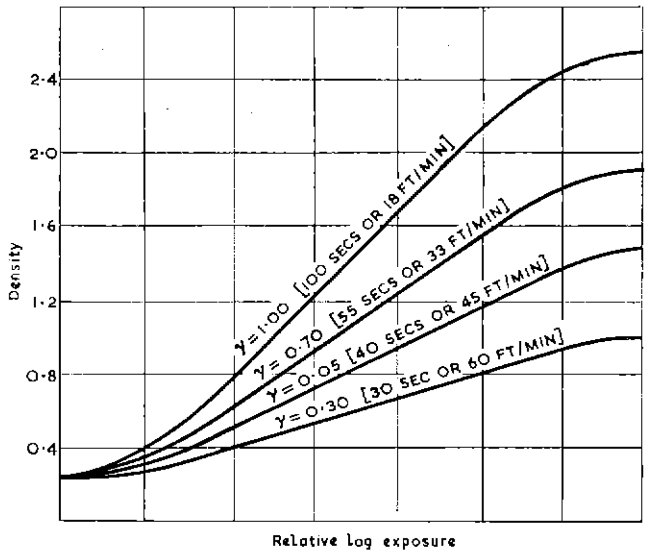

Fig. 3 — Exposure/Density curves for different gamma values resulting from different development times

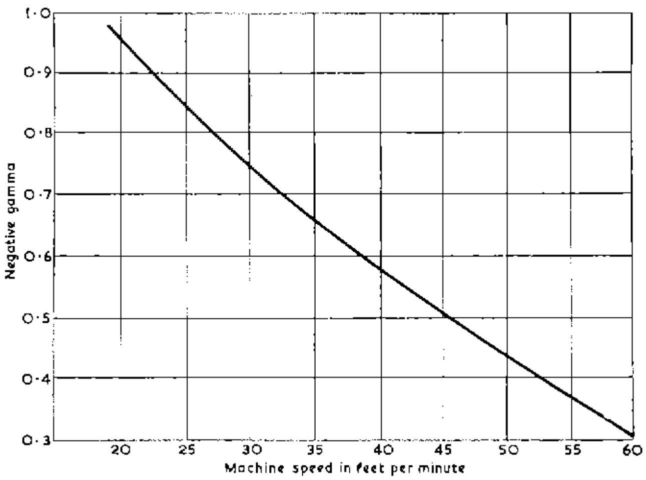

Fig. 4 — Relationship between machine speed and gamma value

7. Constant Performance of the Test Equipment

The processing machines at Alexandra Palace are used to check the adjustment of telerecording equipment in so far as they affect the density distribution produced on the ten-step wedges created by that equipment. Variations in the production of such telerecording wedges approach the tolerances likely to be encountered in the sensitometer and the densitometer used to check the processing machines.

Because of this, a series of tests were made to establish the reproducibility of exposures via the Type X6 sensitometer, and also the degree of variations to be expected in making density measurements on the line densitometer.

TABLE 1

ALEXANDRA PALACE PROCESSING

	Test Strip Number											
	1	2	3	4	5	6	7	8	9	10	11	12
	0·32	0·32	0·32	0·31	0·32	0·31	0·32	0·32	0·32	0·32	0·32	0·32
S	0·33	0·33	0·33	0·33	0·33	0·33	0·33	0·33	0·33	0·33	0·33	0·33
T	0·37	0·37	0·37	0·36	0·37	0·37	0·37	0·37	0·37	0·37	0·37	0·37
E	0·43	0·43	0·44	0·43	0·44	0·44	0·44	0·44	0·44	0·44	0·44	0·44
P	0·52	0·52	0·53	0·53	0·53	0·53	0·53	0·53	0·53	0·53	0·53	0·53
	0·63	0·63	0·64	0·63	0·64	0·64	0·64	0·64	0·64	0·64	0·64	0·64
D	0·75	0·75	0·76	0·76	0·77	0·77	0·77	0·77	0·77	0·77	0·77	0·77
E	0·87	0·88	0·89	0·89	0·89	0·89	0·89	0·90	0·90	0·90	0·90	0·89
N	0·98	0·99	0·99	1·00	1·00	1·00	1·00	1·00	1·01	1·00	1·00	0·99
S	1·07	1·09	1·10	1·09	1·11	1·10	1·10	1·11	1·11	1·10	1·10	1·10
I	1·19	1·20	1·21	1·21	1·21	1·21	1·21	1·22	1·23	1·22	1·21	1·21
T	1·30	1·31	1·31	1·32	1·33	1·32	1·33	1·33	1·33	1·32	1·32	1·33
I	1·40	1·41	1·42	1·43	1·44	1·42	1·42	1·43	1·44	1·44	1·43	1·42
E	1·49	1·51	1·52	1·52	1·53	1·50	1·53	1·52	1·53	1·54	1·52	1·52
S	1·59	1·60	1·62	1·62	1·63	1·60	1·63	1·63	1·61	1·64	1·62	1·62
	1·69	1·71	1·73	1·72	1·74	1·72	1·73	1·73	1·72	1·74	1·72	1·72

TABLE 2

COMMERCIAL PROCESSING

	Test Strip Number											
	1	2	3	4	5	6	7	8	9	10	11	12
	0·35	0·35	0·35	0·35	0·35	0·35	0·35	0·35	0·35	0·35	0·35	0·35
S	0·39	0·39	0·40	0·39	0·40	0·39	0·39	0·40	0·40	0·40	0·40	0·40
T	0·47	0·47	0·48	0·47	0·48	0·47	0·47	0·47	0·47	0·47	0·48	0·47
E	0·57	0·57	0·57	0·57	0·58	0·56	0·56	0·57	0·57	0·56	0·57	0·56
P	0·68	0·68	0·68	0·68	0·69	0·67	0·67	0·67	0·68	0·67	0·68	0·68
	0·81	0·80	0·80	0·79	0·81	0·79	0·79	0·79	0·80	0·79	0·80	0·80
D	0·94	0·93	0·92	0·92	0·94	0·92	0·91	0·92	0·93	0·93	0·92	0·92
E	1·02	1·01	1·01	1·01	1·02	1·01	1·00	1·01	1·01	1·02	1·01	1·01
N	1·12	1·12	1·11	1·12	1·12	1·11	1·11	1·12	1·12	1·12	1·12	1·12
S	1·24	1·23	1·23	1·23	1·23	1·22	1·22	1·23	1·23	1·23	1·23	1·23
I	1·34	1·34	1·33	1·33	1·34	1·33	1·33	1·34	1·34	1·34	1·33	1·33
T	1·44	1·45	1·43	1·44	1·45	1·43	1·43	1·45	1·44	1·44	1·44	1·44
I	1·54	1·55	1·53	1·54	1·55	1·53	1·53	1·54	1·54	1·53	1·54	1·54
E	1·63	1·65	1·62	1·64	1·66	1·64	1·62	1·65	1·65	1·65	1·65	1·65
S	1·76	1·78	1·74	1·74	1·77	1·76	1·74	1·76	1·76	1·76	1·76	1·76
	1·87	1·91	1·87	1·86	1·89	1·88	1·86	1·87	1·89	1·88	1·89	1·89

7.1 *Reproducibility of the Sensitometer*

Any test carried out to check the reproducibility of a sensitometer must be independent of variations in the film-processing machine and in the densitometer used to measure the results.

Variations in the reproducibility of the processing machine were eliminated in two ways. Firstly, twelve sensitometric exposures were made along a single length of F.P.3 film. Whilst making this series the sensitometer lamp-carriage was arranged to travel first to the right and then to the left for each successive exposure. The whole length of film was then processed in one operation. Secondly, a further series of exposures, identical to the first, was then made and sent to the commercial laboratory for processing in one operation.

The densities of each test strip were each measured three times on each of three successive days and the average of each set of nine readings was taken to be the true density of the step.

Table 1 shows the results achieved when such a film is processed on the Lawley 16-mm machines at Alexandra Palace whilst Table 2 shows similar results achieved when such a film is processed at a commercial laboratory. The fact that the whole density range is raised very slightly by processing at the commercial laboratory is of no importance to this test and is explained under Section 9.

The densities read on these strips correspond to all the steps between the sixth and twenty-first steps on the wedge inclusive.

These data can be easily compared by averaging the deviation produced on all twelve strips at each step, extracting a tolerance figure, the average deviation, and the maximum deviation. These results are shown in Table 3.

TABLE 3

Step Number	Alexandra Palace		Commercial Laboratory	
	Average Density	*Density Deviation*	*Average Density*	*Density Deviation*
6	0·32	0·005	0·35	0·000
7	0·33	0·000	0·40	0·005
8	0·37	0·005	0·47	0·005
9	0·44	0·005	0·57	0·010
10	0·53	0·005	0·68	0·005
11	0·64	0·005	0·80	0·010
12	0·77	0·010	0·93	0·015
13	0·89	0·015	1·01	0·010
14	1·00	0·015	1·12	0·005
15	1·10	0·020	1·23	0·010
16	1·21	0·020	1·34	0·005
17	1·32	0·014	1·44	0·010
18	1·43	0·030	1·54	0·010
19	1·52	0·025	1·64	0·020
20	1·62	0·025	1·76	0·020
21	1·72	0·025	1·89	0·025
Average Deviation		0·014		0·010
Maximum Deviation		0·025		0·025

These results show very close agreement between density deviations produced either by processing at Alexandra Palace or the commercial laboratory and argue strongly that, although very small, they are genuine deviations due to the sensitometer and not to variations in the degree of development. In general the results of this test show that one must expect the following deviations due to the sensitometer:

At densities between 0·30–0·60 deviation = ±0·005
,, ,, ,, 0·60–1·10 ,, = ±0·010
,, ,, ,, 1·10–1·50 ,, = ±0·015
,, ,, ,, 1·50–1·70 ,, = ±0·020
,, ,, above 1·70 ,, = ±0·025
Average deviation for the whole density range = ±0·012

It must be remembered that this error is revealed when F.P.3 negative film is processed to a gamma of 0·65. When 8374 telerecording film is processed to a gamma of 1·0 the average deviation will be of the order of 0·018. Thus, in round figures it is fair to say that, when processing to a motion picture gamma of 0·65, the average density error due to the sensitometer is 0·01 and, when processing to a telerecording negative gamma, the average density error due to the sensitometer is 0·02.

7.2 *Reproducibility of the Densitometer*

This factor was checked by reading the same sensitometric wedge twenty-five times, each reading being made on a different day and after the densitometer had been recalibrated each morning. All the readings were made by the author and, therefore, do not contain any person-to-person errors in calibrating the densitometer.

Table 4 shows the minimum and maximum density readings achieved on all the steps which were measured, together with average step densities and the deviation from these averages. These results are obtained from the sixteen steps between step 6 and step 21 on each of twenty-five readings—thus they cover 400 readings in all.

Here again it is seen that the density deviation increases as the average density also increases in a similar pattern to that found in testing the sensitometer. The average deviation for the density-range covered by the test is 0·015 which is within the accuracy claimed by the manufacturers of the densitometer.

Unlike the tests on the sensitometer, readings of density are not in any way affected by the gamma to which the negative is processed and, therefore, the average deviation will hold good for both motion picture and telerecording negatives.

TABLE 4

Wedge Step No.	*Minimum Density*	*Maximum Density*	*Average Density*	*Density Deviation*
6	0·31	0·32	0·315	±0·005
7	0·33	0·34	0·335	±0·005
8	0·37	0·38	0·375	±0·005
9	0·43	0·44	0·435	±0·005
10	0·51	0·53	0·520	±0·010
11	0·62	0·65	0·635	±0·015
12	0·74	0·77	0·755	±0·015
13	0·86	0·90	0·880	±0·020
14	0·99	1·00	0·995	±0·005
15	1·08	1·11	1·095	±0·015
16	1·20	1·23	1·215	±0·015
17	1·32	1·35	1·335	±0·015
18	1·43	1·47	1·450	±0·020
19	1·54	1·58	1·560	±0·020
20	1·66	1·71	1·685	±0·025
21	1·80	1·84	1·820	±0·020

Telerecording negatives are processed to a control gamma of 1·0 at Alexandra Palace and the densities achieved on selected steps on the wedge are maintained within certain tolerances. Because of this it is useful to know the combined errors created by sensitometer exposure and densitometer measurement in order to relate the control tolerances to practical conditions.

Fig. 5 shows the sum of the errors in these two instruments at all levels of density between 0·30 and 1·80 as created when developing F.P.3 picture negative to a gamma of 0·65 and when developing Type 8374 telerecording negative to a gamma of 1·0.

This figure is very important and illustrates, for example, that tolerances applied to the 10 per cent step on a ten-step wedge in telerecording tests can be much closer than must be allowed at the peak-white level. This point is discussed more fully in Section 10.2 but if, for the moment, it is assumed that the 10 per cent step results in a density of 0·35 this density could be achieved within a tolerance of ±0·015, whereas if the peak-white density is 1·45 this density may be expected to 'wander' by as much as ±0·055.

Before leaving this figure it must be remembered that the deviations shown therein are achieved under rigid control of precise developer temperature and absolute machine speed. The deviations obtained under practical operator-conditions are wider than shown in Fig. 5.

8. The Operator-factor in Machine Control

Several factors, both in setting exposures on the sensitometer and in operating the Lawley processing machine, remain liable to errors on the part of the operators. These can combine to produce control density step wedges and, of course, day-to-day film processing, which vary between wider limits than those indicated thus far. The main factors which, when misjudged, can cause these variations are as follows:

(*a*) Sensitometer lamp voltage adjustment
(*b*) Processing machine speed adjustment
(*c*) Developer temperature adjustment and control
(*d*) Film path-length in the developing solution
(*e*) Accuracy of mixing the developing solution.

Because of this, a series of sensitometric wedges were exposed and processed by the operating staff as routine daily tests. These were afterwards measured by them on the line densitometer so that the resultant densities include all the 'operator-errors' likely to be met in practice.

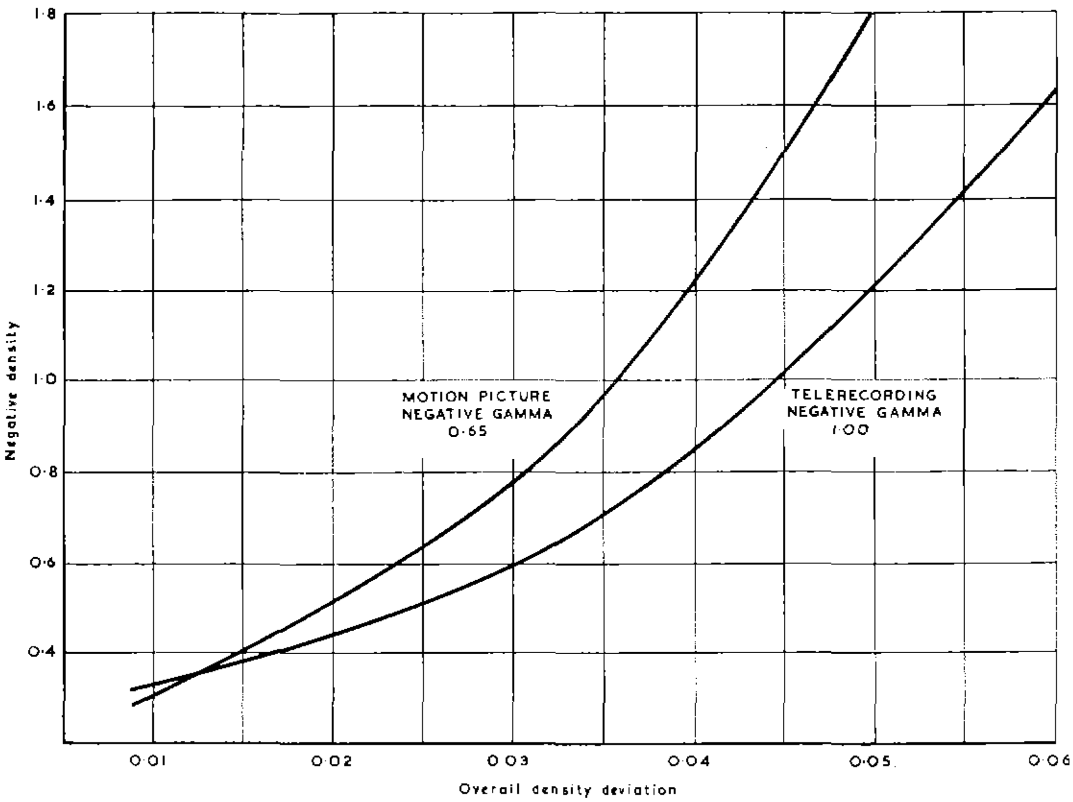

Fig. 5 — Overall variation in measured density due to sensitometer and densitometer combined

The analysis of this work covers 35 Type X6 sensitometric wedges made on Type 8374 telerecording film, and involved 735 individual density readings. Table No. 5 shows the average densities obtained on each step of these wedges, together with the deviation occurring at each density.

TABLE 5

Step No.	*Average Density*	*Density Deviation*
1	0·22	±0·010
2	0·24	±0·015
3	0·27	±0·025
4	0·34	±0·035
5	0·44	±0·030
6	0·56	±0·040
7	0·72	±0·050
8	0·92	±0·050
9	1·10	±0·075
10	1·30	±0·085
11	1·49	±0·085
12	1·68	±0·090
13	1·83	±0·110
14	1·98	±0·125
15	2·10	±0·120
16	2·21	±0·120
17	2·31	±0·120
18	2·39	±0·120
19	2·46	±0·120
20	2·51	±0·120
21	2·57	±0·120

The average density deviation over the effective range of interest (0·30–1·80) is 0·06—four times greater than can be achieved with rigid control. Some increase in average deviation must be permitted in a rapid processing service such as that associated with Television News and, naturally, the ability quickly to control several factors to close tolerances is only acquired after considerable experience in this type of work.

Fig. 6 shows the combined sensitometer, densitometer, and operator deviations as they affect densities over the range 0·30–1·80 both for a negative gamma of 0·65 and 1·00 and these are, in effect, the 'working tolerance curves' for the overall processing conditions as currently employed.

The curves shown in Fig. 6 are very important indeed and are fully recognized when specifying density requirements on routine production work. Their effect is shown below, where two density levels are required both on motion picture negatives processed to a gamma of 0·65 and on telerecording negatives processed to a gamma of 1·0.

Required Negative Density	*Practical Working Tolerances*	
	at gamma 0·65	*at gamma* 1·00
0·35	±0·02	±0·03
1·45	±0·06	±0·09

9. Comparison between Processing at Commercial Laboratories and at Alexandra Palace

It sometimes happens that film may be sent to commercial laboratories for original development—usually when it is known that a print of the material will be required, although

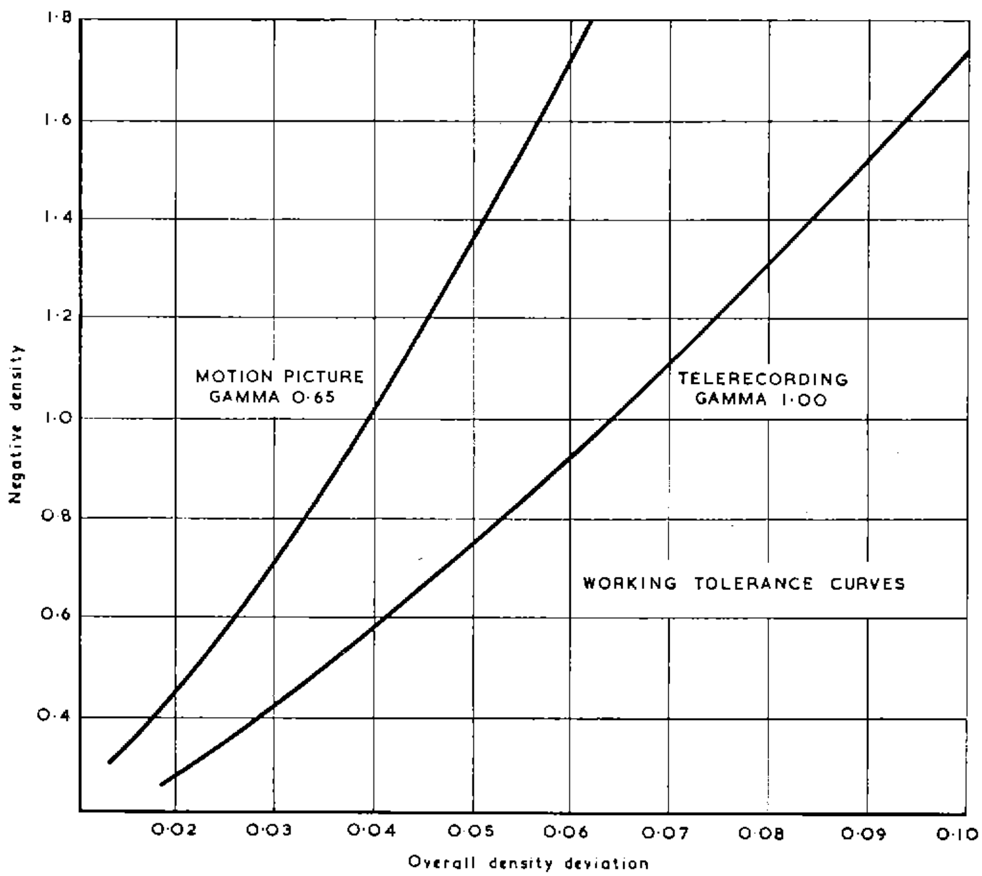

Fig. 6 — Overall variation in measured density due to sensitometer, densitometer, and operator combined

this knowledge is not always available at the time the film is being exposed. It is therefore most important that the cameramen or telerecording operators should know of any differences in the optimum exposure required to produce similar results from either laboratory.

Because of this, twelve Type X6 sensitometric strips were made on F.P.3 film and were processed to a gamma of 0·65 on the 16-mm machine at Alexandra Palace and a similar quantity were also processed at commercial laboratories. Fig. 7 shows the average curve produced at each laboratory. It is important to remember that the log-exposure increments on the Type X6 sensitometer have been correctly plotted in the increments of the wedge contained in that machine.

It will be seen that, apart from the slightly sharper toe in the curve from the commercial laboratories, the two curves are substantially parallel. However, the effective emulsion speed is increased when the film is processed at the commercial laboratories. This causes the curve from the commercial laboratories to be located more to the left than that from Alexandra Palace. It is also noticeable that, for any value of density within the straight-line portions of the two curves, the difference in speed is $\sqrt{2}$. This is equivalent to an alteration of half a stop to the lens diaphragm setting on the camera.

It is not at all surprising that this speed difference exists—comparison tests between a number of commercial laboratories show similar differences. They are the result of differences in the temperature and the composition of the developing solution, the film length, and its speed through that solution. Naturally these factors vary from one laboratory to another and on one type of machine to another although, in all cases, it is possible to achieve identical values of gamma or contrast.

Similar tests have also been carried out when using Type 8374 telerecording film processed to a gamma of 1·0. Here again, speed difference of approximately $\sqrt{2}$ was detected whilst, in all other respects, the curves remained similar. Details of this comparison are given in Section 10.2.

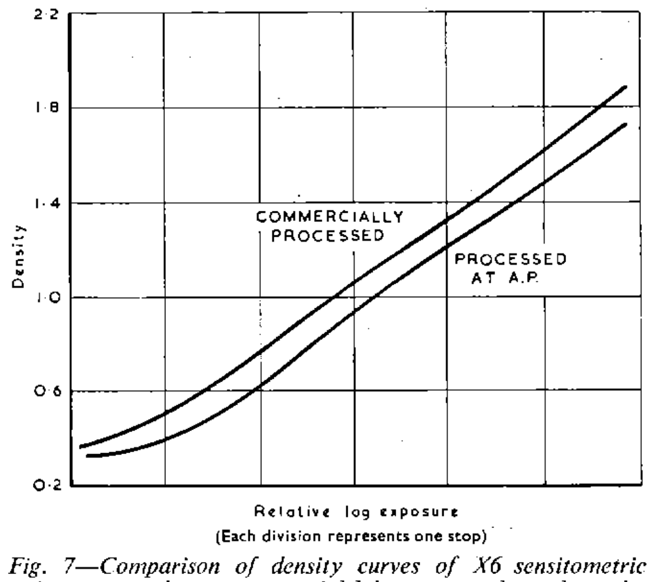

Fig. 7—Comparison of density curves of X6 sensitometric strips processed at a commercial laboratory and at Alexandra Palace

10. Sensitometry Applied in Practice at Alexandra Palace

It has been shown that the exposing of sensitometric strips and the subsequent measurement of the density wedges after processing are relatively simple operations. With reasonable care and attention the reproducibility and consequent control of machine characteristics can be as high as the inherent accuracy of the equipment but, in practice, this is not likely to be achieved under conditions prevailing in a rapid Television News service.

Whilst those variations which do occur are certainly well within the tolerances acceptable for news material, every effort is made to reduce them by vigilant control when telerecording work is handled since the alignment of the channel is based upon a ten-step wedge processed in the Lawley machine.

The processing machine operators record the daily variations in gamma and also the density of two steps on a sensitometric exposure made on F.P.3 film. This exposure is processed each morning and as soon as the new bath of developer has attained working temperature.

The measurement of gamma—or the angle between the straight-line portion of the characteristic curve and the log-exposure axis—is one factor which is very dependent upon the operator. It can be easily achieved by measuring ten units to the right and along the log-exposure axis from the point where the straight-line cuts it and then, from this new position, measuring the vertical units between the axis and the characteristic curve. This vertical reading is then automatically the tangent of the angle, or gamma. However, in practice, difficulty is experienced in deciding the most accurate curve to draw between a series of points, and then to establish a straight line in the most favourable relationship to this curve.

Experience has shown that greater accuracy is obtained by always reading the gamma-value between the densities created at two specific steps on the sensitometric wedge. With F.P.3 film, step 9 and step 19 are used for this purpose. The log-exposure difference between these two steps on the particular wedge fitted to the sensitometer is 1·51. Any value of gamma is then found from the following formula:

$$\text{Gamma} = \frac{D_{19} - D_9}{1\cdot51}$$

From this it has been possible to produce the graph shown in

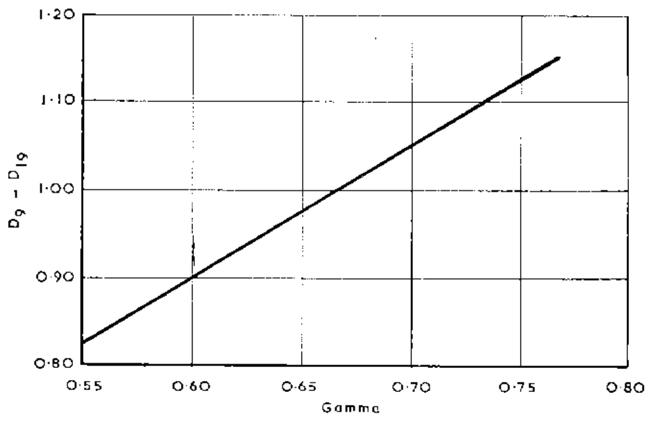

Fig. 8 — Graph enabling gamma-value to be derived directly from two readings of density on F.P.3 film

Fig. 8 and to enable the operator to read gamma directly from his knowledge of the two densities and without the need to plot the actual characteristic curve at all.

The developing solution is discarded each day and well before it deteriorates beyond the point which would cause a drop of 0·02 on a gamma of 0·65, or 0·02 on a density of 0·70. Because of this it is sufficient to make a daily 'check-test' on the sensitometric conditions as applied to the most widely used negative film and, unless any unusual condition is noticed, similar daily tests are not made on every emulsion currently in use for Television News purposes.

Batch-to-batch variations in motion picture negative materials may be safely accommodated by a periodic sensitometric test on all emulsions.

10.1 *Sensitometric Control of Negative Emulsions*

Ilford Types F.P.3, H.P.3, and H.P.S., and also Kodak Types Plus-X and Tri-X emulsions are all currently used by the Television News cameramen.

In every case the film is processed to a control gamma of 0·65. This gamma is measured between two density steps which, although different on each film, all occur on the straight-line portion of the respective characteristic curves.

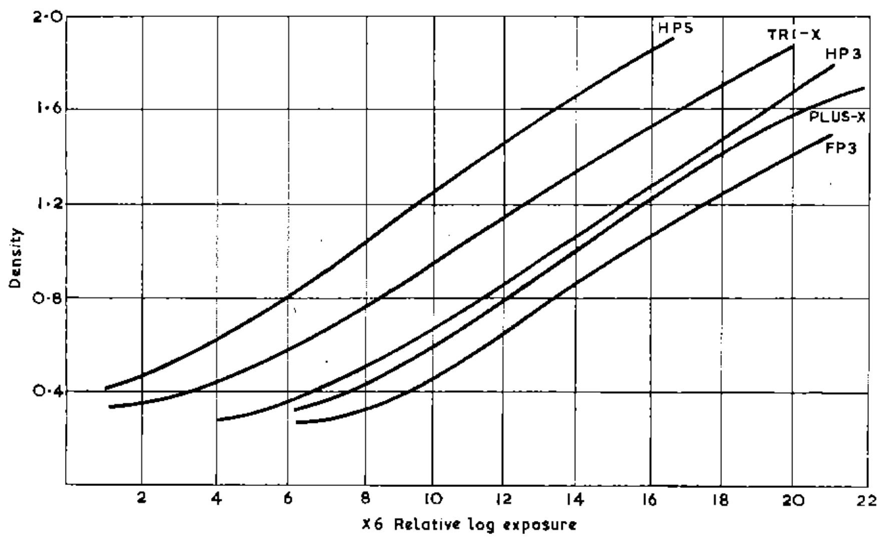

Fig. 9 — Comparison of negative emulsions processed in Lawley 16-mm sprocket-driven machine to gamma 0·65 using Teknol developer diluted to one part in six at 73°F and with the lower film cradles raised by one inch

The control conditions have been summarized for the operators and appear in the form of a chart attached to each processing machine. Such a chart is reproduced below:

TABLE 6

Film Type	*Nominal Machine Speed (ft/min.)*	*Required Gamma*	*X6 Steps Measured*
F.P.3	53	0·65	9–19
H.P.3	36	0·65	8–17
H.P.S.	20	0·65	6–16
Plus-X	65	0·65	8–18
Tri-X	35	0·65	8–18
8374-Neg.	39	1·00	4–11
8374-Pos.	34	1·10	4–11
8374-T.A.T.	29	1·20	4–11
16-mm Sprocket-driven Machine No. 1635001.			
All lower rollers 1 in. from bottom. Dev. Temperature = 73°F			

These machine speeds were achieved by making a family of characteristic curves for each emulsion and then, from this family, extracting a 'time-gamma' curve to establish the precise speed at which to achieve the required gamma. A further sensitometric test was then made at the chosen speed to check the previous work.

The ultimate tests on each emulsion—all processed to a gamma of 0·65—are shown in Fig. 9. These curves are all plotted against the same log-exposure base and, therefore, demonstrate the relative photographic speeds of these emulsions when processed in this manner.

The relationship between the various operations and the complete processing cycle at all machine speeds in the Lawley machine is shown in Fig. 10. The total time required to process a given film of any length at a range of machine speeds is indicated in Fig. 11. Both these figures are consulted when establishing the machine speed for any uncommon emulsion, firstly to ensure that adequate fixing and washing times will be provided, and secondly, to ensure that the total processing time will not be unduly long.

10.2 *Sensitometric Control of Telerecordings*

Telerecordings are made at Alexandra Palace on fast-pull-down cameras and by using Type 8374 film. When negative images are recorded the film is processed to a control gamma of 1·0 and when direct-positive images are recorded, this gamma is raised to 1·10.

Processing variations always increase as the control gamma increases and, therefore, compared with news-film negatives controlled at a gamma of 0·65, it is more difficult to maintain this type of work to a given requirement. Type 8374 film is prone to considerable batch-to-batch variations which require the processing machine speed and the telerecording camera exposure to be adjusted for each batch of film.

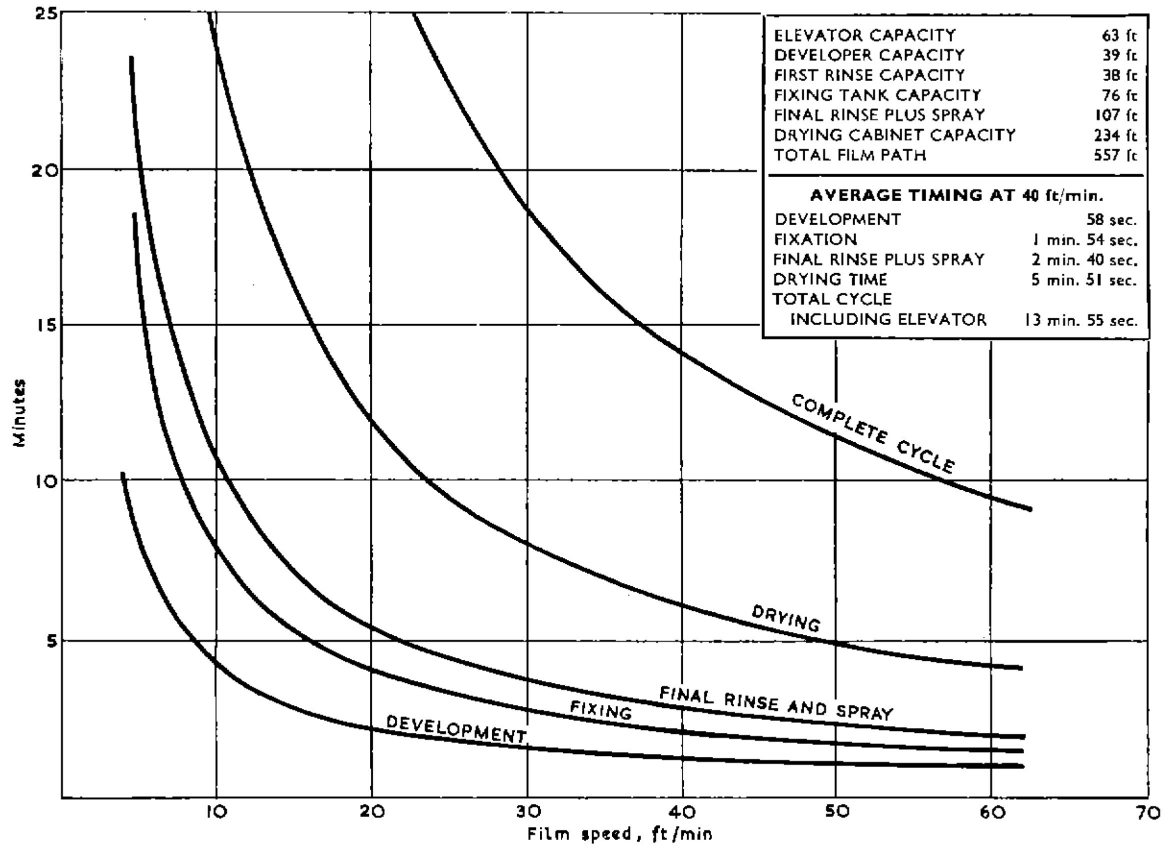

Fig. 10 — Times required for each processing operation, together with times for the complete cycle, at different machine speeds

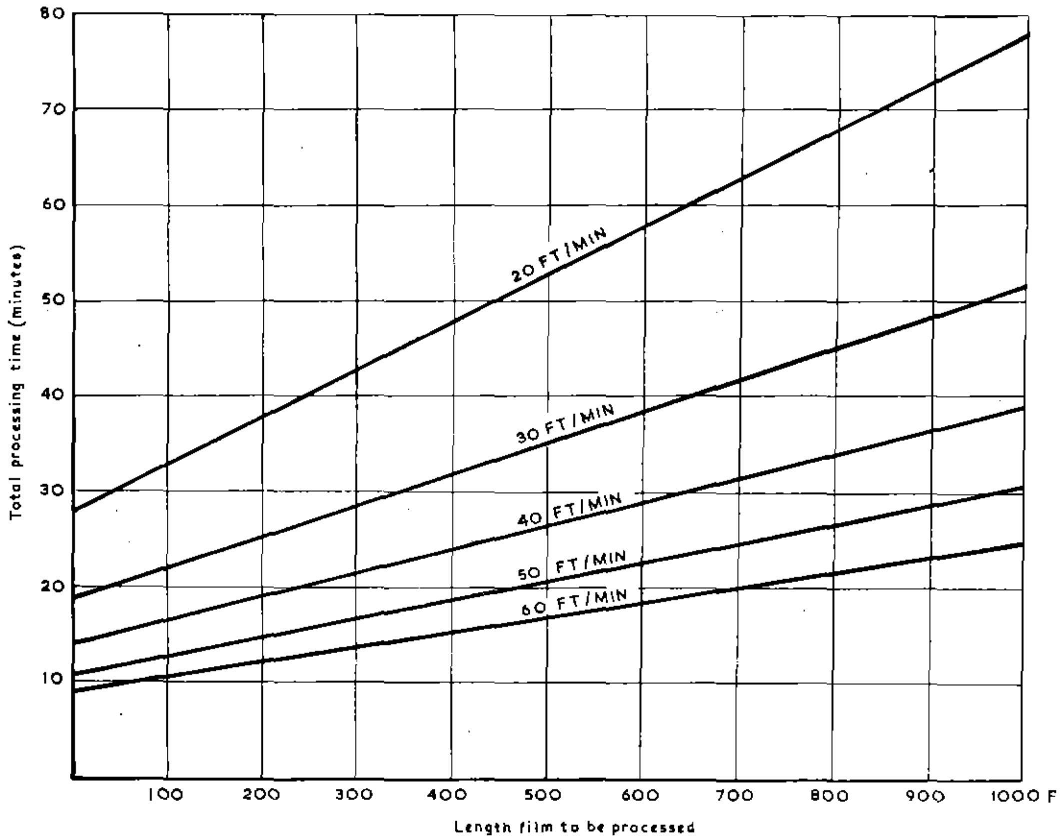

Fig. 11 — Total time required to process a film of given length at various machine speeds

Control of the process is maintained by two step-wedge exposures. Firstly, the conventional Type X6 sensitometric exposure is used to establish the gamma to which the film is processed. Secondly, a 'ten-step' wedge is made in the tele-recording camera to establish the resultant density and gamma when processed under these conditions. The step wedge provides increments of exposure up to peak-white and is so adjusted that, when processing is correct, peak-white exposure produces a density of 1·50.

A gamma of 1·0 is required in the processed film. It follows that, if a density of 1·50 is achieved on the eleventh step on the X6 sensitometric wedge, a density of 0·43 must be produced on the fourth step of that wedge. This is because the log-exposure increment between these two steps is known to be 1·07 on the wedge fitted to the sensitometer and, of course, 1·50–0·43 is also 1·07, thus resulting in a gamma of 1·0. This point is clearly shown in Fig. 12.

Under these conditions it is possible to fix working tolerances to both the densities achieved at two selected steps on the wedge and also to the differences between these densities.

Naturally, it is unlikely that any particular step on the X6 wedge will be precisely at a density of 1·50 and, under such circumstances, one selects that step which is nearest to this

Log E steps used	*Density difference*	*Log E steps used*	*Density difference*
1–8	1·10	5–12	1·08
2–9	1·11	6–13	1·08
3–10	1·06	7–14	1·07
4–11	1·07		

density—apart from processing errors this selection will be greatly influenced by variations from batch-to-batch in the film stock. The table shown indicates the log-exposure between a series of pairs of steps on the wedge—each pair being separated by seven steps.

Thus, if the batch of film is so fast that a density of 1·50 is most nearly approached by step 8 then, since the log-exposure between steps 1 and 8 is 1·10, it is necessary to achieve a density difference of 1·10 between these steps (regardless of their actual density) in order to obtain a gamma of 1·0. Alternatively, if the batch of film is so slow that the log-exposure between steps 7 and 14 is only 1·07, the density difference of 1·07 must be achieved between these two steps in order to maintain a gamma of 1·0.

It is in this respect that sensitometry by means of the Type X6 instrument is somewhat different to a similar control by the Type IIb. In the Type IIb instrument all log-exposure increments are exactly $\sqrt{2}$ and, therefore, the increments between *any* seven steps will always be 1·05, and a gamma of unity is achieved when a density difference of 1·05 is obtained between any seven steps within the straight-line portion of the curve. Practical examples of the difference between these instruments are shown below and were taken from actual working records:

IIb Sensitometer		*X6 Sensitometer*	
10th Step Density	= 1·52	11th Step Density	= 1·47
3rd Step Density	= 0·43	4th Step Density	= 0·38
$D_{10} - D_3$	= 1·09	$D_{11} - D_4$	= 1·09
Log *E* (3rd–10th)	= 1·05	Log *E* (4th–11th)	= 1·07
Gamma	$= \frac{1 \cdot 09}{1 \cdot 05}$	Gamma	$= \frac{1 \cdot 09}{1 \cdot 07}$
	= 1·05		= 1·02

Referring now to the 'working tolerance curve' shown in Fig. 6, it is seen that on a peak-white density of 1·50 at a gamma of 1·00 the deviation to be expected in practice is ±0·095 (this must be taken as ±0·10 since readings of 0·005 are not valid).

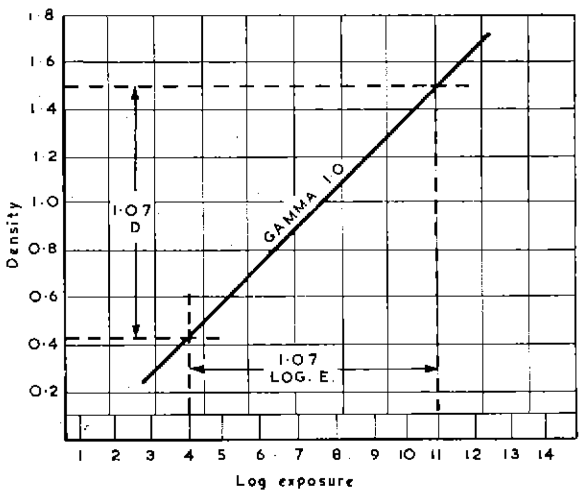

Fig. 12 — Density range of Type 8374 negative when processed to gamma of 1·0

Similarly, at a 10 per cent density of 0·43 a deviation of 0·04 must be permitted. These conditions are summarized below:

	Peak-White	*10 per cent*
Required Density	1·50	0·43
Upper Working Tolerance	1·60	0·47
Lower Working Tolerance	1·40	0·39

These figures also imply that a deviation in gamma will result from these working tolerances; this has been calculated assuming the required density range is measured between the fourth and eleventh steps:

Required Gamma	1·00
Upper Working Tolerance	1·06
Lower Working Tolerance	0·94

Finally, a comparison has been made between telerecording processing control via Type IIb and Type X6 sensitometry both at commercial laboratories and at Alexandra Palace.

Until the Lawley 16-mm sprocket-driven processing machines were thoroughly tested (and their reproducibility had been established) most telerecordings made at Alexandra Palace were processed at commercial laboratories. The method of calibrating the recording channel to establish peak-white and 10 per cent densities on the film had been based upon the degree of contrast achieved when the film was processed to a IIb control gamma of 1·0.

It therefore seemed logical to compare the resultant curves obtained when the following sensitometric exposures and processing conditions were employed:

(*a*) A IIb sensitometric exposure made at the commercial laboratory and processed by them

(*b*) A IIb sensitometric exposure made at the commercial laboratory and processed at Alexandra Palace

(*c*) An X6 sensitometric exposure made at Alexandra Palace and processed at Alexandra Palace.

The results of these tests are shown in Fig. 13. The commercial laboratories produced a gamma of 0·99, Alexandra Palace produced a gamma of 0·97 on the IIb test and 1·01 on the X6 test. Because the differences between these results are so small the curves both in this figure and in Fig. 14 have been expanded to twice the normal scale.

The two exposures processed at Alexandra Palace show remarkable agreement, whilst that processed at the commercial laboratory shows the characteristic speed increase of approxi-

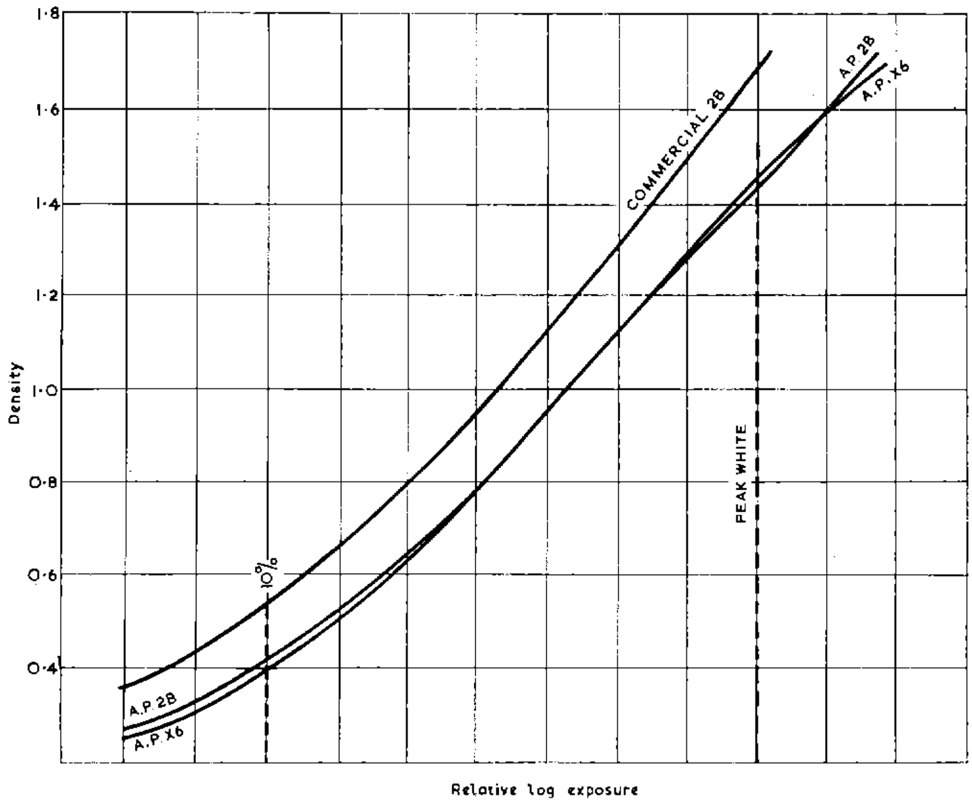

Fig. 13 — Comparison of telerecording processing tests on Type 8374

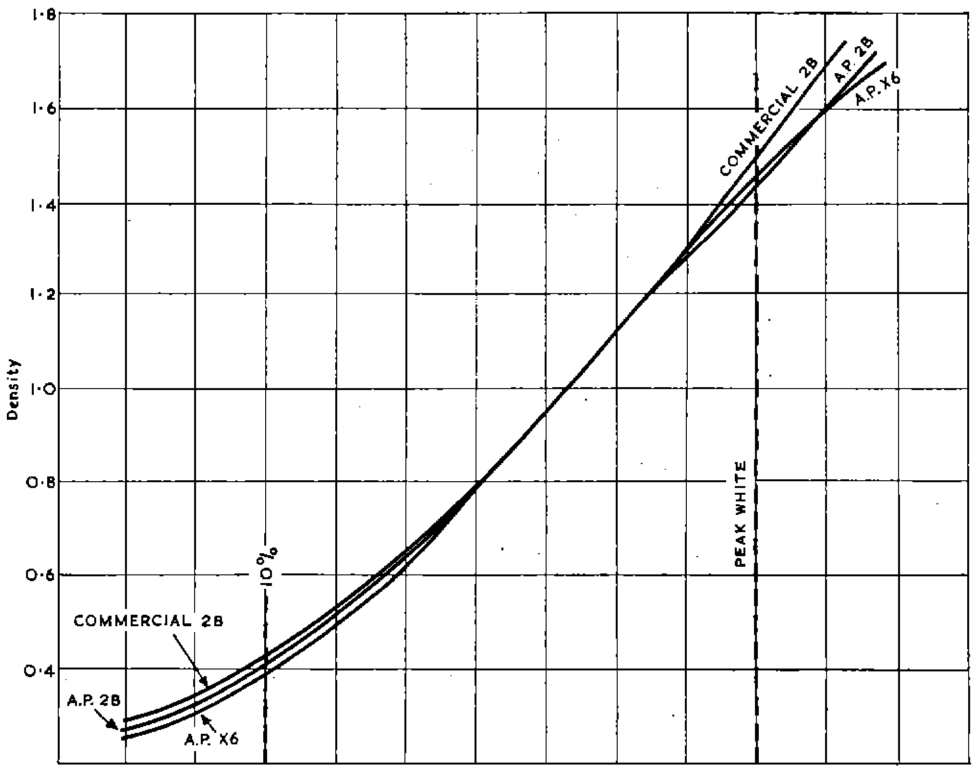

Fig. 14 — Comparison of telerecording processing tests on Type 8374 after allowing for speed differences caused by the developer used in each laboratory

mately half a stop mentioned previously (Section 9). Because of this it is more convenient to compare the results after moving the Alexandra Palace curves bodily to the left along the log-exposure axis so that they coincide with that produced at the commercial laboratory. Such manipulation is equivalent to a change in exposure only and illustrates the condition which exists when—as must happen in practice—the exposure is increased on the telerecording camera for films which are to be processed at Alexandra Palace.

When this is done the results are as seen in Fig. 14. Here it is apparent that a slight falling away at the higher densities in the Alexandra Palace processing is offset by the higher and more curved 'toe' in the commercial processing. This implies that, whilst Alexandra Palace processing may tend slightly to crush white (on negative recordings) more than commercial processing, so also will commercial processing tend to crush black slightly more than Alexandra Palace.

It is, of course, mainly important that the control at Alexandra Palace via the X6 sensitometer should be equivalent to similar control at the commercial laboratory via the IIb sensitometer. To compare this, two levels of exposure separated by seven $\sqrt{2}$ steps are shown in Fig. 14 to represent the relative exposures of 10 per cent and peak-white. The density differences obtained by this means are more important than the actual densities themselves and are shown below:

	10%	*P.W.*	$D-D^2$
IIb strip processed at Commercial Laboratories	0·43	1·51	1·08
X6 strip processed at Alexandra Palace	0·39	1·46	1·07

Thus, providing the exposure level is adjusted according to the laboratory employed, virtually identical results may be achieved on Type 8374 telerecording films either at the commercial laboratories or at Alexandra Palace.

11. Conclusions

A system of sensitometric control has been established and is fully explained in this Monograph. It has been shown that film can be processed at Alexandra Palace to tolerances as close as those imposed on commercial laboratories. At the same time it is recognized that the urgent requirements of processing negative film for the news service may be compared to the daily 'rush-print service' employed in the film industry. Such a service is only possible when the quality of the picture is allowed to fall below that expected when time can be devoted to grading a release print.

In this Monograph the term 'working tolerance' has been used to describe the difference between results obtained when rigid control is applied throughout the system or when normal high-speed operation is permitted. It is due to the degree of care and skill exercised and the time taken in adjusting the variables encountered when operating the sensitometer, the processing machine, and the densitometer and in plotting and interpreting the final results.

It has been shown that, to obtain consistent results, it is necessary to control the following factors:

(*a*) The batch-to-batch variations in developing solution concentration

(*b*) The variations in volume of 'unit-packed' developer supply (*c*) The accurate dilution of the concentrated solution

(*d*) The batch-to-batch variations in photographic speed of the film stock—particularly telerecording Type 8374

(*e*) The exact setting of lamp voltage in the sensitometer

(*f*) Constant check on the developer temperature in the processing machine

(*g*) Precise adjustment of film loop-length in the developing solution

(*h*) Accurate control of processing machine speed

(*i*) Accurate calibration of the densitometer each time it is used and repeated calibration during long periods of constant use

(*j*) Accurate interpretation of density measurements and careful plotting of these measurements.

Under present conditions, including all operational tolerances, films nominally processed to a gamma of 0·65 can be held to within ±0·04, whilst films nominally processed to a gamma of 1·0 can be held to within ±0·06. Corresponding variations in density under these conditions are as follows: a nominal density of 0·40 will be held to within ±0·02 at a gamma of 0·65, or to within ±0·03 at a gamma of 1·0. A nominal density of 1·50 will be held to within ±0·06 at a gamma of 0·65 or to within ±0·09 at a gamma of 1·0.

12. Acknowledgments

Acknowledgment is made to the Director of Engineering of the BBC for permission to publish this paper; to Kodak Ltd for assistance during the initial calibration of the sensitometer, and also to Messrs J. Langham Thompson for their description of the Sorensen voltage regulator.

Erratum

On page 28 of Engineering Monograph No. 32, entitled 'A New Survey of the BBC Experimental Colour Transmissions', in Appendix A, 3.4(e), E_B' should read E_Q'.

Summaries of some recent BBC Patent Applications

PAT. APP. NO. 9616/59

FEEDBACK CLAMP FOR TELEVISION SIGNALS

Inventor D. C. SAVAGE

The statement of invention reads:

According to the present invention a circuit for restoring the D.C. component of a television video signal comprises an input terminal, a sampling stage adapted to sample the level of a recurring element of the signal periodically and produce error signal pulses having amplitudes corresponding to the deviation of this level from a reference potential, means for storing voltages varying in accordance with the said amplitudes throughout substantially the whole of the video signal between the said recurring element thereof and means for applying to the said terminal, in appropriate sense, voltages varying in accordance with the stored voltages.

PAT. APP. NO. 11473/59

IMPROVED NON-LINEAR CIRCUIT FOR TELEVISION SIGNALS

Inventor P. DENBY

The statement of invention reads:

According to the present invention, there is provided a non-linear amplifier comprising an input circuit to which signals to be non-linearly amplified are applied, an intermediate circuit through which the signals from the input circuit are fed to a non-linear circuit including an output element and one or more further elements so arranged as to shunt said output element at a predetermined level or levels of the signals applied to the non-linear circuit, potential biasing means to provide the predetermined potentials for the output shunting element or elements, and an output circuit to which signals from said output elements are applied, said intermediate circuit comprising a pair of electric discharge valves having substantially identical characteristics and corresponding load circuits, said signals being applied to one of said valves, hereinafter referred to as the first valve, to produce at a point in the load circuit thereof a signal for application to the non-linear circuit, the other of said valves, hereinafter referred to as the second valve, being arranged to produce at a corresponding point in the load circuit associated therewith a d.c. component equal to the d.c. component at the point in the first mentioned load circuit in the absence of said signal, and said output element being connected between said points in the two load circuits. Preferably, the valves and the associated load circuits constitute cathode follower circuits, and the output element is connected between the cathodes of the two valves, and preferably the valves are constituted by a double triode or like valve.

PAT. APP. NO. 11896/59

MEANS FOR SYNCHRONIZING A RELAXATION OSCILLATOR OVER A WIDE RANGE OF RECURRENCE FREQUENCIES

Inventor E. R. ROUT

The statement of invention reads:

According to the invention there is provided a circuit including an oscillator and a frequency discriminator adapted to generate from a synchronizing signal applied thereto a control voltage dependent upon the frequency of the synchronizing signal, means for applying the control voltage to the oscillator to vary the free-running frequency thereof in such a manner that the ratio between this free-running frequency and the synchronizing signal frequency is maintained approximately constant, and means for applying the synchronizing signal to the oscillator to effect synchronization thereof.

PAT. APP. NO. 23669/59

CONTROLLED DELAY ARRANGEMENT FOR TELEVISION SIGNALS

Inventors A. V. LORD, R. J. MEARS, E. R. ROUT, and R. F. VIGURS

The statement of invention reads:

According to the present invention apparatus for reducing unwanted low-frequency frequency-modulation in a video signal including line-synchronizing pulses, comprises a delay means adapted to apply the video signal, delayed by successive increments of time, to respective first input terminals of a plurality of gating circuits each further having a second input terminal and an output terminal, the second input terminals being connected in common to a source of reference line-synchronizing pulses and each gating circuit being adapted to pass the signal applied to its first input terminal to its output terminal for the duration of one line interval only immediately subsequent to the application of line-synchronizing pulses to its first and second input terminals which pulses occur at times not separated by more than a predetermined interval approximately equal to the duration of the said successive increments of time.

PAT. APP. NO. 40659/59

TRANSMITTING TELEVISION PICTURES THROUGH A REDUCED BANDWIDTH

Inventor G. F. NEWELL

The statement of invention reads:

According to the present invention there are provided means for dividing a television signal into two or more parts, one of these parts containing components of the signal at frequencies below a predetermined value and another part being a coded signal representative of components of the television signal above the said value but of smaller bandwidth than the television signal components represented thereby, and means for transmitting portions of the said parts in time-interlaced relation.

PAT. APP. NO. 265/60

IMPROVEMENTS IN CLAMP CIRCUITS FOR TELEVISION SIGNALS

Inventor D. C. SAVAGE

The statement of invention reads:

According to the present invention there is provided a television signal clamp circuit having means including a resistance-capacitance network and a switch device for clamping a television signal during recurrent intervals, means for sampling the signal during the said intervals, thereby deriving noise signals occurring in the said intervals, and means for automatically controlling the time constant of the resistance-capacitance network in dependence upon the amplitude of the said noise signals in such a manner that the time constant is increased with increase in noise amplitude.

PAT. APP. NO. 3875/60

IMPROVEMENTS IN THE CONVERSION OF TELEVISION SCANNING STANDARDS

Inventors V. G. DEVEREUX, K. HACKING, and E. R. ROUT

The statement of invention reads:

According to the present invention there is provided apparatus for converting television signals at a first field frequency into approximately corresponding converted signals at a second field frequency different from the first, the first-named signals containing pulses of constant amplitude, wherein the apparatus comprises means for producing a display representative of the first named signals, means for performing a reading scan of the display at the second field frequency, while adjusting the phase of the scanning of the part of the display representative of the said pulses in relation to the scanning of the remainder of the display in such a sense as to advance the pulses in the converted signals relatively to the remainder of the converted signals, the converted signals being amplitude-modulated at a frequency equal to the difference between the first and second field frequencies, and means for applying a control voltage derived from the pulses in the converted signals to vary the amplitude of the converted signals in such a manner as substantially to remove the said amplitude-modulation.

Published by the British Broadcasting Corporation, 35 Marylebone High Street, London, W.1. Printed in England on Basingwerk Parchment in Times New Roman by The Broadwater Press Ltd, Welwyn Garden City, Herts. No. 4354