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Sine-squared pulse and bar testing in colour television

by

L. E. WEAVER, B.Sc., A.M.I.E.E.

(Designs Department, BBC Engineering Division)

PART I

PULSE AND BAR TESTING OF THE CHROMINANCE CHANNEL

PART II

AN AUGMENTED PULSE AND BAR WAVEFORM FOR TESTING THE COMPLETE COLOUR SIGNAL

BRITISH BROADCASTING CORPORATION

PRICE FIVE SHILLINGS

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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.

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SINE-SQUARED PULSE AND BAR TESTING IN COLOUR TELEVISION

SUMMARY

This monograph is a combination in revised form of two technical memoranda, issued during 1964, but not previously available outside the BBC.

Part I describes a programme of work which was carried out with the object of determining how best to adapt sine-squared pulse and bar techniques to the testing of the chrominance region in apparatus and systems which are handling colour television. It was found that only two forms of test-signal need be seriously considered; these were then investigated both theoretically and practically. For the latter purpose a generator was designed and constructed which was capable of providing either signal at will, and comparative tests were then carried out on a wide range of apparatus and links. From these tests it appeared that appreciable waveform distortion of the chrominance test signal is comparatively rare, and that the most important quantities to be measured in practice are luminance-chrominance gain inequality and delay inequality. The accuracy of measurement of both these quantities can be improved considerably by the use of a special measuring set which was designed for the purpose; a description is included in the text.

The tests showed clearly that one of the two test signals has some important practical advantages, and recommendations are made for its adoption and utilization. Under suitable conditions it enables luminance-chrominance gain inequality to be measured to about 0·1 dB, and delay inequality to about 2 ns. A theoretical analysis of this signal is included in the Appendix.

Part II proposes an extension of the test facilities offered by the sine-squared pulse and bar signal by adding to the standard waveform the chrominance pulse described in the first part. The effect of this is to produce an augmented signal which tests in an effective manner both the luminance and chrominance regions simultaneously. For certain purposes, for example the equalization of colour television circuits, this is extremely useful since the simultaneous presentation of the luminance and chrominance information makes possible a better choice of the optimum conditions.

This augmented pulse and bar signal can also be used to advantage in monochrome work, since a certain amount of additional information about the upper part of the video spectrum is afforded by the presence of the chrominance pulse. It is further proposed that this signal could form the basis of an improved test-line signal.

It is suggested that an attempt should be made to devise an overall 'K-rating' system for apparatus handling colour signals which includes both chrominance and luminance performance.

PART I
PULSE AND BAR TESTING OF THE CHROMINANCE CHANNEL

1. Introduction to Part I

The sine-squared pulse and bar method of measuring the linear transmission characteristics of monochrome television links and apparatus has become so firmly established as the most practical and most significant method of carrying out such measurements, that the obvious next step is to investigate whether this method cannot be extended for use with colour television.

Although the normal type of sine-squared pulse and bar signal gives an adequate amount of information about the upper end of the video spectrum when one is dealing with monochrome signals only, this is not by any means adequate for the purposes of transmitting colour signals. For example, a smooth decrease in gain with increasing frequency, provided it is not excessive, may degrade the monochrome picture to a negligible extent, whereas quite a small drop in gain with respect to the lower video frequencies in the neighbourhood of the colour sub-carrier will give rise to a change in the degree of saturation of colours which may be visually very obvious.

Fortunately, whichever of the principal colour television systems is accepted as the European standard, there are two important basic features which they have in common. Firstly the luminance signal, which is also the compatible signal, has the same form as the normal monochrome video signal, and secondly the colour information is carried as a form of modulation of a colour sub-carrier whose frequency, incidentally, has been standardized in Europe. These two signals are added linearly to form the colour picture signal.

It seems evident in view of this that at least two signals are required for the complete testing of a colour television link: the normal sine-squared pulse and bar signal for testing the luminance band, and a lower-bandwidth signal which is modulated on the sub-carrier frequency for testing the chrominance band. In this way the chrominance band can be tested in a completely analogous fashion to the luminance channel.

In principle these two signals should provide the required information about the apparatus or link under test, but in practice, for reasons which will be apparent later, it is desirable to include in addition a low-bandwidth unmodulated signal, which can most conveniently be the sine-squared pulse and bar signal used to modulate the colour sub-carrier. From this point onwards attention will be confined to the chrominance band only, since it is implicit in the principle of a compatible monochrome picture that the testing of the luminance band can be carried out in exactly the same manner as for a normal monochrome system. It appears, therefore, that a suitable waveform for testing the chrominance band must consist at least of (*a*) a sine-squared pulse and bar signal with an appropriate half-amplitude duration and (*b*) the same signal modulated by the colour sub-carrier. Since the information yielded by these two waveforms must be made available either simultaneously or in very rapid sequence in order to ensure that the two output waveforms relate to precisely the same conditions of transmission, it will furthermore be necessary to combine the two waveforms in some manner best designed to provide the information required. This, in fact, turns out to be the crux of the problem.

For the purpose of explaining the use of the chrominance sine-squared pulse and bar signal it will be assumed that an N.T.S.C. system or one of its variants (e.g. PAL) is in use. With SECAM it might be advantageous to use a frequency-modulated test signal, but this is by no means certain. It seems probable, although this would have to be verified by experiment, that the information given by the signals described here would suffice for the measurement of the linear waveform distortion of apparatus handling a SECAM signal.

2. Parameters to be Measured

At this point it is appropriate to consider what actually needs to be known in order to check the linear transmission performance of the chrominance band; that is linear in the sense of excluding any factors which are level-conscious. These linear parameters are:

(i) *Luminance-chrominance gain inequality*
This is the ratio of the gain at the lower video frequencies to the gain in the region of the sub-carrier frequency, and is a measure of the extent to which the saturation of the reproduced colours is correctly transmitted.

(ii) *Luminance-chrominance delay inequality*
This is the difference in mean delay between a signal transmitted at the lower video frequencies and an identical signal which has been transmitted as modulation of the sub-carrier. Any non-zero value of this delay represents an error of registration between the luminance and chrominance components of the picture.

(iii) *Linear waveform distortion of the chrominance signal*
This represents the effect on the waveform of amplitude-frequency and phase-frequency errors in the chrominance region. In practice it is found that such waveform distortion seems to occur much less often than might be imagined. The reason for this may be visualized in broad terms as follows. A not too serious fault at the higher video frequencies in a high-quality system is likely to produce a fairly smoothly progressive variation of gain through the chrominance region, usually a smooth fall-off of the gain. The associated phase characteristic is also likely to deviate in a fairly smooth manner throughout at least the central region, the most important part, of the spectrum of the modulated waveform. If such distortions took the form of straight lines precisely skew-symmetrical with respect to the sub-carrier frequency there would be no waveform distortion, only a change in overall amplitude together with a delay. In practice the curves, although not linear and not precisely skew-symmetrical with respect to the sub-carrier, are sufficiently so for the resulting distortion to be very much lower than would be the case if the test waveform were not double-sideband modulated. This is a rather fortunate circumstance.

(iv) *I-Q cross-talk*
In an N.T.S.C. type system using amplitude modulation with carriers in quadrature, phase errors in the chrominance region can interfere with the decoding process so as to produce a cross-talk signal from the I channel into the Q, and vice-versa. Provided a suitable phase reference is included in the test signal this can easily be measured by the use of a synchronous demodulator of the type used in colour receivers. However, the eye seems to be very tolerant towards this type of distortion, and it seems very probable that this parameter is not of sufficient importance to need individual measurement.

3. General Form of Chrominance Signal

It has been established that the chrominance test signal must comprise a sine-squared pulse and bar signal of relatively low bandwidth and a similar signal which is modulated on the colour sub-carrier. The T parameter of the modulated signal, which to prevent confusion will be designated T_c, ought now to be chosen so that the chrominance region is adequately tested, and here arises a difficulty. The Q component signal in the proposed British standards occupies a symmetrical band with respect to the sub-carrier, which in terms of its 3 dB bandwidth extends approximately 1 Mc/s above and below the sub-carrier frequency. The I component signal, on the other hand, is allocated an asymmetrical band whose upper sideband is only a little wider than that of the Q signal, but whose lower sideband has a 3 dB bandwidth of approximately 2 Mc/s.

There is no completely satisfactory way of dealing with this situation. It would be possible in principle to use two different modulated pulse and bar signals to test the I and Q regions individually, but this would be a very undesirable complication. The compromise which seems most reasonable is to select a value for T_c of $0 \cdot 5\ \mu s$, as was originally proposed by the Post Office,[1] so that the normal test signal, which has a half-amplitude duration of $2T_c = 1 \cdot 0\ \mu s$, occupies a modulated bandwidth of $\pm 1 \cdot 0$ Mc/s. This tests virtually the whole of the Q channel and the most important region of the I channel without the complication of irrelevant distortion due to the upper sideband test-signal spectrum exceeding the upper limit of the video band.

4. Practical Test Signals

After some consideration of the problem as outlined above, it seemed that there are only two major forms of chrominance test signal which need to be taken into account.

The first of these was proposed by the Post Office in 1958.[1] It consists, as is shown in the photograph (Fig. 1), of a chrominance signal and a luminance signal which are carried on successive lines. The first line of the pair in the photograph carries colour sub-carrier 100 per cent amplitude modulated by a pulse and a bar waveform with transitions corresponding to $T_c = 0 \cdot 5$ μs or $2T_c = 1 \cdot 0$ μs. The peak-to-peak amplitude of the modulated wave is 0·7 volt peak-to-peak for a standard 1 volt test signal, and to ensure that it occupies only the amplitude range allocated to the picture-signal component it is placed upon a pedestal of 0·035 volt. For the sake of convenience this will be termed the 'two-line' signal.

In use, this signal is displayed on a waveform monitor which is triggered by every successive line synchronizing pulse so that, in the absence of distortion, the luminance waveform is accurately superimposed upon the upper half of the modulation envelope of the chrominance waveform. This is illustrated in Fig. 2 where, for the sake of clarity, the pulse alone is shown on a larger scale than in Fig. 1. Any displacement between the two signals other than one precise line period and any difference between their levels can then be estimated.

The second waveform is illustrated in Fig. 3 and is formed in the following way. Each of the two signal components of Fig. 1 is repeated at line-repetition rate, instead of half-line-repetition rate as in Fig. 1, and equal amplitudes of the two are linearly mixed in a resistive network. The addition of the positive-going luminance waveform has the effect of raising the lower half of the modulation

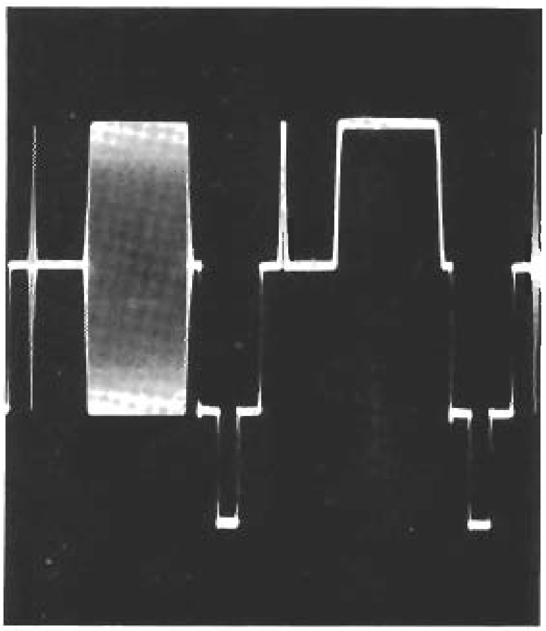


Fig. 1 — The 'two-line' waveform

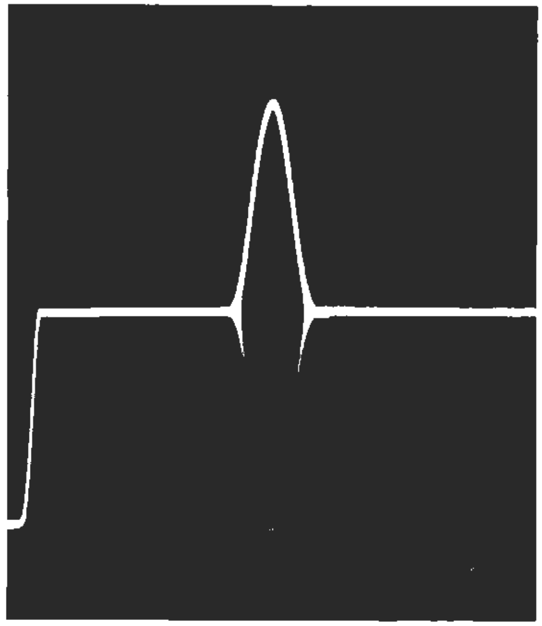


Fig. 2 — Superposition of luminance and chrominance pulses

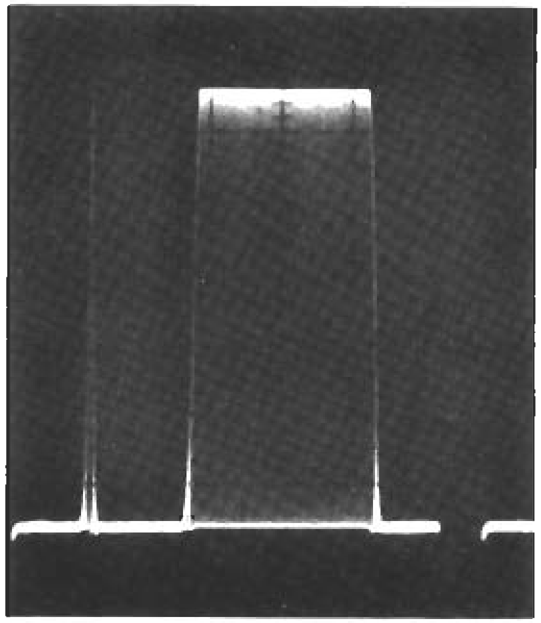


Fig. 3 — The composite waveform

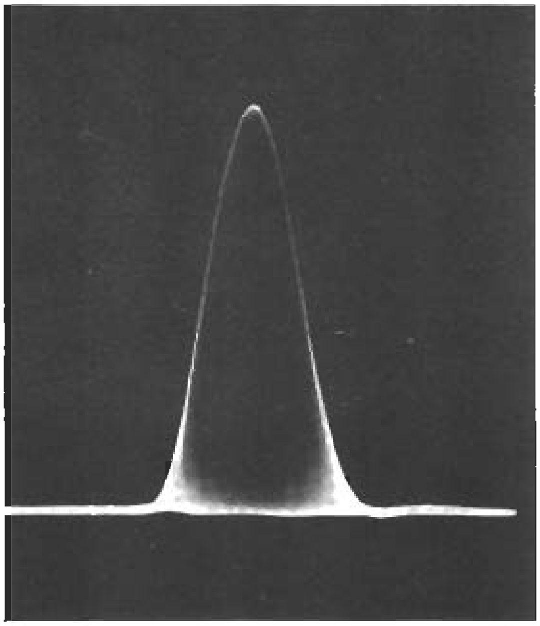


Fig. 4 — The pulse of the composite waveform

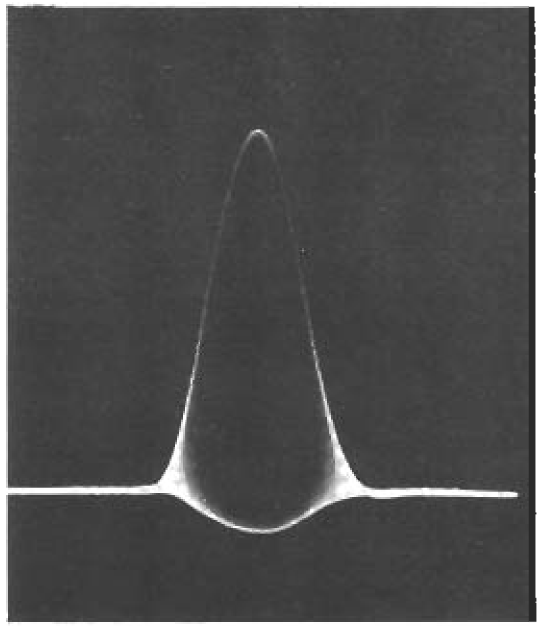


Fig. 5b — As Fig. 4 but with luminance 2 dB low

envelope of the chrominance waveform to the point where the impression is given that the whole of the lower half of the envelope has been sliced off. An enlarged view of the pulse is given in Fig. 4; the small deviations from flatness of the base-line are due to cross-talk effects in the laboratory-model generator used for these experiments. Naturally no pedestal is required for this waveform, so that the amplitude of the signal portion is normally 0·7 volt peak-to-peak.

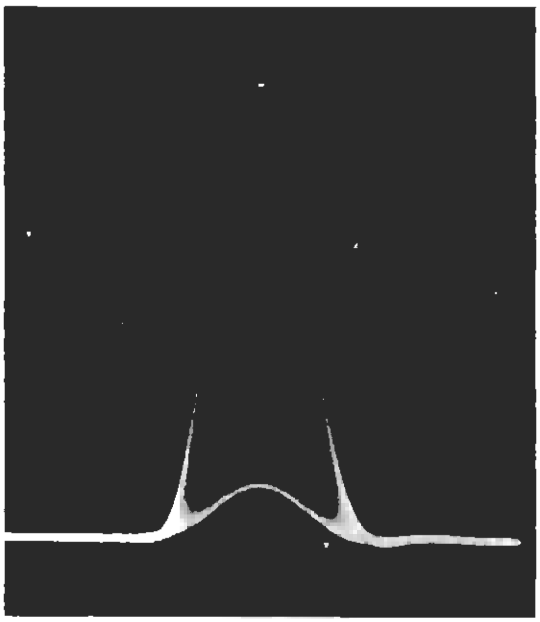


Fig. 5a — As Fig. 4 but with luminance 2 dB high

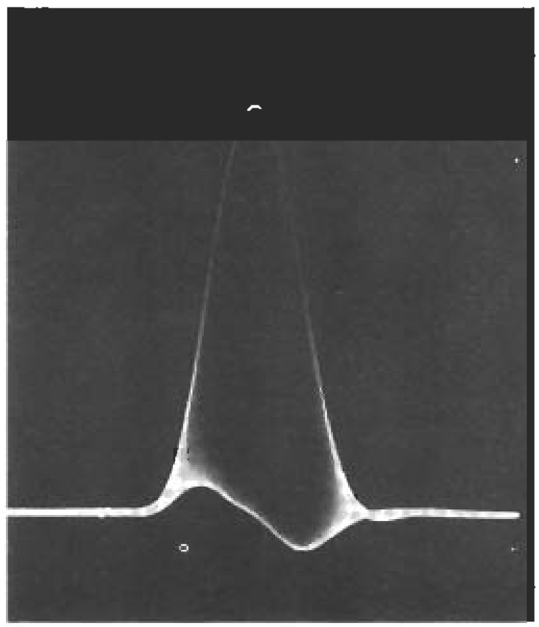


Fig. 5c — As Fig. 4 but with delay distortion of 80 ns

This 'composite' waveform as it is convenient to call it, has some rather elegant properties which are illustrated in the series of photographs in Fig. 5, where it is assumed that the only distortions which are operative are such as to produce only a change in luminance chrominance ratio or a change in relative delay between the two channels, or both of these together, but without any deformation of the wave-shape of either signal.

Since the flat base of the composite waveform is the result of the precise addition of two waveforms, it follows that any variation in either component from the correct amplitude or timing will destroy this flatness in some typical manner. Fig. 5a shows what happens when the luminance pulse is 2 dB greater than the correct value and Fig. 5b shows the luminance pulse 2 dB less than normal. In each case the base-line is bowed in a characteristic fashion. The corresponding distortions for the bar are given in Figs. 6a and 6b; in this instance a characteristic step is produced. A simple analysis (see Appendix) shows that if the luminance to chrominance ratio is e_1/e_2, then the amplitude of the bowing or step as a percentage of the upper peak amplitude of the output waveform is $\frac{e_1/e_2 - 1}{e_1/e_2 + 1} \times 100$ per cent. For small amounts of distortion the percentage bowing or step is approximately one-half of the percentage change in the luminance-chrominance ratio; this enables an estimate to be made of the sensitivity. The peak of the pulse also undergoes a vertical shift of the same amount with reference to the peak of the undistorted waveform.

It is not quite so easy to visualize what happens when the luminance and chrominance waveforms have the correct amplitude but a relative delay. The simplest method is to bear in mind that basically the effect of the addition of the luminance signal to the chrominance is to modify the upper and lower portions of the modulation envelope in different ways. The resultant upper portion is proportional to the sum of the envelope of the chrominance signal and the luminance signal, and the resultant lower portion is proportional to their difference. When these two com-

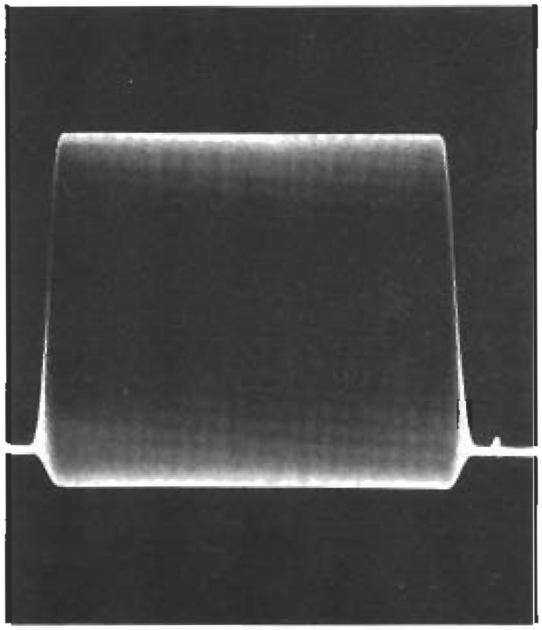


Fig. 6b — The composite bar with luminance 2 dB low

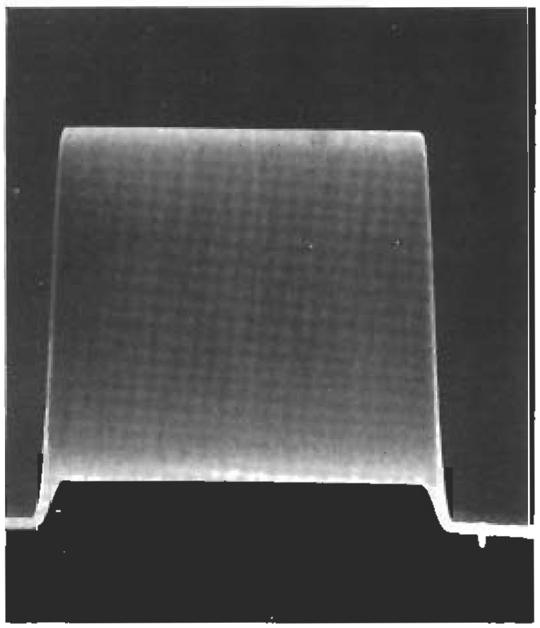


Fig. 6a — The composite bar with luminance 2 dB high

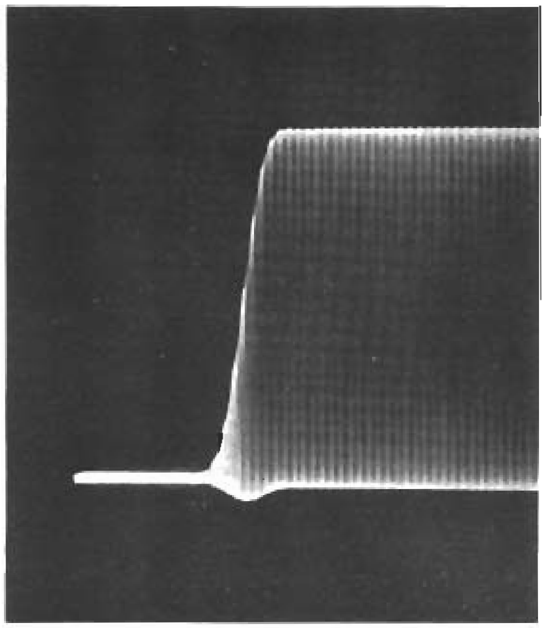


Fig. 6c — The composite bar with delay distortion of 80 ns ponent waveforms are identical and in time coincidence, which is the condition for correct adjustment of the test signal, the lower portion becomes a straight line. When they are identical but have a small time displacement the upper portion of the envelope is slightly broadened, whereas the lower portion has the form of the time differential of the original waveform. Accordingly, when there is a delay error only, the base of the bar appears to be distorted by the addition of two sine-squared pulses, one erect and one inverted, which are located at the transitions of the bar. An example for a delay difference of 80 ns is given in Fig. 6c. With the pulse, since the time differential of $\sin^2 kt$ is $k \sin 2kt$, its base takes on the characteristic appearance of a whole period of a sine wave. The amplitude of this sine wave is proportional to the amount of delay difference and the direction of the displacement determines whether the sine wave starts with a positive or a negative half-cycle. Fig. 5c shows the composite pulse when the luminance signal leads the chrominance signal by 80 ns. The slight asymmetry of the sine wave at the base is due to some cross-talk effects in the generating equipment. It can easily be demonstrated (see Appendix) that for the pulse with half-amplitude duration 1 μs, the peak-to-peak amplitude of the sinusoidal distortion at the base of the pulse is approximately $\sin 0{\cdot}9t^\circ$ times the pulse amplitude, where t is the relative delay in ns. Alternatively expressed, the delay in ns is approximately 6 times the peak-to-peak distortion as a percentage of the pulse height.

5. Experimental Test-Signal Generator

The number of possible signals having been reduced to two, the obvious next step is to determine which of the two is the better for the purpose. As always in cases such as this, it is important that the final decision should not be taken before sufficient practical experience has been obtained. It was therefore decided to construct a generator capable of producing both waveforms, so that comparative tests could be made upon as wide as possible a range of apparatus and circuits for colour transmission, the two signals being used under identical conditions in each instance.

Fortunately, this did not involve the design of two separate signal generators, since the most important basic components of the two waveforms are identical. In each instance the generation begins with an accurate sine-squared pulse and bar signal of the correct half-amplitude duration, which is then used to modulate linearly to a depth of 100 per cent a locally generated colour sub-carrier signal. The linear sum of these two waveforms, with the correct amplitudes and in time coincidence, yields the composite waveform, which then needs only the subsequent provision of synchronizing pulses to complete the final test signal. This is shown diagrammatically in the upper part of Fig. 7, which is not a block schematic of the generator used but a purely functional diagram.

The 'two-line' signal is more complicated to generate because of the necessity for gating both of the two component signals so as to leave each alternate line blank. This must, of course, be done in such a way that when the two gated signals are added the resultant signal has a luminance signal on one line and a chrominance on the next. In addition, a very precise pedestal has to be added to each. The lower part of Fig. 7 shows functionally how this is carried out.

6. Measuring Unit

The original proposal for the sine-squared pulse and bar testing of the chrominance channel envisaged that the various parameters would be measured directly from the screen of the waveform monitor. Some preliminary tests made it abundantly clear that this procedure is not sufficiently accurate for all possible measurement purposes, bearing in mind that the suggested tolerances for a minor local link are 0·1 dB luminance-chrominance ratio and 10 ns delay.

Small differences such as those mentioned above are really impossible to measure directly from a waveform, but they may nevertheless be detectable as distortions of the test signal after transmission over the system under examination. This suggested that the greatest accuracy would be achieved by devising a calibrated equalizing system by means of which the distortion can be removed. The amount of equalization, equal of course to the amount of distortion, can then be read from the calibration of the instrument. The optimum adjustment is indicated, according to the test-signal in use, either by the maximum apparent sharpness of the waveform or by the flatness of the base-line.

One rather elegant scheme due to the Post Office is to make use of echoes of the signal to modify the amplitude and delay characteristics of the signal path in the manner required, but the method adopted in this instance, which was found to be straightforward and highly satisfactory, is the arrangement shown diagrammatically in Fig. 8. The incoming distorted signal is first of all split into two paths. In the upper path it passes through a band-stop filter which removes the chrominance signal, and thus leaves the luminance signal. This is subsequently passed through a variable delay line and then a buffer amplifier.

In the lower path the signal enters a phase-compensated band-pass filter which selects the chrominance signal and rejects the luminance signal, after which the amplitude of the former is adjusted by means of a calibrated control. Some fixed delay is included in this path to provide a sufficient range of adjustment over a range of $\pm$100 ns in steps of 1 ns, and the gain in practice was made continuously adjustable over a range of $\pm$3 dB approximately. Finally, the two paths are recombined in order to reconstitute the signal waveform. The distortion of the device in its latest form is so small that when a signal is applied to the input, the output signal is indistinguishable from it.

7. Accuracy of Measurement

Provided no excessive amount of waveform distortion of the test signal occurs, the use of this device is found to in-

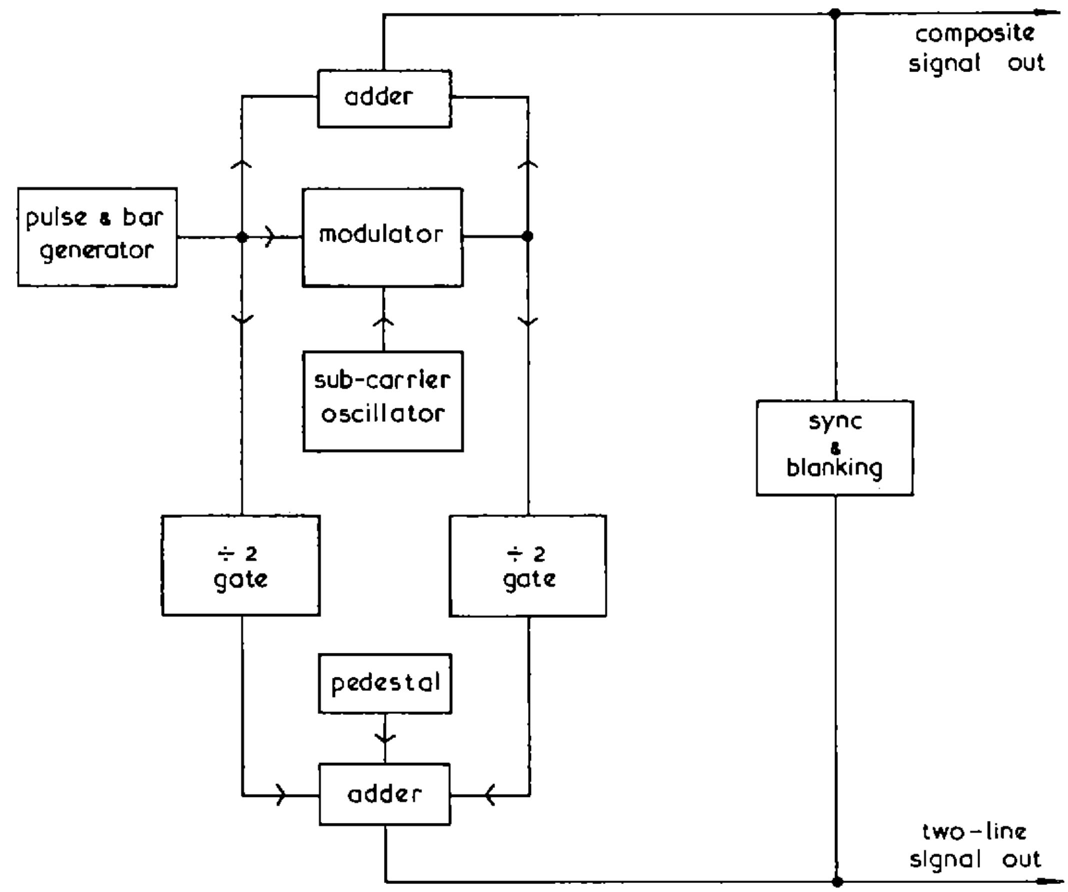


Fig. 7 — Functional schematic of experimental generator

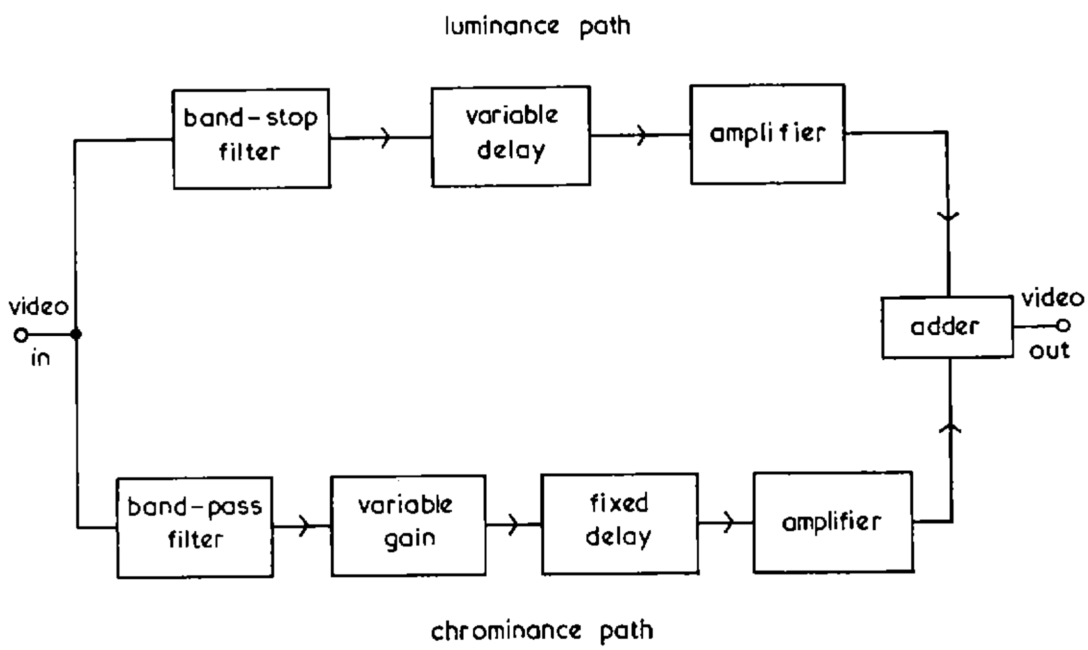


Fig. 8 — Functional schematic of measuring unit

crease the accuracy of measurement very considerably. This is partly due to the avoidance of the measurement of small displacements directly from the face of the tube of the waveform monitor and to the improvement gained by the elimination of parallax, but it is to a larger extent attributable to the accuracy with which it is possible to recognize or judge the position of correct adjustment. The sensitivity of the measurement is decreased if appreciable random noise or waveform distortion are present, but in all instances the use of the measuring unit is advantageous.

In order to form an estimate of the possible accuracy of measurement using the technique of correcting the received waveform, an experiment was arranged in which five experienced engineers carried out a given measurement under identical conditions using a fairly high quality distribution circuit as the test object so as to simulate practical conditions. The measurement of luminance-chrominance ratio seemed to present no difficulties with either of the two test signals, and the accuracy of measurement on a ratio of 0·8 dB was ±0·1 dB. With the 'two-line' signal the range of reading on a mean delay of 44 ns was 5 ns, and this was reduced to 2 ns with the composite signal. In each instance the adjustment for the gain was made first of all using the bar as indicator. For this purpose it is convenient to use a fairly high Y gain and to examine only the vicinity of the area where coincidence is to be established; a fairly low sweep speed is also helpful for this measurement. Attention was then transferred to the pulse displayed with a faster sweep speed, and the delay adjusted for coincidence. Since it is possible in principle to use the bar only for all these measurements, the accuracy was again estimated under these conditions. It was found that the accuracy with the 'two-line' signal was unchanged, but with the composite signal the accuracy of the delay measurement was degraded by a factor of about two. A theoretical analysis given in the Appendix suggests that the degradation should be about three times.

It was during this test that a rather disturbing weakness of the 'two-line' signal came to light. It at first appeared that the two signals were giving answers for the luminance-chrominance delay which differed by about 40 ns. The true explanation was found to be as follows. The 'two-line' signal depends for the measurement of delay upon an accurate apparent superposition of the two component waveforms, brought about by triggering the waveform monitor from the synchronizing pulses of successive lines. It so happened that a potential difference existed between the earth of the Tektronix type 515A Oscilloscope used to display the waveforms and the earth of the cable termination, which introduced a quite small level of hum into the output test signal. This was sufficient to alter the triggering point of successive lines and to give rise to an apparent delay between the signals. As a check, the start of the pedestal was examined under the same conditions; a photograph of this is shown in Fig. 9. The shift between successive displays is clearly visible.

The extent to which this phenomenon occurs is a function of the triggering circuits of the waveform monitor. There are some oscilloscopes whose triggering is relatively

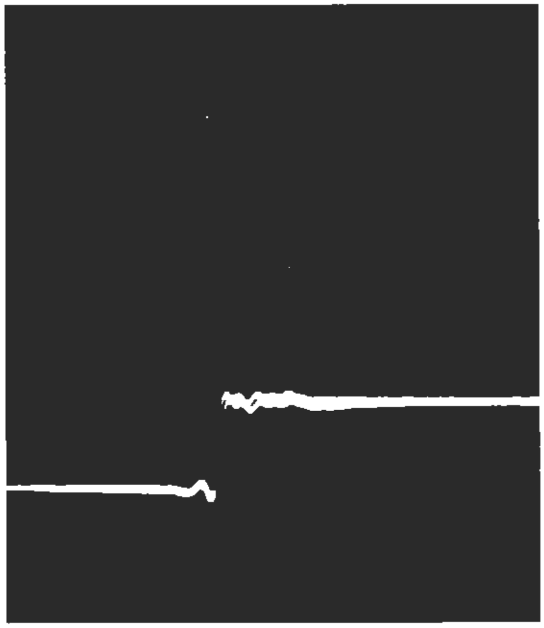


Fig. 9 — Displacement of triggering point of successive lines due to small amount of added hum

insensitive to added hum or similar interfering signals, but certain other widely used waveform monitors do suffer from this. It can also arise from slight fault conditions in the waveform monitor which could pass unnoticed by the operator. Clearly steps may be taken to minimize this effect, but for operational purposes it is highly undesirable that errors of quite large magnitude should occur as a result of small defects of the video signal or waveform monitor which are otherwise unimportant.

The composite waveform, on the other hand, is quite insensitive to triggering defects of this sort. The luminance and chrominance waveforms are transmitted in time coincidence, and the worst which can happen is a degree of horizontal blurring on the display. Even this is of no great consequence since, whether a measurement of luminance-chrominance ratio or a measurement of delay is concerned, the ultimate adjustment is one which produces horizontal lines. In the former, two horizontal lines are brought into coincidence, and in the latter a sinusoidal line is converted into a straight line. In neither case will a reasonable amount of horizontal blur give rise to any difficulty.

In order to confirm that the added hum was the real cause of the difficulty a hum filter was introduced in series with the output test signal, after which the same mean delay reading was obtained by the use of both waveforms.

The insertion of this high-pass filter for the removal of hum gave rise at one stage to a small amount of phase distortion, which pointed out another weakness of the 'two-line' signal. Since the successive lines of test signal are not identical, the whole signal contains an effective spectral component at half-line frequency, which can give rise to a displacement between the luminance and chrominance components if there should be any linear waveform distortion at the lowest video frequencies. This drawback of the 'two-line' signal is perhaps less important than the former, but is nevertheless undesirable.

Unfortunately, although photographs were taken of the above tests they are not suitable for reproduction. However, Figs. 10a, b, and c are representative of some of the measurements which were deliberately made on rather poor circuits in order to test the method. The circuit was a short loop of a carrier-on-cable link which had originally been designed for 405-line signals only and was not really expected to be at all suitable for the transmission of 625-line colour signals. In the event the luminance-chrominance ratio proved to be about 3 dB and the luminance-chrominance delay about 200 ns. Fig. 10a was double-exposed so that the two pulse waveforms could be displayed side by side, and it is evident that the distortion of the pulse shape is extremely small in spite of the poor amplitude and phase characteristics of the circuit in the region of the chrominance channel. Fig. 10c shows the 1T and 2T responses of the circuit; the 'ring' due to the sharp cut-off of the band-limiting filters and the asymmetry of the 'ring' pattern due to the phase distortion at the top of the band are clearly shown.

8. Non-linear Effects

There is a further reason for including Fig. 10. When the luminance-chrominance ratio was measured from Fig. 10b a value of 1·7 dB was obtained, and if no further information had been available this value would have been accepted as being correct. However, closer inspection of Fig. 10b makes it clear that the modulation envelope of the received test signal is no longer symmetrical about the pedestal level, the upper portion being appreciably greater than the lower. This yields too low a value for the luminance-chrominance ratio if measurements are made on the upper part of the waveform, and in fact if on the other

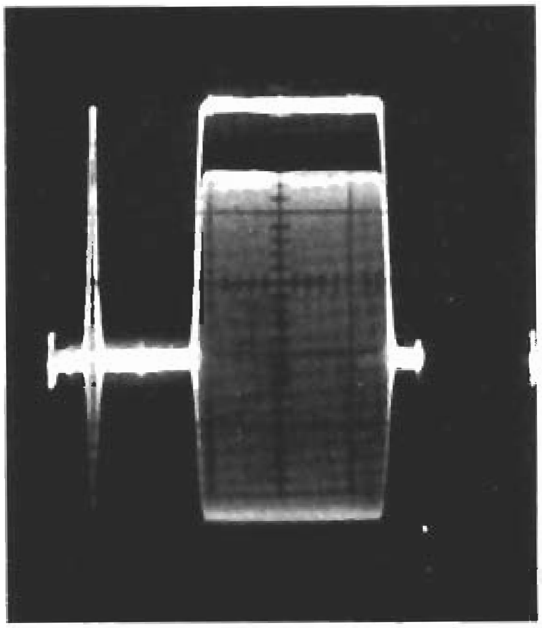


Fig. 10b — Received two-line waveform on 15 Mc/s carrier system loop

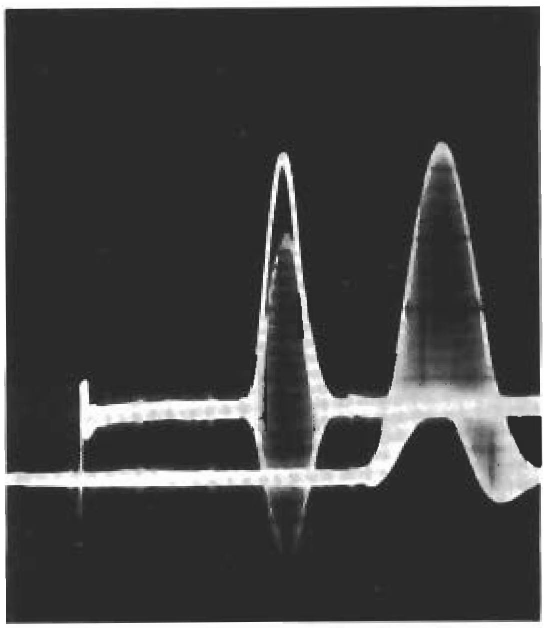


Fig. 10a — Received pulse waveforms on 15 Mc/s carrier system loop

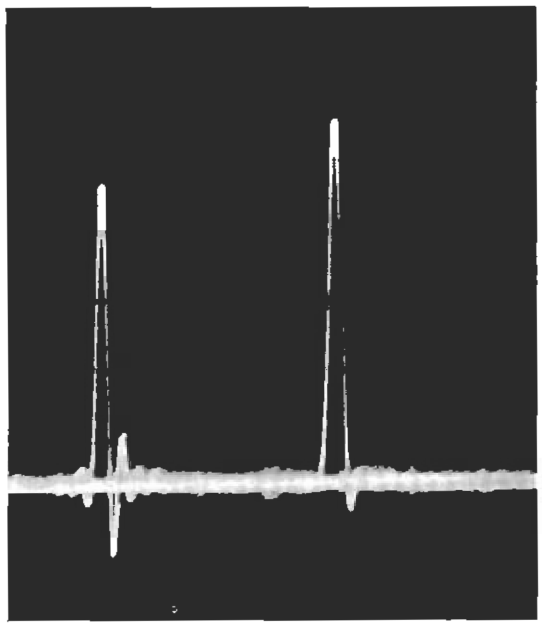


Fig. 10c — Received sine-squared T and 2T pulses on 15 Mc/s carrier system loop hand the mean of the upper and lower portions of the envelope is taken as the correct value the ratio increases to 3·2 dB, which is 1·5 dB greater than the ratio derived from Fig. 10b.

This shift of the mid-point of the modulation envelope occurs as a result of non-linear effects near the upper limit of the band. In particular, it can arise in a transmitter-receiver combination using envelope demodulation, which is distortionless in the sense that all of the circuit elements are operating ideally, because the modulated colour sub-carrier signal is transmitted at a fairly high modulation depth in the wholly single-sideband region of the spectrum of the transmitted signal. As is well known, the envelope detection of a 100 per cent modulated sine wave from which one sideband has been completely removed results in an output waveform which has the shape of the same sine wave after full-wave rectification. Lower modulation depths and varying degrees of restoration of the missing sideband give output waveforms intermediate in shape between the original sine wave and the full-wave rectified case. The asymmetry of the output wave then gives rise to a shift of position on black level or pedestal.

In order to demonstrate this effect some experiments were made with a very high quality UHF modulator and receiver, in which the modulation conditions and the vestigial sideband characteristic were made as close as possible to the standards. The test signal was derived from a video oscillator which was passed through a device having very much the same function as a camera channel, so that the input sine wave emerged with blanking and synchronizing pulses added as in a normal video waveform. Fig. 11a shows the output waveform from the receiver with an input frequency of 300 kc/s and, except for a slight sinusoidal interference it is substantially distortionless. Fig. 11d shows the actual carrier waveform. As one might expect, since the asymmetry of the sidebands at 300 kc/s is negligibly small, the distortion is not perceptible, and accordingly the shift of the baseline in Fig. 11a is not visible either. However, Figs. 11b and 11c demonstrate very clearly how the shift of the baseline increases with increasing frequency as the modulated signal enters the single sideband region. In Fig. 11c, which shows the detail of the output 1·25 Mc/s waveform, the asymmetrical distortion is clearly visible as a sharpening of the positive half-cycle of the wave. Finally, Fig. 12 shows the 'two-line' waveform after passage through the same transmitter-receiver combination under identical conditions; the downward shift of the modulated sub-carrier is present as expected.

A further complication arises from the removal of the harmonics of the chrominance signal after it has been distorted by the modulation process. If the pass-band of the receiver were infinite, the envelope detection of the sub-carrier with single-sideband modulation to a depth of 60 per cent which is the approximate effective modulation depth of the picture component with British 625-line standards, would yield a distorted wave with a distinct resemblance to the full-wave rectified sine wave which has already been mentioned, and which would therefore be rich in harmonics. However, the passband of the receiver must effectively remove all harmonics except the fundamental, which will then have an amplitude different from that of the original wave.

The magnitude of the change can be calculated if the Fourier expansion of the distorted wave can be found. The

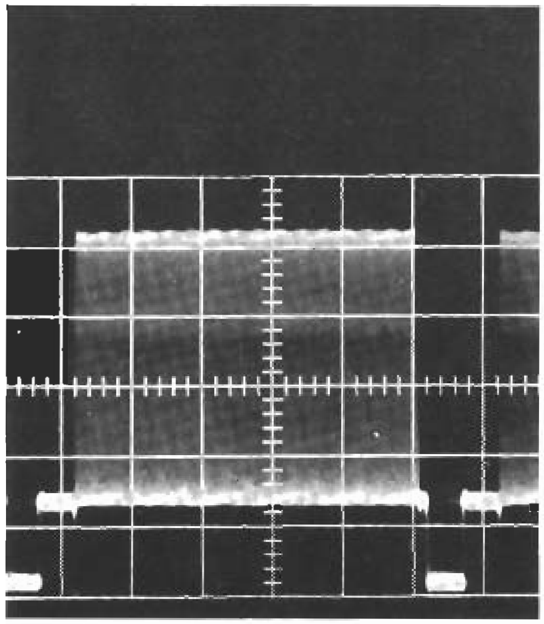


Fig. 11a — 300 kc/s sine-wave after modulation and envelope demodulation

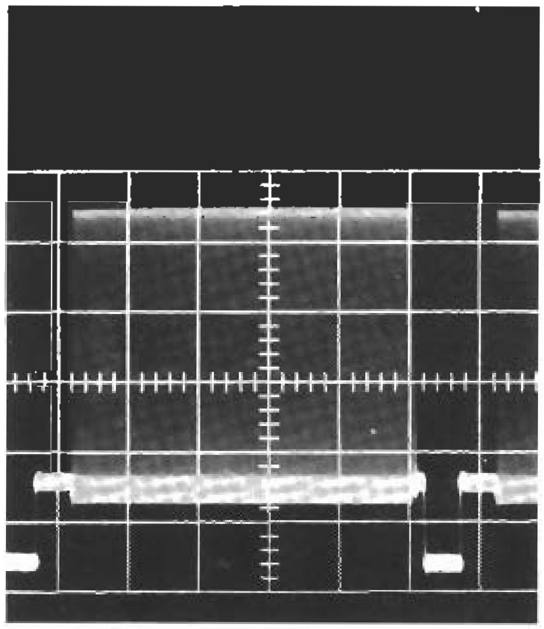


Fig. 11b — 1·25 Mc/s sine-wave after modulation and envelope demodulation

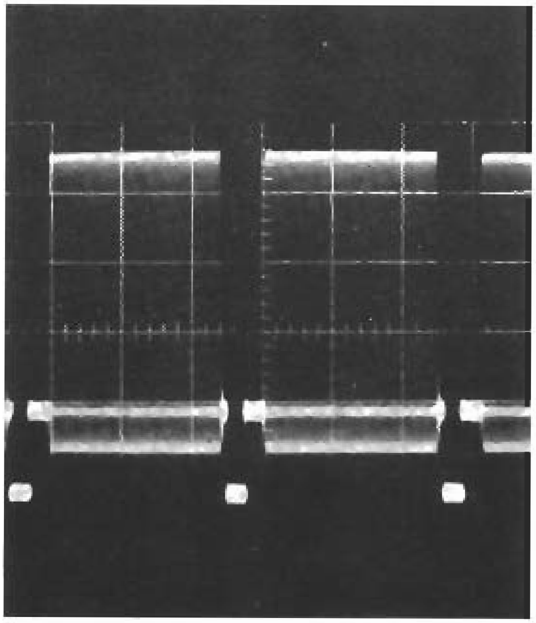


Fig. 11c — 4·4 Mc/s sine-wave after modulation and envelope demodulation

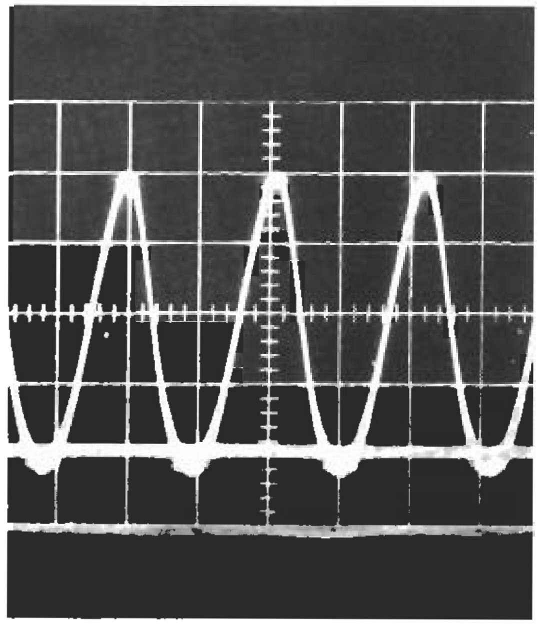


Fig. 11e — Detail of Fig. 11b

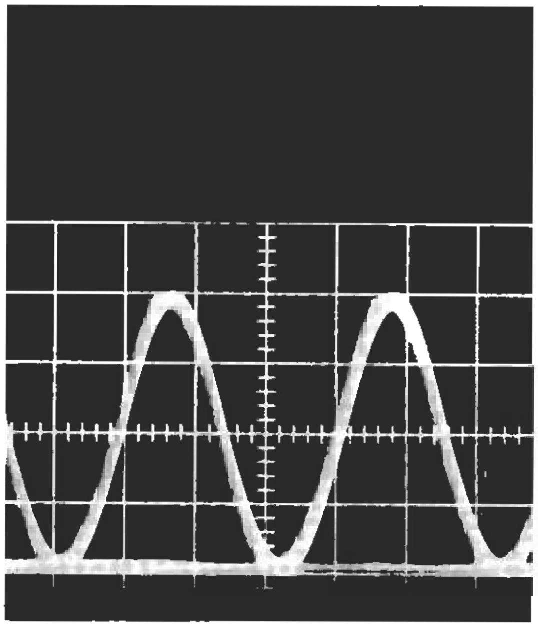


Fig. 11d — Detail of Fig. 11a

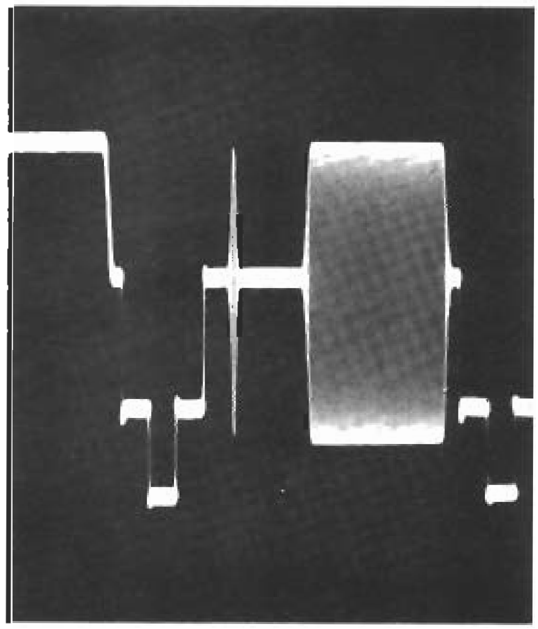


Fig. 12 — Two-line signal after modulation and envelope demodulation

determination of this Fourier expansion turns out to be very much more difficult than one might expect, except in the special case of a modulation depth of 100 per cent, but fortunately the problem has been solved by Vigoureux and the result quoted by Colebrook.[2] The actual expansion is in terms of Legendre coefficients and would be tedious to cite here since the coefficients have a rather complicated form, but application of it to the present problem shows that the final amplitude of the modulated sub-carrier is 0·4 dB less than it should be, if linear envelope demodulation is assumed. Although this is not a large difference it is nevertheless significant, and should be avoided if possible.

The most satisfactory way of separating the linear from the non-linear effects seems to be to halve the amplitude of the test signal when dealing with amplitude modulated systems where this type of distortion is appreciable. In this case, if it is assumed that in both forms of the test signal the lowest points in the modulation envelope once more coincide with black level, then the effective modulation depth is decreased to about 23 per cent and the consequent change in amplitude of the sub-carrier with demodulation becomes negligibly small. The d.c. shift is also very much reduced, to a point where it can be neglected for most purposes.

9. Comparison of the Two Test Signals

At this point it would be useful to summarize the results of the work which has been described above by drawing up a list of the respective advantages and disadvantages of the two waveforms. The order in which these are presented is no indication of relative importance.

9.1 *'Two-line' Waveform*

(i) It provides a clear indication of the presence of single-sideband distortion.

(ii) This signal is more complicated to generate than the composite, and the generating equipment is inherently more prone to instability. For example, the amplitudes of the pedestals in the two successive lines must be maintained equal within very small limits.

(iii) It is liable to errors arising from the effect of external factors upon the triggering of the waveform monitor.

(iv) The accuracy may be affected by linear waveform distortion in the vicinity of one-half line repetition frequency.

9.2 *Composite Waveform*

(i) Simpler to generate and the generating equipment is likely to have a higher intrinsic stability.

(ii) Lends itself particularly well to measurement by correction of the errors. Tests show that the accuracy of measurement is distinctly better, and the measurement is simpler and more convenient to carry out.

(iii) Quite insensitive to waveform monitor triggering errors introduced by small hum amplitudes, for example.

(iv) On the other hand, this waveform does not make it very obvious that single-sideband type distortion is present, and the effects of any waveform distortion of the envelope are less clearly distinguishable.

10. Conclusions on Part I

The immediately preceding list makes it quite clear that the composite waveform has a number of very important advantages over the 'two-line' waveform. Indeed, its main failing is its lack of clarity when single-sideband and linear waveform distortion are present. It is therefore suggested that generating equipment for linear waveform tests on the chrominance region should provide the following facilities:

(i) The composite waveform as described above with transitions corresponding to $2T_c = 1 \cdot 0\ \mu s$. Apparatus to be used for investigational purposes might also include the waveform corresponding to $T_c = 0 \cdot 5\ \mu s$.

(ii) A switch position to halve the amplitude of the test signal, but leaving the sync pulse amplitude unaltered.

(iii) The chrominance signal of the 'two-line' signal, but on every line instead of every other line. This should be available on another switch position. Its inclusion would add very little to the complexity of the generator, and would provide a valuable check on any distortion of the modulation envelope quite independently of the measuring unit.

(iv) The luminance component on every line. As with (iii), the cost of this facility would be extremely small, but it would make possible an individual check on any waveform distortion of the luminance component.

(v) If it should be required to demodulate the received signal, for the measurement of I-Q cross-talk or for any other reason, it would also be necessary to make provision for the addition of the standard sub-carrier burst to the above test signal.

The measurement of luminance/chrominance ratio and relative delay should preferably be made by the measuring unit described above. The apparatus used need not have the precise form of Fig. 8, but in any case it should introduce no perceptible waveform distortion with the controls set to zero. For acceptance testing and general measurement purposes the range of delay correction should be at least ± 100 ns, and the fine adjustment should preferably be by means of a continuously variable control. The range of amplitude should not be less than ± 3 dB, and the fine adjustment should again be continuously variable. However, for maintenance testing the range of measurement can be considerably less, and it is highly probable that a much simpler and cheaper unit could be designed for this purpose. In either case it is desirable that a switch should be included so that one can examine the separated chrominance and luminance waveforms individually when required. For some purposes, for example the routine checking of reasonably stable circuits, it may well prove sufficient in certain circumstances to examine the base-line of the waveform with a suitable graticule.

The inclusion of a sub-carrier regenerator and synchronous demodulator into the measuring equipment would make it possible to measure the effective I-Q or Q-I cross-talk. So far, this quantity seems not to have been found particularly significant, but it might be prudent to make arrangements in the equipment for the appropriate facilities to be added at a later stage if it should seem desirable.

PART II

AN AUGMENTED PULSE AND BAR WAVEFORM FOR TESTING THE COMPOSITE COLOUR SIGNAL

11. Introduction to Part II

In the not too distant future, most if not all circuits which have to handle 625-line signals will also have to be capable of handling colour television signals, and it will be necessary to have available a test signal or signals which will indicate clearly and quickly the state of a circuit with respect to the linear waveform distortion experienced by both monochrome and colour video signals.

As is well known, the spectrum of the 2T sine-squared pulse falls to one-half of the low frequency value at a frequency equal to $\frac{1}{4T}$, and becomes zero at $\frac{1}{2T}$. This is shown in Fig. 13a. Although the signal contains some energy above $f=\frac{1}{2T}$, this is negligibly small for all practical purposes. In order to fall into line with Post Office practice, the BBC has adopted a value of $T=0\cdot1\ \mu s$ for 625-line operation, so that the spectrum of the 2T pulse can be said to contain zero energy above 5 Mc/s. In fact, of course, the nominal upper limit of the video band with British standards is 5·5 Mc/s, so that it appears that the last 0·5 Mc/s is not tested by the 2T pulse. This is a point about which there has been a certain amount of controversy, although it is not proposed to examine the arguments here.

The result of this spectrum shaping is that progressively less information is provided by the signal as the frequency increases. With monochrome video signals this is not necessarily a disadvantage, and it can be argued that the shape of the spectrum provides a suitable weighting curve to take account of the known continually decreasing importance with frequency of the higher video components of the picture signal. This agrees with the view of the 2T K-rating as a measure of the viewer's subjective appreciation of the quality of the monochrome picture.

However, the situation is radically altered by the addition of the chrominance channel to the luminance signal in a colour video signal, since the colour information must also be transmitted with minimum distortion, and this can only be ensured by tests made with a signal capable o yielding much more information in the upper third of the video band than is possible with the 2T pulse and bar.

One possible solution would seem to be the use of the 1T pulse and bar signal, which has a spectrum such that the harmonic amplitude has only fallen to one-half at 5 Mc/s. Unfortunately, the presence of a very appreciable amount of energy in the test signal above the upper limit of the video band can give rise to a large amount of irrelevant information which may have the effect of obscuring the wanted information. The situation is aggravated when filters are used to define the band, since the 'rings' resulting from the filter cut-off obscure the wanted information even more effectively. This difficulty is overcome in the classical use of the 1T pulse for acceptance testing by using mathematical methods to reject information relating to out-of-band frequencies, but this is too indirect for the method to be of use for the maintenance testing of either monochrome or colour systems, at least in the reasonably near future.

However, the principal failing of the 1T pulse as far as chrominance region testing is concerned is that it does not immediately provide the detailed information of the kind described in the first part of the monograph which is required for a knowledge of the characteristics of the chrominance channel. The information is potentially available from the 1T signal, but its extraction would be quite pointlessly difficult.

An obvious solution to the difficulty is to use a normal sine-squared pulse and bar signal for the assessment of the luminance performance, and the composite chrominance pulse and bar waveform for the assessment of the chrominance performance, and in fact this is the method to be preferred for the majority of purposes. Nevertheless, the situation does arise from time to time that an immediate check is required of both luminance and chrominance channels, and the use of two individual signals is then undesirable.

12. The Augmented Pulse and Bar Signal

A signal which enables measurements to be made on both the luminance and chrominance regions simultaneously can be generated quite simply by adding to the standard T or 2T sine-squared pulse and bar signal a composite chrominance pulse of exactly the same amplitude as the normal pulse. The result is the waveform shown in the photograph of Fig. 14a, where the chrominance pulse can be seen to have been added at a point a few μs later than the 2T pulse of the original waveform, and both pulses have the same amplitude as the centre of the bar.

Measurements with this waveform on monochrome circuits or on the luminance region of a colour circuit can be carried out exactly as usual, the presence of the chrominance pulse being ignored for this purpose. For measurements on the chrominance region the waveform monitor is double-triggered to give the kind of display shown in Fig. 14b.

Now since the composite pulse is the linear sum of a low-frequency video waveform and a modulated waveform at sub-carrier frequency, it follows that any change in the gain of the chrominance region will change the amplitude of the composite pulse with reference to the amplitude at the centre of the bar. Any change in gain at the lower video frequencies will change the amplitude of the bar and the luminance component of the chrominance pulse by the

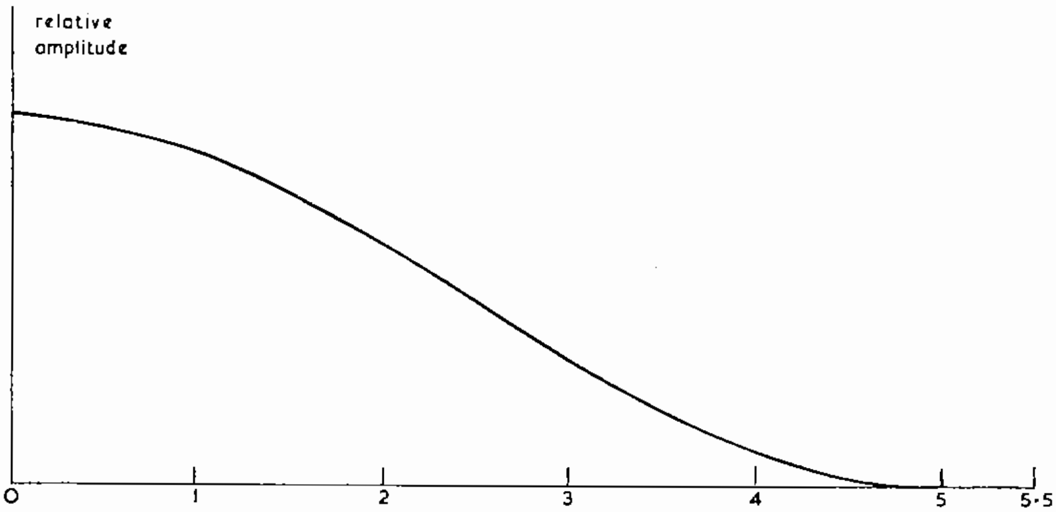


Fig. 13a — Spectrum of 2T pulse ($T=0\cdot1\ \mu s$)

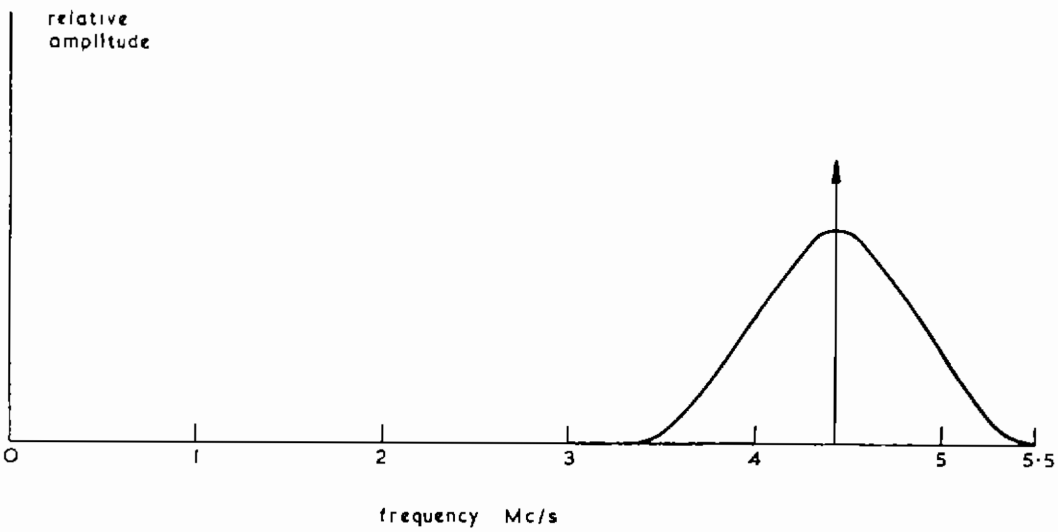


Fig. 13b — Spectrum of modulated 10T pulse

same amount, so that any variation of the luminance to chrominance gain ratio results in a change in the ratio of the chrominance pulse and bar amplitudes. Any variation of the relative delay between the channels will result in a sinusoidal effect on the base of the pulse, exactly as described in Part I. It is therefore possible to measure both of these important parameters in addition to the normal K-rating, for which reason this signal has been named the 'augmented pulse and bar signal'.

It can easily be demonstrated by the method of the Appendix, that if the ratio of the chrominance pulse to the bar amplitude is P, then the luminance-chrominance gain inequality is 20 $\log_{10}$ (2P$\sim$1), but this expression must be used only in the absence of delay inequality, or provided the delay inequality is quite small. Any appreciable displacement between the peaks of the two waveforms which form the composite chrominance pulse also gives rise to a reduction in the pulse height.

This error can be completely avoided, and the measurement made to a higher degree of accuracy, if the measuring unit described in Part I is utilized. The separating networks cause a certain distortion of the monochrome sine-squared pulse and bar signal, but this does not affect the accuracy or the operation of the measurement in any way.

12.1 *Use in Equalization*

The BBC makes frequent use of an analogue method for the rapid equalization of circuits. This utilizes a wide-range variable equalizer and amplifier, devised in such a way that when the optimum adjustment has been reached the values of the components for constant-resistance equalizers of standard form can be found very quickly from the settings

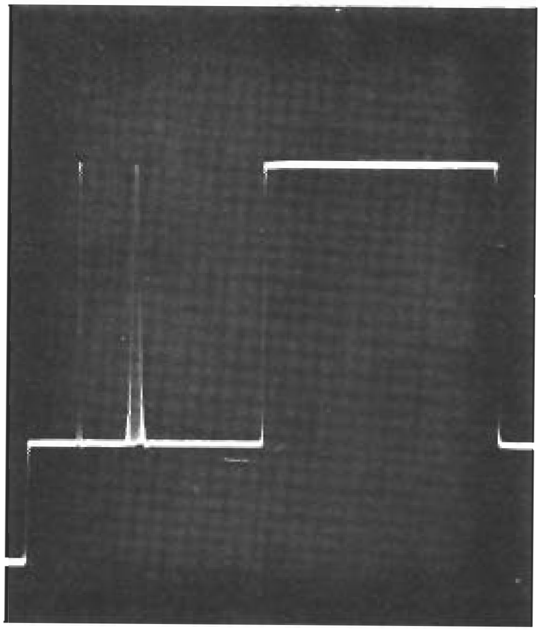


Fig. 14a — The augmented sine-squared pulse and bar signal

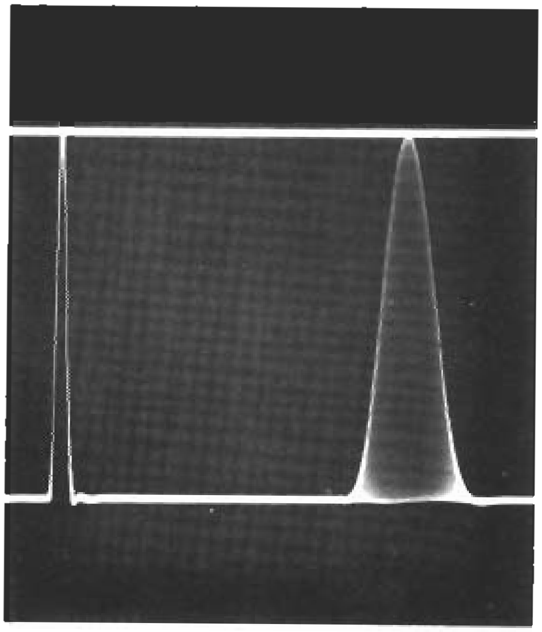


Fig. 14b — As Fig. 14a but double-triggered to superimpose the bar upon the pulses

of the equalizer controls by means of simple transformations. Printed boards are available for a range of capacitors inductors, and resistors, from which a given equalizer can be realized extremely quickly. The method has been adapted from a proposal by the Post Office.[3]

The equalization has hitherto been carried out on monochrome circuits by using a standard sine-squared pulse and bar signal, and adjusting the controls until the combination of the circuit to be equalized, the variable equalizer, and the amplifier yields a signal with a minimum K-rating. This, in practice, turns out to be extremely simple. The great advantage of the method, apart from its speed, is that a positive criterion is available for the condition where the residual error is a minimum, the sine-squared pulse and bar signal serving as an analogue of the video signal.

This method is less convenient for the equalization of colour circuits when two separate test signals are employed for the luminance and chrominance channels, owing to the necessity for switching from one signal to the other in order to apportion the residual errors between the two channels. The augmented signal, on the other hand, presents a simultaneous display of the luminance and chrominance distortions, and it becomes very much easier to estimate the optimum condition.

12.2 *Augmented K-rating System*

The statement made in the previous section about the optimum opportioning of a residual error between the luminance and chrominance channels implies that some definite criterion is available for this purpose. In practice, when the augmented signal is used for equalization it is easy to reach an optimum by visual inspection of the waveform which seems intuitively satisfactory, and experience has shown, at least in a small number of straightforward instances, that a number of experienced engineers will independently arrive at closely similar optimum settings.

Nevertheless, no objective criterion is available, and there is a very real need for this, not only for equalization purposes but more generally for estimating the quality of colour television circuits by waveform methods: in other words an extension of the monochrome K-rating system to colour television. This could be done in the first instance by introducing the linear chrominance distortions into the rating system, since for example there seems every reason to suppose that values of chrominauce-luminance gain and delay distortions could be found which subjectively have degrees of annoyance in a given picture comparable with the various parameters of the normal K-rating system, which in this instance would be affecting the luminance region. It seems possible that even differential gain and phase might also be brought into such an augmented rating system, but of course the choice of the colour television standards would have a much greater influence if this were done.

In the opinion of the writer such an extension of the rating system would prove of inestimable benefit to administrations transmitting colour television signals, and he would like to urge strongly that tests should be made to establish its practicability as soon as the definitive specification has been laid down for the colour television system which will be finally adopted.

12.3 *The Augmented Signal for Monochrome Testing*

As was pointed out in the Introduction the normal sine-squared pulse and bar signal has a certain shortcoming in that the 2T signal, which has the spectrum shown in Fig. 13a in order not to transmit appreciable energy outside the nominal video band, gives little information about the upper one-third of the video band. On the other hand the 1T signal gives a high degree of information about the whole of the video band, but such information may have to be separated from any unwanted information corresponding to frequencies above the nominal band.

However, the combination of the 2T pulse and a modulated chrominance pulse with $2T_c = 10T$ has a spectrum which, as can be seen from Figs. 13a and 13b, maintains a high value almost to the upper band limit. Since the 2T bar (omitted in Fig. 13 to simplify the diagram) has a spectrum which falls much more rapidly than that of the 2T pulse, it follows that the augmented signal with these parameters also has a spectrum which fits remarkably well into the 625-line video band. Similar conclusions would apply to 405-lines with the value of T changed appropriately.

At first sight this might lead one to suppose that the augmented signal possesses, as far as monochrome testing is concerned, all the advantages of the 1T signal without its disadvantages. Unfortunately, this expectation is not fully realized. The information given by the modulated signal at the upper part of the band about the distortion occurring in that region cannot be utilized in the same way as that given by the 2T pulse and bar signal. It is possible that the use of the augmented K-rating system proposed above, perhaps suitably modified, might provide an acceptable and simpler alternative to the 1T signal, but this would have to be proved.

Nevertheless, some valuable information is offered by the presence of the chrominance pulse in the form of the luminance-chrominance gain inequality, which in this instance corresponds to the gain at 4·43 Mc/s compared with the low-frequency gain. As can be seen from Fig. 13a the spectral amplitude of the 1T pulse is very low at that point, so that the gain in that region has only a small influence upon the pulse-to-bar ratio. It has been found by experience, for example, that it is possible to equalize a circuit by the use of the 2T sine-squared pulse and bar signal in such a way that, without realizing it, the gain is made unduly high at the very top of the band. This is of no great consequence for the majority of transmitted pictures, but exceptional pictures which have high energy at the top of the band, for example test cards, can at times give rise to severe overloading effects as a consequence. The augmented signal would effectively prevent that state of affairs occurring.

12.4 *Single Sideband Distortion*

It was shown in Part I of the monograph that vestigial sideband transmission can give rise to a vertical shift of the modulated envelope which could be mistaken for a luminance-chrominance gain inequality with the composite waveform if care is not taken. The criterion for recognizing the presence of this distortion in the absence of delay inequality is as follows. A luminance-chrominance gain inequality under linear conditions always gives rise to a chrominance pulse in which the shift of the peak is exactly equal to the amplitude of the bowing at the base of the pulse. If this is not the case, then non-linearity is present.

The observation of this effect is facilitated by the use of the measuring unit, since, when the base of the pulse has been made as flat as possible by the use of the gain and delay controls, any error in the pulse-bar ratio is most likely to be the result of non-linearity.

12.5 *Waveform Specification of Augmented Signal*

The major part of the augmented signal for 625-line testing consists of a perfectly standard 2T sine-squared pulse and bar signal as specified for maintenance testing. The chrominance pulse waveform has $2T_c = 1 \cdot 0\ \mu s$, and is produced, as has already been described, by the addition of such a sine-squared pulse to the same pulse which has been 100 per cent modulated on to colour sub-carrier. When the relative amplitudes are correct the base-line of the composite pulse becomes flat, assuming that the two signals are coincident in time. Finally, as has already been mentioned above, the amplitudes of the 2T and chrominance pulses are made precisely equal to the amplitude of the bar.

The colour sub-carrier which is used for the modulation of the chrominance pulse is preferably not locked to an odd multiple of one-half the line frequency, but is obtained from a free-running oscillator. This ensures that the envelope of the chrominance pulse will be smooth and continuous when viewed on a waveform monitor triggered from the synchronizing pulse or one of the edges of the bar.

The only difference from the standard sine-squared pulse and bar signal consists in the addition of the chrominance pulse. Its position does not appear to be at all critical: in the present series of experiments it was placed about 3 μs later than the 2T pulse. If the separation is too great it is not convenient to display both pulses together as in Fig. 14b, and if they are too close together there may be mutual interference when distortion is present.

When the augmented signal is used principally for monochrome work, or where the quality of the colour television circuit is poor so that appreciable distortion of the modulation envelope occurs, it may be preferable to use a chrominance pulse defined by $4T_c = 20T$. The reason for this is that the consequent halving of the pulse bandwidth frequently reduces the waveform distortion to a marked extent, and it therefore becomes easier to separate the gain and delay inequalities from the envelope distortion. It would be useful in the signal generator to have the facility available of changing rapidly from a $2T_c$ to a $4T_c$ pulse, and for investigational work it might also be advantageous to have a $1T_c$ pulse available.

12.6 *Effect of Echoes*

In instances where echoes of appreciable magnitude occur with a long delay, say greater than 2 μs, difficulties may be experienced with the augmented pulse and bar signal. If such long-term echoes occur with distribution circuits and studio apparatus it is to be hoped that their amplitude will be small since a luminance or monochrome echo of 1 per cent amplitude corresponds to a K-rating of

1 per cent and consequently only a very small echo can be allowed. Large echoes can, however, occur during the reception of radiated signals, and it is also possible with video signals under exceptional conditions to have a large echo in the region of the sub-carrier, but a negligible error at lower video frequencies.

The most serious consequence of such an echo is that the chrominance pulse remains undistorted, due to the separation of the pulse and the echo, but the amplitude of the major part of the top of the chrominance bar, had it been present in the signal, would have been modified owing to the superposition of the echo. Now any saturation error due to a change in luminance-chrominance gain ratio is perceived principally in the large areas, so that the modulated bar amplitude is the more correct criterion for luminance-chrominance gain inequality. Furthermore, since the phase of the sub-carrier in the echo is a function of the delay, a given echo may either add to or subtract from the top of the bar, which means that a measurement of the magnitude of the echo of the pulse is not in itself sufficient to determine the gain inequality.

Under these circumstances the augmented signal may give an incorrect value for the gain inequality. Nevertheless it should be clear that such conditions ought to occur very infrequently in practice, and the fact that a certain error is possible for the reasons stated above should not be taken as a major criticism of the proposed signal.

12.7 *I.R.T. Proposal*

A similar proposal to this augmented sine-squared pulse and bar signal has been put forward by the Institut für Rundfunktechnik in Munich; it is fully described in an article by P. Wolf.[4] The principal difference lies in the fact that the I.R.T. signal consists of two consecutive lines, instead of one, the first of each pair of lines carrying the bar and the second carrying the two pulses.

This has the advantage of eliminating the need for double-triggering, since a repetitive sweep automatically provides a double-triggered display. On the other hand it has the disadvantage of being somewhat more difficult to generate as well as being liable to error from distortion at low video frequencies, particularly since the two consecutive lines differ markedly in the video signal energy which they carry.

In the article by Wolf more stress is laid upon the use of a signal of this type as an improvement to the normal sine-squared pulse and bar signal than is the case in this monograph. The BBC experience has been that, while it is admittedly useful to have additional information about the upper portion of the video band, the amount of information furnished is rather restricted and suffers greatly from the fact that it cannot be brought within the K-rating system.

12.8 *Experimental Results*

A number of experiments have been carried out with this augmented signal in order to assess its usefulness. In particular, tests have been carried out on the equalization of short cable lengths and studio equipment.

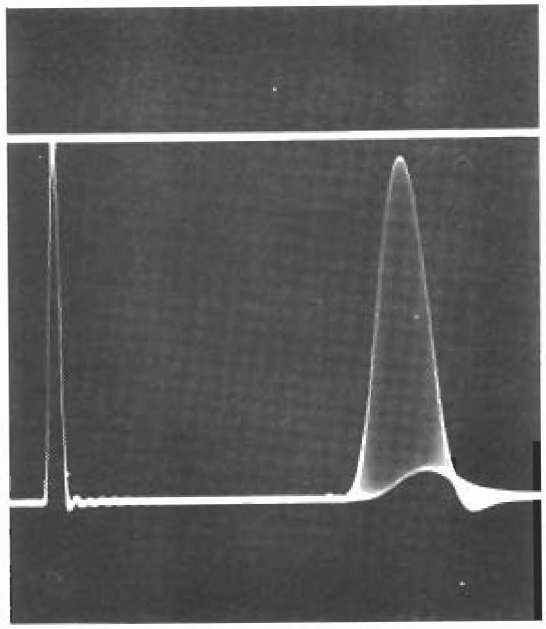


Fig. 15a — Augmented pulse and bar signal at output of notch filter: double-triggered

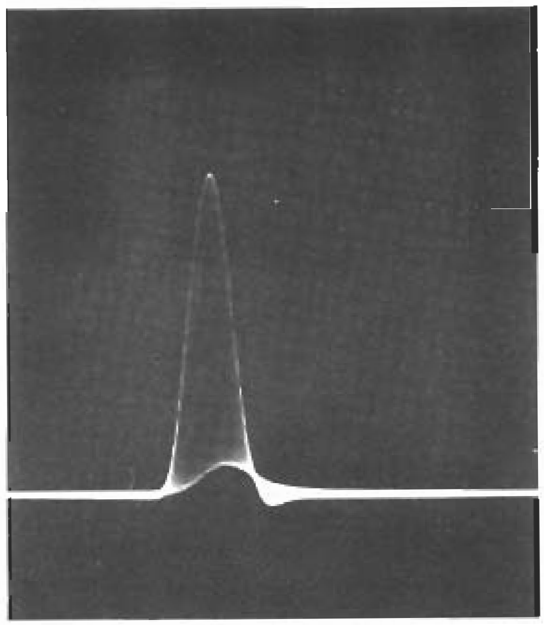


Fig. 15(b) — As Fig. 15a showing 10T pulse alone

The test of cable equalization showed no great improvement from the inclusion of the chrominance pulse, but this was simply due to the precision with which it was possible to correct for this type of cable characteristic with the particular variable equalizer used. However, when tests were made in a studio which included various items of studio equipment in addition to a number of cable lengths, the great usefulness of the augmented signal became apparent. With the available equalization it was not possible to correct the distorted frequency characteristic completely, but it was easily possible to find a compromise setting for the equalizer at which the distortion of both luminance and chrominance test signals appeared to be reasonable. It further became apparent that the signal would be even more useful, as had already been discussed, if some criterion were available to assist in the choice of the optimum compromise for the equalization.

Finally, an experiment was carried out with the primary object of investigating to what extent fairly serious chrominance distortion can be measured in the presence of the monochrome pulse and bar, but incidentally demonstrating that it is possible for significant distortion of the chrominance region to occur with very little distortion of the 2T pulse and bar signal.

The distorting network used produced a symmetrical notch centred on the colour sub-carrier with an overall width of $\pm$400 Kc/s and a maximum attenuation of rather less than 2 dB. The resulting distorted pulses are shown in Fig. 15a, which should be compared with Fig. 14b; the distortion of the bar was negligible. It is clear that whereas the 2T pulse shows only a very small 'ring', the chrominance pulse shows a combination of appreciable amounts of luminance-chrominance gain inequality, luminance-chrominance delay distortion, and waveform distortion of the pulse itself. The latter is to be expected since the width of the notch filter was less than the spread of the sidebands of the modulated pulse. This is probably a rather unlikely type of distortion to occur in practice: at all events if a dip occurs in the frequency characteristic its effect is likely to extend over a greater frequency range than in this instance, which decreases the distortion. However, it was thought that it would be interesting to see how the measurement method is able to deal with such distortion. The undistorted and distorted 2T pulses, expanded to fit the K-rating graticule, are shown in Figs. 16a and 16b respectively. The K-rating of the distorted pulse is about 1 per cent.

The amount of distortion undergone by the chrominance pulse was measured by the technique described in Part I. Of course, in this instance the situation is complicated by the relatively large amount of envelope distortion of the chrominance pulse, but in fact one of the objects of this experiment was to investigate the extent to which the measurement is hampeerd by the presence of this type of distortion.

The double-triggered pulse and bar waveform available at the output of the measuring device with no compensation introduced is shown in Fig. 17a. The distortion visible on the 2T pulse and bar is a result of the separating networks used, and does not in any way impair the measurement of the chrominance pulse. The procedure used for measurement was as follows. The relative luminance-chrominance gain was adjusted until the chrominance pulse-bar ratio was restored, and then the luminance-chrominance delay was adjusted until the greatest symmetry of the base of the pulse was obtained; for this purpose the 'ring' at the right-hand side of the pulse was ignored. The equalized condition is shown in Fig. 17b. The readings obtained were a little under 2 dB for the gain inequality and approximately 40 ns for the delay inequality. The sensitivity of the adjustment was distinctly poorer than is the case when no envelope distortion of the chrominance pulse is present, but the measurement was nevertheless perfectly practicable.

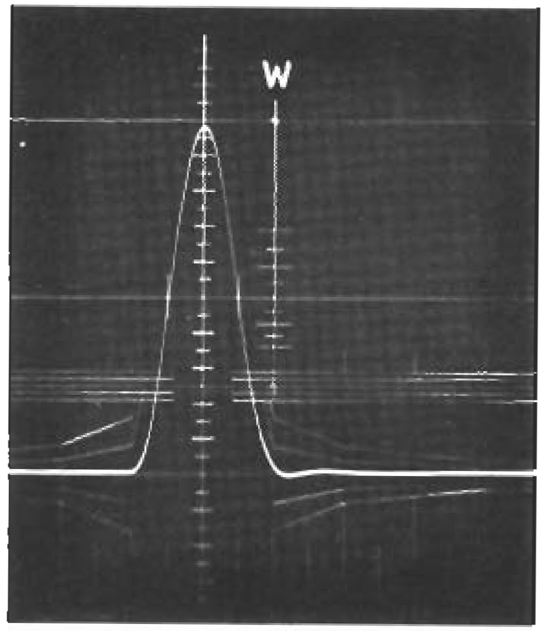


Fig. 16a — Sine-squared pulse of Fig. 14a expanded against graticule

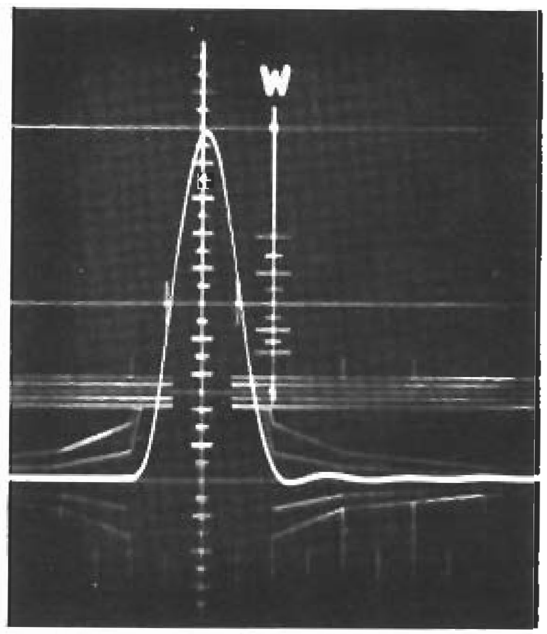


Fig. 16b — Sine-squared pulse of Fig. 15a expanded against graticule

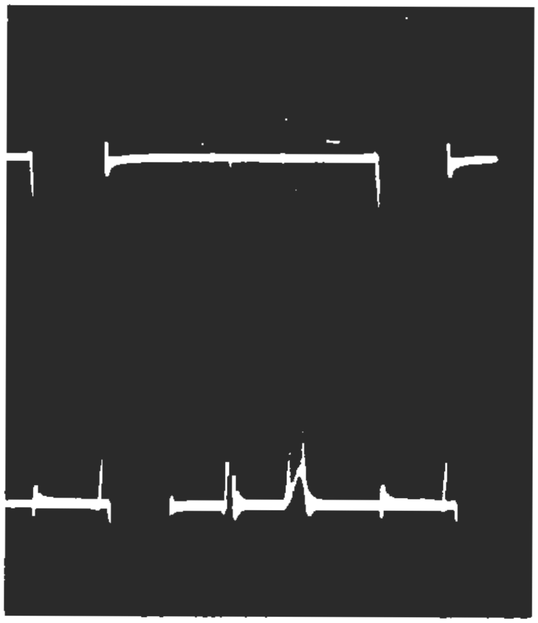


Fig. 17a — The distorted signal after passing through the measuring device: no correction

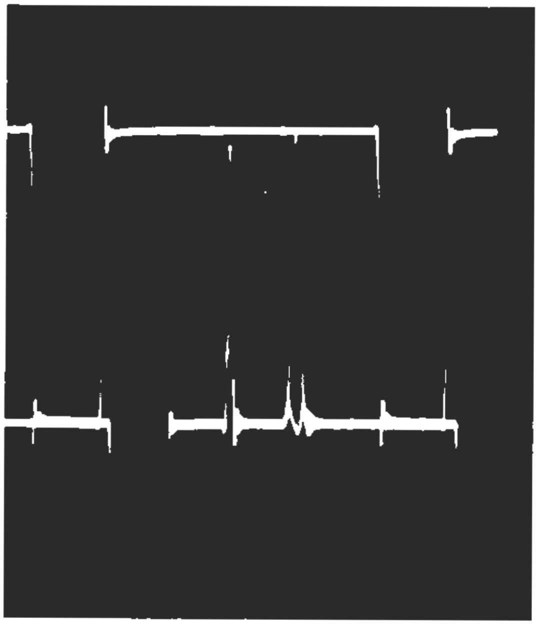


Fig. 17b — As Fig. 17a but with optimum correction

13. Colour Test-line Signal

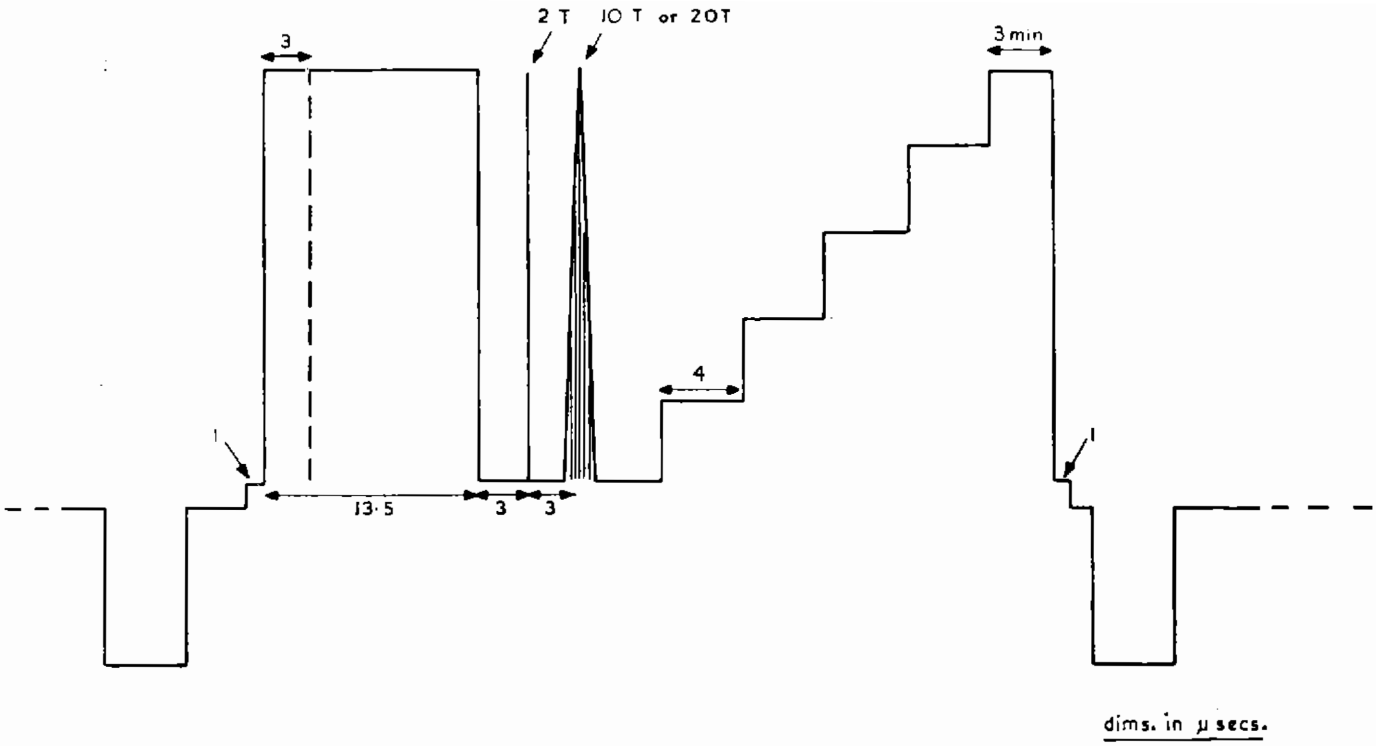
The experimental work carried out on the augmented pulse and bar system indicated clearly that another field where the principle could very usefully be applied is that of the test-line signal.

The principal reason for this is the necessity with the test-line signal for designing it in such a way that the maximum of information can be derived from the minimum of signal. If a circuit, for example, is to handle NTSC colour signals two sets of information at least are required: the linear waveform characteristics of the circuit such as are provided by sine-squared pulse and bar methods, and the non-linear characteristics. These latter comprise the luminance non-linearity and the differential gain and phase. In addition, it may be convenient to transmit one line per field of colour bars, since experiment has shown that a vectorscope display under these conditions is quite feasible, and the result is a very useful immediate, even if not highly accurate, check on the state of the circuit. This signal is particularly useful for monitoring transmitter performance.

The luminance waveform distortion and non-linearity distortion can be measured to a useful degree of accuracy, as is known, by means of the test-line signal consisting of a 2T sine-squared pulse with half-width bar and a five-step staircase waveform. The 405-line version of this signal has been for some time an agreed common standard between the United Kingdom television administrations and the Post Office. The addition of a composite chrominance pulse then makes it possible to measure the linear waveform parameters of the chrominance region in addition to the luminance parameters. The result is the waveform shown in Fig. 18, which is the analogue of the augmented sine-squared pulse and bar signal, and in the same way it is also advantageous for monochrome purposes only. The measurement of the linear chrominance parameters can be carried out just as has been described with the augmented sine-squared pulse and bar signal except, of course, that a line-selector must be employed to view the signal.

The best method of measuring differential phase and gain would be to include another test-line signal, on another line of the field blanking period, consisting of a staircase or sawtooth waveform with superimposed colour sub-carrier. However, the use of another line can be avoided by the simple device of adding the sub-carrier frequency to the staircase waveform of the test-line signal of Fig. 18, care being taken to include a sufficient duration of sub-carrier at black level before the start of the staircase. This introduces no difficulty whatsoever into the luminance non-linearity measurement, since the sub-carrier component is completely eliminated by the filter used for the shaping of the pulses corresponding to the heights of the steps.

The amplitude of the added sub-carrier frequency is not critical, provided it is not unduly great. A convenient value in this instance is a peak-to-peak value of 0·14 volt, that is equal to the height of each of the steps of the staircase, since it enables a very simple check to be carried out of the level of superimposed sub-carrier. A larger level of sub-carrier is desirable from the point of view of signal-to-noise ratio but, apart from the error introduced as a consequence of the sub-carrier amplitude being a large fraction of the test signal amplitude, errors may be introduced into the luminance non-linearity measurement by distortion of the type described in Part I as a result of vestigial sideband



The vertical dotted line shows the position of an optional inverted 2T pulse.

Fig. 18 — *A suggested* 625-*line test-line signal*

transmission. For this reason it would be advisable to omit the superimposed sub-carrier whenever the signal is used purely for monochrome testing.

The accuracy of the differential phase measurement inevitably depends upon the signal-to-noise ratio of the signal which carries the test-line signal, and in order to minimize the error it is essential to provide the best possible reference for sub-carrier regeneration, preferably in the form of a burst on every line. It was found with such a signal under rather good signal-to-noise conditions that a measurement of about $\pm 0{\cdot}3°$ of differential phase was possible. It is difficult to give a figure for worse signal-to-noise conditions since much depends upon the measuring equipment, the type of display, and whether the display is photographed.

14. Conclusions on Part II

Considerable advantages are gained by:

(i) The addition of a composite $2T_c$ chrominance pulse to the standard 2T pulse and bar waveform. On the one hand this can serve as an improved pulse and bar signal with enhanced information about the upper video band, but without the spectrum of the test signal exceeding the nominal upper limit of the video band. On the other hand it can serve as a combined signal for testing the linear waveform distortion of both the luminance and chrominance channels. Experiment shows that such a signal is not greatly inferior in accuracy for measurements on the chrominance channel than the proposed chrominance pulse and bar signal.

(ii) The addition of the chrominance pulse to the form of test-line signal standardized for 405-line use would produce a signal having the advantages given above in addition to the proven good practical features of the test-line signal. The superposition of a suitable amplitude of colour subcarrier on the staircase waveform makes possible the measurement of differential gain and phase as well. In other words such a test-line signal allows the measurement of the linear and non-linear parameters, both luminance and chrominance.

(iii) Where appreciable envelope distortion of the chrominance test signal occurs it might prove useful to have available an alternative signal of lower bandwidth, say a $4T_c$ pulse instead of the $2T_c$. This situation appears to occur relatively seldom with the BBC distribution network, but might be encountered on international links, for example.

(iv) It would be extremely advantageous if the chrominance channel distortion parameters could be brought into the scope of a combined luminance-chrominance 'K-rating', since this would enable a single figure of merit to be given to a link or equipment handling colour signals. Such a rating factor might even include differential gain and phase as well as the linear waveform distortion parameters, for example luminance-chrominance gain and delay inequalities. This would have to be done on the basis of subjective tests with representative colour pictures, using the colour system and standards finally to be put into service.

15. Acknowledgement

The author would like to thank Mr J. E. Holder for his valuable assistance in the design of the measuring equipment discussed in this monograph, and engineers of BBC Communications Department for their co-operation in the practical tests.

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17. Appendix

Change in the Waveform of the Composite Signal for a Given Distortion

The test waveform is formed by the linear addition of a pulse and bar signal, and the same signal which has been used to modulate sub-carrier frequency to a depth of 100 per cent. This signal is positive-going, and hence has identically the same waveform as the upper portion of the modulation envelope. Likewise the lower portion of the modulation envelope is exactly the negative of the unmodulated signal. Consequently, the resultant signal possesses an upper portion of the modulation envelope which is the sum of the two waveforms, and a lower portion which is the difference. In the special case when the peak-to-peak amplitude of either portion of the modulation envelope is equal to the peak-to-peak amplitude of the unmodulated signal, and the two signals are in precise time coincidence, the lower portion of the envelope becomes a straight line. This is the normal correct adjustment for the test signal.

17.1 *Pulse Waveform*

17.1.1 *Amplitude Difference Only*

Let the amplitude of the luminance pulse be e_1, and let the amplitude of either side of the modulation envelope be e_2.

Then the peak-to-peak amplitude of the test-pulse = the amplitude E_U of the upper modulation envelope $= e_1 + e_2$.

The amplitude of the lower modulation envelope E_L similarly $= e_1 - e_2$.

$$\therefore \text{The luminance-chrominance ratio} = \frac{e_1}{e_2} = \frac{E_U + E_L}{E_U - E_L}$$

$$\therefore E_L = \frac{e_1/e_2 - 1}{e_1/e_2 + 1} \cdot E_U \qquad (1)$$

For small errors in e_1/e_2 the amplitude of the lower modulation envelope

$$\simeq \tfrac{1}{2} E_U \left(\frac{e_1}{e_2} - 1 \right) \qquad (2)$$

In other words the displacement of the base-line from the horizontal is approximately equal to one-half of the error in the luminance-chrominance ratio times the amplitude of the test-pulse. It is obvious that the peak of the pulse will be displaced vertically by the same amount as the base line.

17.1.2 *Delay Difference Only*

In this instance the amplitudes are equal. The luminance and chrominance waveforms can therefore be written respectively as $e = e_1 \sin^2\theta$ and $e = e_1 \sin^2 (\theta - \phi)$ over the range of pulse duration, where $\theta = \frac{\pi t}{2T_c}$ and $\phi = \frac{\pi \tau}{2T_c}$; T is the half-amplitude duration, and τ is the delay between the two waveforms.

Then the lower envelope is given by

$$e = e_1 [\sin^2\theta - \sin^2 (\theta - \phi)] \qquad (3)$$
$$= e_1 \sin (2\theta - \phi) \cdot \sin \phi$$

by a well-known trigonometrical identity.

When ϕ is small, as is normally the case, the shape of the base-line is

$$e \simeq e_1 \sin 2\theta \cdot \sin \phi \qquad (4)$$

which is a sinusoid of amplitude

$$\sin \phi = \sin \frac{\pi \tau}{2T_c} = \sin \frac{\tau}{T_c} \times 90^\circ \qquad (5)$$

In practice the quantity measured is the peak-to-peak amplitude $= 2\sin \phi$, but the amplitude of the test pulse is $2e_1$, so that the ratio of the peak-to-peak amplitude of the base-line to the amplitude of the test pulse is $\sin \phi$.

For the sake of example, if $T_c = 1\ \mu s$ and $\tau = 10$ ns, $\sin \phi = \sin 0{\cdot}9^\circ = 0{\cdot}016$. The amplitude of the sinusoid on the base-line is thus 1·6 per cent of the test pulse amplitude.

An alternative derivation is indicated in Section 4, p. 10. The lower envelope is formed by the subtraction of two waveforms having a small time displacement, and can therefore be regarded approximately as the time derivative of the pulse waveform.

The envelope is therefore given by $\tau \times \frac{d}{dt} \sin^2 \frac{\pi t}{2T_c}$

$$= \frac{\pi\tau}{2T_c} \sin \frac{\pi t}{T_c}$$

which is identical with Equation (4) above if $\sin \phi$ is replaced by ϕ, which is admissible since the delay error τ, and hence ϕ, is assumed to be extremely small.

17.2 *Bar Waveform*

17.2.1 *Amplitude Difference Only*

In view of the relatively long flat portion of this waveform one obviously ignores the transitions and measures a displacement of the flat portion of the base-line of $e_1 - e_2$.

Then $E_L = e_1 - e_2$ and $E_U = e_1 + e_2$, so that as before

$$E_L = \frac{e_1/e_2 - 1}{e_1/e_2 + 1} \cdot E_U \qquad (1)$$

and for small values of e_1/e_2, $E_L = \frac{1}{2} E_U \left(\frac{e_1}{e_2} - 1\right)$ (2)

17.2.2. *Delay Difference Only*

The bar waveform is given by

$$e = \tfrac{1}{2}e_1 \left(\frac{t}{T} - \frac{1}{\pi} \sin \frac{\pi t}{T_c}\right) \quad 0 \leqslant t \leqslant 2T_c$$

$$e = e_1 \qquad t \geqslant 2T_c \qquad (6)$$

For the sake of simplicity the approximate expression will be derived directly by differentiation as for the pulse waveform above.

$$\text{Then } E_L = \tau \frac{d}{dt} \tfrac{1}{2}e_1 \left(\frac{t}{T_c} - \frac{\pi t}{T_c}\right)$$

$$= \tfrac{1}{2}e_1 \frac{\tau}{T} \left(1 - \cos \frac{\pi t}{T_c}\right)$$

$$= e_1 \frac{\tau}{T_c} \sin^2 \frac{\pi t}{2T_c} \qquad (7)$$

In other words the transitional portion of the lower envelope has the same shape as the sine-squared pulse in the test waveform but with an amplitude $\frac{\tau}{T_c} e_1$. Also since the amplitude of the bar $= E_U = 2e_1$:

$$E_L = \frac{\tau}{2T_c} E_U \qquad (8)$$

where in this context E_L is the amplitude of the transitional portion of the lower envelope. This is $\frac{1}{\pi}$ of the value obtained for the pulse, which helps to explain the lower sensitivity of the bar for the purpose of measuring the delay.

CORRECTIONS TO MONOGRAPH NO. 18

Attention has been drawn to hitherto unobserved errors in Monograph No. 18, *The BBC Colour Television Tests: An Appraisal of Results*, first published in May 1958, and reprinted in November 1964 with the title amended to *The BBC 405-line Colour Television Tests: An Appraisal of Results*.

In Table 17 on page 25, and also in Tables 18 and 19 on page 26, the 'Buzz' column should be under 'Individual Effects' instead of 'All Effects'.

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