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AUSTRALIAN BROADCASTING CONTROL BOARD

TECHNICAL SERVICES DIVISION

REPORT No. 18

TITLE: Delay and Transient Problems in Television Broadcasting

Issued by:-

The Chairman,
Australian Broadcasting Control Board,
Rialto Building,
497 Collins Street,
MELBOURNE, C.1.

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Date of issue
15/5/1959

Abstract

The paper presents a survey of transient distortions in a television broadcasting system. It is shown that in monochrome video circuits, their main source lies in imperfections in the amplitude/frequency and delay/frequency responses. The vestigial sideband radio systems employed introduce additional non-linearity and amplitude-dependent phase errors.

Definitions of some of the observed effects of transient distortion, such as ringing, streaking, smearing, overshoot, preshoot, and tilt are given. Based on subjective estimates of the tolerable limits of these, a system of maximum values of waveform distortion is developed, used by the Australian Broadcasting Control Board for checks on television transmission equipment and radiated signals.

The checking of radiated signals requires a monitor receiver of standard characteristics. Commercial receivers will tend to approximate these characteristics, which have been established in consultation with the industry.

Methods of transient response measurement are described, and the relation between transient and steady-state response outlined. Different ways of specifying delay, and methods of measuring them, are surveyed. This leads to a description of amplitude, delay and waveform correctors, and the paper ends with a discussion of present tendencies in development, and some future prospects.

CONTENTS

DELAY AND TRANSIENT PROBLEMS IN TELEVISION BROADCASTING

1. Introduction

1.1 The picture shown by the viewer's receiver has many distortions, compared with the original scene imaged on the television camera. These distortions may be divided into four main groups:-

(1) Those inherent in the television system, even with perfect equipment.

(2) Those produced by imperfections in the equipment converting the optical image to an electrical signal.

(3) Those introduced by the transmission system from camera output to picture tube input.

(4) Those produced by imperfections in the equipment re-converting the electrical signal to an optical image.

1.2 Inherent distortions

The distortions inherent in the television system include:-

(a) Lack of colour (in monochrome systems).

(b) Picture composed of horizontal lines.

(c) High brightness flicker.

(d) Errors in reproduction in movement.

(e) Limited resolution due to system bandwidth.

1.3 Distortions of picture generating equipment

These include:-

(a) Loss of detail due to optical system.

(b) Loss of detail due to picture analysis (aperture distortion).

(c) Limited contrast range

(d) Departure of the variation of output voltage as a function of input brightness from the desired law (errors in gamma).

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(e) Geometrical non-uniformity of scanning circuits.

(f) Spurious effects in camera tubes; (edge effects, shading, spots, mesh patterns, microphony).

(g) Noise generated by pick-up device.

1.4 Distortions of picture reproducing equipment

These include such items as:-

(a) Time errors, or jitters of the time basis.

(b) Time base non-linearities.

(c) Imperfect interlacing.

(d) Incorrect picture tube gamma.

(e) Limitation of contrast range produced by internal reflections in picture tube screen, and by room lighting.

(f) Loss of detail due to aperture distortion.

(g) Curvature of picture surface, etc..

1.5 Despite all these possibilities for distortion, if the picture quality of the station monitors is compared with that in the average home, when good quality material is being transmitted by well-adjusted equipment, it becomes evident that the limiting factor in the television system is, at present, the transmission path between camera output and picture tube input. Loss of resolution due to bandwidth limitation is inevitable, but the observed degradation is too great to be accounted for on this basis alone.

During the past few months, considerable effort has been expended by television broadcasters and receiver designers, in reducing the distortions of this path, and a noticeable improvement in picture quality has resulted. The object of this paper is to survey some of the problems of this work, and describe the main concepts involved.

2. Distortions of the transmission path

Despite the complexity of the transmission path - it comprises studio switching equipment, stabilising amplifiers, micro-wave links, vestigial sideband transmitter, transmitting aerial, propagation path, receiving aerial, RF, IF and VF stages of the receiver - this path may be regarded as a four terminal

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~~network~~ which for distortionless operation, must transmit the voltage variations with time corresponding to the original brightness changes between black and white or any intermediate levels at rates of change up to the maximum permitted by the system bandwidth, without any distortion of the waveform of such variations. In addition, the noise level introduced in the path must be low compared with that in the original signal, and the amplitude non-linearity small. (This last requirement is not very critical for monochrome television, but becomes stringent for colour signals.)

The human eye is sensitive to brightness changes of the order of 2% and upwards (Refs. 1, 2). It is reasonably easy to achieve levels of noise and non-linearity lower than this in present television systems, but the overall waveform distortions with an average receiving installation, are considerably higher than this, and are thus the limiting factors in determining overall picture quality.

3. Transient response and steady-state response

Linear defects of the video system may be described directly in terms of the time response to a transient signal (Ref. 3) or alternatively in terms of the "steady-state" amplitude/frequency and delay/frequency responses to a sinusoidal signal. Though the former method is more direct, and is likely to come increasingly into use (Refs. 4, 5) it possesses two disadvantages. Firstly, with the present body of design and adjustment knowledge, and the equipment available it is easier to make adjustments to the steady-state response of a piece of equipment than to the time response. Thus in practice, when a defect in the time response is observed, it is often more convenient to compute or measure the steady-state response and make changes accordingly. Secondly, the steady-state response of a number of cascaded parts of the system is simply obtained by adding the responses of the separate parts; computation of cascaded time responses from individual time responses is more complex and difficult (Ref. 6). Both methods are therefore, needed, and the present tendency is to check or specify the overall performance of a television system, or major part of it, in terms of time responses, while using steady-state response for the detailed study of individual items of equipment.

4. Distortions of the vestigial sideband system.

Though the vestigial sideband system has many advantages in increasing the number of channels available, increasing radiated power for a given cost, increasing coverage, reducing receiver noise, and reducing receiver cost, it gives rise to certain additional distortions (Refs. 4, 5, 7, 8, 9). These comprise linear delay distortions in the transmitter vestigial sideband filter, linear delay and amplitude distortions produced by the "Nyquist slope" errors in the receiver, and non-linear delay and amplitude distortions produced by the quadrature component of the signal during envelope detection at the receiver. All linear distortions will produce identical distortions, with skew symmetry, of the "up" and "down" transitions of a step wave; quadrature components produce differing distortions on the "up" and "down" transitions, and are usually identified by this means; combinations of quadrature and linear distortions give complex effects. The quadrature distortions are a function of the depth of modulation; they are negligible for small brightness changes, become perceptible for changes over 20 to 30% of the black to white range and are severe for black to white changes - in fact for such changes the vestigial sideband system offers no benefit (this is the reason radar systems use double-sideband reception). Fortunately much of the detail in a television picture comprises fairly small brightness changes, which are not distorted by quadrature effects.

There are several techniques of reducing these quadrature distortions to very low levels. At present, however, they involve appreciable increases in transmitter or receiver cost and complexity.

Until the linear distortions in the system have been reduced to small amounts, however, such techniques would be of small value.

The linear errors of the vestigial sideband systems are at present reduced by video pre-compensation for the delay errors of the transmitter vestigial sideband filter, and much work is proceeding on "phase-linear" receivers to reduce Nyquist slope errors (Refs. 3, 5, 10, 11, 12, 13).

These linear errors may be expressed in terms of the time response or steady-state response defects of the overall video quadripole from transmitter modulator to receiver detector output, and may be lumped together with those of the purely video circuits for specification or correction.

5. Definitions and causes of particular waveform distortions

5.1 The different forms of waveform distortion have been given a wide range of names, suggested by their appearance either on a picture tube, or a waveform monitor. Unfortunately, there is no general agreement on some of these and much confusion and misunderstanding occurs.

It is proposed to define a number of these in terms suitable for the present usage, and to give some general discussion of their form and the conditions which produce them.

5.2 "<u>Ringing</u>" of a vision signal means the distortion of a step wave by the appearance of trains of approximately sinusoidal oscillations superimposed on the initial and final near-horizontal axes of the step wave.

This ringing usually occurs at or near the upper frequency of the system passband, being produced by a peak near the upper frequency limit of the amplitude/frequency response, or by a steep cut-off in frequency response. If the amplitude peak or cut-off is unaccompanied by any departure from constant time delay over the passband, then the ringing will be distributed symmetrically before and after the main transition.

If, however, as is more usual there is no correction for the delay errors introduced by the amplitude variations and the equipment comprises only minimum phase-shift networks, then the ringing occurs only after the transition, and is approximately twice the amplitude of that occurring with no delay errors. Far example, an extremely sharp cut-off low-pass filter produces ringing of 9% of the step amplitude both before and after the transition if delay correction is used. In the absence of delay correction there is no disturbance before the transition, but a 19% following ring (Fig. 1). The disturbance in the corrected case would be much less noticeable on a picture tube.

This is one particular case of a general rule, that amplitude variations on their own produce disturbances which are symmetrical about the main transition; delay variations on their own produce disturbances skew (anti) symmetrical about the transition; while the combined amplitude and delay changes produced by "ordinary" (i.e. minimum phase-shift) networks, produce two sets of disturbances which cancel before the main transition, and reinforce each other after the transition. By regarding the disturbance of the transient as the sum of symmetrical and antisymmetrical components, it is possible relatively easily to estimate how much improvement is available by delay correction.

The amplitude of ringing is a function of the sharpness of cut-off; as the amplitude response falls more slowly beyond the passband, the ringing amplitude falls, until with a steadily falling Gaussian amplitude response, ringing vanishes.

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5.3 "Streaking" of a vision signal means the distortion of a step wave by the ending of the main step transition at a level above or below the final level, followed by a slow approximately exponential transition to the final level. The appearance in a picture is of a streak following a boundary between relatively large areas of differing brightness. There is no distortion before the boundary.

If the transition undershoots its final value then we get "like streaking", "black-after-black" or "white-after-white"; if it overshoots, the more noticeable "white-after-black" and "black-after-white". Since it relates to large brightness areas, when it occurs in the line direction it is associated with frequencies of the order of 20-200 kc/s, and if, more rarely, in the frame direction, it is associated with frequencies of 20-200 c/s. From the comments on phase and amplitude errors under "Ringing" it will be evident that the following streaks correspond to simultaneous variations in amplitude and phase errors of the lower frequencies produced by "minimum-phase-shift" circuits or their electro-optical analogues (Fig. 2).

A rising low frequency response with accompanying delay errors produces a rounded waveform or "like" streaking; and a drooping low frequency response, in contrast, produces "unlike" streaking.

5.4 "Smearing" of a vision signal means a distortion of a step wave by the beginning and ending of the main step transition at levels differing from the initial and final levels.

The essential differences from streaking are that the disturbances are approximately the same magnitude before and after the step, and are anti-symmetrical (Fig. 3). Smear is therefore produced by delay errors, most often in the range below 1 Mc/s. A typical case is produced by an increased delay at the lower frequencies which gives a leading preshoot and a following smear. Conversely a less usual decrease in delay at low frequencies would give a leading smear and a following overshoot (Refs. 14, 15).

Delay errors at the lower frequencies produced by the Nyquist slopes of receivers are a frequent cause of smear. The magnitude and frequency range of the delay error may be estimated from the amplitude and duration of the smear (Ref. 14).

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5.5 "Echo distortion" of a step wave means the presence after the main transition of a smaller distinguishable transition of similar shape.

It is produced by small ripples in the amplitude response at low frequencies, or by propagation phenomena on transmission lines or in free space (Fig. 4).

5.6 "Square wave tilt" is the tilt of the initially flat top of a square wave produced by passage through the whole or part of the television system. It is defined as the drop in level between the ends of the straight line which best fits the top of the distorted wave expressed as a percentage of the average level change between top and bottom of the square wave (Fig. 5).

The concept of tilt is usually confined to use at very low frequencies - line and field rate - to check the performance of television systems for slow brightness changes over large areas.

5.7 "Rise time" of a vision signal means the time for a step wave to change from 10% to 90% of magnitude of the step. In the presence of ringing, streaking, or smearing, rise time is measured by drawing the main axes through the leading and following ringing oscillations - these axes will slope exponentially if streaking or smearing is present - to intersect a straight line drawn to coincide with the steep part of the transition. Rise time is then defined as the period for the wave to change from 10% to 90% of the difference in levels between the intersections (Fig. 6).

Since all the Fourier components of a step wave are equally important in contributing to the steepness of the transition, then, provided that all their steepest parts emerge from the system together, i.e. there are no delay errors, the steepness of the transition is proportional to the sum of all their amplitudes i.e. to the integral of, or area beneath the amplitude/frequency response curve. Thus a low pass system giving perfect transmission up to a frequency fc, will convert a zero rise time step wave into one with rise time $\frac{1}{2fc}$ e.g. for a 5 Mc/s bandwidth, the rise time would be 0.1 microseconds.

In the case of a number of cascaded parts of a system, each of which have a rectangular passband, only the narrowest will determine the rise time. However, a cascade of parts of the system each with a near-Gaussian drooping characteristic will give an overall rise time which is the r.m.s. sum of the rise

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times of the individual sections. It is for this reason that a drop in the quality of transmission is quite easily detected using a receiver whose transmission characteristics are very much poorer.

5.8 "Overshoot" of a step wave means the percentage excess of the maximum value reached after the step relative to the final magnitude of the step. Overshoot may be produced by ringing, smear, streaking or a combination of these (Figs. 2, 3).

5.9 "Undershoot" of a step wave means the percentage deficiency of the value reached immediately after the step transition relative to the final magnitude of the step (Figs. 2, 3).

5.10 "Preshoot" means a distortion of a step wave similar to overshoot or undershoot, but preceding the steep transition of the step, defined as the percentage departure from the initial level of the step of the beginning of the steep transition, relative to the magnitude of the step (Fig.3).

6. Subjective estimates of tolerable limits of waveform distortion

6.1 As for any other form of distortion, the tolerable limits of waveform distortions are found by subjective experiments with a representative audience. Basic work of this type has been carried out in a number of countries. Based on this work (Ref. 16), a system of maximum values of waveform distortion has been developed by the Australian Broadcasting Control Board (Ref. 17), and is used for checks on television transmission equipment and radiated signals.

6.2 Rise Time

Experiments have shown that for the 625 line system, a rise time of 0.1 microseconds for 10% to 90% is a satisfactory limit to choose on the grounds of resolution. A reduction in rise time to 0.08 microseconds is barely detectable, and then only when using special test patterns. On the other hand an increase in rise time to 0.12 microseconds is clearly detectable as a degradation in resolution. It is well known that small amounts of overshoot increase the apparent resolution, and these were carefully avoided in this work.

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6.3 Overshoot

Rapid overshoots are not very disturbing, and may even "crispen" a picture slightly. Typical limits found are, for an overshoot lasting 0.1 microseconds, a 12% overshoot is detectable, and 20% objectionable; whereas, for an overshoot lasting 0.5 microseconds, 3% is detectable and 7% objectionable.

6.4 Echo Distortion

Echo distortions produced by reflections, depend on their severity, as for overshoots, not only on their magnitude, but on their time delay. There is also a difference in the subjective effect of positive and negative echoes.

Quite strong reflections are permissible after 0.1 microseconds, - again 12% is detectable, 20% objectionable but with increasing delay the eye rapidly becomes more critical, and at delays of the order of 1.5 microseconds 2-3% echoes are detectable and 4-6% objectionable. At longer delays, echoes as low as 1% are detectable, particularly with certain bold picture material.

6.5 Smear

Smears which have durations in the overshoot range of 0.1 to 0.5 microseconds have similar subjective limits to those of overshoots, however, much longer smears from 1 to 20 microseconds (i.e. up to half way across the screen) are sometimes encountered, and are detectable with 3% amplitude and objectionable at 5%.

6.6 Ringing

A succession of high frequency rings is found to be much less visible than an exponential smear of the same amplitude and duration. This is due to the fact that at normal viewing distance the fine alternate light and dark bands produced in the picture tend to average out at the eye. A ring amplitude of 5% is about as disturbing as a smear of 3%.

7. Australian Broadcasting Control Board Limits of Waveform Distortion

7.1 It will be apparent that on inspecting a particular distorted step transition, it is often difficult even to identify which faults are causing the distortion, let alone attempting to measure the contribution of each. It is therefore impracticable to lay down limits separately for streaking, smear, ringing, echo distortion etc.. Instead the limits have been defined in the form of "masks" or boundaries ~~to~~ within which the transient must fall when drawn on standardised axes (Refs. 16, 17).

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At present two sets of transient response limits have been determined.

7.2 The first applies to studio equipment, OB equipment, or microwave links, the required performance corresponding closely to the threshold values described in 6 above.

<u>Transient response of studio, OB, or link equipment (Fig.7)</u>

The equipment shall have a transient response to a black-white step, or the reverse, or intermediately, within the following limits -

(a) Rise time 10% - 90% of step - not greater than 0.1 microseconds

(b) Resolution - greater than 450 lines horizontal, 400 lines vertical

(c) Ringing frequency - greater than 6 megacycles per second

(d) Departure from step transition due to overshoot, undershoot, ringing, or echo distortion - to be within the following limits

Departure from final value of step (percentage)	Time interval after centre of step
- 10%	0.05 microseconds
+ 9%	0.1 "
± 5%	0.2 "
± 5% (sinusoidal)	0.4 to 1.0 "
± 2% (exponential)	
± 2%	over 1 microsecond.

(e) Departure from step transition due to preshoot etc. - as for (d) measured downwards from initial value of step, time intervals before centre of step.

(f) Tilt of 50 c/s square wave plus line synchronising pulses - less than 2%

(g) Tilt of line frequency square wave - less than 2%

A 50 c/s square wave plus line synchronising pulses is specified in (f) for the very low frequency tests, because of the common practice of maintaining low-frequency response by line-to-line clamping. Without clamping, the video response must extend downwards uniformly to a fraction of a cycle per second - with clamping, a lower limit of about 50 c/s is permissible to meet the requirements of this test; even higher minimum frequencies are possible with more sophisticated clamping circuits. Because of these possibilities the separate check of the line frequency tilt in (g) is included.

The required resolution and rise time ensure that the bandwidth and general performance of these sections of the television system are considerably better than those of the high-powered transmitting equipment, which is thus the limiting factor in performance of the transmission system.

7.3 Transient response of picture transmitter (Fig. 8).

The transient response of the transmitter combined with a standard monitor shall be within the following limits for a step transition from 50% to 70% of the peak carrier amplitude or the reverse -

(a) Rise time 10%- 90% of step - not greater than 0.15 microseconds

(b) Resolution - greater than 400 lines horizontal, 400 lines vertical.

(c) Ringing frequency - greater than 5 megacycles per second

(d) Departure from step transition due to overshoot, undershoot, ringing or echo distortion. - to be within the following limits.

Departure from first value of step (percentage)	Time interval after centre of step
- 10%	0.075 microseconds
+ 11%	0.1 "
± 7%	0.2 "
± 5% (sinusoidal)	0.4 to 1.0 microseconds
± 3% (exponential)	
± 3%	over 1 microsecond

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(e)	Departure from step transition due to preshoot etc.	As for (d) measured downwards from initial value of step, time intervals before centre of step
(f)	Tilt of 50 c/s square-wave plus line synchronising pulses	less than 2% of step for a step from 15% - 70% of peak carrier
(g)	Tilt of line frequency square wave	less than 2% of step for a step from 15% - 70% of peak carrier.

The longer rise time and greater transient disturbances permissible are realistic values for the performance of present-day equipment; it must be remembered that these standards are lower limits of performance.

The transient response is measured not with a black-to-white step but with a smaller step near black. This is in order to avoid the additional quadrature distortions which occur at higher modulation levels. In the case of the line and field frequency square wave tests, a black-to-white step is used, because at low frequencies the system operates with double sidebands; quadrature distortion should be absent.

8. Standard Monitor Receiver

8.1 In order to check the transient performance of a picture transmitter, it is necessary to demodulate the signal under standard conditions. The characteristics chosen for the standard demodulator are important, because in practice the transmitter will be adjusted for best results from the demodulator output. It follows that the best picture quality will be obtained with receivers which approximate in characteristics to those of the demodulator. Such characteristics should therefore be chosen to render the manufacture of receivers as cheap and simple as possible, even at the expense of transmitter complication.

8.2 There are two schools of thought in this field - one (Refs. 8, 9) considers that the receiver should have the simplest tuned circuits necessary to achieve the correct amplitude response, and that the resulting large receiver delay errors should be precompensated by radiating a signal with opposite delay errors. The second school (Refs. 10, 11, 12, 13) considers this undesirable: the receiver delay errors will only balance the radiated errors for one setting of the fine tuning control, so that in practice critical receiver adjustment for best picture quality is necessary - or, more often, a poor picture is tolerated. This school maintains that the

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production of receivers with negligible delay errors - so-called "phase-linear" receivers - is hardly more costly than for the conventional design.

The Australian Broadcasting Control Board has studied this question in conjunction with the industry, and a generally acceptable compromise has been achieved (Ref. 17).

8.3 Most of the arguments for "phase-linear" receivers have their greatest weight at low and medium video frequencies, where the importance of constant delay is greatest and in which region satisfactory "Nyquist slope" designs giving nearly constant delay have been evolved. It has therefore been agreed, that transmitters shall be required to radiate signals with constant delay at frequencies corresponding with low and medium video frequencies.

As an indication of the importance of delay variations at the low and middle frequencies, a delay increasing by only 120 millimicroseconds as the frequency is reduced from 1 Mc/s to very low frequencies, will give rise, in an otherwise perfect step transition, to a 12% preshoot lasting 1 microsecond before the transition, and a 12% following smear again lasting 1 microsecond. (Ref. 14)

8.4 At the upper end of the video frequency range conditions are somewhat different. All receivers have to cut off by 5.5 Mc/s to prevent the sound transmission from interfering with the picture. The better the receiver response is maintained at the upper video frequencies, the more sharply does its amplitude response have to fall near 5 Mc/s, and the greater the increase in delay produced by the high Q circuits required for this. Delay correction in the video circuits of a receiver is too complicated and expensive to be practical; designers have therefore sought compromises by "rolling off" the IF response to maintain constant delay - typically by about 6 db at 4.0 Mc/s. This practice increases rise time and decreases resolution appreciably - about 20% for the case quoted above. The technique of radiating a signal from the transmitter with some reduction in delay at the higher frequencies to enable the amplitude response of receivers to be improved, has therefore been adopted, without going to the other extreme of radiating a highly corrected signal. The reduction in radiated group delay is 120 millimicroseconds at 4.5 Mc/s, which is to be compared with 700 millimicroseconds as recommended by the "full correction" school. This amount of correction permits receiver characteristics to be maintained to over 4.5 Mc/s at the 6 db point. It is stressed that this is a very small correction - indeed the difference observed by cutting it in or out is only about two liminal units (Ref. 18) - i.e. twice the minimum difference detectable by 50% of a critical audience when the correction is suddenly switched in or out.

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One other consideration favoured the choice of this compromise. Whereas in monochrome receivers delay errors can be avoided by rolling off the amplitude response, this is not permissible in the case of N.T.S.C. type colour systems which are likely to be adopted. These require the response to be quite accurately flat in the neighborhood of the colour sub-carrier, which for the 625 line system is likely to be 4.43 Mc/s. Otherwise distortion of the relation between the sub-carrier and its colour sidebands will occur, with resultant errors in hue and saturation. To avoid these difficulties, the U.S. colour transmission standards call for a reduction in delay of the radiated signal at the higher frequencies (Refs. 3, 19), which when converted to 625 line system frequencies and bandwidth, corresponds fairly closely with the reduction standardised by the Australian Broadcasting Control Board (Ref. 17). The net result is that if and when colour television tarts, the compatible black and white picture on existing receivers will be better in quality than if it were necessary to change transmitter delay characteristics appreciably from the present standards.

The precise delay/frequency curve standardised for the monitor is the smooth curve of a single-section all-pass delay network, following a receiver of uniform delay. Details are given in Appendix 1.

8.5 If transmitters had zero delay errors, no further specification of the ideal monitor would be required. However, the delay errors produced by vestigial sideband filters at the transmitter are different for the upper and lower sidebands. At present high-power radio-frequency delay correction is not possible, and in practice the filter delay errors are precorrected by means of networks in the transmitter video input. The particular compromise between error correction for the two sidebands chosen depends on the Nyquist slope of the monitor used at the transmitter. In principle, herefore, only a receiver with this particular slope will give best results on the transmission when its own delay errors are zero (Refs. 5, 20). Receivers with differing Nyquist slopes should have slight delay variations for best results. The optimum values may vary slightly from transmitter to transmitter.

These effects are small, but have to be taken into account in precision checking of transient performance. The Nyquist slope is specified in the definition of the standard monitor given in Appendix 2.

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9. Measurement of Transient Response

9.1 It has been implied thus far that transient response should be measured with a square wave of negligible rise time. In practice, this rise time will be finite (Ref. 21), as will that of the oscillograph used at the output of the system under test. Provided the square wave is free from overshoots, and also the oscillograph response, these rise times may be added on an r.m.s. basis. How short does this test system rise time need to be? If the system under test has a flat frequency response with a fairly sharp cut-off, then so long as the test rise-time is appreciably less than $\frac{1}{2Fc}$ (e.g. 0.1 microseconds for a complete 625 line system) it will not affect the results. If on the other hand part of the system has a gradually drooping response (e.g. studio equipment) then the test rise time will add to that of the equipment on an r.m.s. basis. Thus a system having a rise time of 0.1 microseconds if measured with a square wave and oscillograph of combined rise time 0.03 microseconds, will have an indicated value of 0.11 microseconds, and a correction must be made for this. So long as the test waveform is at least 3 times as fast as the system, the correction is small and its error negligible. The spectrum of the square wave comprises a number of lines at the harmonics of the repetition frequency, with each component inversely proportional in amplitude to the order of the harmonic, with a tailing off above the frequency corresponding to half the reciprocal of the rise time. The repetition frequency must be chosen low enough to fill adequately the frequency range to be studied, remembering that the very low frequency response is best measured separately. If the repetition frequency is chosen too high - e.g. 0.5 Mc/s, then the square waves are of duration only 1 microseconds, and pre-and-post transition disturbances lasting over 0.5 microseconds - which are quite common - will tend to run into and confuse one another. On the other hand, too low a repetition rate gives rise to instrumental difficulties of oscillograph synchronisation and brightness.

A further point to be considered is that it is necessary to add at least line synchronising pulses to the square wave, so that the clamping circuits in the television system will locate the square wave in the desired picture amplitude region. For these reasons, square waves of period twenty microseconds or so, with a repetition rate of once or twice line frequency, interspersed with line synchronising pulses, form a convenient test signal (Fig. 9).

9.2 In order to determine the limits of performance of a system, it is necessary to test it with signals containing energy beyond the frequency limits of the system. Under these conditions, complex phenomena e.g. of ringing, occur, which are not so noticeable

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when signals whose energy spectrum is limited to the bandwidth of the system are used. Because of this, some authorities employ "band-limited" test signals such as sine squared impulses or square waves with sine squared transitions having rise times comparable with those of typical camera signals - say 0.1 microseconds for the 625 line system. These are very convenient for day-to-day checks, giving simple results easily interpreted by normal operators; but they cannot detect incipient falling-off in performance before it becomes operationally noticeable, as can the wider-spectrum signals. This is recognised by all - indeed the users of sine-squared impulses have two impulse widths, one whose spectrum fits within the system bandwidth and one with twice the spectrum width. Such impulses may be combined with a square wave to constitute a "pulse and bar" signal. (Refs. 22, 23, 24) (Fig. 10).

Only experience will show which method will be most convenient - it does however appear that two sets of test signals will be required.

9.3 In any event, if the performance of a system is measured by one test signal - e.g. an impulse - having an energy spectrum of a given width, then the response to another test signal - e.g. a square wave - of similar spectrum width, can be calculated with sufficient accuracy for most purposes by a fairly simple numerical method (Ref. 25).

9.4 To ensure that the television system remains in optimum adjustment at all times, there are proposals to transmit appropriate transient test signals, amongst others, on the last three or four lines of the vertical suppression interval. These signals would be particularly valuable for the alignment and monitoring of television networks. If desired, they could be eliminated before the signal is finally radiated (Refs. 15, 26, 27).

0. Relationship between Transient Response and Steady-State Response

As indicated in 3 above, there is a rigid relationship between transient response and steady-state amplitude/frequency and delay/frequency response. Given the former, it is possible to calculate the latter two, by simple numerical methods e.g. based on the approximation of the transient response by a stack of time-spaced elementary square waves, (Ref. 28) or alternatively of elementary sin x/x functions. (Ref. 29)

Conversely the transient response may be computed from the frequency and delay responses empirically (Ref. 30), or by a similar method. If the system under test comprises only minimum-phase-shift networks, it is possible to calculate the delay response from the amplitude response alone; this is used extensively in audio work, but has limited application under television conditions (Ref. 31).

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11. Specification of Delay and Phase Shift

11.1 Normally the absolute value of delay through a system is of no consequence; we are concerned only with the variations in delay across the pass-band of the system. There are various ways of defining and measuring the delay errors in a system; provided that we require the delay errors in the system to be zero, it does not matter which we use, as all the defined delays approach zero together. However, in the case where we wish to specify complementary errors in two parts of the system, e.g. in transmitter and receiver, or in receiver IF and Video stages, we must be careful to use matching definitions for the delay errors of the two sections (Refs. 3, 10, 11, 14, 20, 32, 33).

11.2 Consider a quadrupole having a

$$\text{transmission} = \alpha \angle \phi$$

where α Is a scalar quality specifying the attenuation at radian frequency w.

ϕ is an angle specifying the phase shift at radian frequency w.

Then, phase delay through system at w

$$P = \frac{\phi}{w}$$

This corresponds to the phase velocity at which a steady sinusoid at w would travel through the system.

If ϕ is plotted as a function of w (Fig. 11) this corresponds to the slope of the line from the origin to the point (ϕ, w). If however, a burst of energy is fed through the system, comprising a number of components grouped near w, this transient "burst" will travel through the system with the group velocity, giving rise to a group delay

$$G = \frac{d\phi}{dw}$$

This delay corresponds to the slope of the tangent to the ϕ, w curve at the point (ϕ, w).

11.3 It can be shown that the relationship between phase and group delay is

$$G = P + \frac{dP}{dW}$$

If $Ø$ is proportional to w, then both P and G are invariant with w, and equal to one another, and there are no delay errors.

In purely video circuits, the more stringent requirement is that the phase delay be constant; this implies that the group delay will be constant; the converse is not necessarily the case (Ref.20).

In circuits where the picture information is modulated on a carrier e.g. RF and IF circuits, colour information in video circuits, - constancy of phase delay is not necessary, as the detectors employed do not use the phase information of the carrier. It is only necessary that the "modulation phase delay" be constant. At the higher video modulating frequencies where the television system is purely single sideband, the modulation phase delay is given by, M.P.D. $= \frac{Øm - Øc}{Wm - Wc}$ where m and c refer to the sideband and carrier frequency respectively.

At lower frequencies where both sidebands contribute, the modulation phase delay is given by M.P.D. $= \frac{a_L Ø_L + a_u Ø_u - Ø_C}{Wm - Wc}$ when L and U refer to upper and lower sidebands. In the absence of amplitude distortions, the sum of a_L and a_U will be equal to unity.

12. Measurement of Delay Characteristics

12.1 Of the quantities phase shift, phase delay, modulation phase delay, and group delay, the last is the easiest to measure; delay specifications and the design of delay correctors are usually carried out in terms of group delay.

2.2 Direct measurement of phase shift can be carried out in the video range (Ref. 34), the input and output to the system being compared in a phase meter as a sinusoidal signal is varied or swept over the video-frequency range. Phase delay is calculated from the phase shift/frequency curve. Great accuracy in measurement of phase shift is necessary to give reasonably good accuracy of the deduced phase and group delay values.

An alternative method (Refs. 35, 36) is to use a pulse of low video frequency repetition rate as test signal and pick out the harmonics of the output signal with a selective detector, measuring the phase shift through the system for each harmonic in turn.

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12.3 Measurements at IF and RF are almost always of group delay (Refs. 37, 38, 39). One method used is to modulate a sinusoidal test signal of variable frequency with a fixed low video frequency. This signal is fed through the system under test, demodulated, and the phase shift between the recovered modulation and the original modulating signal measured. In effect this measures the average value $\frac{\Delta\phi}{\Delta w}$ over a bandwidth twice the modulating frequency, rather than $\frac{d\phi}{dw}$. For this reason the modulating frequency must be kept low, otherwise details of the group delay curve will be obscured. Unfortunately, this results in a very small time delay to be measured, and a compromise is necessary.

It is possible to apply the output of the phase meter to the Y plates of an oscillograph, to sweep the test (carrier) frequency over the frequency range concerned, and drive the plates in synchronism with the sweep to give a direct display of group delay/vs frequency. (Fig. 12)

12.4 Considerable difficulties exist in the testing of television systems by any of these methods, because of the non-standard conditions to which the clamping, stabilising and processing circuits of the system are subjected by the delay test signals. It is possible to get over these difficulties by special methods (Refs. 40, 41) but these impose their own limitations, and are complex and costly. Measurement of the system under non-standard conditions is often of little value, as e.g. the characteristics of some equipments change violently between clamped and unclamped conditions of operation. It is for this reason that the relatively tedious process of computing the delay response from the transient response, as described in Section 10, is often preferred.

13. Amplitude, delay and waveform correctors

13.1 The present normal procedure for correction of system distortions is first to adjust the amplitude response to the desired accuracy and then to correct the delay errors of both the system and the amplitude corrector.

In amplifiers following picture generators such as camera tubes, there are amplitude errors to be corrected accompanied by delay errors, due to time constants of camera output circuits, and also amplitude errors unaccompanied by delay errors, due to the "aperture loss" of the finite size of scanning beams. Thus a complex corrector, part delay corrected, part uncorrected is required. Similar arguments apply to the circuits feeding picture - tubes.

13.2 Wherever low-impedance levels are present, as at equipment inputs and outputs throughout the transmission system, a very convenient form of video delay-corrector is the passive constant-impedance all-pass network usually built in the bridged-T form (Refs. 42, 43, 44) (Fig. 13). These networks have delay characteristics peaking to a maximum at one particular frequency this frequency and the sharpness of peak being variable by suitable choice of component values. Using a cascade of these simple circuits, any reasonable delay/frequency response can be built up. Combinations of fixed units may be constructed to match the delay correction curves arrived at as in 11 and 12 above; alternatively variable units may be employed, and adjusted for best overall results while observing the output waveform on an oscillograph; fixed networks are then built up to correspond to the calibrated setting of the variable units.

13.3 The procedure detailed above is long and tedious: alternative methods have been devised for direct correction of the waveform, and these are likely to come increasingly into use as the equipment becomes available.

One method employs what is known as a "transversal filter"; it is based on a theoretical treatment which shows that all distortions can be represented as the addition of pairs of signals to the main signal (Ref. 45), one member of each pair being advanced and one delayed by the same amount about the main signal. The transversal filter (Refs. 46, 47) reverses this process. The signal is fed to a terminated delay line. The main signal is tapped off near the centre and combined through amplifiers with smaller advanced and delayed signals, whose amplitude and polarity are adjusted by direct observation of the output signal.

If the distortions to be corrected are produced by minimum-phase networks, then only delayed signals are required, and a simplified equipment is permissible (Ref. 48), wherein the main signal is undelayed, and a lower standard of delay line is permissible.

13.4 A second method is based on a theoretical treatment showing that distortions of a low-pass system by minimum-phase networks can be represented as the addition of differential coefficients of the signal, to the main signal; (Ref. 49) again, the equipment provides correction by reversing the process; usually voltages corresponding to first and second differential coefficients are generated, and added to the main signal, with variable amplitude and polarity. Further improvements may be made by non-linear processing (Ref. 50). Correction is usually limited to two orders, and also in magnitude, by the accentuation of noise which unfortunately accompanies the process; for this reason the first method is likely to find more use.

14. Present tendencies in development, and some future prospects.

14.1 The stage has now been reached when transmission equipment can be relied upon to give consistently good amplitude response with negligible disturbing effects on picture signals. It thus becomes possible to obtain the benefits of accurate delay response correction, with the waveform response improvements discussed above. Such delay corrections are of little value in the presence of inferior or varying amplitude response. The situation is now being reached where routine day-to-day checks are being carried out on a transient basis, and reference is made to frequency response measurements only when transient distortion appears.

No assemblage of equipment so complex as a television transmission chain ever retains its characteristics identically the same for many days; the next step is to provide "daily touch-up" equalisers to give the optimum overall transient response. Such equalisers may vary amplitude and delay response separately; as time goes on they are likely to operate directly on the waveform in the time domain.

With better and more consistent transmitted signals, receiver designers will be spurred on to make corresponding improvements, until the overall linear distortions are reduced to near threshold levels. The non-linear distortions due to the Nyquist slope and the quadrature component will then be the limiting factors (Refs. 51, 52).

14.2 There are certain developments which may overcome these. The "brute-force" method is to use amplitude - dependent delay correctors in the video circuits; this is in the laboratory stage, but may be too costly and complex. One method which is in use in Germany for rebroadcasting receivers (Ref. 53) is the use of an auxiliary oscillator locked to the IF vision carrier, providing an exalted carrier" at the second detector which so reduces the modulation percentage that quadrature distortion becomes very small even for black - white transitions.

The main difficulty here would seem to be locking the oscillator sufficiently accurately when switching between stations. The existing receivers have a phasing control which is set manually for each channel to be received by the crystal controlled receiver.

Another receiver technique (Ref. 54) avoids the Nyquist-slope errors completely by not using a Nyquist slope, but a response flat over the same frequency range as the transmitter. Conventional double sideband reception is used up to about 1 Mc/s; it is argued that the high modulation levels which produce quadrature distortion

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in Nyquist slope receivers occur only at the lower frequencies, and will be absent in their double sideband reception. An amplitude equaliser is used in the video circuits to restore a flat amplitude response; it is claimed that this introduces negligible delay distortion. The main disadvantage of this type of receiver would appear to be the increased cost of the greater bandwidth, and the video correction network (Ref. 13, p. 659) but the technique may come into use in the higher quality and price range. Finally one very complex technique which is in use by the West German Post Office for point-to-point vestigial sideband television cable systems could conceivably be applied to television broadcast transmitters. It is well-known (Ref. 55) that the quadrature distortions of a positive modulation system are opposite to those of a negative modulation system. Video signals are fed through a complete low-power modulation vestigial sideband system, demodulated, ıd then fed to the transmitter. The radiated amplitude-dependent predistortions will then tend to cancel the detector distortions at the receiver. However, this may, as with previous predistortion systems, give rise to very critical tuning of the receiver for best picture quality.

Appendix 1

Delay characteristic of Standard Monitor for Australian Television System (Ref. 17)

The characteristic shall have a constant group delay at low and medium video frequencies and an increased delay at high video frequencies equal to the increase in delay of a single section all-pass network having a maximum delay at 5.5 Mc/s and a group delay increase at 4.5 Mc/s of 120 millimicroseconds.

The delay/frequency characteristic is shown in Fig. 14, and is tabulated below.

One particular form of network, for 75 ohm unbalanced operation, which has this characteristic, is shown in Fig. 15. It is emphasised that there are equally valid networks of other forms which would produce the required delay characteristic.

If networks are designed in accordance with Reference E, the relevant parameters are (F_o = 5.5 Mc/s, γ_o = 1.525 Mc/s.) If the method of Reference D is used, the corresponding parameters are (F_o = 5.7 Mc/s, m = 0.935).

Frequency	Absolute group delay Millimicroseconds	Increase in group delay Millimicroseconds
0 Mc/s	30	0
2 "	42	12
3 "	63	33
4 "	111	81
4.5 "	150	120
5 "	193	163
5.5 "	210	180

Appendix 2

Amplitude characteristic of Standard Monitor for Australian Television System (Ref. 17)

The standard monitor shall have an amplitude characteristic substantially flat to 5 Mc/s, with a Nyquist slope within the following limits:-

Frequency	Amplitude
+ 1.5 Mc/s	94 - 106%
+ 1.0 "	91.5 - 101.5%
+ 0.5 "	75 - 85%
Vision Carrier	50% Reference
- 0.5 Mc/s	15 - 25%
- 1.0 "	3.5 - 8.5%
- 1.5 "	less than 3%

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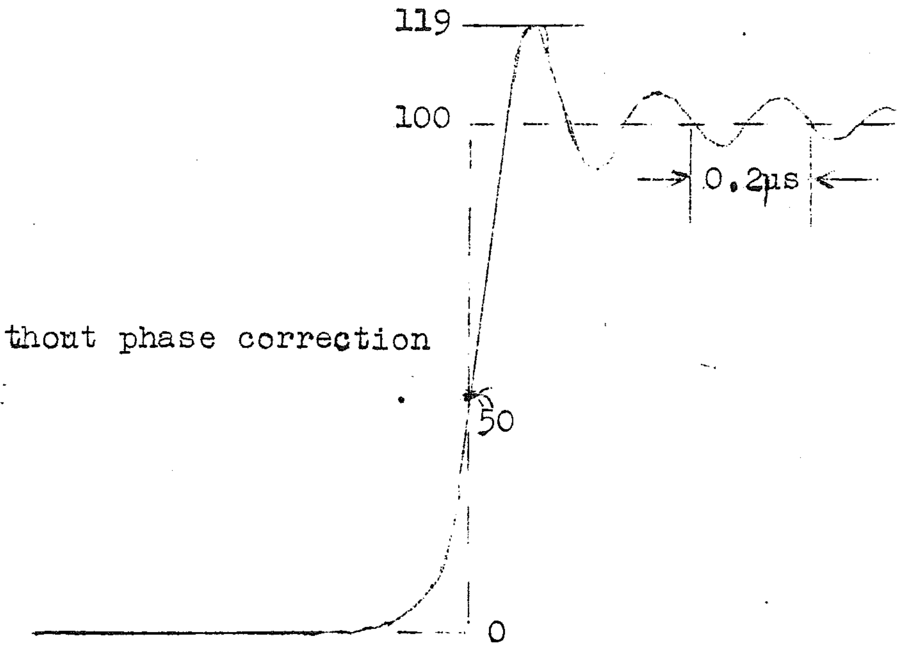
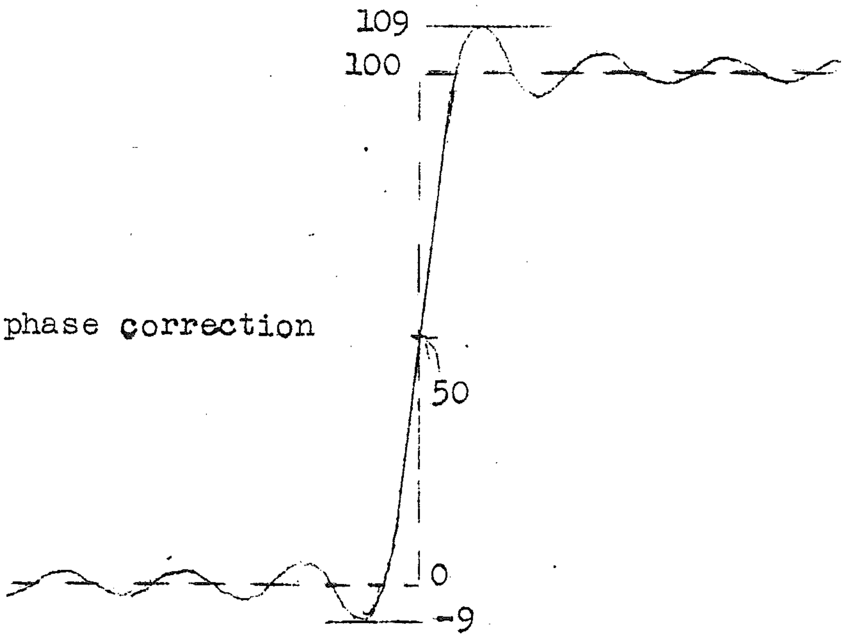


(a) Without phase correction



(b) With phase correction

FIGURE I - RINGING

Produced by 5 Mc/s sharp-cut low-pass filter

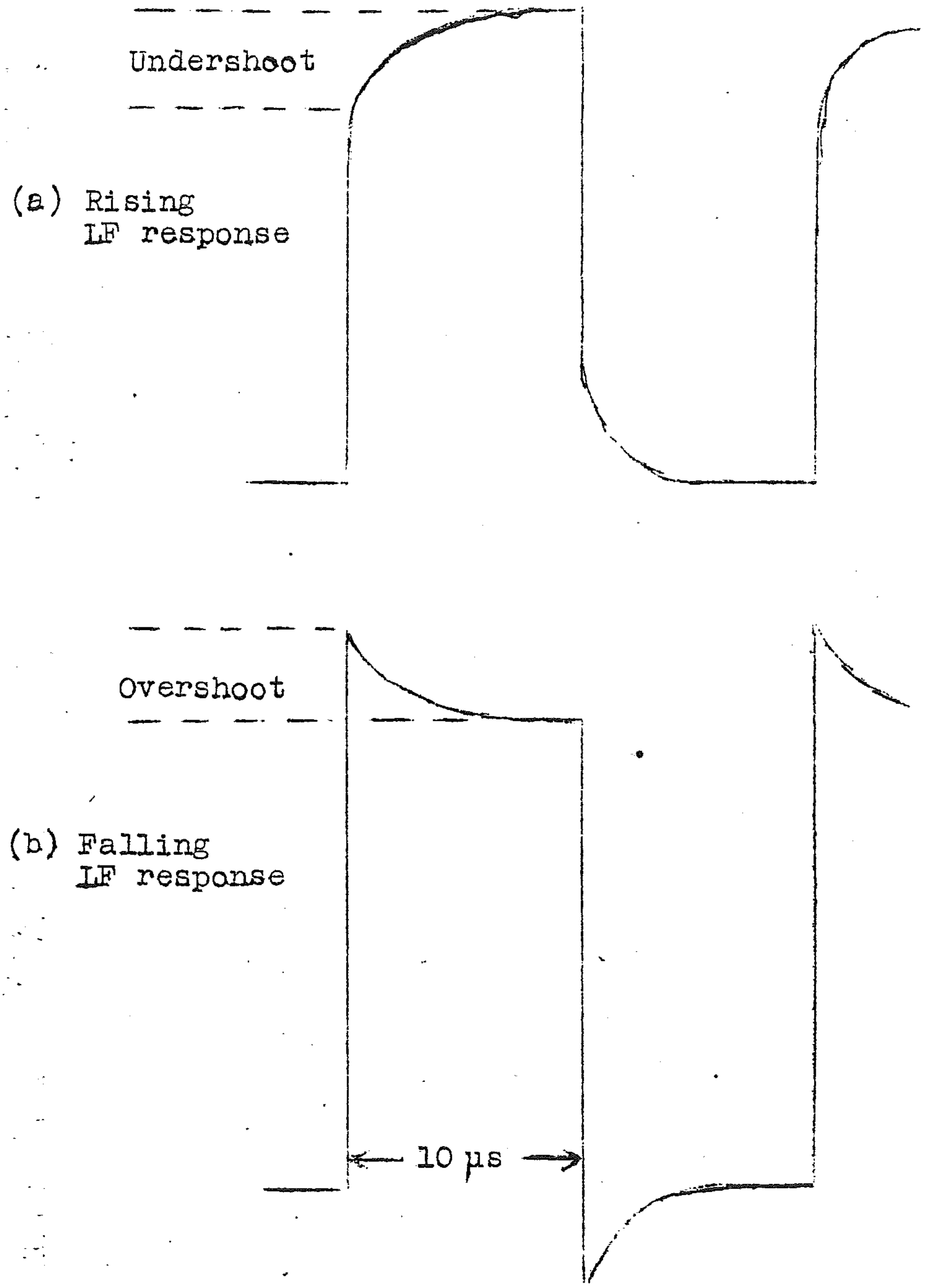


FIGURE 2 - STREAKING

Produced by changing low-frequency response
with accompanying phase errors.

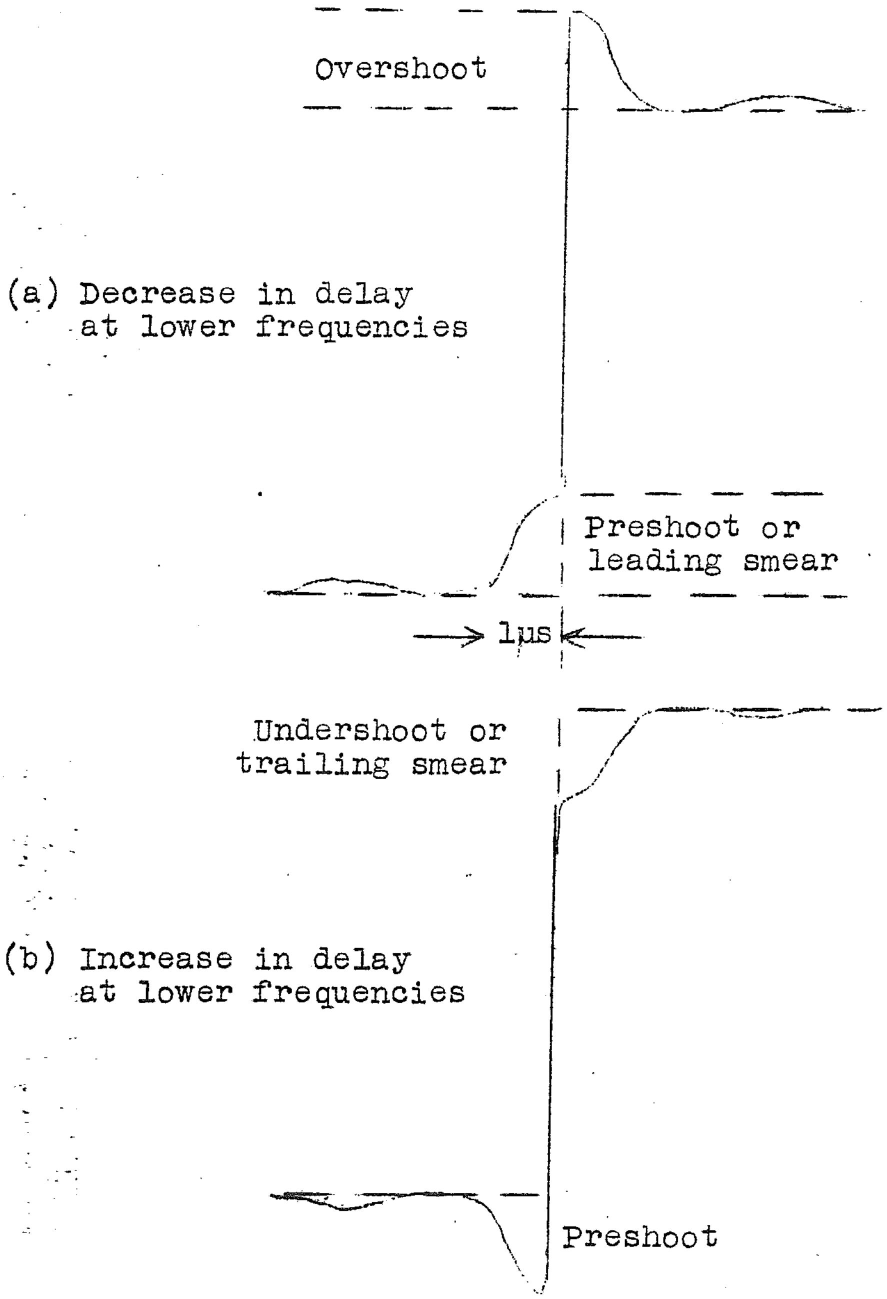


FIGURE 3 - SMEARING

Produced by delay errors at low and medium frequencies

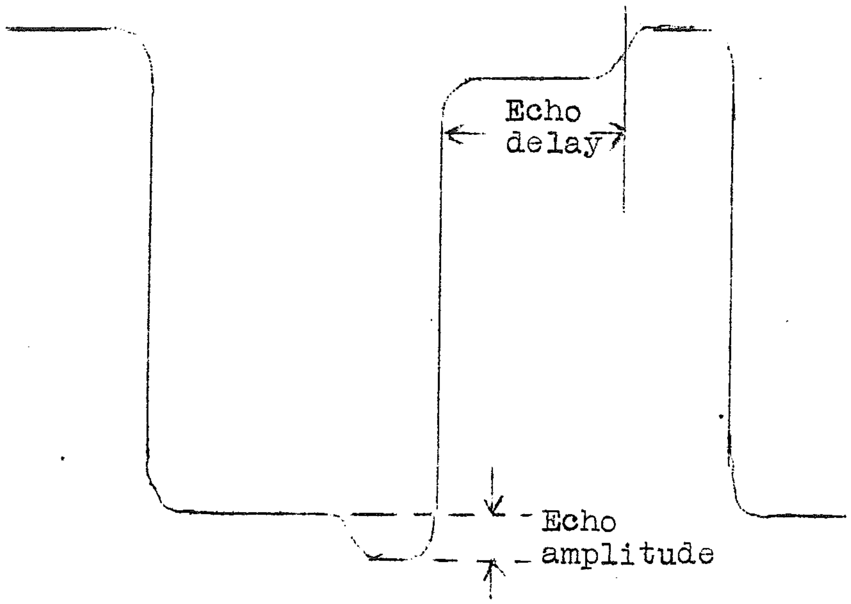


FIGURE 4 - ECHO DISTORTION

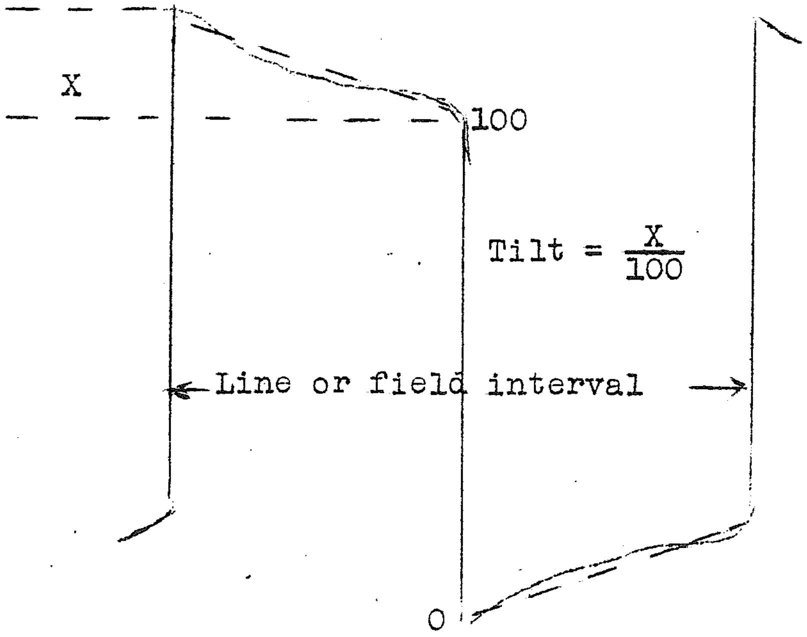


FIGURE 5 - SQUARE WAVE TILT

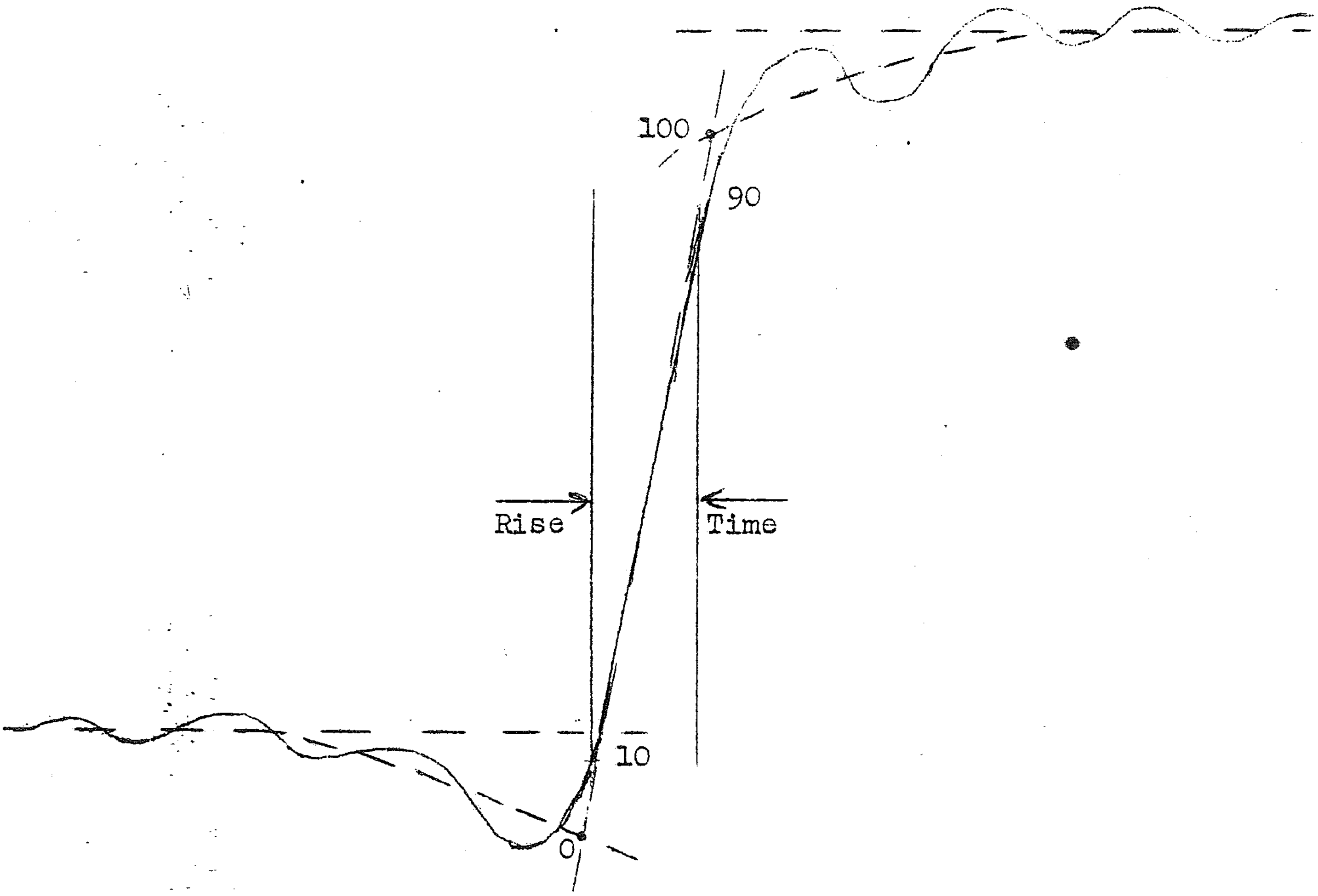


FIGURE 6 - Measurement of rise time in the presence of ringing, streaking, or smearing.

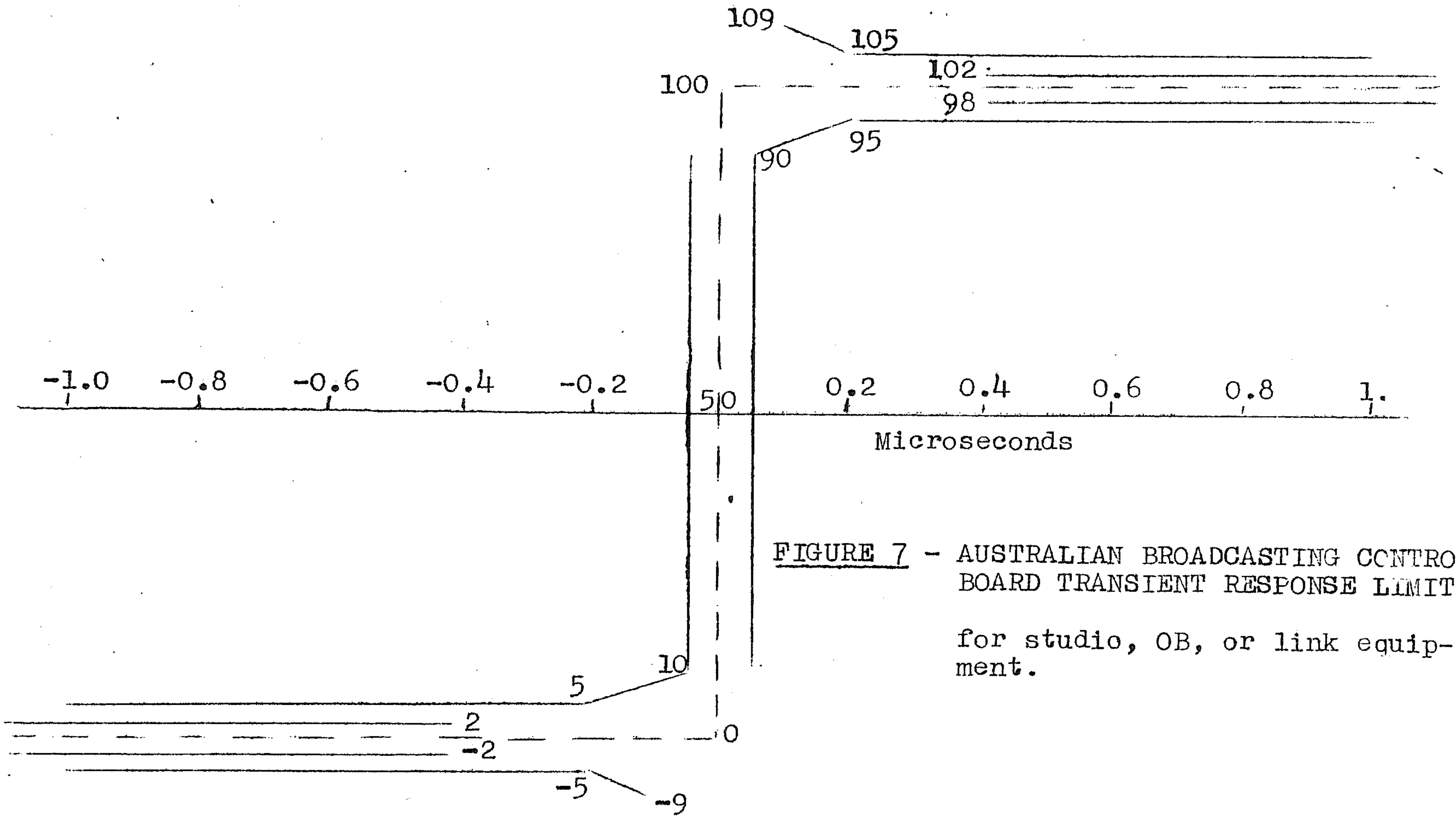


FIGURE 7 - AUSTRALIAN BROADCASTING CONTROL BOARD TRANSIENT RESPONSE LIMITS

for studio, OB, or link equipment.

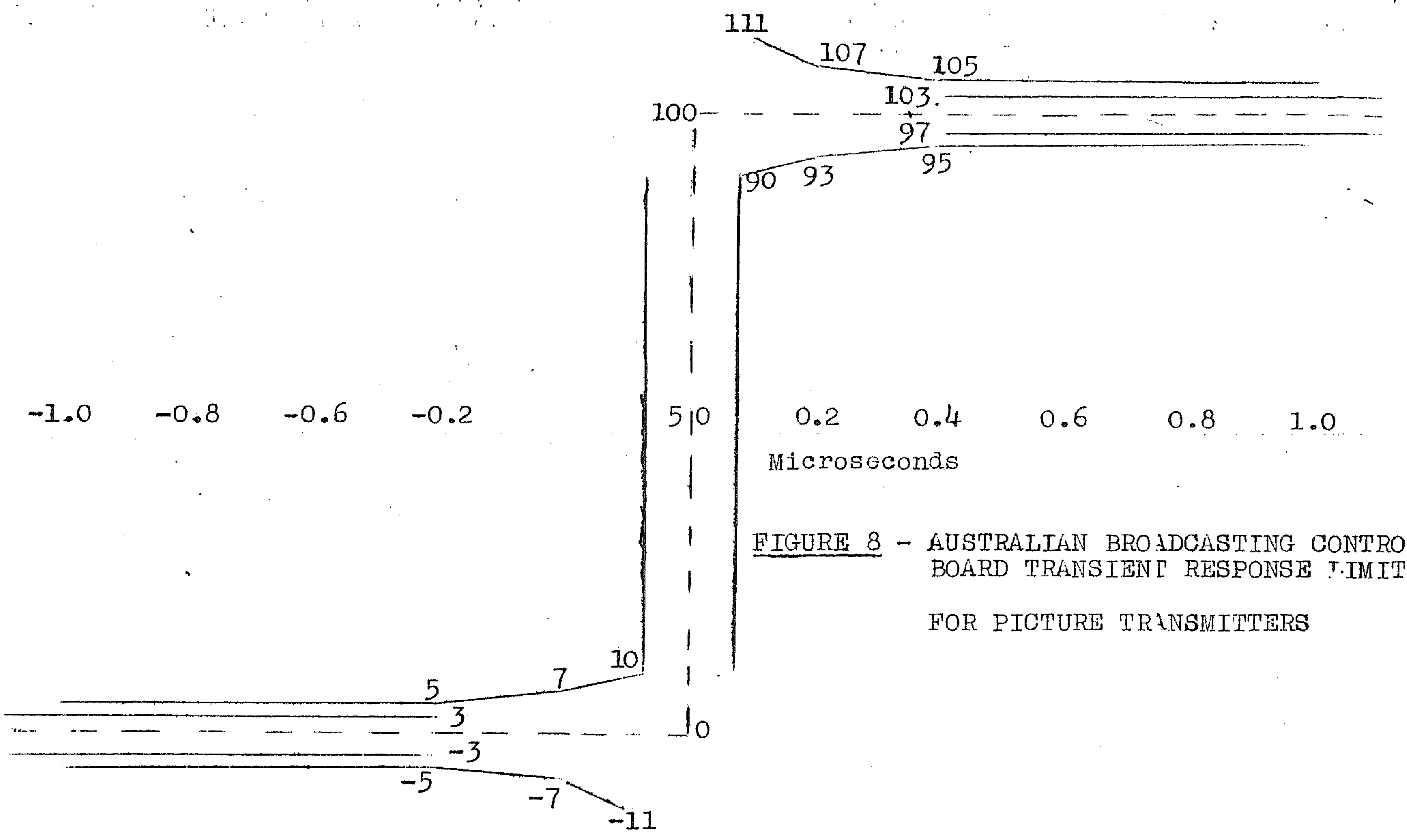


FIGURE 8 - AUSTRALIAN BROADCASTING CONTROL BOARD TRANSIENT RESPONSE LIMITS

FOR PICTURE TRANSMITTERS

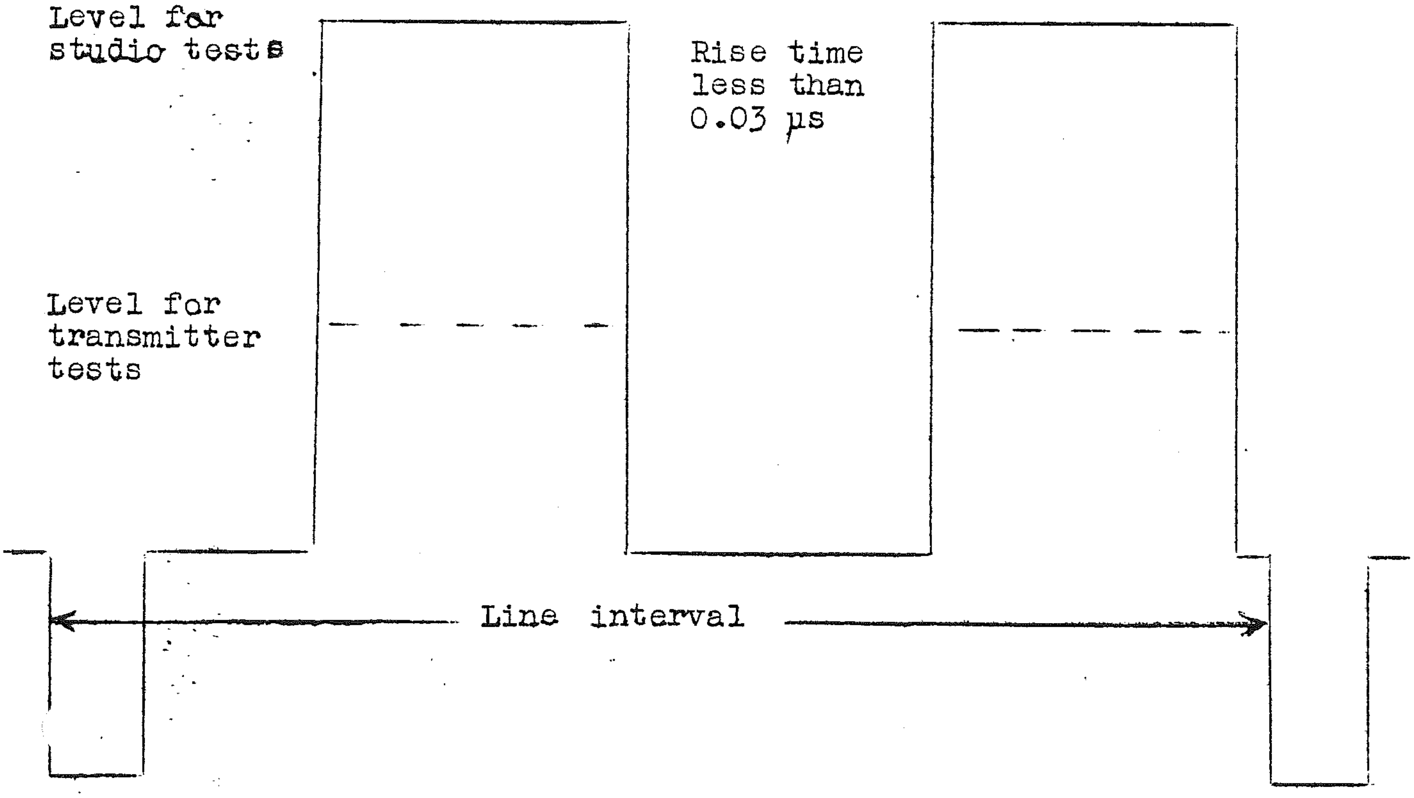


FIGURE 9 - Composite square-wave test signal

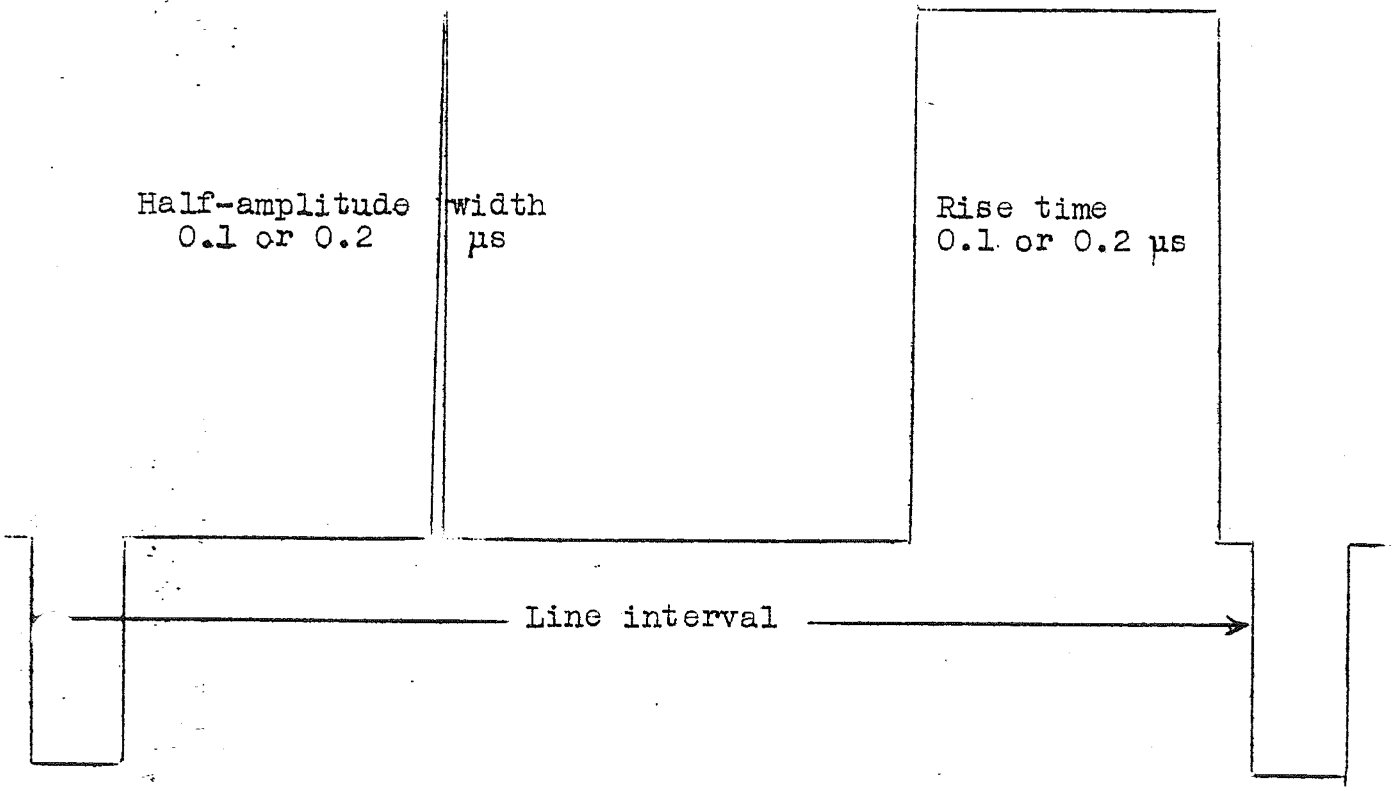


FIGURE 10 - Composite ' Pulse and Bar ' test signal

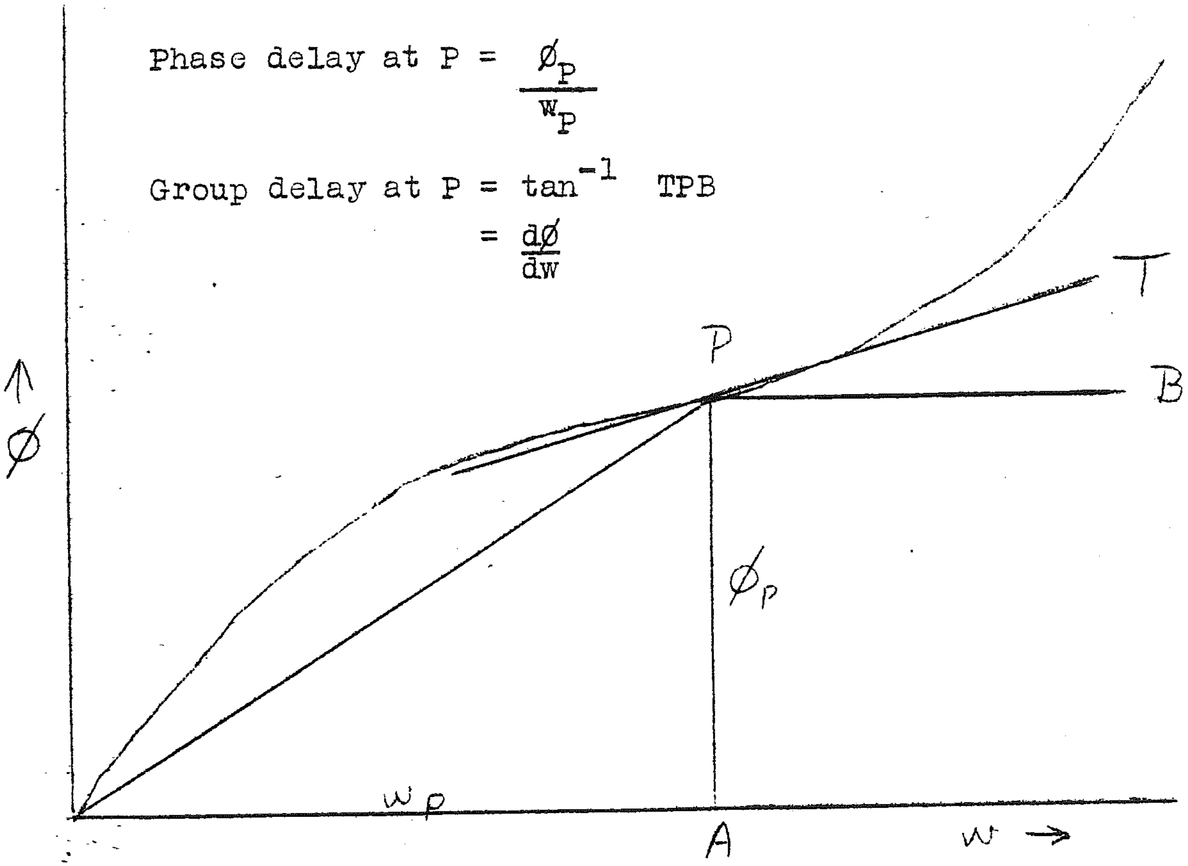


FIGURE 11 - Phase and Group delay

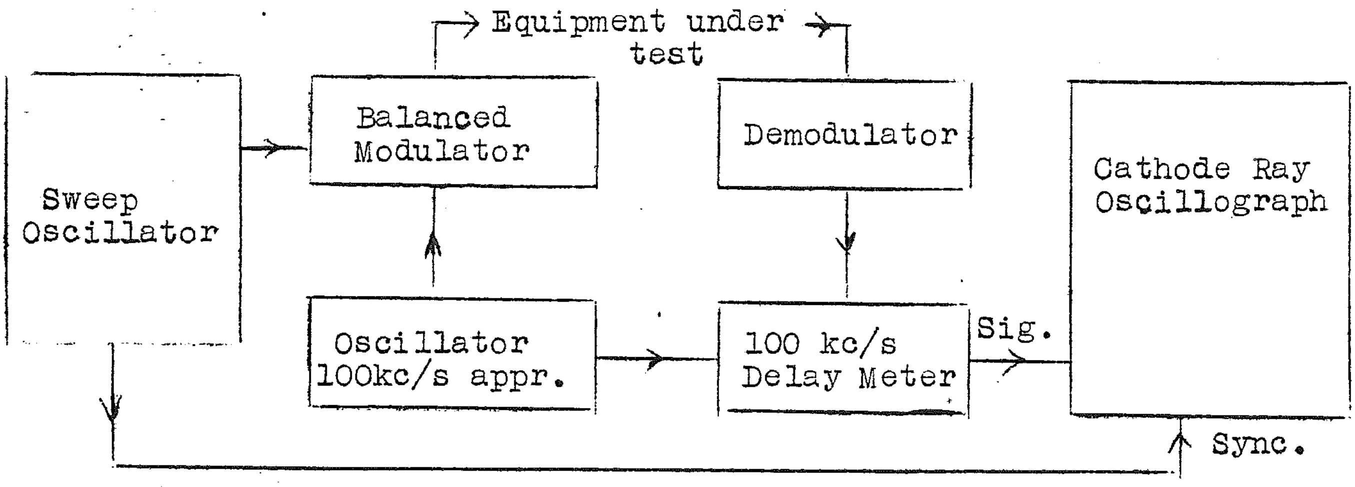


FIGURE 12 - Block diagram of Group Delay Meter

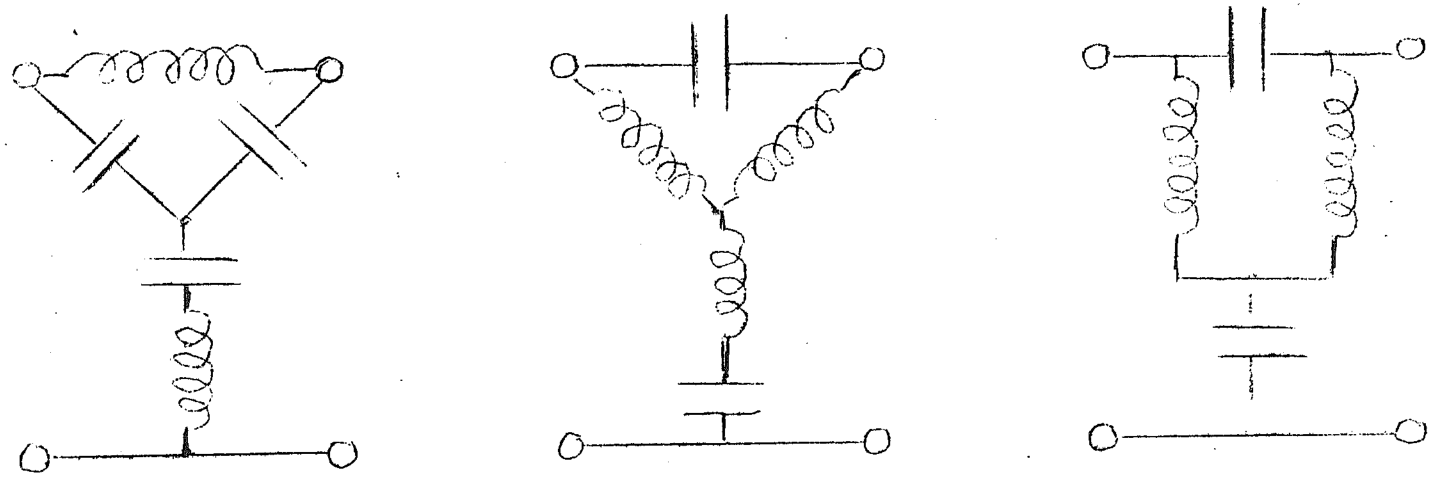


FIGURE 13 - Typical unbalanced constant-impedance all-pass networks for delay correction.

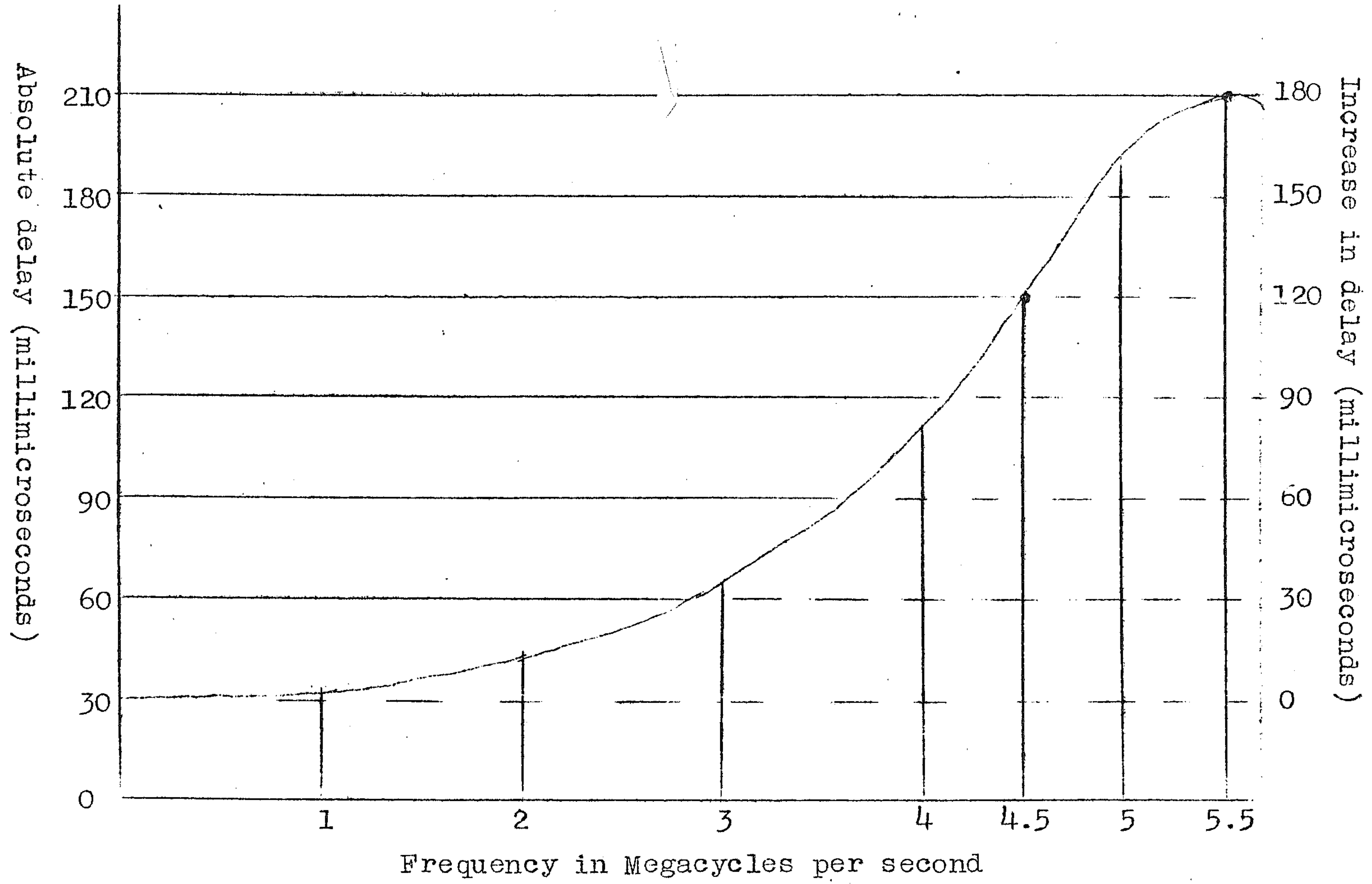
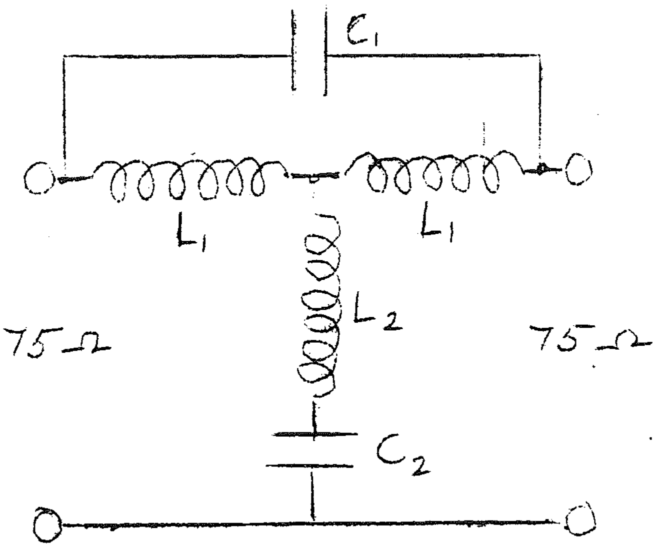


FIGURE 14 - Delay/frequency characteristic of standard monitor network for Australian television system



$C_1 = 348\,pF$

$L_1 = 1{\cdot}12\,\mu H$

$C_2 = 397\,pF$

$L_2 = 1{\cdot}40\,\mu H$

FIGURE 15 - Delay corrector network, to convert phase-linear monitor to Australian standard