A delay line for PAL colour television receivers

F. Th. Backers

In colour television receivers for the PALd system the colour information is derived from the chrominance signal for each line and from the delayed signal of the preceding line of the field. If colour errors are to be avoided a delay line that gives an extremely accurate phase delay must be used. The subject of the present article is an ultrasonic delay line developed for this purpose, made from a type of glass specially developed for this delay line.

The Oslo Conference of 1966 was unfortunately unable to agree on the use of one single colour television transmission system for the whole of Europe. In the meantime most European countries have made their choice of system. The Netherlands, Germany, Great Britain, Ireland, the Scandinavian countries, Switzerland and Austria have all adopted the PAL system; France, Russia and a number of East European countries have chosen the SECAM system. These systems have previously been discussed at some length in this journal [1]. In receivers for both systems, *delay lines* are used, which delay the chrominance signal by a time virtually equal to the period of the picture lines (64 μs). The use of such a delay line is essential in a receiver for the SECAM system. A PAL receiver can work without a delay line (PALs receiver), but the PALd reception system, which does use a delay line, offers certain advantages. A discussion of this subject will be found in reference [1].

The subject of the present article is an ultrasonic delay line developed for PAL colour television receivers at Philips Research Laboratories in Eindhoven [2]. The operation of this line depends on the well-known method of propagating ultrasonic vibrations in a piece of suitably shaped material, and it is made with a type of glass specially developed for the purpose.

First of all, we shall recall the principle underlying the decoder used in a PALd receiver. *Fig. 1*, corresponding to fig. 9 in reference [1], gives the vector diagram of the chrominance signal of two successive lines of a field (assuming of course that the colour between the two lines does not change). This chrominance signal consists of two components, $0.49(B' - Y') \sin \omega_s t$ and $0.88(R' - Y') \cos \omega_s t$, each of which contains colour information. Here B' and R' are the gamma-corrected blue and red signals respectively, and Y' is a combination of these signals and the green signal G':

$$Y' = 0.30\,R' + 0.59\,G' + 0.11\,B'.$$

ω_s is the angular frequency of the subcarrier. The func-

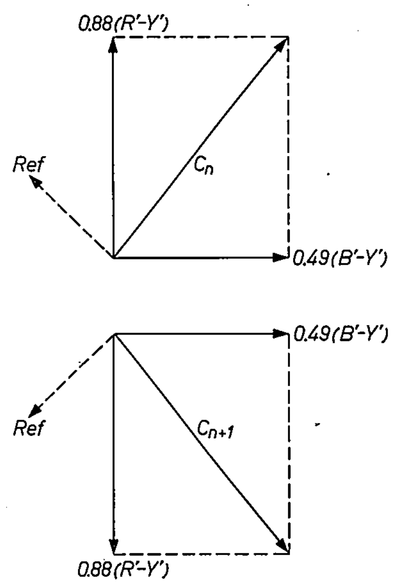

Fig. 1. Vector diagram of the chrominance signals C_n and C_{n+1} of two successive lines with the same colour, in a PAL transmission. The phase of the component $0.88(R' - Y') \cos \omega_s t$ differs in each successive line by 180°. *Ref* indicates the simultaneously transmitted burst, which is used for synchronous detection of the chrominance signals (see [1]).

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[1] F. W. de Vrijer, Colour television transmission systems, Philips tech. Rev. **27**, 33-45, 1966. See also reference [4], p. 247 *et seq.*

[2] The delay line in question can also be used in SECAM receivers. The requirements to be met by the delay line in this system are in many respects not so strict as in the PAL system.

tion of the decoder is to split the chrominance signal into these two components. In a PALd receiver this is done by forming the sum and the difference of the chrominance signal of each line and the delayed signal from the preceding line. We shall first make the usual assumption that the sum yields the $(B'-Y')$ component, and the difference yields the $(R'-Y')$ component. Since in the PAL system the component $(R'-Y')\cos\omega_{s}t$ changes sign at every alternate field line, the same change of sign takes place in the corresponding signal delivered by the decoder. This change of sign is subsequently eliminated in another part of the receiver.

Requirements to be met by a PAL delay line

Phase delay and group delay

Since receivers for the PALd system derive the colour information for each line from the line itself and from the preceding one, proper colour rendering is only possible at places where the colour at corresponding points of two successive field lines is the same. This restriction is not a disadvantage in practice, and we shall therefore take it as a basis in formulating the requirements for the delay line. We shall first assume that the two lines have the same colour over the whole of their length. The chrominance signal then has a constant amplitude and phase (neglecting the brief interruptions during the line-synchronizing pulse).

Let us first assume that the phase delay is *exactly* 64 μs; the decoder is then supplied with two signals whose vector diagram is as shown in *fig. 2*. The phase relation between the delayed signal $C_{n\tau}$ and the non-delayed signal C_n in fig. 1 is found from the relation between the line frequency f_L (15 625 Hz) and the subcarrier frequency f_s. This relation in the PAL system is given by:

$$f_s = (283\tfrac{3}{4} + \tfrac{1}{625}) f_L = 4\,433\,619 \text{ Hz}.$$

The phase delay of 64 μs thus corresponds to a phase shift of $64 \times 10^{-6} \times 4\,433\,619 = 283.752$ periods, and $C_{n\tau}$ will therefore lead in phase with respect to C_n by $0.248 \approx \frac{1}{4}$ period, i.e. about 90°.

It can be seen from fig. 2 that in this case the two components of the chrominance signal are *not* obtained by adding or subtracting $C_{n\tau}$ and C_{n+1}; a phase delay of exactly 64 μs is therefore of no use for this method of signal splitting. To obtain the desired result it is necessary to choose the phase delay such that the $(B'-Y')$ component of the delayed signal $C_{n\tau}$ is *in phase* with the corresponding component of the signal C_{n+1} of the next line. This means that the chrominance signal C_n in the delay line must undergo a phase shift of an integral multiple of 2π radians. This situation arises when the phase shift is exactly 284, or $284 \pm p$, periods (p being an arbitrary integer), corresponding to a phase delay of

$$\tau = (284 \pm p)/f_s = 63.943 \pm (p \times 0.226) \text{ μs}.$$

It is not absolutely essential, however, to obtain the $(B'-Y')$ component by the *addition* of $C_{n\tau}$ and C_{n+1}, and the $(R'-Y')$ component by *subtraction*. The

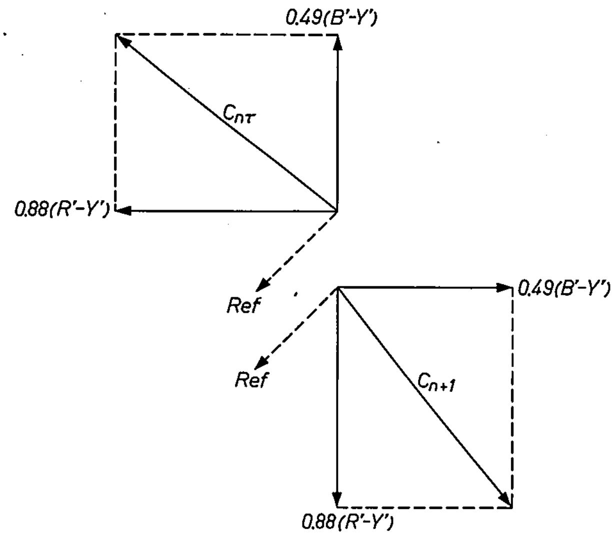

Fig. 2. The chrominance signal $C_{n\tau}$ of a line, delayed by exactly 64 μs, together with the non-delayed signal C_{n+1} of the next line. In this case the two components can *not* be obtained by simple addition and subtraction of the two signals.

signal C_n can also be given a delay such that the addition of $C_{n\tau}$ and C_{n+1} gives the $(R'-Y')$ component and subtraction gives the $(B'-Y')$ component. Obviously, the phase shift produced by the delay line must then be an odd multiple of π radians. The vector diagram of the signals for this case is shown in *fig. 3*.

In a PALd receiver a deviation from the phase delay quoted above causes the same impairment of the picture as that produced in a PALs receiver by differential phase errors, i.e. apparently moving strips, known sometimes as "Hanover bars" or "Venetian blinds". Since, where there is an error in the delay line, only the delayed signal has the wrong phase, the permissible phase error in this case is twice as great as the permissible differential phase error in the PALs system. Experiments have shown that the phase error in a PAL delay line may be allowed to reach ± 12°, corresponding to a permissible deviation in the phase delay of about 7.5 ns.

If the area being scanned is not all of the same colour, the two components of the chrominance signal are modulated in amplitude. Signal components then occur with frequencies on either side of the subcarrier frequency. These sideband components lie approximately in the frequency range 4.43 ± 1 MHz. If two successive lines show the same colour variation, which is the case, for instance, when the picture consists of vertical coloured bars, sideband components then occur only at frequencies that are an integral multiple of the line frequency (15 625 Hz) higher or lower than the

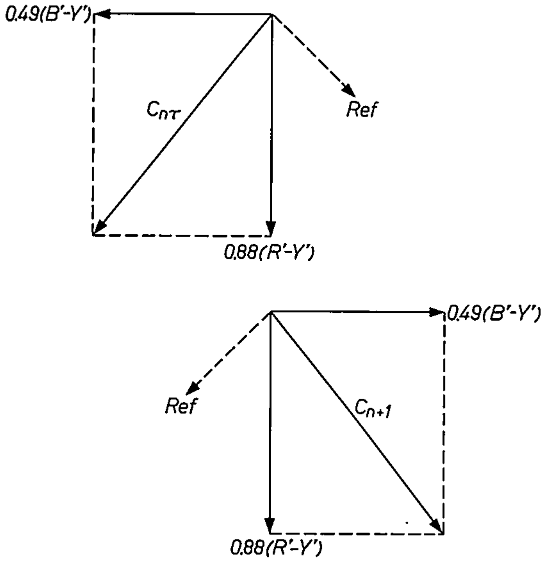

Fig. 3. When the delay line causes a phase shift of an odd multiple of π radians, the $(R' - Y')$ signal can be obtained by the addition of the $C_{n\tau}$ and C_{n+1} signals, and the $(B' - Y')$ signal by their subtraction.

subcarrier frequency. The phase shift which these sideband components undergo in the delay line is different from that of the subcarrier. The whole signal will, however, be delayed without distortion if the phase shift for all components is an integral multiple of 2π radians. This is illustrated in *fig. 4* for a special case. For simplicity it is assumed here that the colour difference signals $R' - Y'$ and $B' - Y'$ consist of a d.c. component on which a sinusoidal signal is superimposed. In this case the two components of the chrominance signal C_n each contain only two sideband components (fig. 4*a*). If we assume further that, owing to errors in the transmitter, in the transmission or in the receiver, the two sideband components have undergone a change in magnitude and in phase with respect to their carrier, the vector diagram $C_n{}^*$ of the input signal of the delay line may take the form illustrated in fig. 4*b*. If all the components undergo a phase shift of an integral multiple of 2π radians, then fig. 4*b* also represents the output signal $C_{n\tau}{}^*$ of the delay line. The undistorted signal C_{n+1} of the next line is shown in fig. 4*c*; if this signal undergoes the same distortion as C_n, the result is then $C_{n+1}{}^*$ (fig. 4*d*). This latter signal is then available simultaneously with $C_{n\tau}{}^*$. By the addition and subtraction of $C_{n\tau}{}^*$ and $C_{n+1}{}^*$ we obtain once again the two components of the chrominance signal.

Fig. 4 also illustrates an incidental, though not unimportant, advantage of the PAL system. If the chrominance signal has undergone linear distortion, this need not lead to crosstalk between one component and the other (quadrature cross-colour), as it would in an NTSC decoder. The same advantage is obtained with a PALs receiver, provided at least that the eye effectively averages out the delayed and non-delayed signal. Averaging-out by means of a delay line works much better, however.

It is perhaps interesting to note here that the poor averaging-out ability of the eye, giving rise to quadrature cross-colour and "Hanover bars" in a PALs receiver, is probably largely due to

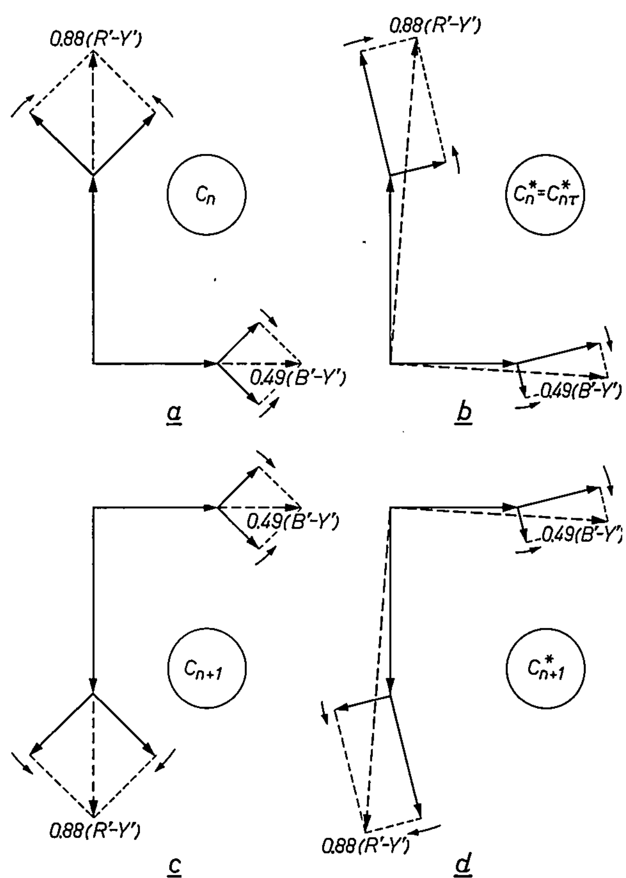

Fig. 4. *a*) Vector diagram of the two components of the chrominance signal C_n where the colour difference signals consist of a d.c. part and a purely sinusoidal part. Each component of the chrominance signal contains two sideband components.
b) The components of the chrominance signal $C_n{}^*$ obtained when the sideband components show an error in magnitude and phase. If the phase shift for all components is an integral multiple of 2π rad, this figure also represents the delayed signal $C_{n\tau}{}^*$.
c) The undistorted chrominance signal C_{n+1} of the next line.
d) The signal $C_{n+1}{}^*$ obtained from C_{n+1} when the sideband components here also show an error in magnitude and phase. This distortion does not lead to quadrature cross-colour in a PALd decoder.

the fact that, because of the interlacing, the interfering effect appears to move in a vertical direction. If the eye follows this movement, there can indeed be no question of averaging-out. This would also explain the fact that this effect is not found to be such a nuisance in the parts of the picture which are rich in detail, where the movement is constantly interrupted.

Generally speaking, the modulation of the chrominance-signal components will not be purely sinusoidal and there will therefore be more than two sideband components. A signal of this kind is delayed without distortion if the phase shift per 15 625 Hz increases by 2π radians. The phase characteristic (phase shift as a function of angular frequency) is then a straight line with a slope of 2π rad/($2\pi \times 15\,625$ rad/s) = 64 µs. A second condition for the phase characteristic has already been mentioned, i.e. that at the subcarrier frequency the phase shift must be an integral multiple of π rad. *Fig. 5* shows a number of characteristics (the solid lines) which satisfy these two conditions. The

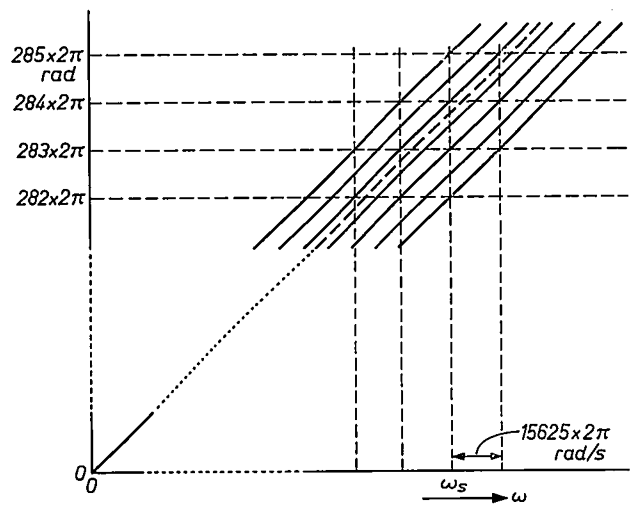

Fig. 5. Phase characteristics of the delay line. For all lines the group delay is 64 µs. The dashed line for the subcarrier does not correspond to a phase shift amounting to an integral multiple of π rad and therefore cannot be used. The solid lines satisfy the necessary conditions.

dashed line, which passes through the origin and corresponds at the subcarrier frequency to a phase delay of exactly 64 µs, does not satisfy the second condition, for although its slope has exactly the right value, the phase shift at the angular frequency ω_s is $283.752 \times 2\pi$ radians.

The slope of the phase characteristic of a network is equal to the *group delay* [3]; therefore the requirements to be met by a PAL delay line may also be defined as follows. The phase shift for the subcarrier must be an integral multiple of π radians and the group delay must be 64 µs. The accuracy of the group delay, however, is not so critical as that of the phase shift. A deviation of ± 50 ns in the group delay has been found to be permissible. The phase characteristic may also deviate slightly from a straight line.

Unwanted reflections

It is possible that signals will arrive at the output transducer of the delay line which have traversed the delay line more than once, as a result of unwanted reflections, and have thus undergone a delay several times longer than the desired delay. These reflections are referred to here as 2τ or 3τ reflections, etc. The colour information which these signals contain thus arrives one or two picture lines too late. Since in the PAL system the $(R' - Y')$ component changes sign at successive picture lines, a 2τ reflection is much more of a nuisance than a 3τ one, for a signal that originates in a 3τ reflection is of course added to the signal of a line of the same type. In equally coloured areas this effect is not visible; interference is seen only at places where vertical colour transitions are present. The signal of a 2τ reflection, however, is added to a line of the other type. This can give rise to an effect rather like "Hanover bars" in patches of certain colours. For this reason 2τ reflections need to be much more strongly suppressed than 3τ reflections.

Other requirements

Finally, we shall mention a few other requirements which have to be met by a PAL delay line.

The *amplitude characteristic* must of course be reasonably flat. A 3 dB bandwidth of 1.8 MHz has been found acceptable, the centre frequency being of course at 4.43 MHz.

The *insertion loss* must obviously be as small as possible to avoid loss of signal strength.

The *temperature* at which the delay lines in television receivers are used is between 20 and 50 °C. All the above-mentioned requirements must therefore be met within this temperature range. This is a difficult requirement, particularly for the phase delay, and it has been met by the use of a specially developed type of glass. Rather larger temperature variation, from —20 to +70 °C, should not give rise to any permanent changes in line characteristics.

Design

The design of ultrasonic delay lines and their various applications in television were dealt with in this journal a few years ago [4]. It was mentioned at that time that a piece of glass of suitable form and dimensions could be a very useful medium for delaying an electrical signal by one line period. The glass block of the delay line which we have developed measures about 80×40×18 mm (*fig. 6*). The *input transducer* T_1 converts the electrical input signal into mechanical shear waves, which are propagated in the glass in the direction denoted by *A*. The waves reflected from the face *F* then move along the line *B* and so arrive at the *output transducer* T_2, where they are converted back into electrical signals.

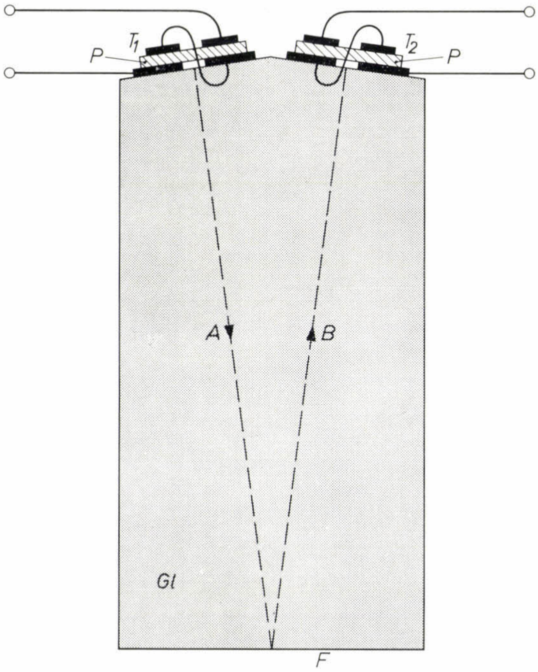

Fig. 6. Form of the delay line. *Gl* glass block. T_1 input transducer. T_2 output transducer. *P* piezoelectric plates. *A* and *B* direction of propagation of the ultrasonic shear waves. *F* reflecting face.

The transducers consist of thin plates *P* of ceramic piezoelectric material (a solid solution of lead zirconate-titanate, code name PXE 3). The large faces of the plates are provided with vacuum-deposited electrodes. To give it piezoelectric properties, the material has to be polarized. This is done by raising the transducers to a high temperature in a strong electric field which is maintained while the material is cooled down. The direction of polarization is perpendicular to the plane of fig. 6. Within a certain frequency range, determined by the thickness of the material, the transducers can then excite and receive shear waves. The material PXE 3 transmits these waves to the glass with fairly low insertion loss, permitting the desired bandwidth to be obtained.

If the large faces of a plate of the dimensions used here ($10 \times 12 \times 0.23$ mm) were to be completely covered with metal films, the impedance of the transducer would be very low. For this reason each electrode is split into two equal parts down the centre (see fig. 6), thus effectively making two transducers which form a single mechanical entity and produce coherent mechanical vibrations. The two parts are connected electrically in series, increasing the impedance by a factor of 4. The same increase of impedance could of course also have been obtained by making the area of the surface four times smaller. In that case, however, the directivity pattern of both the transmitting and the receiving transducer would have been less sharp, and the transmission consequently less efficient.

To facilitate the mounting of the transducers on the glass block, a metal coating is applied to the faces where the transducers are to be attached. This coating takes the form of a divided patch on each face, to suit the electrodes of the transducers, which are then soldered in position.

The main advantage of using a reflecting face is that it offers a simple means of meeting the very close tolerance required for the phase shift. By grinding away the reflecting face in this way the path length can be reduced after the transducers have been mounted. The phase shift can be measured during the grinding operation, which is continued until the phase shift is an integral multiple of π radians. We shall return to this point presently.

Properties of the glass

The phase delay of a delay line constructed as illustrated in fig. 6 consists of two parts. By far the greater contribution comes from the glass block, and a much smaller one from the transducers, the generator and the load to which the transducers are connected. Both parts of the phase delay vary with temperature, and here again the glass block makes the greater contribution to this variation. The phase delay in the glass depends both on the dimensions of the glass and on the velocity of propagation of sound in it. This is determined by the specific mass of the material and, if shear waves are employed, by its rigidity modulus. Since all these properties are temperature-dependent, the glass is not required to have a zero coefficient of expansion; but it should have properties such that the effect of any expansion due to temperature variations is compensated by the change in the velocity of propagation. A type of glass that meets this requirement has been developed at the Philips Glass Development Centre. It has in fact been found possible to give the glass properties which enable it to compensate for the effect of temperature on all of the contributions to the phase delay. This type of

[3] Also known as modulation phase delay, since the delay is that of the envelope of a modulation signal; see H. J. de Boer and A. van Weel, An instrument for measuring group delay, Philips tech. Rev. **15**, 307-316, 1953/54.

[4] C. F. Brockelsby and J. S. Palfreeman, Ultrasonic delay lines and their applications to television, Philips tech. Rev. **25**, 234-252, 1963/64.

glass has been used in the PAL delay line. Details of the composition and properties of this glass will be found in an article by Zijlstra and Van der Burgt [5]. We shall just mention here that in addition to SiO_2 the glass contains about 48 % PbO and 3 % K_2O, and that it is subjected to a special heat treatment to give it the required properties.

Owing to the elastic after-effect in the glass and the transducers, it is not possible to give a unique relation between phase delay and temperature. A better idea of the results achieved can be given by quoting the magnitude of the maximum deviation in phase delay which is found when the delay line is subjected to the kind of heating cycle that would be experienced in practice. When the delay line is raised in temperature linearly from 20 to 50 °C in three hours and then kept at 50 °C for two hours, the phase delay varies by no more than $\pm$ 5 ns compared with the value at 25 °C.

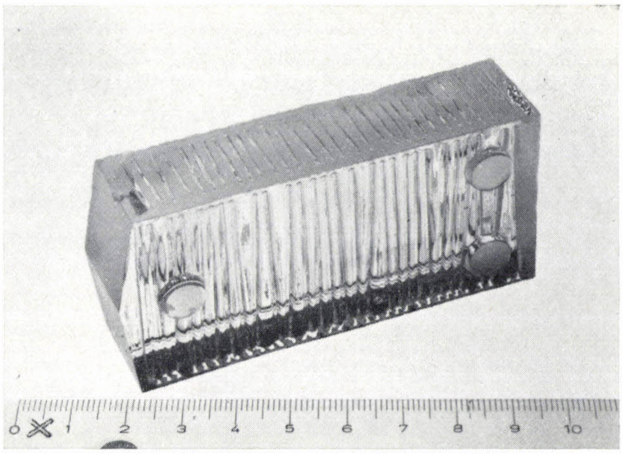

Fig. 7. The glass block of the delay line. The side walls have been "roughened" to minimize unwanted reflections of the ultrasonic waves. The three small protruding faces are used for fixing the block when the reflecting face is ground away.

Suppression of unwanted reflections

Only a negligibly small part of the acoustic energy in the glass escapes through the walls. This is due to the very great difference between the acoustic impedances (the product of density and propagation velocity) of glass and of air, and also to the fact that shear waves are used, which cannot be propagated as such in a gas. Measures have to be taken, however, to ensure that the acoustic waves, which are reflected one or more times from the side walls, do not reach the output transducer. These unwanted waves cover a distance which is longer (often very much longer) than the required path, indicated in fig. 6. This can give rise to irregularities in the amplitude characteristics and in the phase characteristic, and these irregularities can cause colour errors. This effect is opposed by making the four side walls of the glass block much "rougher" than would be necessary to make them non-reflective to light. Any acoustic waves which arrive at these walls from an incorrect path are thus scattered rather than being truly reflected. The grooves made in the glass (about 1 mm deep) can clearly be seen in the photograph in *fig. 7*. They do not follow any ordered pattern. (They have been omitted in fig. 6 for simplicity.)

In general, a certain part of the signal arriving at the output transducer will be reflected. After having covered the complete return path, this signal again arrives at the input transducer, where a further partial reflection takes place. As a result there appears at the output transducer a weak signal which has passed three times through the glass block: this is the 3τ reflection mentioned earlier, also called the "third-time-round" signal.

On page 246 we also mentioned a signal that can appear at the output transducer after having traversed the glass block *twice* ("second-time-round" signal or 2τ reflection). If it is assumed that the waves only propagate along the lines marked *A* and *B* in fig. 6, one might conclude that such a signal would arrive only at the *input* transducer. In practice, however, the wave fronts extend some way; after 2τ seconds the whole cross-section of the glass is occupied so that the *output* transducer also receives part of the energy. Fortunately in this case the transducer is not parallel to the wave front, which means that it is much less sensitive to the 2τ reflection than to the wanted signal.

To reduce the 3τ reflection to a negligible amplitude, the face of the output transducer T_2 (see fig. 6) is shifted a little from the plane perpendicular to the line *B*. If the angle of incidence of the wanted signal differs by a small amount ε from zero, the angle of incidence of the 3τ signal will be 3ε. Although this also causes slight attenuation of the wanted signal, the unwanted signal is attenuated to a much greater extent. It can in fact be eliminated completely, though only at one particular frequency (*fig. 8*).

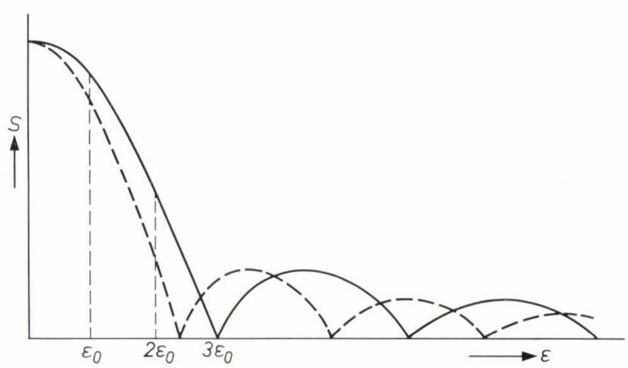

Fig. 8. Magnitude of the signal S delivered by a transducer as a function of the angle of incidence ε of the ultrasonic waves. At a particular angle ε_0 the angle of incidence $3\varepsilon_0$ of the 3τ reflection is such that the transducer is insensitive to it at the frequency corresponding to the solid curve. At other frequencies (dashed curve) and the same value of ε_0 this does not apply.

Measurements; grinding to size

Some circuits that can be used for measuring the chief characteristics of a delay line are shown in figs. 9 and 10. Circuits based on the same principles are also used when grinding down the reflecting face F in fig. 6 to bring the delay to the exact value required. First of all the reflecting surface is ground away until the group delay is a little greater than the correct value. This is most easily done if a standard delay line is available. An arrangement for comparing its group delay with that of any arbitrary line is shown in the block diagrams of *fig. 9*. The generator *Gen* delivers bursts with the frequency of the subcarrier. (The repetition frequency is fairly low.) These pass through the two delay lines, and are then detected and applied to the vertical deflection circuits of a double-beam oscilloscope. The horizontal deflection is synchronized with the repetition frequency of the bursts from the generator. The difference in group delay is found from the horizontal displacement of the two trains of detected pulses.

When the group delay has reached a value a little greater than the correct value, the next procedure is to measure the *phase shift*. The circuit used for this is shown in *fig. 10*. The generator now delivers a sinusoidal signal with a very constant frequency of 4 433 619 Hz. This signal is conducted along two paths to the amplifier A, one via the delay line and the other via a potentiometer *Pot* which causes no significant delay. The amplitudes of the two signals are equalized and the reflection face F is ground away until the amplifier input signal is zero. Here again, the measurements can be displayed on an oscilloscope.

The phase shift of the delay line is then an odd multiple of π radians. An additional phase shift of π radians can be obtained if necessary by switching the pairs of input or output terminals, so that the phase is shifted through an even multiple of π radians.

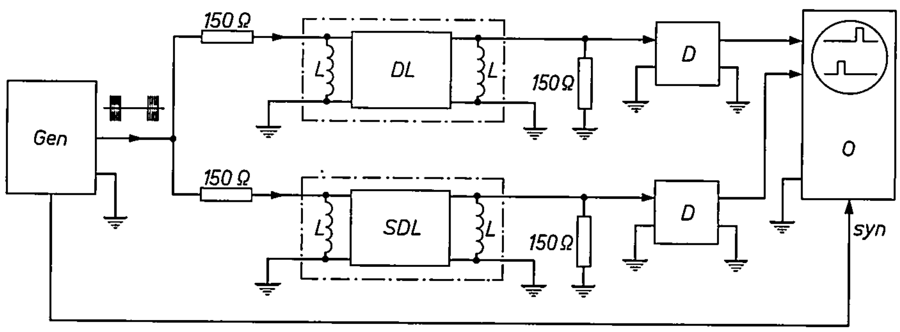

Fig. 9. Diagram for comparing the group delay of any given delay line DL with that of a standard delay line SDL. *Gen* generator delivering bursts at the frequency of the subcarrier (4 433 619 Hz). D detectors. O double-beam oscilloscope. *syn* synchronizing signal. L coils for compensating the input and output capacitances of the delay lines.

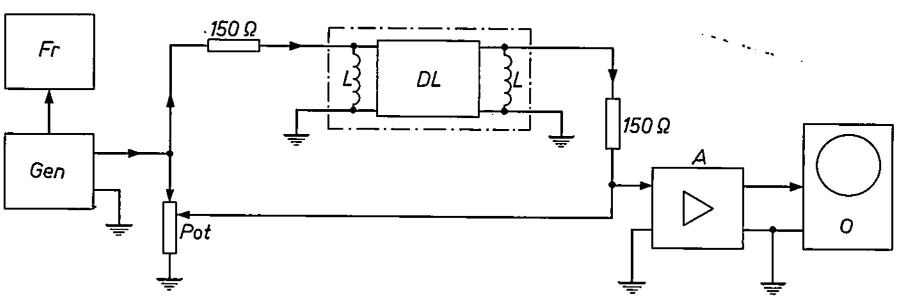

Fig. 10. Circuit that can be used when grinding off a reflecting face in a delay line for setting the correct phase shift. A amplifier with very low input impedance. *Pot* potentiometer. *Fr* frequency meter.

[5] A. L. Zijlstra and C. M. van der Burgt, Isopaustic glasses for ultrasonic delay lines in colour television receivers and in digital applications, Ultrasonics **5**, 29-38, 1967 (Jan.).

The velocity of propagation of sound in glass is approximately 2.5 mm/μs, and since the wave front is virtually parallel to the reflecting face, about 1.25 μm of glass must be ground away to reduce the delay by 1 ns. The required accuracy of the grinding is therefore of the order of 1 μm. Fortunately the reflecting face does not have to be optically flat.

The *insertion loss* is measured by comparing the output signal of the delay line with the signal from a calibrated attenuator having matched terminations at both ends. The generator used can be a type that delivers a sinusoidal signal, the loss then being measured as a function of frequency. It is also possible, however, as in the group-delay measurement, to use bursts. The advantage of this is that the oscilloscope used as indicating instrument then shows, in addition to the wanted signal, the signals due to unwanted reflections. The 3τ reflection, for example, can then be measured at the same time.

Performance and applications

Fig. 11 shows a complete delay line with the cover removed. Inductances are connected across the input and output terminals to compensate for the capacitance of the transducers (see figs. 9 and 10). The inductances have the same values as the ones that were used when the glass was being ground. There is then no error in the phase delay, which would be the case if different coils were used. (A change of 10% in the inductance causes an error of about 5 ns.) The shape of the loss characteristic can also be changed quite appreciably by a change in the inductance.

As mentioned earlier, the phase shift is set to an integral multiple of π radians by means of grinding. Some other performance figures and tolerances are listed in *Table I*.

Table I. Performance of the delay line (at 25 °C).

Phase-delay tolerance	± 5 ns
Bandwidth (3 dB): lower limit	< 3.43 MHz
Bandwidth (3 dB): upper limit	> 5.23 MHz
Insertion loss (at 4.43 MHz)	10 ± 3 dB
Terminating resistances	150 ohms
Attenuation of 3τ reflections	> 21 dB
Attenuation of other reflections	> 26 dB

Figs. 12 and *13* present some results of measurements on a delay line chosen at random. Fig. 12 gives the insertion loss as a function of frequency, both for the wanted signal (curve *a*) and for the signal due to the 3τ reflection (curve *b*). It can be seen that the 3τ signal has been attenuated by about 30 dB with respect to the wanted signal. Fig. 13 shows, again as a function of frequency, the extent to which the phase shift deviates from the ideal value, established by the phase characteristics in fig. 5. In this particular line the maximum phase error is seen to be ± 4°.

Finally, we give two circuits for a decoder incorporating the delay line. In *fig. 14* the undelayed signal appears across the resistance R_1, whose magnitude is such that this signal is equal to half the output signal from the delay line. If R_1 is connected as shown to the centre of the 2×75 Ω terminating resistance, the sum signal $B' - Y'$ and the difference signal $R' - Y'$ are obtained at the output terminals *p* and *q* respectively. With this arrangement any circuit connected to these terminals should have a fairly high input resistance (at least 1 kΩ).

In the circuit of fig. 14 the output signal has a spread equal to the spread in the insertion loss of the delay

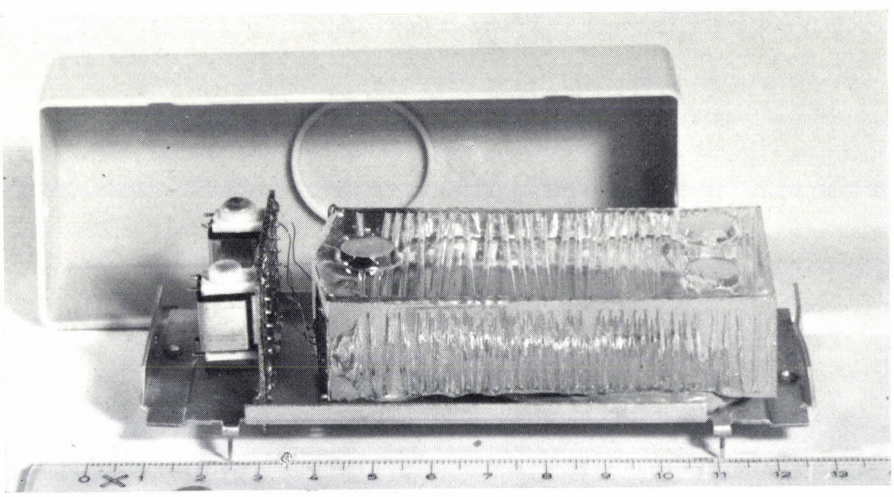

Fig. 11. Delay line with the cover removed.

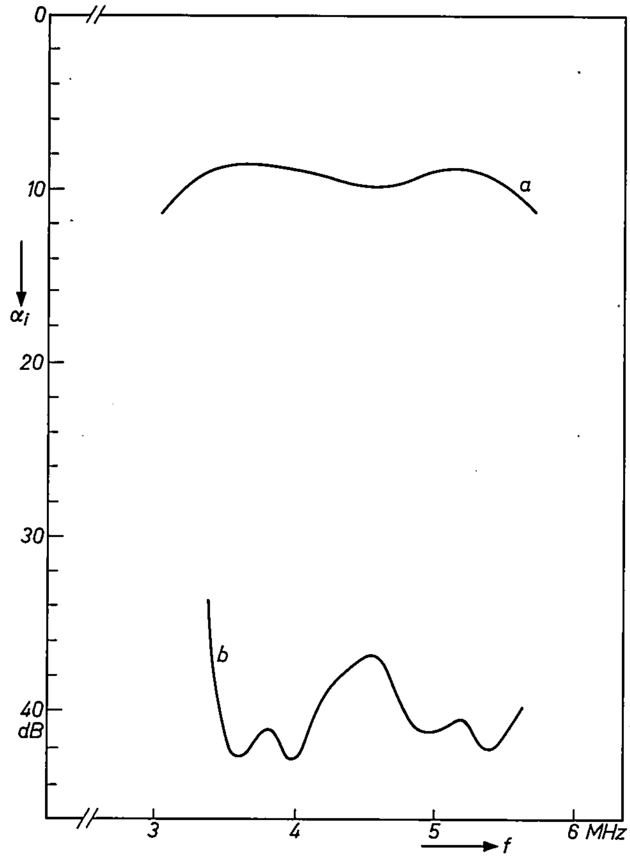

Fig. 12. Insertion loss α_i as a function of frequency f; curve a for the wanted signal, b for the unwanted signal due to the 3τ reflection.

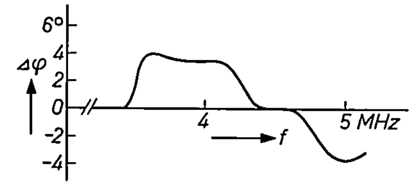

Fig. 13. Phase error $\Delta\varphi$ as a function of frequency.

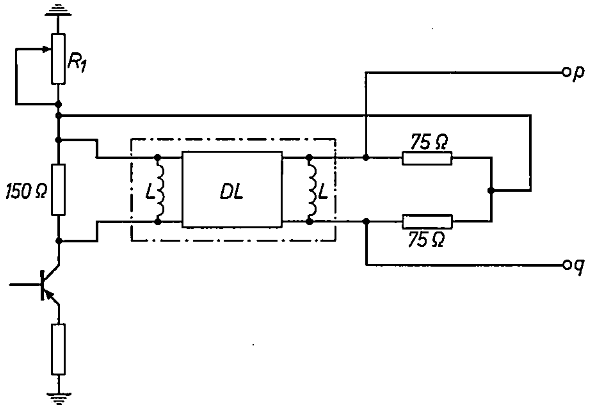

Fig. 14. Circuit of a decoder for a PALd receiver. The transistor amplifies the chrominance signal. The value of the resistor R_1 is such that the signal voltage across it is equal to half the output signal of the delay line DL, so that the $(B' - Y')$ component and the $(R' - Y')$ component of the chrominance signal appear at the output terminals p and q.

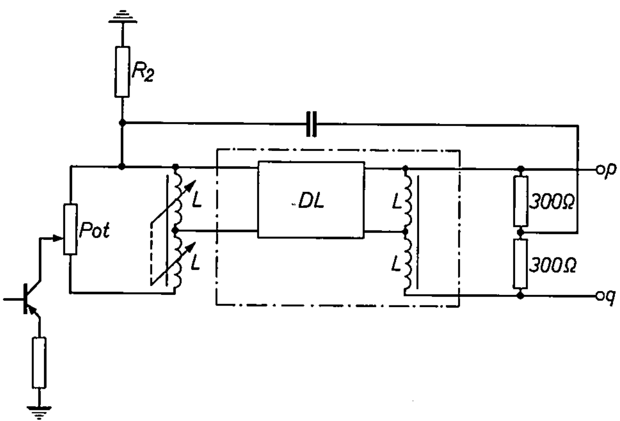

Fig. 15. The magnitude of the output signal is made independent of the spread in the insertion-loss values of the delay lines by means of the potentiometer *Pot*.

lines. This drawback is not found in the arrangement of *fig. 15.* The undelayed signal across resistance R_2 now has a fixed value which is independent of the setting of the potentiometer *Pot* used for regulating the input signal of the delay line. In this way the delayed signal can be made equal to the constant undelayed signal. Since input and output of the delay line are now provided with balanced transformers, the sum and difference signals again appear at the output terminals p and q.

Summary. In the PALd colour television receiver a delay line is used which delays the chrominance signal by one line interval. In the decoding, which is done by simple addition and subtraction of the delayed and undelayed signals, the group delay (not the phase delay) is required to be equal to the line interval (64 μs). The value of the phase delay has to be such that the phase shift for the subcarrier is an integral multiple of π radians. The permissible deviation from the required phase delay is extremely small, approximately 5 nanoseconds. The article describes a delay line which operates through the propagation of ultrasonic shear waves in a block of glass. The glass is of a specially developed type to permit the very strict tolerances to be met in the whole of the desired temperature range. The glass block has a reflecting face, which is ground away until the required phase shift is obtained. The ultrasonic waves in the glass are excited and received by transducers, which consist essentially of thin ceramic piezoelectric plates. Particular care is taken to suppress parasitic signals due to unwanted reflections. Finally, two decoder circuits are discussed which use a delay line of the type described in this article.