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V.1

PICTURE-SOURCE SYNCHRONISING

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PART 1

PICTURE SOURCE SYNCHRONISING

SECTION 1

INTRODUCTION

General

To mix or superimpose video signals it is necessary that they arrive at any mixing point in time coincidence with respect to their line and picture periods. This time coincidence is achieved by one of two methods. Where the video signals are derived from the same sync pulse-generator, the method used is to equalise the time taken over all routes from the sync pulse-generator to the mixing point. This method, known as picture source timing, is described in Instruction VTC.2.

The other method, known as picture source synchronising and described in this Instruction, is used where there are two or more sync pulse-generators which may be at different studio centres or O.B. sites.

Nomenclature

The following technical terms are used:

Picture-source synchronising	A method of making video signals, derived from two sync pulse-generators, arrive at a mixing point with their line and picture timing-pulse edges coincident within given limits. Additionally, in N.T.S.C. or PAL colour television signals, the colour-burst subcarrier signals must be coincident within given limits. Picture-source synchronising systems may work in either a *Genlock* or a *Slavelock* mode.
Genlock	To synchronise, at a mixing point, video signals derived from two sync pulse-generators; that generator which supplies the sync component of the mixer output signal is controlled by the other one.
Slavelock	To synchronise, at a mixing point, video signals derived from two or more sync pulse-generators; that generator which supplies the sync component of the mixer output signal controls one or more other generators.
Original slave-lock system	A system of picture source synchronising in which the control signal is a twice-line-frequency sine wave.
Natlock system	A system of picture source synchronising in which both sync pulse-generators are driven from stable crystal oscillators and synchronising is achieved by using digital phase-shifting techniques.
Mains lock	A condition wherein a sync pulse-generator is locked at field frequency to the National Grid mains frequency. When two sync pulse-generators are mains-locked their outputs are not necessarily coincident in time. Their outputs have a certain phase relationship but this is subject to random variations to the extent of several lines.
Crystal lock	A condition wherein a sync pulse-generator is locked at twice-line frequency to the output of a crystal oscillator.
Odd and even fields	The start of a field is defined as being coincident with the start of the first broad pulse in the field-synchronising period. The picture information on odd fields starts with a full line and ends with a half line. The picture information on even fields starts with a half line and ends with a full line. These definitions are illustrated in Fig. 1.1.

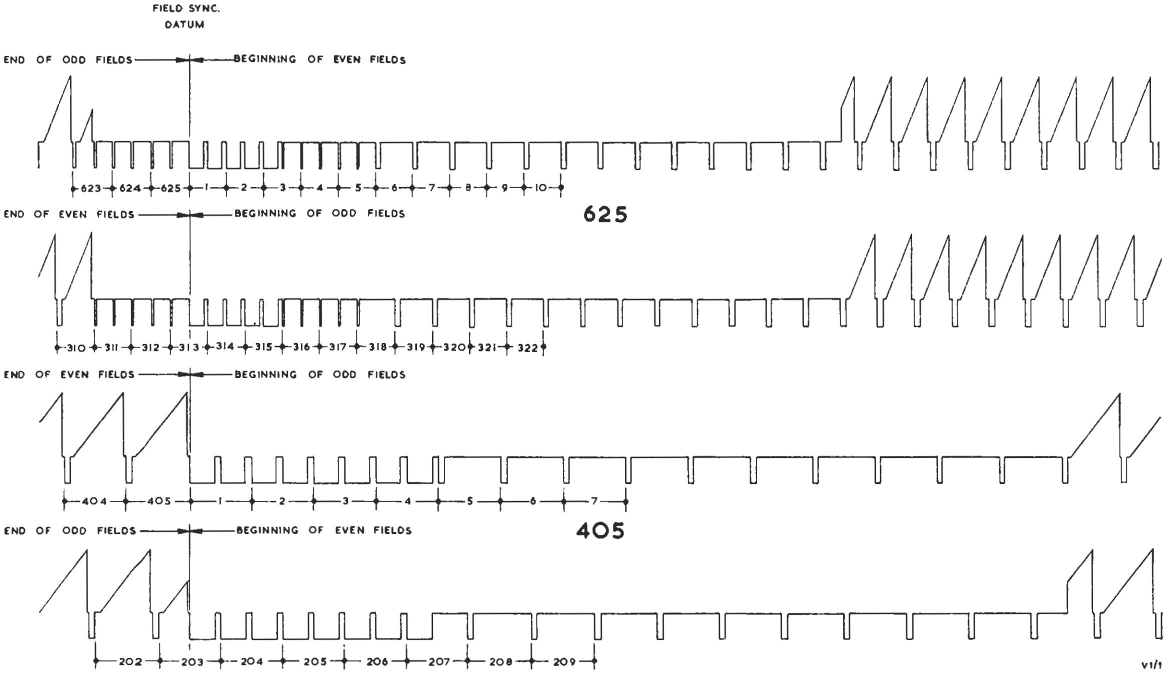

Fig. 1.1 Television Waveforms showing Odd and Even Fields

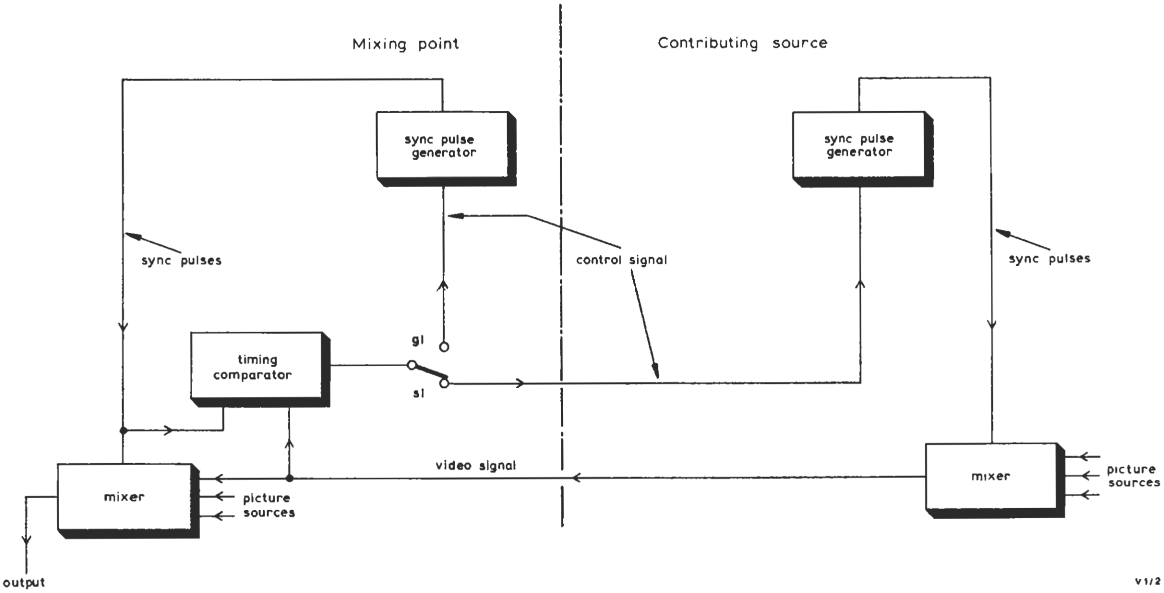

Fig. 1.2 Block Diagram Illustrating the Difference between Genlock and Slavelock

Difference between Genlock and Slavelock

Genlock and slavelock are identical except for the feedback arrangements. This is shown in Fig. 1.2. In both modes the timing comparator is situated at the mixing point but, in slavelock, the control signal from the timing comparator is fed to the contributing source and, in genlock, the control signal is fed to the sync pulse-generator at the mixing point.

If the locking equipment is integral with a sync pulse-generator (as in the Ferguson WG61 and Pye 2520), and the control signals are not available for transmission to another generator, this equipment cannot be used for slavelock. However, any system capable of being used for slavelock can also be used for genlock.

Order of Phasing

Two sets of continuous pulses of the same duration may be made coincident by temporarily changing the repetition rate of one of the sets. To make two video signals synchronous, both their line and picture periods must be made coincident. This gives two basic methods of synchronising. Either the controlled sync pulse-generator can be synchronised by first phasing the line periods and then the picture periods or this order may be reversed. The tolerances on phasing are of the order of 50 ns on line periods and 10 µs on picture periods.

If line phasing is carried out first and maintained during picture phasing, the change in the picture repetition rate can be achieved only by changing the number of lines per picture by some integer. This implies that the minimum rate of change by this method is two lines per picture (to maintain interlace); this is equivalent to a correction of one field in about four or six seconds. A disadvantage of this method is that the mechanical systems used in television (telecine, video tape and film recorders) are locked to field frequency and are unable to accommodate such a rapid change of picture phase. Furthermore, a video signal which has had lines added to or subtracted from it is non-standard. The output of a video tape machine that is synchronous with the station sync-pulses becomes non-synchronous when such a non-standard waveform is replayed.

The other basic method enables the number of lines per picture to be kept constant by altering the line repetition rate only. Approximate picture phasing is completed first, followed by line phasing. By this method the phasing processes may be made slow enough to avoid disturbance to mechanical systems.

The timing comparator in the original slavelock system is sometimes referred to as a CLNPS (constant line number picture synchroniser). The term is inappropriate because the principle of a constant number of lines per picture is a feature of all modern slavelock systems.

Picture Phasing

The time required to synchronise a source, without disturbing mechanical systems, is about one minute to correct one field and this may be too long for operational requirements. A programme may consist of a series of O.B. contributions linked by studio inserts. If the studio is to genlock in turn to each of the O.B. sources, the time taken to synchronise may be made much shorter if the outside sources are all in approximate picture phase before synchronising is commenced.

Non-synchronous sources are usually brought into approximate picture phase, or even field phase, to permit cuts to be made between sources without frame-rolls appearing on picture monitors or domestic receivers.

Sync pulse-generators can be picture-phased manually by the use of one of the following units:—

Drive Unit	GE1/520	(Instruction V.10)
Drive Unit	GE1/517	(Instruction V.10)
Phase Shift Unit	TV/PSU/1	(Instruction V.9)

The difference in picture phase between two video signals may be measured on a Picture Phase Indicator (Instruction V.9) in conjunction with a Picture Phase Meter PA15/501 (Instruction V.13).

SECTION 2

ORIGINAL SLAVELOCK SYSTEM

A simplified block diagram of the original slavelock system is shown in Fig. 2.1 which should be compared with Fig. 1.2. The timing comparator is a picture synchroniser (such as a UN1/528 described in Instruction V.14) whose output control-signal is a twice-line frequency sine wave. This signal is fed to the controlled sync pulse-generator.

In the slavelock mode, the control signal is fed to the contributing source via a music circuit. This circuit must not contain any repeating amplifiers because these might impose random phase changes on the control signal, thus causing jitter on the outputs of the controlled sync pulse-generator. The maximum distance over which the control signal may be transmitted is restricted by two factors: the worst signal-to-noise ratio that can be tolerated (about 45 dB) and the attenuation at twice-line frequency (not more than about 20 dB). These restrictions are met in practice if the cable length of the music circuit does not exceed 5 miles and the loop resistance does not exceed 500 ohms.

At the contributing source, the control signal is fed to the sync pulse-generator via either a slavelock receiving amplifier (such as an AM1/517 described in Instruction V.7) or a slavelock receiving unit which includes the amplifier.

The original slavelock system forms a continuously operating servo feedback loop. Synchronism may be lost if the system is disturbed either by breaking the loop or by including a second picture synchroniser within the loop. The effect of these disturbances can be minimised by both the correct operation of the system and the inclusion of protective circuits; see Instruction V.14.

The most likely cause of a break in the servo loop is a cut to a non-synchronous input at the slavelocked site. The mixer at the slavelocked site will feed through the non-synchronous sync pulses in place of the slavelocked sync pulses. If this occurs, the control signal from the picture synchroniser changes frequency as though to correct any phase error from the contributing source; it has no effect on the phase error because this error is not produced by the slavelocked sync pulse-generator, but by the sync pulse-generator at the non-synchronous source. Thus the frequency of the control signal continues to change until it reaches one end of its range.

When, at the contributing source, a cut is made

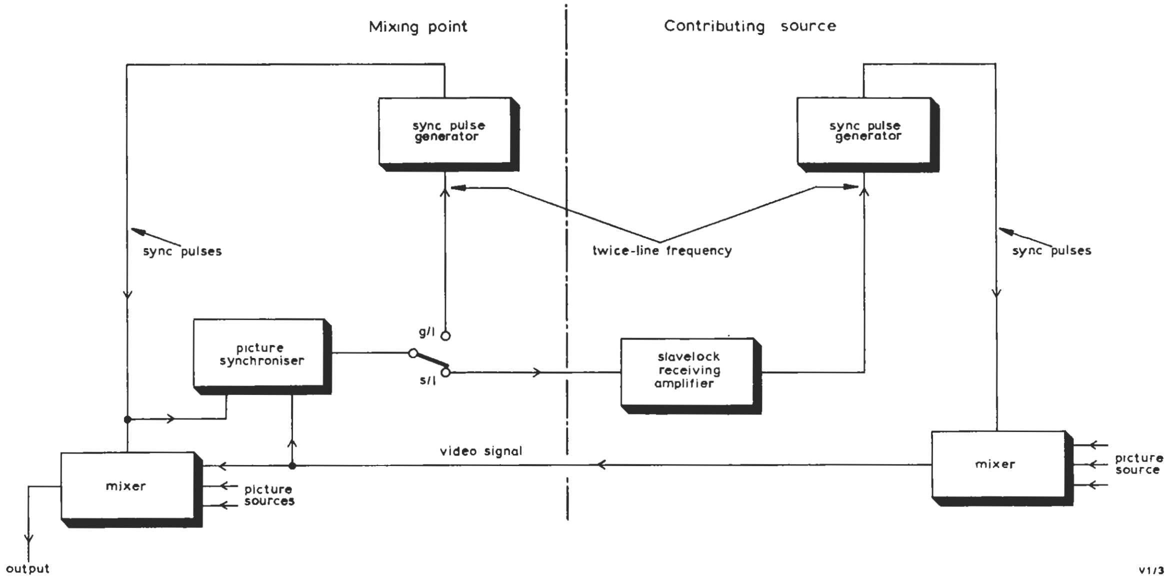

Fig. 2.1 Block Diagram of the Original Slavelock System

back to one of its synchronous inputs the twice-line frequency of the slavelocked sync pulse-generator differs from that of the sync pulse-generator at the mixing point. Under these conditions it takes some time for synchronism to be re-established. For correct operation, the slaved input to the picture synchroniser must be disconnected before such a cut to a non-synchronous input is made at the contributing source. If this is not done, a *Reset* control on the picture synchroniser can be used to bring the control signal back to its nominal frequency.

The inclusion of a second picture synchroniser within the loop can arise in using cascaded slavelock. If a mixing point is slavelocking a contributing source A and in turn A is slavelocking another source B, the video signals from both A and B arrive at the mixing point in synchronism with the output of the controlling sync pulse-generator. The video signal from source B must be mixed as a synchronous source at A and must have its own sync-pulses removed and replaced by those from the sync pulse-generator at A. If this is not done the mix at A converts the two feedback loops into a single loop containing two picture synchronisers and so instability may occur.

Operating genlock systems in cascade is usually a simpler operation provided that the whole system is given ample time to settle down before being used for transmission. In both cascaded modes of operation, it is essential not to disturb any of the sync pulse-generators; for example, the controlling sync pulse-generator must not be either switched from internal M.O. to external M.O. or slavelocked to another source.

SECTION 3

NATLOCK SYSTEM

A simplified block diagram of the Natlock system is shown in Fig. 3.1 which should be compared with Figs. 1.2 and 2.1. Each sync pulse-generator is driven at twice-line frequency from a separate Drive Unit (Instruction V.10) each of which contains a stable crystal reference oscillator.

The timing comparator (such as an Error Signal Generator GE1/523, Instruction V.10) compares the phase error between its *Local* and *Remote* inputs. The error is analysed into five ranges:

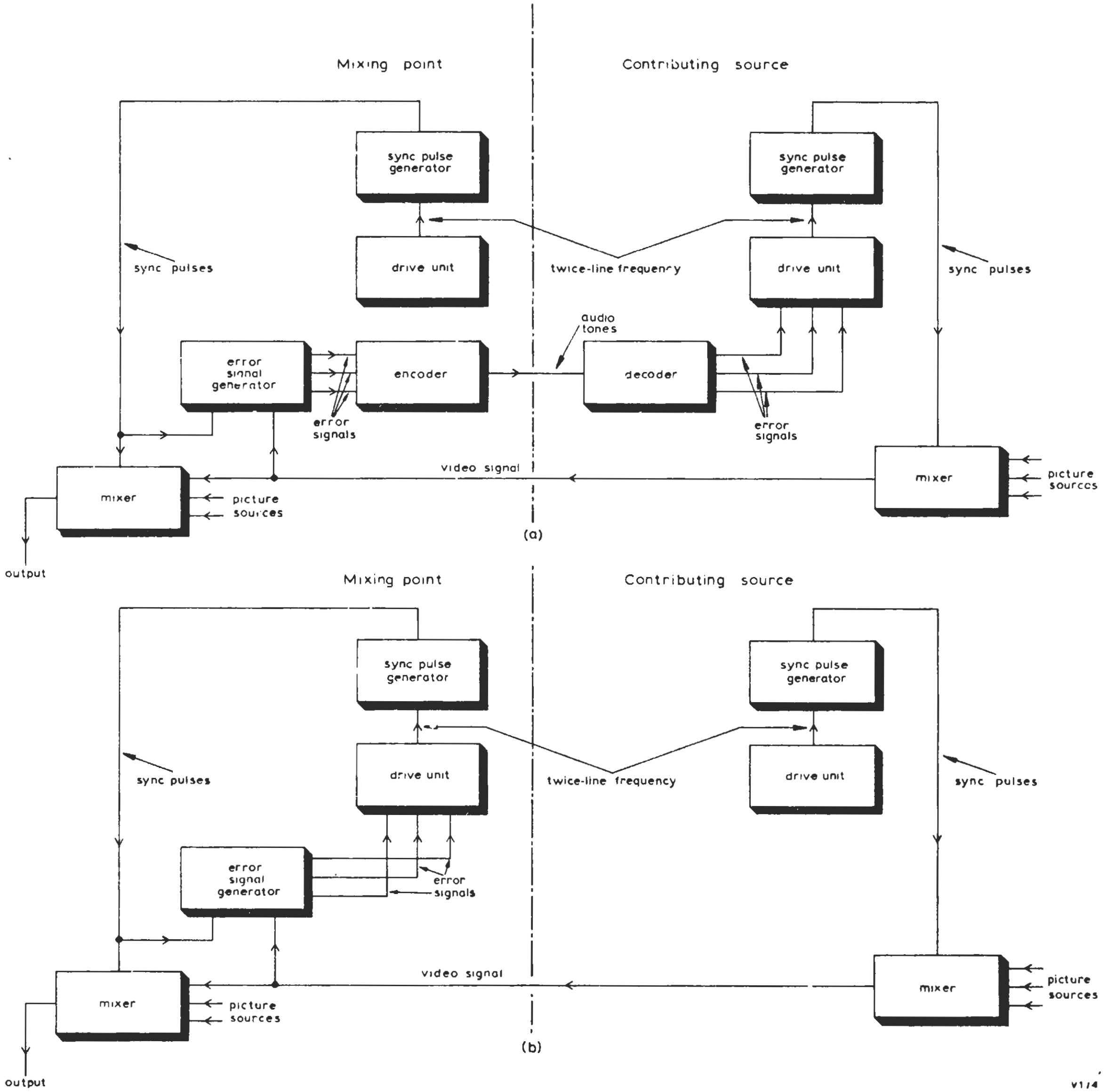

Fig. 3.1 Block Diagram of the Natlock System
(a) slavelock mode (b) genlock mode

1. *Remote* signal arrives early by more than 8 µs.
2. *Remote* signal arrives early by less than 8 µs.
3. Error too small to detect (say less than 30 ns).
4. *Remote* signal arrives late by less than 8 µs.
5. *Remote* signal arrives late by more than 8 µs.

The Error Signal Generator produces three d.c. binary-coded error signals which correspond to the ranges of error. These combinations are known respectively as:

1. Fast retard.
2. Retard.
3. Normal.
4. Advance.
5. Fast advance.

In the genlock mode the error signals are fed directly to the mixing-point Drive Unit, but in the slavelock mode the signals are encoded for transmission to the Drive Unit at the contributing source. One such encoding system uses three audio tones that can be sent over a low-grade audio circuit.

The error signals control the phase of the twice-line frequency output of the controlled Drive Unit and may also control the frequency of the reference oscillator (see Oscillator Correction Unit UN17/509, Instruction V.14). The effects on the phase of the twice-line frequency output of the Drive Unit corresponding to the error signal combinations are:

1. Continuous phase shift obtained by decreasing the twice-line frequency by 5·6 Hz.
2. Phase retarded by about 0·2° (18 ns) at the start of each picture period.
3. No effect.
4. Phase advanced by about 0·2° (18 ns) at the start of each picture period.
5. Continuous phase shift obtained by increasing the twice-line frequency by 5·6 Hz.

The Natlock system is relatively immune to noise on the feedback circuit and does not hunt provided that the loop distance does not exceed about 3000 miles. If the servo loop is broken, synchronism is lost after a short period owing to oscillator drift, but the video signal from the contributing source is otherwise unimpaired.

Natlock is adaptable for colour television.

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SECTION 4

COLOUR NATLOCK SYSTEM

Factors Affecting Colour Natlock

Picture-source synchronising is affected by certain aspects of a PAL colour video signal:

(*a*) *Subcarrier-sync Phase*

The subcarrier signal in the colour burst has no specified phase (or time) relationship with the start of line-sync pulses (see Appendix B). Thus the timing limits for sync-pulse edges are independent of the phasing limits for the subcarrier signal in the colour burst and so the phase of this subcarrier signal can be varied independently of the sync-pulse phasing.

The limits for the sync-pulse timing of colour video signals are 50 ns, the same as those for monochrome video signals. The phase limits for colour burst subcarrier signals are 0·8 ns (1·25 degrees at 4·43 MHz).

The ability of the subcarrier-sync phase relationship to be varied, and the technique used for varying the phase of the subcarrier signal, imply that the picture source synchronising processes for subcarrier signals and for sync pulses are separate. For example: the subcarrier signal used at a mixing point can be genlocked to that used at a contributing source while the sync pulses from the contributing source are slavelocked.

(*b*) *Bruch Blanking*

The phase of the subcarrier signal in the colour burst is advanced and retarded 45 degrees from its mean value on alternate lines. This variation in phase is produced by the PAL square-wave, a square-wave with a two-line period. Blanking of the colour burst in the field interval signal is arranged to finish with a positive-going edge of the PAL square-wave. This Bruch blanking, as it is called, has therefore a fundamental period of four fields which is shown in Fig. 4.1. This four-field period is used in colour Natlock as opposed to the two-field (picture) period which is used in monochrome Natlock.

(*c*) *Subcarrier frequency*

The Natlock reference frequency f_n is related to line frequency f_l by the equation:

$$f_n = \tfrac{567}{2} \times f_l$$

Colour subcarrier frequency f_{sc} is also related to line frequency by the equation:

$$f_{sc} = (\tfrac{567}{2} + \tfrac{1}{4} + \tfrac{1}{625}) \times f_l$$

Thus there is a fixed relationship between Natlock reference frequency, line frequency and colour subcarrier frequency. Note that in practice this relationship is not disturbed by the small phase shifts introduced to maintain picture source synchronism.

The subcarrier frequency can also be expressed in terms of field frequency f_f:

$$\begin{aligned} f_{sc} &= (\tfrac{567}{2} + \tfrac{1}{4} + \tfrac{1}{625}) \times \tfrac{625}{2} \times f_f \\ &= (88{,}593\tfrac{3}{4} + 78\tfrac{1}{8} + \tfrac{1}{2}) \times f_f \\ &= 88{,}672\tfrac{3}{8} \times f_f \end{aligned}$$

Thus in a colour video signal, a particular subcarrier-sync phase relationship repeats after an eight-field period. Although an eight-field period is the true fundamental period of a PAL colour video signal, the independence of the subcarrier-sync phase relationship makes this period of no consequence except for video tape recordings.

The subcarrier-sync phase relationship on a video tape recording is fixed in the recording process and so the subcarrier and the sync pulses cannot be slavelocked independently on replay. In practice, the output signal of a video tape-recorder is first locked to a fundamental four-field period by comparing a four-field control signal with a similar signal, generated from station sync pulses and PAL squarewave, and by comparing the output sync pulses with station sync pulses. Secondly the phase difference between the subcarrier signal in the colour burst of the output signal and the station subcarrier signal is reduced to a small fraction of a cycle at 4·43 MHz in a d.c.-controlled variable delay line. This second

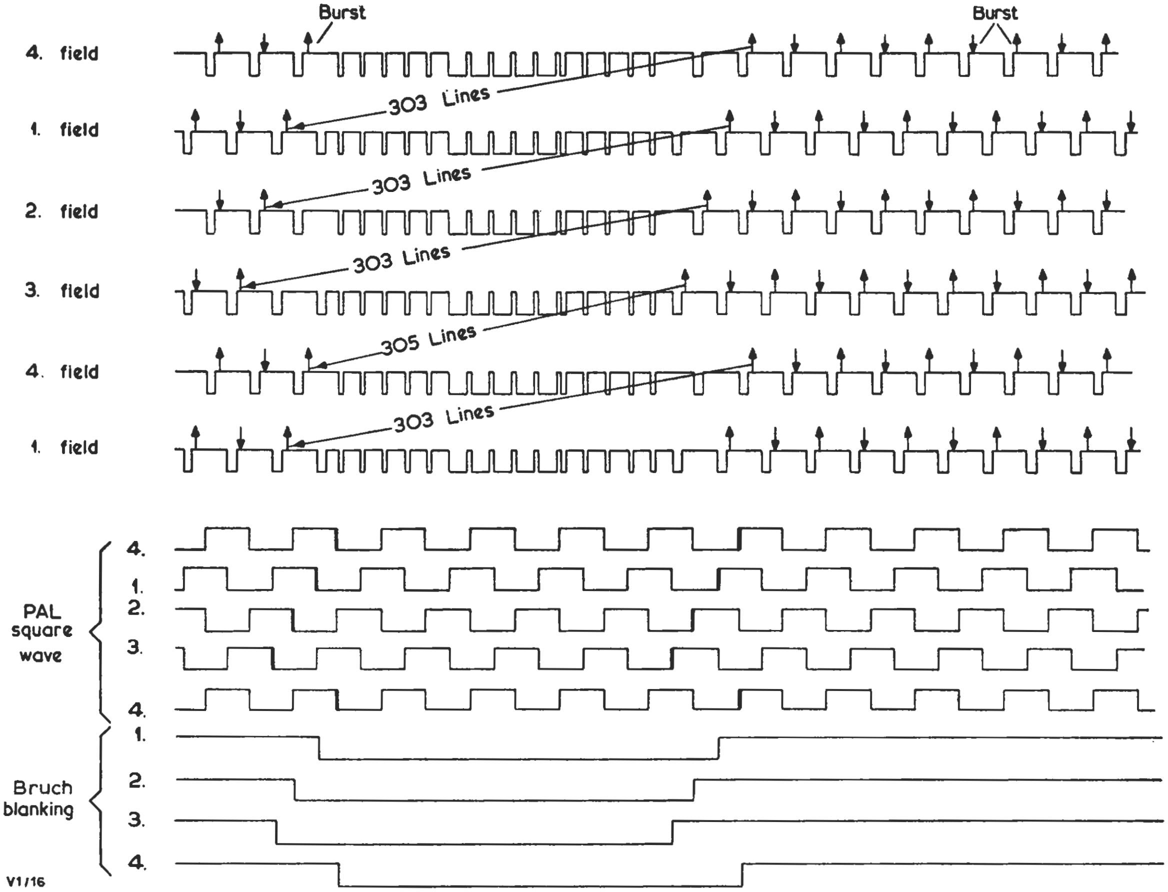

Fig. 4.1 Colour Field-interval Signals

process results in a sync-pulse timing error which may be up to 113 ns (180 degrees at 4·43 MHz). If the output signal of the recorder were locked to the appropriate four fields in an eight-field period this maximum error would be reduced to 56·5 ns which is almost within tolerance. Instead the sync pulses of the output signal are replaced with station sync pulses.

The use of the four-field period as a fundamental period for video tape recordings also introduces problems in editing colour video tape. In cutting portions out of a single tape the join can either be right or cause a jitter in the picture luminance signal of 113 ns. Similarly in joining portions of different tapes jitter of up to 113 ns can occur. Recording of animation effects also suffer from the 0·5 probability of jitter on every discrete recording period.

Colour Natlock Correction Rates

The basic arrangement of the colour Natlock system is shown in a simplified form in Fig. 4.2. Two colour video signals A and B are fed to sync and subcarrier timing comparators which produce error signal outputs depending upon the difference in timing between the input signals. The error signals are fed to a drive unit to control the phase of a twice-line frequency signal and to a

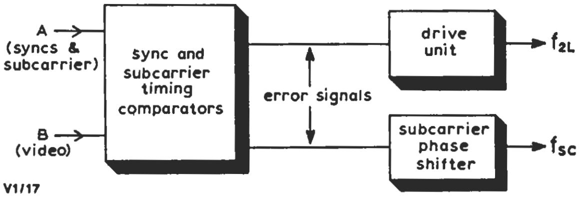

Fig. 4.2 Basic Arrangement of Colour Natlock

subcarrier phase shifter. If the A input to the system is taken as the timing reference and the timing of the B input is controlled by the phase of the output twice-line and subcarrier frequencies, the comparators analyse the timing errors into the following ranges:

1. The sync pulses of B are early by more than 12 µs.
2. The sync pulses of B are early by less than 12 µs and more than about 40 ns.
3. The sync pulses of B are early by less than about 40 ns and the subcarrier signal in the colour burst of B is early by more than 0·8 ns.
4. The error is too small to detect (less than 0·8 ns).
5. The sync pulses of B are late by less than 40 ns and the subcarrier signal in the colour burst of B is late by more than 0·8 ns.
6. The sync pulses of B are late by less than 12 µs and more than about 40 ns.
7. The sync pulses of B are late by more than 12 µs.

The comparators produce combinations of error signals which correspond to these ranges of error. The combinations are known as:

1. Fast retard.
2. Retard.
3. Colour retard.
4. Normal.
5. Colour advance.
6. Advance.
7. Fast advance.

These combinations of error signals fed to the drive unit and subcarrier phase shifter produce the following effects:

1. The twice-line frequency is reduced by 5·6 Hz to produce a continuous phase shift in video signal B corresponding to a rate of two field periods in approximately four minutes.
2. The phase of the twice-line frequency signal is retarded in steps of 18 ns (approximately 0·2 degrees at twice-line frequency) once in each picture period. The frequency of the twice-line frequency signal is also reduced in steps of roughly 0·01 Hz at a maximum rate of 12·5 times per second.
3. The phase of the subcarrier signal is retarded in steps of 1·5 degrees (approximately 0·94 ns) once in each picture period. This corresponds to a rate of 180 degrees in 4·8 seconds.
4. No effect.
5. The phase of the subcarrier signal is advanced in steps of 1·5 degrees (approximately 0·94 ns) once in each picture period. This corresponds to a rate of 180 degrees in 4·8 seconds.
6. The phase of the twice-line frequency signal is advanced in steps of 18 ns (approximately 0·2 degrees at twice-line frequency) once in each picture period. The frequency of the twice-line frequency signal is also increased in steps of roughly 0·01 Hz at a maximum rate of 12·5 times per second.
7. The twice-line frequency is increased by 5·6 Hz to produce a continuous phase shift in video signal B corresponding to a rate of two field periods in approximately four minutes.

Applications of Colour Natlock

The block diagrams shown in Figs. 4.3 to 4.6 illustrate some practical applications of colour Natlock. The block diagram given in Fig. 4.3 shows the colour Natlock system operating in the sync slavelock and subcarrier slavelock modes. In Fig. 4.4 the system is operating in the sync genlock and subcarrier genlock modes. These modes can be mixed.

The block diagram given in Fig. 4.5 shows colour Natlock being used to slavelock the subcarrier signal at a contributing source. Sync pulse synchronising is achieved by timing. Such an arrangement can be used in a studio centre.

The block diagram given in Fig. 4.6 shows an arrangement that can be used at a satellite studio centre such as Lime Grove. Natlock reference and subcarrier signals are received from a main studio centre and distributed around the satellite centre.

Sync Slavelock: Subcarrier Slavelock

In the arrangement shown in Fig. 4.3, which should be compared with Fig. 3.1(a), both sync pulse generators are driven at twice-line frequency f_{2L} by a drive unit[1]. These drive units also drive a subcarrier generator[2] at Natlock reference frequency f_n. The subcarrier generators feed the picture sources at subcarrier frequency f_{sc} either directly (as at the mixing point) or via a digital phase shifter[3] (as at the contributing source).

The colour video signal from the contributing source is fed at the mixing point to the mixer, to an error signal generator[4] and to a subcarrier comparator[5]. The error signal generator compares the timing of the sync pulses from both sync pulse generators. It produces three binary-coded d.c. error signals corresponding to five error ranges; 1, 2, (3 to 5), 6, 7. The subcarrier comparator compares the phase of the subcarrier signal derived from both the subcarrier generators and produces a single ternary-coded d.c. error signal corres-

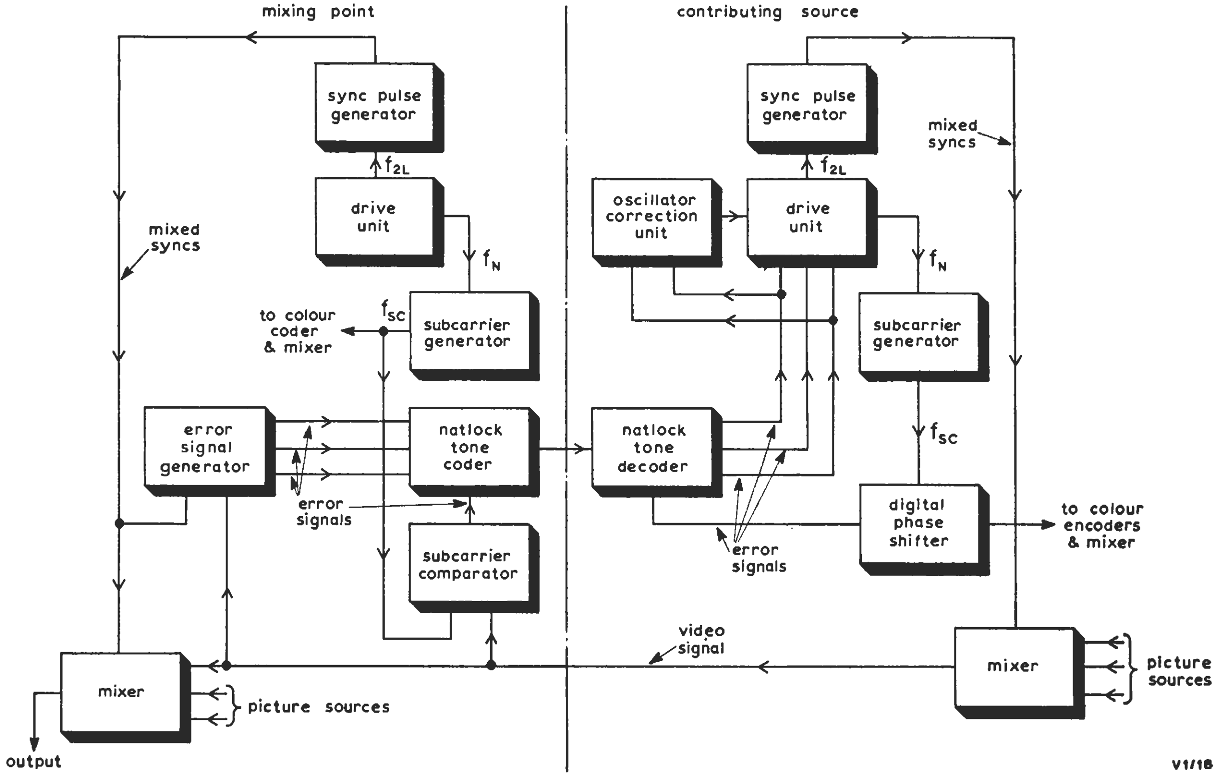

Fig. 4.3 Colour Natlock used in the Sync Slavelock and Subcarrier Slavelock Modes

ponding to three error ranges (1 to 3), 4 and (5 to 7).

The four d.c. error signals are combined in a Natlock coder[6] for transmission over a low-grade sound circuit to the contributing source. At the source a decoder[7] reconstitutes the d.c. error signals and these are used to control the drive unit and the digital phase shifter. An oscillator correction unit[8] must be used at the contributing source so as to tune the drive unit to be near-isochronous with the drive unit at the mixing point.

Sync Genlock: Subcarrier Genlock

In the arrangement shown in Fig. 4.4, which should be compared with Fig. 3.1(b), the error signals generated at the mixing point are used to control the adjacent drive unit and digital phase shifter.

Timed Syncs: Subcarrier Slavelock

In the arrangement shown in Fig. 4.5 the feeds of sync pulses to both mixers are taken from the same sync pulse generator and the feed to the mixer at the mixing point is delayed either by lumped constant delay networks or by additional cable to achieve sync pulse synchronism. This method of timing is more difficult to apply to the subcarrier signal because of the tighter tolerance required. A tolerance of 0·8 ns is equivalent to a change in length of 6 in. of coaxial cable. Thus the subcarrier signal is slavelocked at the contributing source.

Slavelock using Distributed Natlock Reference and Subcarrier Signals

In the arrangement shown in Fig. 4.6 Natlock reference and subcarrier signals are derived from a main studio centre (not shown) and distributed to a subsidiary mixing point and its associated contributing source. This gives the advantage that the drive units can be of a simpler type and that oscillator correction units are not required.

The error signals can be coded d.c. signals on two wires which are in use only while synchronism is

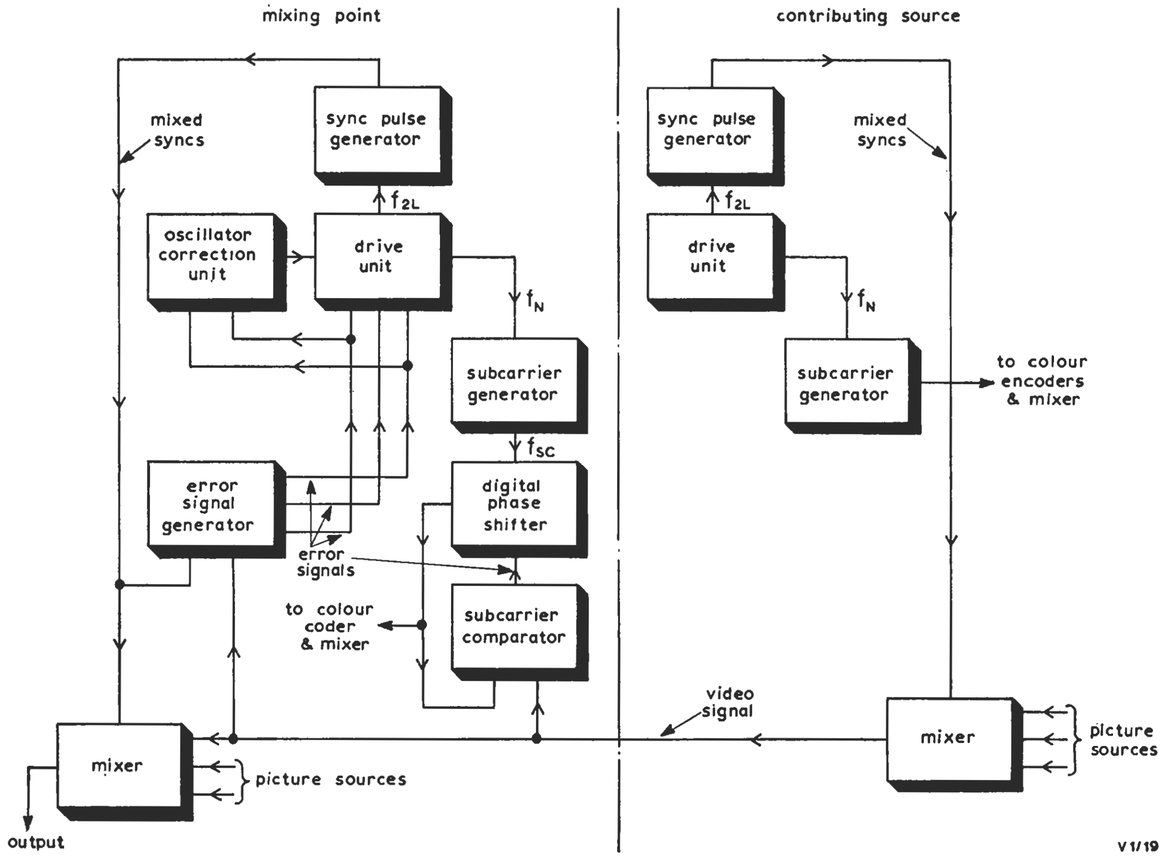

Fig. 4.4 Colour Natlock used in the Sync Genlock and Subcarrier Genlock Modes

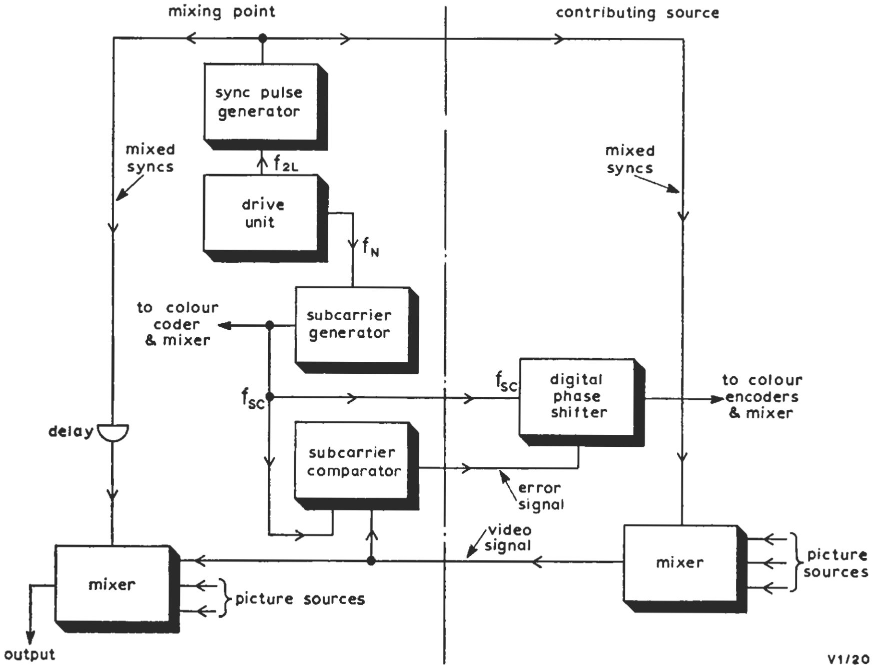

Fig. 4.5 Colour Natlock using Timed Syncs and Slavelocked Subcarrier

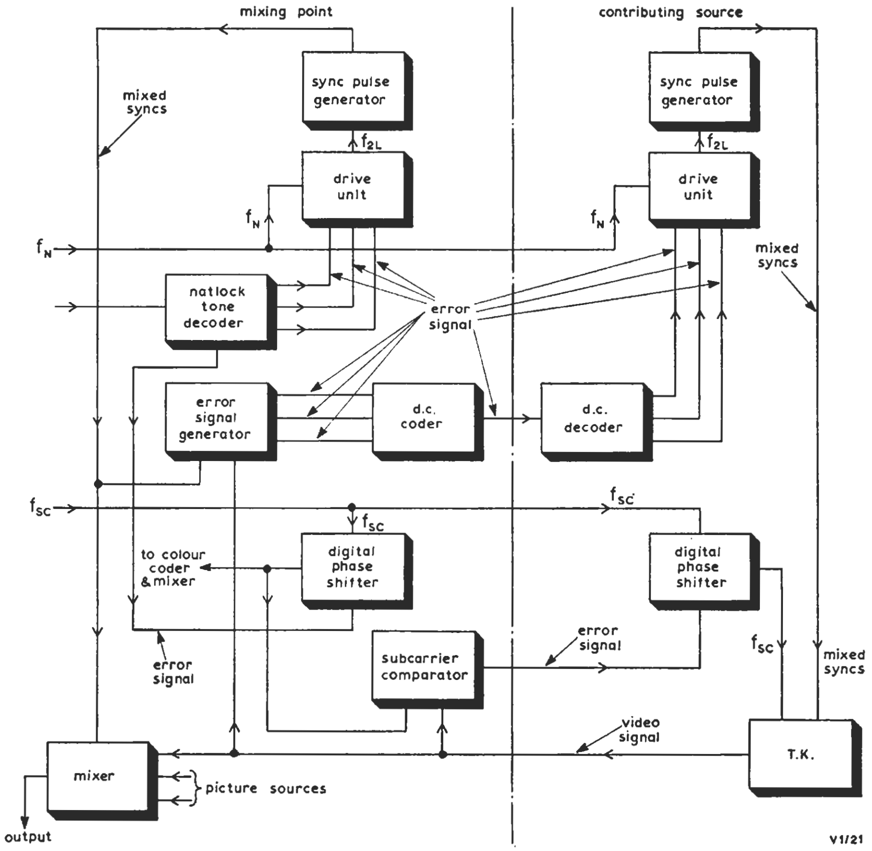

Fig. 4.6 Isochronous Colour Natlock

being achieved. Thereafter these connections can be used for other purposes.

References to Typical Colour Natlock Equipment

1. 625-line Waveform Generator Drive Unit GE1/520; Instruction V.10.
2. Natlock-PAL Colour Subcarrier Frequency Converter CO2L/523; Designs Department Technical Memorandum 10.9(67).
3. Colour Subcarrier Phase Shifter EP1L/509; Instruction V.15.
4. Error Signal Generator GE1M/532; Instruction V.10.
5. Colour Subcarrier Phase Comparison Studio Equipment EP5M/505; Instruction V.15.
6. Error Signal Tone Encoder CD2/501; Instruction V.9.
7. Error Signal Tone Decoder CD3/501; Instruction V.9.
8. Oscillator Correction Unit UN17/509; Instruction V.14.

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APPENDIX A

DIGITAL METHODS OF CONTROLLING FREQUENCY AND PHASE

Frequency Dividers With Fractional Division Ratios

The use of bistable multivibrator counting circuits is described in Television Engineering, Vol. 4. The division ratio of such circuits is always a whole number. Frequency translation by means of a modulator can be used to obtain a division ratio which is a fraction and not a whole number. Such a modulator is usually followed by a band-pass filter, to select the required sum or difference frequency, and by a Schmitt trigger circuit to reshape the output waveform of the filter.

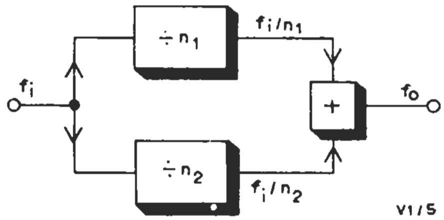

Fig. A.1 Frequency Divider with Fractional Division Ratio

A block diagram of such a divider is given in Fig. A.1. In this Appendix the symbol with the + sign represents a combination of modulator, band-pass filter tuned to the *sum* frequency and a Schmitt trigger circuit. If the filter is tuned to the difference frequency, the symbol contains the − sign. The output frequency of the divider (f_o) is given by:

$$f_o = f_i/n_1 + f_i/n_2$$
$$= f_i \frac{n_1 + n_2}{n_1 . n_2}$$

The division ratio is given by:

$$f_i/f_o = \frac{n_1 . n_2}{n_1 + n_2} \quad \dots \dots \dots \quad (1)$$

More complicated circuits involving more counters and modulators can be used.

Digital Phase Shifting

Each time a counter circuit produces an output pulse, it is said to have completed a count. By changing the division ratio for just one count the output pulse can be advanced or retarded relative to the input waveform. This change of timing of the output pulse can also be regarded as a phase shift and the change in timing, as a fraction of the output pulse period, can be expressed in degrees.

The waveforms in Fig. A.2 illustrate the change produced by altering the division ratio for one count only. Fig. A.2(a) shows the input waveform of a divide-by-5 counter and Fig. A.2(b) shows its normal output waveform. In Fig. A.2(c) the division ratio is changed to divide-by-6 for the first count and in Fig. A.2(d) the ratio is changed to divide-by-4 for the first count.

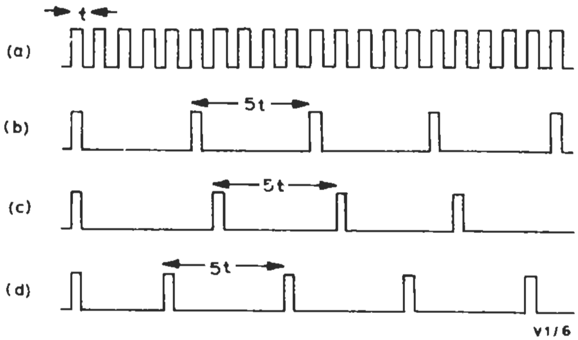

Fig. A.2 Waveforms Illustrating Digital Phase Shifting

In both these instances, the normal division ratio is maintained after the altered count. The change in timing in these examples is the period of one input pulse, *t*, and the phase shift is the ratio of this time to the normal period of the output pulse. The phase shift expressed in degrees is, therefore, 360/5: i.e. 72 degrees.

When the frequency is changed, either by dividing or modulating, the change in timing or the phase-shift (but not both) is altered. These effects are explained in detail below.

Effects On Timing and Phase Shifts

Counter Circuits

The block diagram shown in Fig. A.3 is used to illustrate the manner in which a counter affects a timing change and a phase shift in its input waveform. This timing change and phase shift are

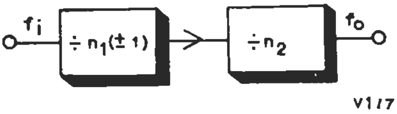

Fig. A.3 Counter Arrangement used to Illustrate Affect on Change of Input Timing and Phase

considered as being produced by a single miscount in the first counter circuit in the manner described above.

In this instance the normal output of the first counter circuit has a frequency of f_i/n_1. The period t_1 of this waveform is given by:

$$t_1 = n_1/f_i$$

If the division ratio of the first counter is changed by one the period t'_1 is given by:

$$t'_1 = \frac{n_1 \pm 1}{f_i}$$

The difference between these two periods is clearly the period of the input waveform, $1/f_i$.

The phase shift in the output waveform of the first counter is given by:

$$\frac{t_1 \sim t'_1}{t_1} \times 360° = (1/f_i \div n_1/f_i) \times 360°$$
$$= \frac{360°}{n_1} \quad \ldots\ldots\ldots \quad (2)$$

Consider the second counter. For each pulse which appears at the output of the counter, n_2 pulses are required at the input. If the period between two of these input pulses is changed for any reason, the output period of the counter is changed by the same amount of time.

Thus a change in timing of the input waveform is unaffected by a counter circuit.

The normal period of the input waveform of the second counter t_1 is given by:

$$t_1 = n_1/f_i$$

The normal period of the output waveform t_2 is given by:

$$t_2 = (n_1 \times n_2)/f_i$$

The time change $1/f_i$ causes a phase shift in the input waveform a_i given by (see equation 2):

$$a_i = (1/f_i \div n_1/f_i) \times 360°$$
$$= \frac{360°}{n_1}$$

The corresponding phase shift in the output waveform a_o is given by:

$$a_o = (1/f_i \div n_1 n_2/f_i) \times 360°$$
$$= \frac{360°}{n_1 n_2} \quad \ldots\ldots\ldots\ldots \quad (3)$$

Thus phase shift at the output of a counter, relative to the phase shift at its input, is reduced by the division ratio.

Modulators

Consider a modulator whose inputs have pulse repetition frequencies of f_1 and f_2. These input signals can be represented by their fundamental components

$$\text{Sin } 2\pi f_1 t$$
$$\text{and Sin } (2\pi f_2 t + a)$$

where a is the relative phase difference between the signals at time $t = o$.

All modulation processes of the type considered here produce terms which are the product of the input signals. These product terms may be expressed in terms of the sum and difference frequencies which shows how a modulator can be used as a frequency adder.

The output of the modulator is given by the product:

$$\text{Sin } 2\pi f_1 t \times \text{Sin } (2\pi f_2 t + a)$$

$$= \text{Cos } (2\pi\overline{f_2 - f_1}t + a) - \text{Cos } (2\pi\overline{f_2 + f_1}t + a)$$

Thus the phase shift a as an angle is not changed by the modulation process. The change in timing varies inversely as the change of frequency through the modulator. This is given by the relationship between a timing change t, the frequency f and a phase shift a:

$$t = 1/f \times a/360° \quad \ldots\ldots \quad (4)$$

Examples of Digital Control

(a) In this example, shown in Fig. A.4 and taken from a Drive Unit GE1/520, a fractional division ratio is required. Substituting in

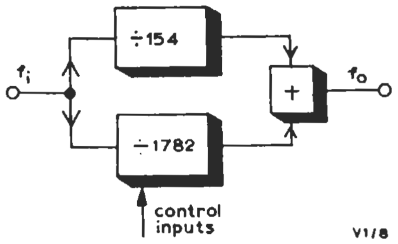

Fig. A.4 Fractional Divider from GE1/520

equation (1), the division ratio is given by:

$$\frac{f_i}{f_o} = \frac{154 \times 1782}{154 + 1782}$$
$$= 141{\cdot}75$$

The timing change produced by altering the division ratio of the divide-by-1782 counter by one (to either divide-by-1781 or divide-by-1783) for one count is

$$= 1/f_i$$

This can be expressed as a phase shift by substituting in equation (2):

$$= 360°/1782$$
$$\approx 0{\cdot}2°$$

The phase shift produced in the output signal is also approximately 0·2 degrees, but the change in timing of the output signal is given by substituting in equation (4):

$$t = 32 \times 10^{-6} \times \frac{0{\cdot}2}{360}$$
$$= \frac{32 \times 10^{-6}}{1782}$$
$$\approx 18 \text{ ns.}$$

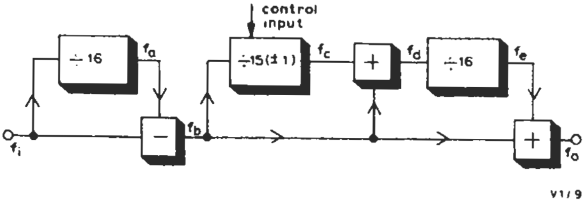

Fig. A.5 Digital Phase-shifter from EP1L/509

(b) In this example, shown in Fig. A.5 and taken from a Colour Sub-carrier Phase Shifter EP1L/509, the output frequency is the same as the input frequency. This can be shown as follows:

$$f_a = f_i/16$$

$$f_b = f_i - f_a$$
$$= \tfrac{15}{16} f_i$$

$$f_c = f_b/15$$
$$= f_i/16$$

$$f_d = f_b + f_c$$
$$= \tfrac{15}{16} f_i + \tfrac{1}{16} f_i$$
$$= f_i$$

$$f_e = f_d/16$$
$$= f_i/16$$

$$f_o = f_e + f_b$$
$$= \tfrac{1}{16} f_i + \tfrac{15}{16} f_i$$
$$= f_i$$

The phase shift is produced by changing the division ratio of the divide-by-15 counter to either divide-by-14 or divide-by-16.

The phase shift in the signal out of the divide-by-15 counter due to a miscount is given by substituting in equation (2):

$$a_c = 360°/15$$
$$= 24°$$

This phase shift is unaffected by the modulator and so the phase shift a_d is given by:

$$a_d = a_c = 24°$$

The phase shift is reduced in the following divide-by-16 counter to give:

$$a_e = 24°/16$$
$$= 1{\cdot}5°$$

which is also the phase shift produced in the output signal by one miscount in the divide-by-15 counter.

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