ELECTRONIC TIME BASE CORRECTION

Summary of Problems and Activities

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FOREWORD

The purpose of this report is to present a condensed survey on the subject of time base stabilization for wideband tape recorders. The causes of time base errors, the present state of the art, and the requirements for some specific applications are outlined. The problems involved in an electronic approach to the subject, and the programs now in progress in Ampex Professional Products Company are discussed.

I. Introduction:

A. General Problem:

In the process of recording an electrical signal on a storage medium such as magnetic tape, thermoplastic film, a record disc, or even an oscilloscope, a characteristic transformation of some of the qualities of the signal takes place. The time relationship between successive electrical events (pulses or frequency components, including their relative phase relations) is translated into the domain of space. In some cases, as in magnetic tape recording, signal amplitudes are translated into intensity variations. The process of retrieving the signal from the storage medium must be capable to truly reverse these transformations. With the exception of the oscilloscope, all the other methods depend on mechanically-moved parts at critical places in the system. Thus, the quality of performance of such a system, as well as the possibilities of improving present applications and extending them into still unknown areas, depends to an extremely high degree on the establishment of an exact translation from time to space, and vice versa.

B. Accuracy Requirements:

The electrical signal retrieved from the storage medium contains, besides distortions originating in the electronic parts of the system, the sum of the inaccuracies of both the time-space and space-time transformations occurring during record and playback process, respectively. This is the time base error with which we are concerned. The necessary or desirable degree of time base stability depends, of course, on the specific application under consideration. A few examples may be given here.

1. Monochrome Video Recording:

The FCC specification requires the timing of the horizontal sync pulses to vary less than 0.15% per second. This means that for an angular acceleration of the magnetic head drum (head hunting) occurring at a rate of 5 cps, the total time displacement of the record and playback process must be held within ± 1.5 usec. This tolerance varies proportionally with $1/f^2$, where f is the frequency of the timing error.

2. Direct Color Video Recording:

The stability specifications for a color video signal require the phase variations of the color bursts to be within ± 5°. This is equivalent to a timing stability of ± 4 nsec.* Because no tape recorder is capable of this degree of accuracy as yet, it is the purpose of our present color kit to circumvent this difficulty by means of special processing of the playback signal.

3. Digital Recording:

Here, the stability requirements depend on tape speed and pulse density. A typical example is: For a tape speed of 150 ips and a density of 600 bits per inch, the total interchannel time displacement error must be less than ± 5 usec. The error caused by tape speed variations only is specified to be approximately ± 0.5 usec. A goal for further development toward higher pulse densities will require a tape speed stability which keeps the displacements within ± 50 nsecs.

4. Channel Multiplexing:

If any information having a bandwidth of 10 Mc is to be split and recorded in two 5-Mc channels, the timing between both channels must be such that no serious phase discontinuity occurs in the cross-over region of the two channels. Preliminary considerations on this subject indicate that a sufficiently smooth transition in the recombining process may occur if both channels remain within one-tenth of the period of the cross-over frequency, relative to each other. In the example given above, a timing stability of ± 10 nsecs. would be required.

C. Causes of Time Base Errors:

The sources contributing to time base errors are so numerous that it seems to be almost impossible to set up a complete list. Three groups of such errors arising in the mechanical parts of the system can be distinguished: fixed errors, variable errors having specific frequency components, and random errors.

1. Fixed errors occur from differences in alignment of critical

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* nsec. (nanosecond) = 0.001 usec.

quadrature
Tape engagement

parts when a tape is recorded on one machine and reproduced on another machine, or from alignment errors between channels in multitrack machines. Factors contributing to such errors are the flatness of the precision plate, tape guide height, head azimuth, gap scatter in multichannel machines, and many others.

2. Variable errors arise mainly in the mechanical parts of the tape and head driving systems; i.e., hunting of the motors due to non-symmetrical motor fields, variations in the motor load, non-continuous action of the brakes, etc. All these factors give rise to more or less damped, or even undamped, oscillatory time displacements usually called "wow" and "flutter".

Dyn.
Tape skew

3. Random errors originate from irregular changes in head-to-tape speed and may be called tape jitter. Variations in tape friction and tape dimensions are probably the chief sources. Very little is known about this type of timing error.

Besides all the mechanical sources of time displacement, there are others in the electrical system. These errors can be fixed delays with uniform action on the entire signal (delay lines, flat-response filters), or frequency-dependent, thus affecting only certain components of the signal (resonant circuits including the electrical head circuit, pre- and de-emphasis networks, etc.). Finally, when processed through the whole record-playback system, the signal will contain some noise. To some degree, this noise will cause phase- or time-modulation of the signal and therefore give rise to random time errors.

D. Electromechanical Time Base Stabilization (State of the Art):

With respect to the requirements given in Paragraph B for certain applications, the question arises, "Where are we at this time when the problem of Electronic Time Base Correction (E.T.C.) is being attacked?" Two factors have contributed to achieve a degree of precision and perfection of the tape & head drive system so that further refinements seem to be impractical.

1. Tight production tolerances.
2. The elaborate application of the electromechanical servo loop.

Little information is available on the stability performance of our machines. Practically nothing is known about timing errors occurring during short time intervals, e.g., one line of video recording. This makes it necessary to develop a test system which will allow accurate measurements of these errors with respect to amplitude and rate of occurrence during different time intervals.

As differences between individual machines can be very significant, the figures given below should be taken as informative items rather than precise values.

1. VR-1000A, B, and C:

The long-time stability can be as poor as ± 20 usec. because of drifts in the motor drive frequency control circuits. Short-time variations in the order of ± 2 usec. are mainly due to head hunting and quadrature errors of the head drum. This last figure, as compared with that one given in Paragraph B1, indicates that these machines are just satisfactory for direct monochrome video recording.

2. VR-1100:

Specifications and actual performance at the present time are as follows:

a. Static error (mainly originated by tape stretch differences between record and playback): ± 0.25 usec.

b. Dynamic error (tape stretch variations from eccentricity of capstan, etc., frequency up to 10 cps): ± 0.1 usec.

c. Waterfall error (tape vibrations -- 500 to 1200 cps): ± 0.05 usec.

d. Drum hunting, at 2 cps: ± 30 usec.
(Drum hunting design goal:) (± 5 usec.)

3. Intersync System:

Long-time stability: ± 0.4 usec.
Short-time stability: ± 0.1 usec.

The figures given above do not include errors occurring from tape splices. In the VR-1100, if the splicing is made perpendicular to the edges of the tape, the picture disturbance (complete loss of proper timing) lasts for 1.8 seconds. Empirical observations on the VR-1000 have discovered time displacements of up to 0.5 msec.* The intersync system is capable of keeping time displacements due to splices within approximately 1 usec.

II. Methods of Approach:

It should be pointed out that Electronic Time Base Correction is conceived as an improvement or refinement, and not as a substitute for the electro-mechanical methods used at the present time. Therefore, it was necessary to gather the available information on the accuracy achieved with electro-mechanical methods and on the accuracy required or desired for some specific applications as outlined in the previous section. In attacking the problems of E.T.C., the following general considerations and the proper respective decisions should be made at the beginning:

A. Area of Applications:

The most desirable solution for E.T.C. would be a system which is applicable, with minor changes, to any type of recording system handling any type of intelligence (pulses, analog, amplitude or frequency modulated signals). For the time being, our programs are aimed toward applications on the four-headed machines (VR-1000A, B, C) and the one-headed machine (VR-1100). While two of these projects are designed for the processing of video signals, a third has a broader scope in evaluating methods of E.T.C. which are independent, as much as possible, of the type of the recorded signal.

B. Timing Reference:

Because of the complexity of the total timing error occurring in the record and playback process, it is indispensable to measure this error and use the result of this measurement for correction in an appropriate device. Therefore, the entire problem of E.T.C. is split into two main sections: the generation of the error signal, and the correction of the error. It seems that the former problem is much more difficult to solve. It would be very desirable to perform both the measurement and the correction instantaneously and continuously. General considerations with respect to the

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* By C. Newell

measurement of the time errors will be outlined here, while the correction system is discussed subsequently. There are not many approaches toward a measuring system (error signal generator), and they are outlined in the discussions of our current programs in Part III. A description of possible correction systems (delay devices) is given in Part IV.

The only way to measure the timing error in a record-reproduce system is to record signals or markers at equi-distant time intervals and to measure the time difference between the reproduced displaced signal and a standard. The standard can be either a separate, external source of markers (pulses, sine waves, etc.) for absolute correction or the long-time average of the reproduced signal yielding a relative correction. If the recorded intelligence contains sufficiently precise recurrent information (sync signals and/or color burst in video recording), it is entirely feasible to use this information for E.T.C. The E.T.C. system is then restricted to the recording of this special type of intelligence.

To make the time measurement as rapid and continuous as possible, the marker frequency should be high; but this postulate on the other hand restricts the range of time which can be measured. This range can never be greater than the time between two successive markers.

For example, if the VR-1000A has a maximum time error of ± 2 usec., the marker frequency must be lower than 0.5 Mc. This requires the phase measurement to be accurate within 0.7° in order to keep a recorded color signal within 5° of its subcarrier. This accuracy demands a very high signal-to-noise ratio for the marker frequency, the exact ratio depending on the desired probability of being within the specified accuracy.

The following table shows, for a sine wave marker signal of any frequency, the probability for a specified phase error being exceeded by noise of a gaussian distribution (computed by H. Walsh):

	S/N in db			
Phase Error	10	20	30	40
0.5°	0.97	0.89	0.67	0.16
1.0°	0.93	0.78	0.40	0.005
3.0°	0.84	0.50	0.04	10^{-5}
5.0°	0.77	0.24	10^{-4}	$< 10^{-6}$
10.0°	0.48	0.01	$< 10^{-5}$	$< 10^{-7}$
15.0°	0.20	4.10^{-4}	$< 10^{-6}$	$< 10^{-8}$

Because of these considerations, a compromise is necessary. One method is to use two marker frequencies -- one sufficiently low to obtain the range of measurement, and the other high enough to have the accuracy.

Using the color burst for timing measurement has a severe disadvantage. It is present only during a small time interval at the beginning of each line scan of the video signal. This prevents the compensation of errors which accrue within the period of one video line.

C. Correction Systems:

After a suitable error signal is developed, it should be used to control the delay of a variable delay element. Increase or decrease of the delay time of the latter is made to be in the opposite direction to the error which is detected in the intelligence signal from tape. Several possibilities for such an automatically-controlled delay device are discussed in Part IV.

Two methods which are commonly used in any corrective system are applicable to introduce the correcting delay: the open-loop or tracking method, and the closed-loop method.

1. Open Loop:

The important advantage of this system is the possibility of introducing the correction at the very instant it should occur. Also, it is possible to cancel the error completely if the system is properly adjusted. Its disadvantage is the necessity of establishing a relationship between the actual error and its correction which is very linear and free of d-c drift. If a 1 usec. error is to be reduced to 4 nsec., the overall linearity and drift of the E.T.C. system must be within 0.4%. This figure clearly shows the necessity of doing the work with a machine which is already stabilized electro-mechanically to a high degree.

2. Closed Loop:

Advantages and shortcomings are exactly reversed with respect to the open loop. The linearity is of minor importance, but since the error signal is derived from the already-corrected intelligence, the correction can only be applied to the delay device after the relevant intelligence has passed through the device. Also, a small error always remains. To keep the remaining error and the elapsed time small, the gain of the correction system must be very high and its response very fast. Detailed evaluations show that it is not possible to construct a closed-loop E.T.C. system with satisfactory results. It might be feasible for the correction of very small errors left by an open-loop system.

III. Programs:

Three programs are now in progress at Ampex Professional Products Company.

A. AUTOTEC:

This system, also known as "picture straightener", was designed by Charles Coleman at CBS. He is now continuing this work at Ampex. This device will be incorporated into our video product line as an accessory.

The AUTOTEC unit takes the composite video signal from the demodulator output and delays it according to a control voltage derived from comparison of the time of occurrence of leading edges of horizontal sync pulses with the time of occurrence of pulses from a local oscillator in the unit. The local oscillator is synchronized on a long time basis to the horizontal sync pulses, but does not follow short-term variations in pulse repetition rate. The error signal obtained is fed into a delay line, the capacitance of which is made of voltage-variable semiconductor capacitors (Varicaps). The present unit uses 120 of these Varicaps.

The AUTOTEC unit corrects geometric distortions, such as those resulting from improper tip pressure, head quadrature misalignment, and small amounts of tape guide height misadjustment, in a video picture display up to ± 0.5 usec. The unit cannot correct distortions due to non-uniform tape stretch within one horizontal picture line because correction information is obtained only at horizontal sync pulse leading edges. Noise on the sync signal is the only limitation on the possible accuracy of operation. A signal-to-noise ratio of about 30 db will produce a generally acceptable result.

B. Video Engineering Project:

This project is carried by Ches Newell and his group. It is aimed at the direct recording of color video signals. It comprises a coarse regulation and a fine vernier system.

1. The coarse system uses a delay line matrix consisting of three registers. The first register has ten sections with 6.4 usec. delay each; the second register has eight sections with 0.8 usec. each; and the third register has eight sections with 0.1 usec. each. The off-tape frequency-modulated video signal is fed into the delay line matrix carrying a timing pulse related to leading edge of sync. All delay line sections are connected to coincidence gates to which search pulses from a local time reference are supplied. Coincidence will occur between search and off-tape pulses at one gate only in each register. This gate will pass the r-f signal, thus providing the proper delay within ± 0.1 usec.

2. The fine vernier system uses a voltage-controlled carrier phase modulation to introduce a variable time delay. The zero crossovers of the frequency-modulated video signal retrieved from tape trigger a sawtooth. The sawtooth is terminated by a control voltage proportional to the phase shift required. At the time of termination of the sawtooth, a new square wave is generated, thus providing a signal which is delayed an increment of time linearly proportional to the control voltage. The range of such a modulation is limited to one wavelength of the highest carrier frequency, or approximately 0.1 usec. By cascading several of these modulators, a larger range of delay may be realized.

To obtain a timing reference for the fine vernier system, a pilot frequency amplitude-modulates the frequency-modulated video carrier. The pilot frequency must be selected carefully, and the degree of amplitude modulation must be held low enough to keep interference signals, caused by cross-modulation in the non-linear record-playback process, at an unobjectionable level. A pilot frequency of 2.86 Mc was chosen, i.e., 4/5ths of the 3.58 Mc color subcarrier frequency.

C. Advanced Video Project:

1. The first part of this project is to develop a test system which allows us to accurately measure the timing errors of different machines in the present state of electro-mechanical stabilization, as well as the improvements accomplished by any one of the E.T.C. systems. This system will be capable of measuring the magnitude of the timing errors and their rate of occurrence during various time intervals.

   An unmodulated crystal-controlled frequency is recorded through the normal operational record amplifier. The crystal frequency being recorded is selected according to the desired range of measurement of time variations. A 3.58 Mc continuous wave was chosen for high accuracy, because it is readily available from the Color Frequency Standard which also furnishes fractions of that frequency for measurements over extended ranges.

   In playback, both the off-tape and the standard signals are limited and converted into square waves. The difference between the square waves contains the timing error in a pulse-width modulated form. A low-pass filter, 0-500 kc, then converts it into an analog error signal which can be evaluated on an oscilloscope and/or a spectrum analyzer.

2. The second part of this project is concerned with the generation of a timing error signal which is independent of the type of intelligence recorded on tape and which should be applicable to the four-headed and the one-headed machines.

   Two approaches are being evaluated:

a. A pilot signal is added to the intelligence before recording. Pilot frequencies, which are located above the upper limit or below the lower end of the frequency band of the intelligence, will be evaluated. The off-tape signals are separated by filters. Cross-modulation is the main problem, and methods to counteract it will be investigated.

b. The most attractive solution would be to record the pilot on a separate track between the intelligence tracks. A twin-headed system for the evaluation of this method is being built.

3. Several possibilities exist for delay devices. The question of which delay device will eventually be used is left open because it is realized that the main burden of the problem is to develop a meaningful error signal, and the means used to develop the error signal may affect the desired characteristics of the delay device. However, development is planned on the Circle Delay Tube (as described in Para. E-2 of Part IV) if preliminary investigations indicate its feasibility.

IV. Delay Devices:

At the present time, our list of proposed electronically-variable delay devices has grown to fifteen items. The more important ones are mentioned below. According to the physical principles involved, the following groups can be distinguished:

A. Purely Electronic Devices:

This is C. Newell's method, as described in Para. III-B-2. It allows a high degree of linearity (less than 0.5%). The range is relatively small (0.1 usec.), but this is not necessarily a disadvantage because the unit is simple and can easily be cascaded. As discussed earlier, a separate coarse regulation will be necessary in most cases. The system is applicable only for signals of constant amplitude and limited bandwidth (an f.m. carrier).

B. Electron Beam Transition Time Delay:

These devices need electron beam tubes of considerable length. They have inherent non-linearity, focusing and surface charge problems. The output signal is very low and depends on the amount of delay. The achievable change in delay is relatively small. Two methods are possible (both proposed by Phil Smaller and Ches Newell):

1. Beam Length Modulation: The path of the beam between the gun and the collector is deflected to a helix, the pitch of which is varied according to the error signal.

2. Beam Velocity Modulation: Reference is made to the Research Report, "Continuously Variable Signal Delay using Electronic Transit Time Device", by Philip Smaller, January 1958, Ampex Document Center Accession No. A8 #8. A delay change of 0.25 usec. was obtained in a tube with 100-cm path length.

C. Switched Delay Lines (or Delay Line Sections):

This is not a continuously-variable delay device but, theoretically, the single sections can be made as small as desired. Such a device would have a high degree of linearity. For larger delays, the passband (or frequency response) becomes a serious problem. Any such device is subject to switching transients which must either be made to occur at an instant where they do not affect the signal too much or be made so fast that their spectrum is outside the passband of the signal. This group comprises six items differing in the techniques of switching. The switching process can be done by beam switching tubes (either tapping or short-circuiting delay line sections), by a cathode ray switching device, by a diode gate, or by a coincidence gate.

D. Continuously Variable Delay Lines:

1. Allen Delay Tube:

A prototype of this tube is now available for evaluation. A delay line inside a cathode ray tube is scanned by an electron beam in a very acute angle, thus tapping the line according to the beam position (deflection). The prototype produces delay variations up to 0.3 usec. The performance of the tube is now being evaluated. The linearity is very poor; exact values are not known, as yet. Further development, using a different layout of the tube, might bring about a linearity of approximately one per cent (according to Steve Allen).

2. Varicap Delay Lines:

Reference is made to Para. III-A. A similar delay line is being developed by Paul Drapkin in Ampex Data Products Company. This type of delay line is also subject to a large inherent non-linearity because the delay is proportional to the square root of the capacitance which, in turn, is approximately proportional to the square root of the applied voltage. Also, the characteristic impedance varies with the change of capacitance (or delay), and it is difficult to terminate the line properly.

3. Lossy Delay Line:

C. Newell suggested building a Varicap delay line with a large insertion loss to reduce reflections occurring from the varying terminating conditions caused by the error signal.

4. Magnetically-Controlled Delay Line:

General Electric produces a delay line which is variable by means of a magnetic or electromagnetic field. The specified linearity is 5%; modulation frequency can be up to 100 kc.

E. Storage and Reading Devices:

1. Capacitor Storage:

A possible way to produce a variable signal delay is to sample the signal and store the samples on a series of capacitors. While the sampling rate is constant, the readout discharge of the capacitors is done by pulses derived from the error signal at a variable rate, or vice versa.

2. Electron Beam Storage:

If the intensity of an electron beam is modulated by the signal which is to be delayed, a correspondent charge pattern can be deposited on a suitable surface at a constant rate. This can be read out by another electron beam at a variable rate defined by the error signal. In order to make this a continuous process, the writing and reading should be done on a circle trace produced by a deflecting signal, which consists of two 90° out-of-phase sine waves derived from the standard frequency for one of the two electron beams, and from the off-tape pilot for the other beam. This pilot contains the timing error already in a phase-modulated form, and needs no further processing except perhaps a frequency division. In order to alleviate the tracking problem between the write-in and read-out circle traces, at least one trace (or better, both of them) should be defocused in a radial direction. For a resolution of 1000 lines on the screen (target) and a desired accuracy of 2 nsec., a range of approximately 2 usec. delay change will be available in one unit. Therefore, no separate coarse regulation would be necessary in many applications. The linearity between timing error and delay should depend only on the degree of harmonic distortion of the deflecting waveform.

There are many different types of storage tubes available which should be investigated in this respect. A major problem is to have an erasing process which is continuous, fast, and complete enough to ensure a good signal-to-noise ratio. A practical solution might be to write with a normal cathode ray gun on the target of an image-orthicon, the image section of which has been removed.

F. Semiconductor Dynamic Delay:

For completeness, reference is made to L. P. Hunter's "Handbook of Semiconductor Electronics", pages 15-50, where it is shown that the minority-carrier storage effect can be used to construct a delay device. The realizable amount of delay would be small and an appreciable restriction of signal bandwidth (due to carrier diffusion) would result. However, the unit would be small in size.