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GUIDE TO
SYNCHRONIZATION OF VIDEO SYSTEMS
TO
IRIG TIMING

Prepared by
OPTICAL SYSTEMS GROUP

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Guide to Synchronization of Video Systems to
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This document addresses a broad field of video synchronization to IRIG timing with emphasis on color synchronization. This document deals with fundamental synchronization principles, numerical relationships, and the basis of implementation techniques. Chapters are devoted to synchronization principles, RS-170 monochrome, NTSC color methods, high-speed monochrome and high-speed color synchronization.

Synchronization principles, IRIG timing, color synchronization

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CHAPTER 1

INTRODUCTION

1.1 Background. The synchronization of monochrome Electronic Industries Association (EIA) RS-170 standard video to the interrange instrumentation Group (IRIG) timing has been used on DOD test ranges for more than a decade now. The fundamentals of this subject were presented in a previous Range Commanders Council, Optical Systems Group (RRC/OSG) technical report published in the 70TH OSG Meeting minutes in February 1983. The National Television Systems Committee (NTSC) color synchronization to IRIG timing was discussed very briefly in this report. As shown in the above referenced technical report, RS-170 monochrome video synchronizes very well to IRIG timing with a repetition period of 0.05 seconds between IRIG timing and video fields. The desirability of synchronizing color video to IRIG timing is growing because color video is presently being used in a substantial number of range instrumentation systems and that number is increasing rapidly. However, the standard for NTSC color video has slightly different frequencies than the RS-170 monochrome video by 0.1 percent. Consequently, the NTSC color video frequencies are not very conducive to synchronizing with IRIG timing. The repetition period between NTSC color video and IRIG timing is necessarily long in comparison to the RS-170 monochrome video. The coincidence period between IRIG timing and NTSC color video is 1.001 seconds. A more thorough explanation can be found in chapter 5. The repetition period of 1.001 seconds gives rise to a coincidence sequence that does not repeat over a year period and has an annual step discontinuity.

1.2 Scope. This document addresses a broad field of video synchronization to IRIG timing with emphasis on color synchronization. The chapters of this document are devoted to synchronization principles, RS-170 monochrome synchronization, NTSC color synchronization, hybrid color synchronization, synchronization methods, high-speed monochrome synchronization, and high-speed color synchronization. In addition, this document deals with fundamental synchronization principles, numerical relationships, and the basis of implementation techniques. References to the sources of detailed performance information, engineering information, and the availability of the synchronization units known is given in appendix C.

1.3 Overview. Chapter 2 reviews the technical reasons for synchronizing video to IRIG timing on test ranges. Chapter 3 discusses the fundamental aspects of synchronization and then explains some key principles of monochrome and NTSC color video synchronization to IRIG timing. Chapter 4 presents the top level aspects of RS-170 monochrome synchronization to IRIG timing. Additionally, chapter 5 highlights the top level aspects of NTSC color video synchronization to IRIG timing and recommends an

approach, while chapter 6 includes four workable hybrid-color standards which synchronize to IRIG timing with the same 0.05 second coincidence period as RS-170 monochrome. In the first two methods, the line, field, and frame rate are the same as RS-170 monochrome; however, they necessarily have to compromise the NTSC color standard to achieve the improved synchronization characteristics. An undesirable consequence with any of these hybrid-color standards is that there are certain types of color video equipment that will not function properly. A table of equipment functionality, given in appendix C, is intended to help users make an informed judgement as to which approaches are best suited to their application. Chapter 7 deals with the most popular high-speed video formats commercially available, whereas chapter 8 gives a technical overview of how synchronization of video equipment is accomplished. Drawings of the structure and details of electronic signals that will synchronize video equipment are presented. Appendix A consists of more details of the numerical relationships involved in the generation of these waveforms. Appendix B contains a listing of the salient performance characteristics, block diagrams, and procurement and fabrication assistance available of IRIG to video synchronization units that have been developed by test ranges and industry.

CHAPTER 2

SYNCHRONIZATION

Before delving into the details of synchronization, a review is needed of the reasons for synchronizing video to IRIG timing. Video cameras are synchronized to IRIG timing in range instrumentation systems to achieve one or more of the following.

2.1 Simultaneous Video Image Exposure Times. Usually, a video-based instrumentation system images an event from many perspectives. Simultaneous exposures are almost always desirable from a data-reduction standpoint in terms of the ease, accuracy, and certainty of the interpretation of the three-dimensional event derived from two-dimensional images from various perspectives. Often the individual imaging instruments are spread over a wide geographic area, and IRIG timing is the only convenient reference for synchronization. In most situations, the exposure of the video cameras is shuttered or gated.

2.2 IRIG Coincident Exposures. Here the video exposures are coincident with simple exact (untruncated) IRIG time events, that is, the instant of zero phase decimal rates. Typical range instrumentation systems take data at one of the following decimal rates: 1, 5, 10, 20, 50, and 100 Hz. The time instant of the data points correspond to untruncated IRIG event times (zero phase). Examples of instruments that typically operate in this manner are radar and lidar, telemetry, and synchronized film cameras. Video equipment synchronized in this manner will, therefore, be coincident with data points from most other systems and, of course, other similarly synchronized video cameras. This form of synchronization simplifies data reduction and facilitates quick-look comparisons between video derived information and other systems. If video image exposures are coincident with simple exact IRIG time events, then the exposures will be simultaneous with one another. However, the converse is not necessarily true; that is, simultaneous exposures are not necessarily coincident with simple exact IRIG time events. There is a growing trend to have multiple video camera and lens systems on an optical-tracking mount such as a Kineto mount. For simplicity of video alpha-numeric annotation, data-in-video (DIV) insertion and ultimately, data reduction, it is necessary to synchronize the entire video system starting with the cameras. The preferred method is to synchronize cameras and other video sources to a master synchronizer which is itself synchronized to IRIG timing in a manner so as to achieve IRIG coincident exposures.

2.3 Time Staggered Video Exposures. In effect, this technique is a means to achieve a multiple of the standard video-image rate by using multiple standard video cameras. In this technique,

multiple cameras are synchronized in different phase to IRIG timing so that they expose images evenly interspersed in time to achieve a higher image-exposure rate. This technique has not been used frequently in the past, partly because of the lack of the necessary IRIG synchronizing equipment. The use of time-staggered video exposures is not expected to increase greatly in the future; however, its usefulness in particular applications and situations is important, and the availability of suitable IRIG to video synchronization equipment will increase the utilization.

2.4 Synchronization of Video Rasters. In video cameras, the image exposure occurs as part of a complex sequence of operations or events that are all synchronized to the camera's master (or raster) timing. To synchronize the exposure, the master timing of the camera has to be synchronized. To synchronize the camera master timing, a suitable set of video-synchronization waveforms must be fed into the camera. Hence, synchronization of a video camera requires generation of video-synchronization waveforms that are themselves synchronized to IRIG timing. See subparagraphs 3.6.4 and 3.6.5 for additional discussion on the synchronization between the camera-video raster and the video-image exposure. The basic nature of video camera synchronization requires that the synchronization waveforms be very precise and jitter free. If the synchronization phase accuracy is less than 0.2 microseconds and the jitter is less than 0.05 microseconds, an additional technique that is useful in some applications and situations becomes possible. Highly precise video to IRIG synchronization can be used to permit image splitting (raster multiplexing) and other special effects on the video signals from widely separated cameras. Video splitting or raster multiplexing is used most frequently in impact and fuse scoring video systems. It allows combining a portion of the camera's images from various perspectives into a single video signal. This combining reduces the required number of video recorders and facilitates a more rapid and error free analysis of the video images. For color video, time-base correctors will have to be used to achieve the level of synchronization required for splitting. However, IRIG synchronization of the video cameras in the field is still necessary to achieve simultaneous image exposure. It also allows the use of small, low-cost, time-base correctors.

2.5 IRIG Timing as Master. IRIG timing is desirable as the synchronizing source on DOD Test and Evaluation (T&E) ranges because it is widely available. In addition, it is the master timing system to which everything else is time-tagged and synchronized

CHAPTER 3

SYNCHRONIZATION PURPOSES

3.1 **Frequency and Phase Synchronization.** The word "synchronized" by itself is not entirely precise. A frequency or phase synchronization must be specified. Frequency synchronization can be achieved between two signals or systems by making them the exact same frequency (inverse of repetition period). In figure 3.1, frequency synchronization implies $P1$ equals $P2$, and the phase, shown as ϕ is constant but arbitrary.

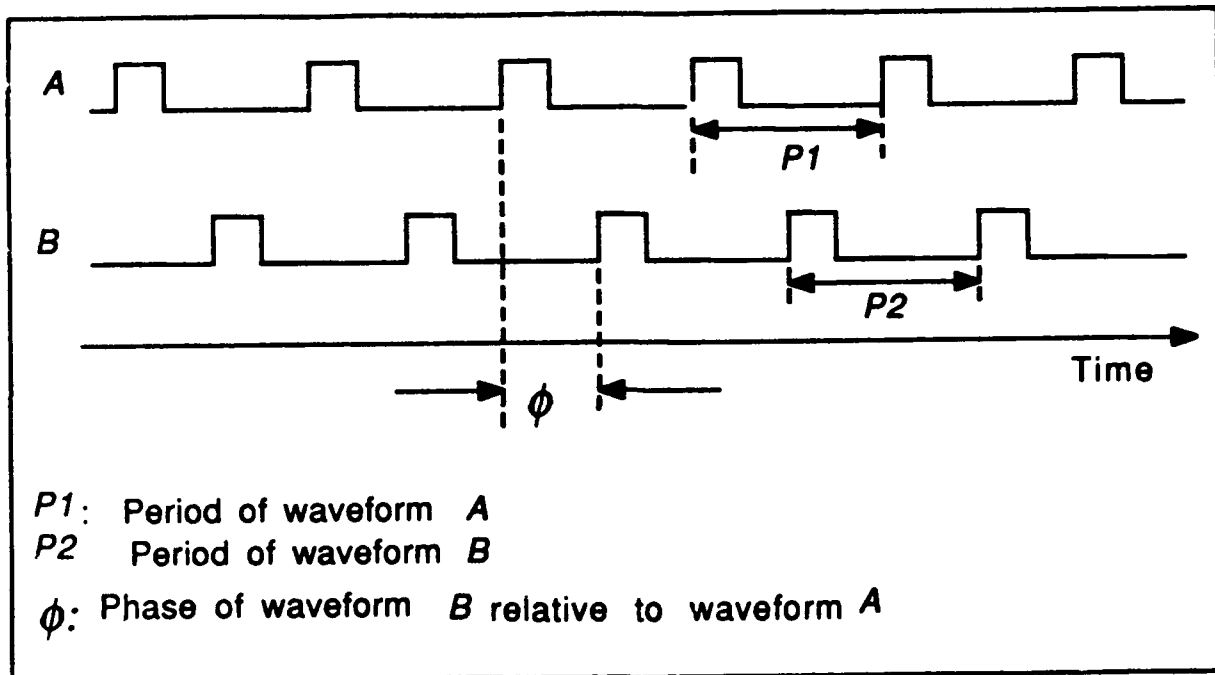


Figure 3-1. Simple synchronization.

The next level is phase synchronization (see figure 3-1). In phase synchronization, the phase is a specified constant (often zero). Phase synchronization necessarily includes frequency synchronization, but the reverse is not true. Phase synchronization of video and IRIG timing is necessary to meet each of the purposes listed in the subparagraphs of chapter 2. It will be shown that video and IRIG timing could be frequency synchronized, that is, synchronize line and subcarrier but not fields and frames. Because the video exposure time, which is of major concern, is tied to the video raster vertical interval, video field **phase** synchronization is imperative.

3.2 Simple Synchronization. Figure 3-1, depicts simple synchronization where the periods of the two signals in question are equal. The synchronization of video and IRIG timing is more complex. To understand video and IRIG timing synchronization, the concept of subrate synchronization is discussed next.

3.3 Subrate Synchronization. A more general type of synchronization can be achieved where an integer m times the period of one signal equals another integer n times the period of another signal. Subrate synchronization is shown in equation 3-1.

$$mP_1 = nP_2 \text{ where } m \text{ and } n \text{ are positive integers} \quad (3-1)$$

(1, 2, 3, 4...)

In rearranging equation (3-1),

$$P_1/P_2 = n/m \quad (3-2)$$

where n/m is expressed as the ratio of smallest integers for which the relationship is true. The ratio n/m (also written as n:m) is called the subrate repetition ratio (SRR). In figure 3-1, the SRR is 1:1, and the phase is offset by a fixed amount designated ϕ . Figure 3-2 shows an example where the SRR is 3:4, and the repetition points are offset by a fixed phase ϕ . Phase is defined, in subrate synchronization, at the subrate repetition points only. The time offset of the subperiods in between the repetition points does not define phase.

3.4 Video IRIG Timing Synchronization. Nomenclature convention for application of equation 3-1 to video and IRIG timing synchronization is shown in equation (3-3).

$$mP_V = n P_T \quad (3-3)$$

$$P_V/P_T = n/m$$

$$P_V = (n/m)P_T$$

where

P_V = Video period

P_T = IRIG time period

m = number of video periods

n = number of IRIG periods

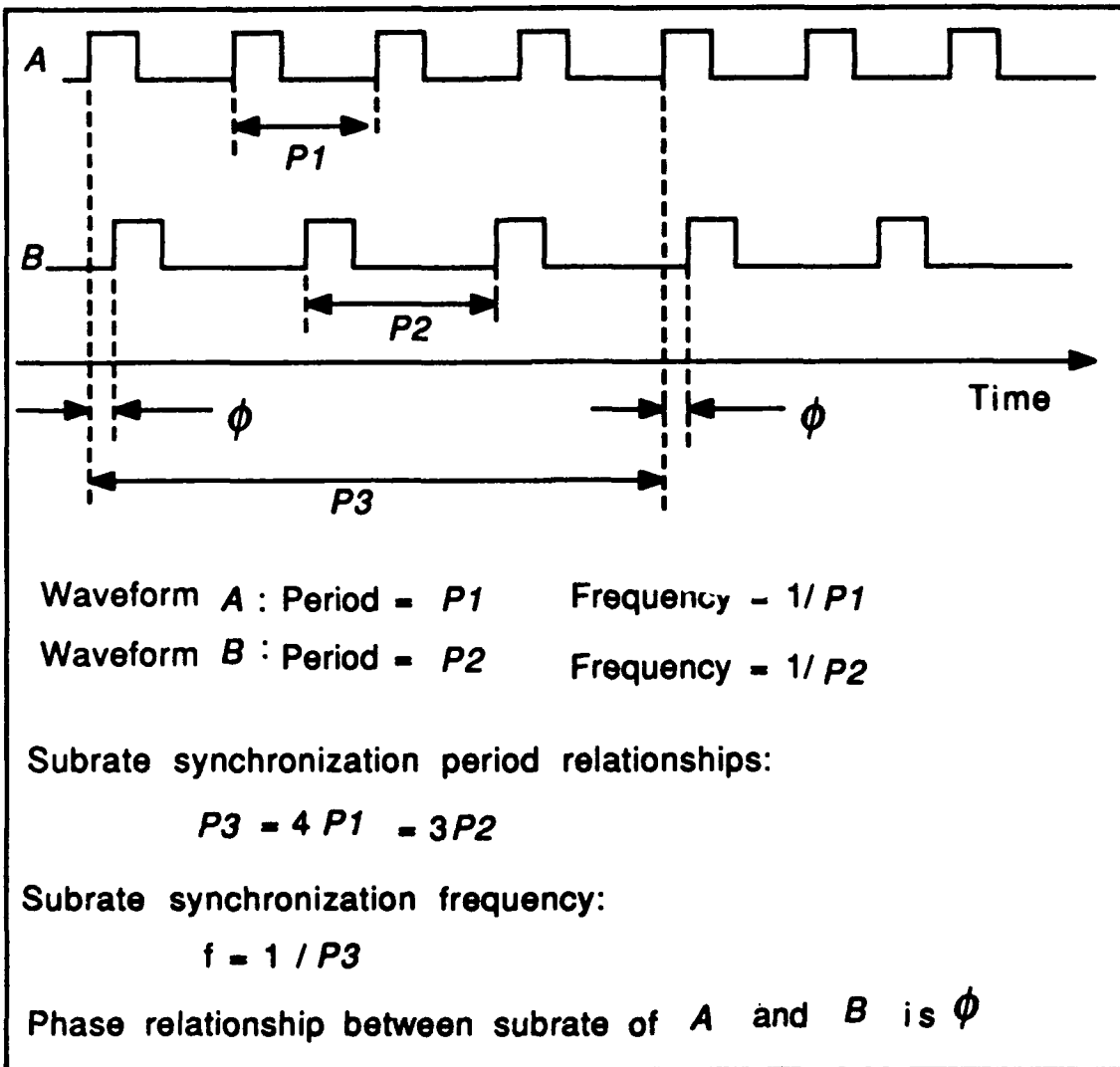


Figure 3-2. Subrate synchronization.

Notice that P_3 , the synchronization period, is longer than the period of either member of the synchronized waveforms, and thus the frequency of the synchronization is a subrate (simple fraction) when compared to either member.

3.5 General Video Synchronization to IRIG Timing.

3.5.1 The expression "IRIG Timing" has been used to refer to a family of decimal-based timing signals. Table 3-1 lists the IRIG formats found on T&E ranges that are most applicable to video synchronization.

TABLE 3-1. IRIG TIMING SIGNAL FREQUENCY CONTENTS

IRIG Format Name	Carrier Frequency	Bit Rate	Position ID Rate	Frame Rate
IRIG-B without carrier	N/A	100	10	1
IRIG-B with carrier	1,000	100	10	1
IRIG-A without carrier	N/A	1,000	100	10
IRIG-A with carrier	10,000	1,000	100	10
IRIG-G without carrier	N/A	10,000	1,000	100
IRIG-G with carrier	100,000	10,000	1,000	100
Rates and frequencies in Hertz				

3.5.2 From examining table 3-1 it is not obvious what periods are present in the IRIG timing formats. In this paper, an IRIG timing format is considered to contain

1. the period that is there simply and explicitly (the highest frequency),
2. the period that can be obtained by decoding the position identification markers and those periods with repeating coincident epochs that can be obtained from decoding the position identification markers and counting down the highest frequency,
3. the periods that can be obtained from decoding the time code and those periods with repeating coincident epochs that can be obtained from decoding the time code and counting down (dividing) the highest frequency, and
4. nonrepeating epochs formed by a multiple of n (shortest interval), for example, 1.001 second, which is (1001)(0.001 second). This particular period will appear again in chapter 5 on color video synchronization.

3.5.3 Subparagraph 3.5.2 can perhaps be better described by the following two examples. The frequencies considered to be contained in IRIG-B with carrier are 1000, 500, 250, 200, 100, 50, 25, 20, 10, 5, 2.5, 2, 1, 0.5, 0.25, 0.2, 0.1, ... to 1/year. The frequencies that are contained in IRIG-A without carrier are also 1000, 500, 250, 200, 100, 50, 25, 20, 10, 5, 2.5, 2, 1, 0.5, 0.25, 0.2, 0.1, ... to 1/year.

3.5.4 Other frequencies can be derived from IRIG timing formats by a more complex process that is usually called synthesis. The most practical form of synthesis for the frequencies involved in video is by Phased Locked Loop (PLL) (see subparagraph 3.6).

3.5.5 European Phase Alternating Line (PAL) and Sequential Couleur À Memorie (SECAM) (50 field per second and 25 frame per second) video systems synchronize to IRIG timing very well. The synchronization of 50/25 Hz video to IRIG timing may be considered simple synchronization because the 25 and 50 Hz rates are contained in IRIG timing. In other words, the epoch of every PAL and SECAM video field has a corresponding repeating IRIG-timing epoch. The synchronization of high-speed video at 200 fields/100 frames per second may also be considered simple synchronization.

3.5.6 Standard EIA RS-170 monochrome video synchronization to IRIG timing is necessarily a subrate synchronization, because IRIG timing is based on decimal periods as shown in figure 3-3. The RS-170 video timing is based on periods of 1/30 second or 1/60 second depending on whether video fields or frames are being considered. The subrate repetition frequency between IRIG timing and RS-170 video timing is 20 Hz when fields are considered and 10 Hz when frames are considered.

3.5.7 The NTSC/RS-170A color video is very much a subrate synchronization with large numbers in the SRR and with a very long subrate period. The subrate period is 0.5005 second when fields are considered and 1.001 seconds when frames are considered. More details are presented in chapter 5. Additional supporting concepts are first developed in paragraph 3.6 and chapter 4 before presenting color synchronization in chapter 5.

3.6 Phased Locked Loop Synchronization Techniques.

3.6.1 A PLL may be used to achieve three critical functions for video synchronization. First, a rational fractional multiplication of a given frequency as expressed in equation (3-4) can be produced.

$$f_{out} = (n/m) f_{in} \quad (3-4)$$

where n and m are integers.

For example, this capability allows the generation of a 60 Hz rate from a 100 or 1000 Hz rate. Second, a very high precision phase comparison and alignment can be performed, and third, the jitter (phase noise) associated with timing transmission can be substantially reduce. All of these features are employed in practical IRIG timing to video synchronizers. Figure 3-4 shows the block diagram of the basic PLL used for rate multiplication, phase alignment, and jitter reduction.

3.6.2 For video synchronization from a transmitted IRIG timing signal, the phase-comparison rate should be at least 100 Hz and preferably 1000 Hz or greater to achieve practical setting times

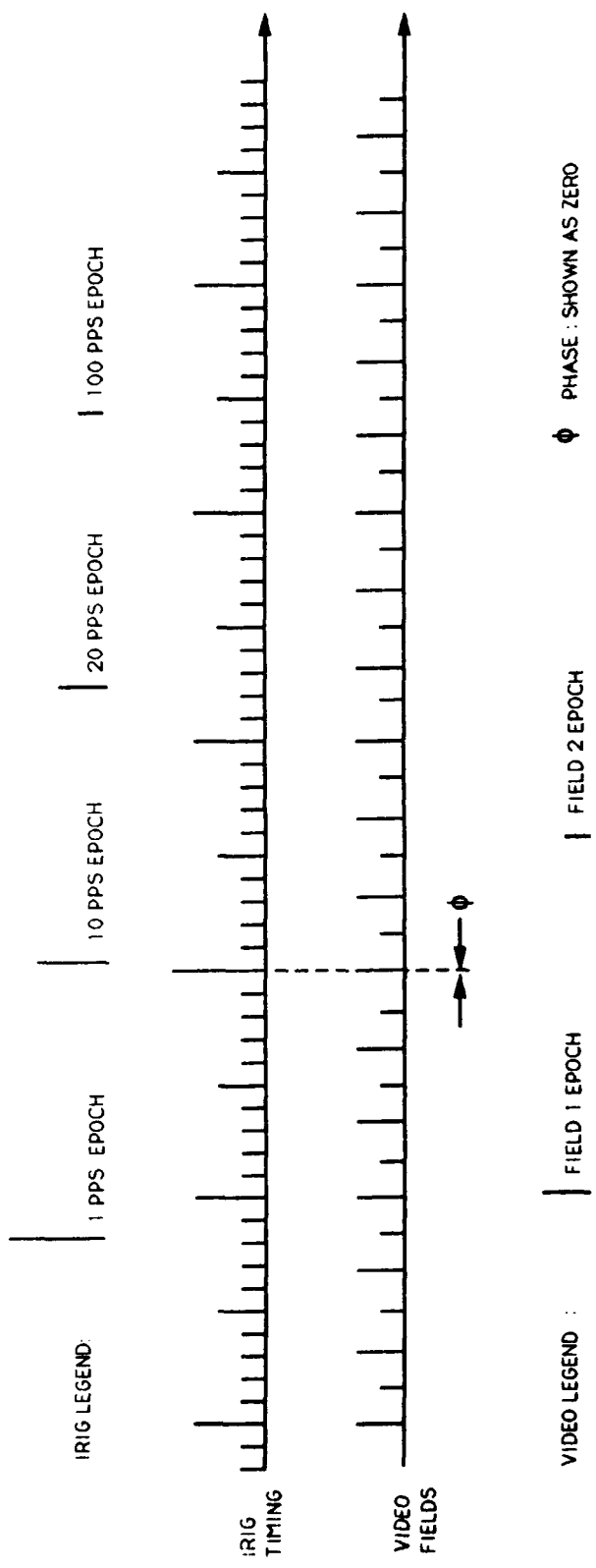


Figure 3-3. IRIG timing and video field synchronization.

with excellent jitter reduction. To achieve good jitter reduction, the PLL needs a highly stable local oscillator and a long time constant in the loop-control filter. Higher phase-comparison rates than those shown in figure 3-4 (60 Hz) can be attained with little additional effort. Phase comparison at a faster rate allows shorter system settling times, more accurate phase control, and better jitter reduction.

3.6.3 Figure 3-5 shows the basic video PLL system. The PLL generates the highly precise and stable basic-clock rates and controls the fine-scale (small-time period) aspects of phase synchronization. The large-scale aspects of the phase of the video-timing waveform are set (with offset if desired) at a slower rate by decoding the IRIG time code and loading the video-rate counters at predetermined epochs. For repeating epochs, decoding complexity is simple. For nonrepeating epochs, decoding is much more complex. Microprocessor implementation makes nonrepeating epochs much more practical. Nonrepeating IRIG phase setting epochs are required in true National Television System Committee (NTSC) RS-170A synchronization and will be explained in chapter 5.

3.6.4 To control or fix the absolute time of video camera exposures, it is generally necessary to generate both field and frame video raster timing because of the nature of video-camera synchronization. In the approach shown in figure 3-5, if the key frequencies are chosen correctly, an almost endless variety of video-synchronizing signals, including all of the commonly used synchronizing signals, may be produced by this type of system. For different types of synchronization, see individual chapters. Additional details are also given in appendix A.

3.6.5 Although the image exposure of a video camera is locked to its video-raster timing, there is no universal standard of the phase (time) relation between the image exposure and the video raster. The technology and the design of the image sensor determine this relationship. For entertainment purposes, this phase relationship is of no consequence; however, for instrumentation purposes, it is of great importance. The electro-mechanical video-shuttering system developed at the Naval Air Warfare Center, Weapons Division, China Lake, was designed so that the center of the exposure-time interval corresponds to the beginning of vertical synchronization pulse in the vertical interval of the video raster which is true at all exposure settings. The beginning of the vertical synchronization period is the usual characteristic of the video raster signal sensed or detected by video timing insertion devices and the time inserted into video or logged for a computer corresponds to this time. In almost all cases, the vertical synchronization period does not necessarily correspond to the video image exposure time. In the modern electronically shuttered, solid-state image sensors, the

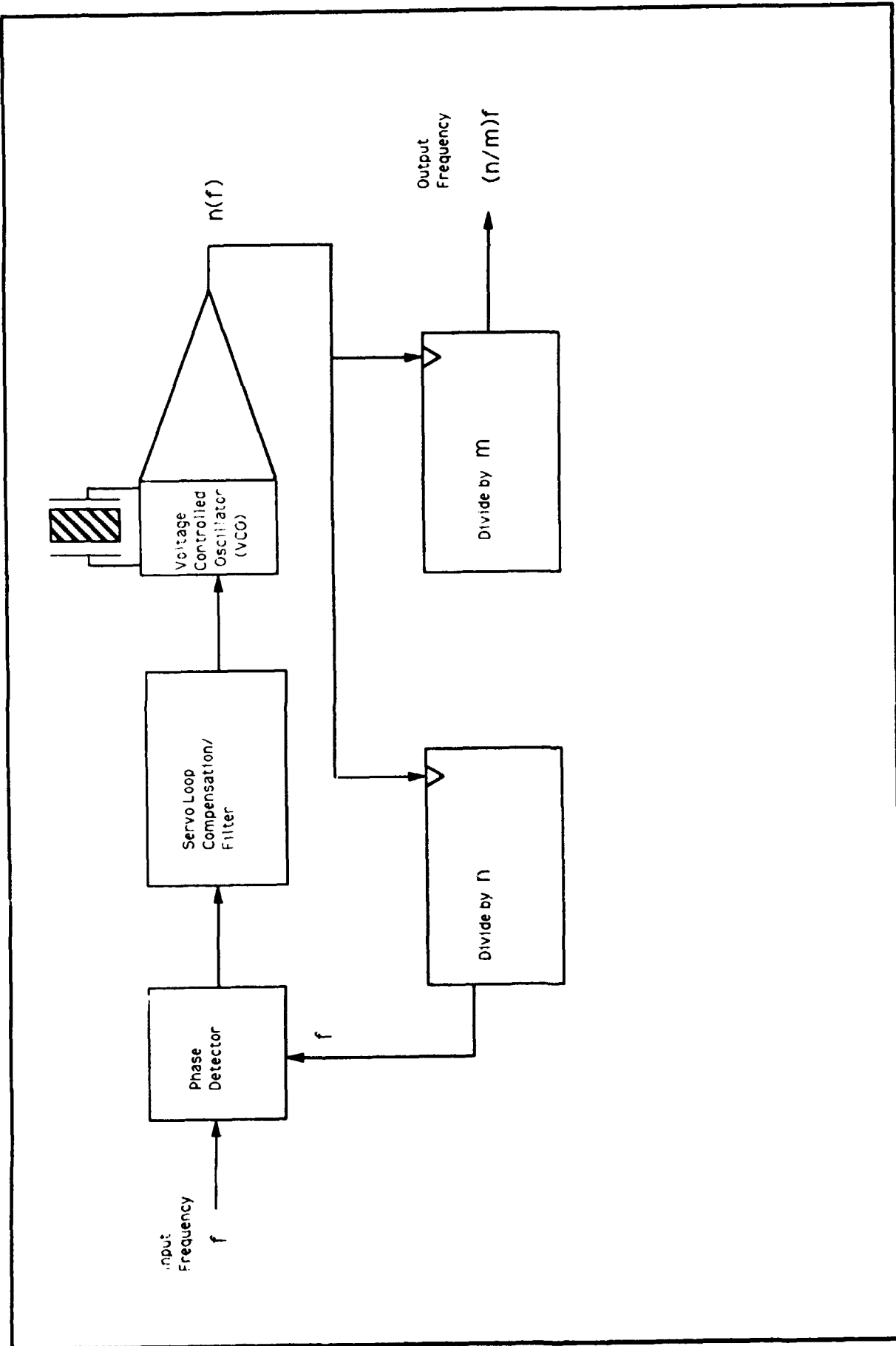


Figure 3-4. Frequency synthesizing phase locked loop.

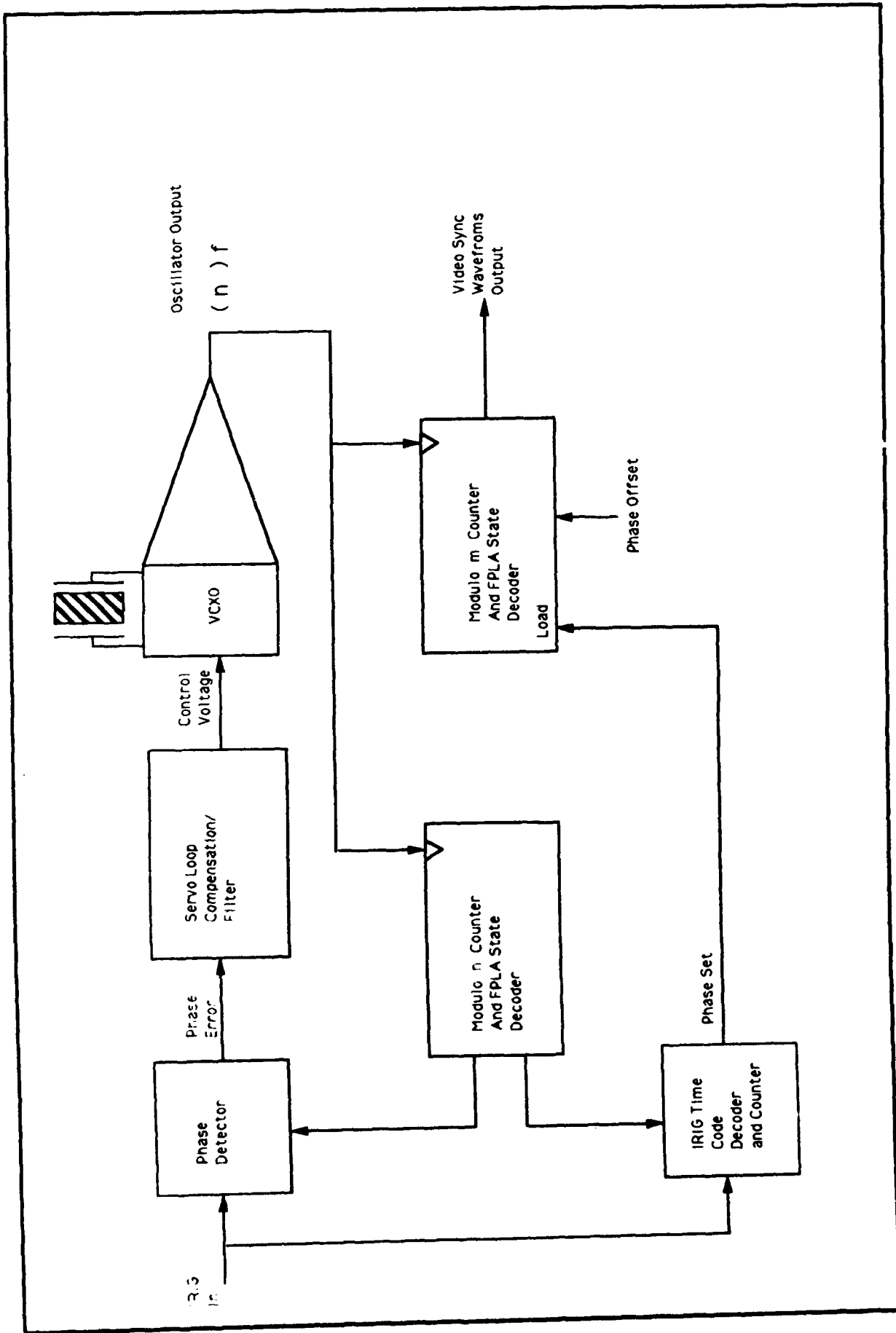


Figure 3-5. Basic video synchronization phase locked loop.

exposure usually takes place somewhere before the vertical interval. Additionally, the beginning of the exposure advances in time as the exposure gets longer, but the end of exposure is fixed in reference to the video raster. Hence, the center of the exposure time advances with respect to the video raster as the exposure gets longer. The user must understand and account for the timing characteristics of the camera chosen. Image intensifier gated exposures are very controllable, are generally very short, and are accurately known because of the exposure control mechanism.

3.6.6 As equation 3-4 indicates, PLLs are restricted to producing frequency multiples with exact numerical relationships. There is no round off or approximation. The numerical relationships are different for the various video formats. The following sections discuss the basis of the numerical relationships in some detail.

CHAPTER 4

RS-170 MONOCHROME VIDEO SYNCHRONIZATION TO IRIG TIMING

The fundamental synchronization characteristics will be derived for the basic video period associated with a distinct image (field/frame) and IRIG timing by using equation 4-1. For this discussion "IRIG timing" is restricted to those common IRIG time formats given in table 3.1. For the IRIG timing period, the following derivation will use the shortest period of the slowest IRIG format (IRIG-B without carrier). However, the relationships derived are invariant to the IRIG timing period used in the derivation, providing the period (inherent in IRIG) is equal to or shorter than (1/20) second. The RS-170 frame at 1/30 second will be used for video. Substituting these values into equation 4-1,

$$mP_v = n P_T \quad (4-1)$$

$$m(1/30) = n(1/100)$$

$$m/n = 30/100$$

The smallest integer values for m and n that satisfy this relationship are m = 3 and n = 10. Then the subrate period P is given by

$$P = 3(1/30) = 10(1/100) = 0.1$$

and the subrate frequency f is given by

$$f = 1/P = 10 \text{ Hz.}$$

When considering a video field as the basic image element which is common in shuttered video,

$$mP_v = n P_T$$

$$m(1/60) = n(1/100)$$

$$m/n = 60/100$$

The smallest integer values for m and n that satisfy this relationship are

$$m = 3 \quad \text{and} \quad n = 5. \quad \text{It then follows that}$$

$$P = 3(1/60) = 5(1/100) = 0.05$$

The subrate frequency is given by

$$f = 1/P = 20 \text{ Hz.}$$

These basic RS-170 video to IRIG-timing relationships are shown graphically in figure 4-1.

4.1 As discussed in subparagraph 3.6.2, it is desirable to have the phase comparison at 100 Hz or greater to synchronize video and IRIG timing. To accomplish synchronization, the higher frequencies in the video and timing waveforms must be matched, which can easily be done. The video-line rate is 15,750 Hz in direct synchronization of the video raster from IRIG timing. There are 262.5 lines per video field occurring at the rate of 60 Hz, and 525 lines per video frame occurring at the rate of 30 Hz. To derive these rates by counting and detecting states from a single oscillator source such as in a PLL, the basic frequency must be twice the line rate or 31,500 Hz. A frequency of 1000 Hz will be chosen for IRIG timing because it is more desirable than 100 Hz and available in all but the IRIG-B-without-carrier format. (IRIG-B without-carrier format is seldom available or used). Using equation 4-1,

$$mP_v = n P_T$$

$$m(1/31,500) = n(1/1000)$$

$$m/n = 31,500/1000$$

The smallest integers that satisfy this relationship are

$$m = 63 \text{ and } n = 2.$$

Figure 4-1 shows the block diagram of a PLL that will generate this relationship. The procedure is

1. multiply m times the IRIG rate (1000 Hz in the example) to get VCXO center frequency,
2. divide VCXO output by a counter placed in the feedback loop from VCXO to phase comparator,
3. divide VCXO by $2n$ to get video line rate, and
4. divide output of the first counter by $525n$ to get the video-field rate and divide by $1050n$ to get the video-frame rate.

The gross phase is set at the subrate frequency or some lower fraction of that rate. For RS-170 frames, this rule implies 10 Hz, 5 Hz, and 1 Hz for example. The modulo of the video waveform counter allows the system phase to be set at a rate

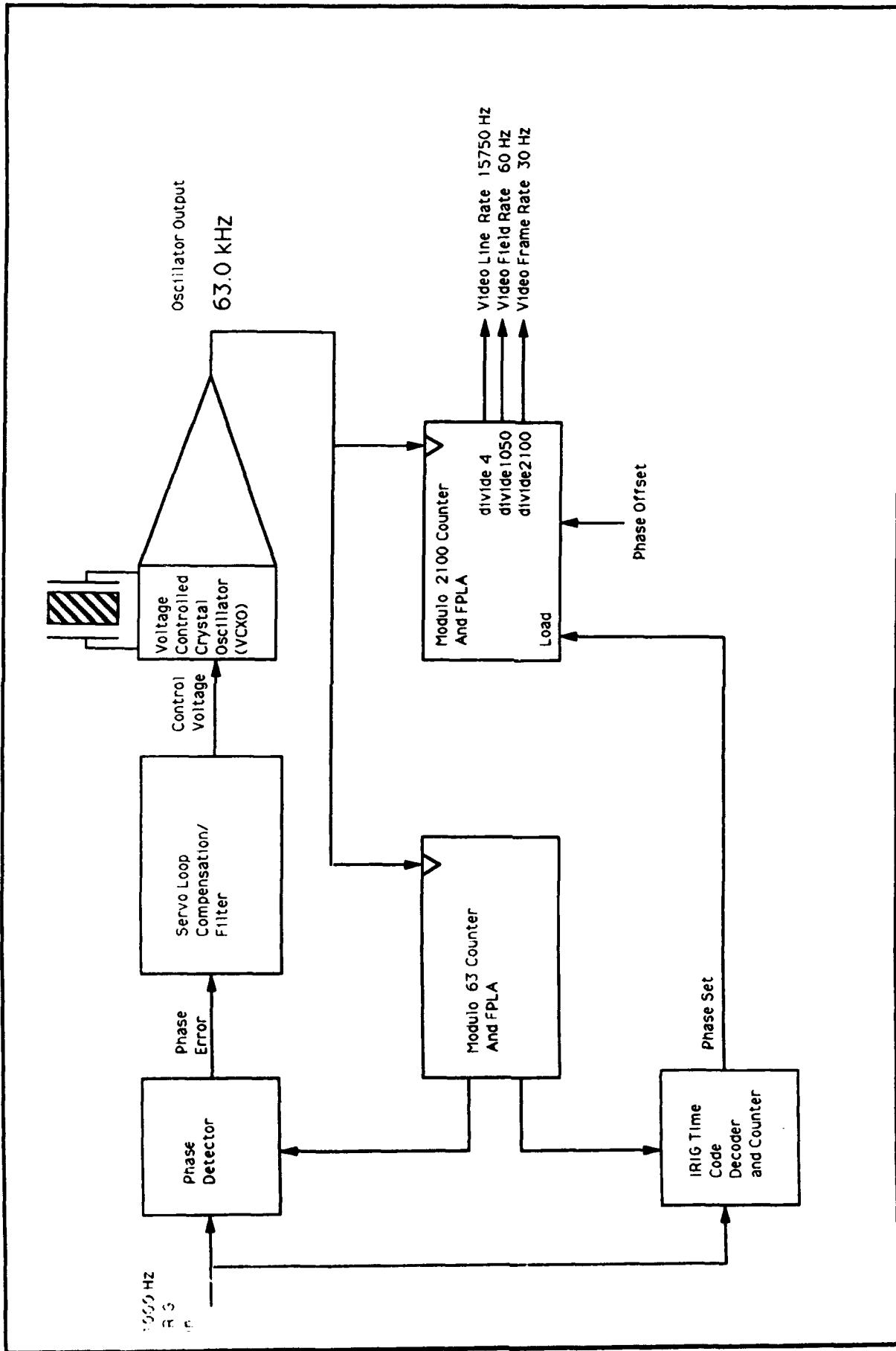


Figure 4-1. Basic RS-170 video synchronization locked loop.

lower than the repetition period; that is, phase set is not necessary each time through the loop. Phase can be set at epochs, which is an integer multiple of the modulo period. Counter modulo (roll over) will keep the system in phase synchronization. In other words, once synchronization is established, the load count and the toggle count will be the same.

4.2 Although these numerical relationships produce all the correct frequencies for video synchronization, they cannot produce acceptable video synchronization waveforms, because the period of the oscillator is too coarse. (See chapter 8 for details on waveforms). In addition, 63 kHz is too low a frequency for a conventional voltage-controlled crystal oscillator (VCXO). To directly produce a video synchronizing signal, the frequency of the oscillator needs to be higher.

To make the PLL work at a higher frequency, a multiplier k may be added to the basic relationship. The procedure is

1. multiply k_m times the IRIG rate (1000 Hz in the example) to get VCXO center frequency,
2. divide the VCXO output by K_m in a counter placed in the feedback loop from the VCXO to the phase comparator,
3. divide the VCXO output by $2 K_n$ to get the video line rate, and
4. divide the output of the VCXO by $525 K_n$ to get the video-field rate and divide by $1050 K_n$ to get the video-frame rate. $1050 K_n$ becomes the video counter modulo.

The gross phase may be set at the subrate synchronization frequency or some lower fraction of that rate. For RS-170 frames, this means 10 Hz, 5 Hz, or 1 Hz could be used. The modulo of the video waveform counter will allow the system phase to be set a rate lower than the repetition period.

4.3 For RS-170 video timing, $m = 63$ and $n = 2$ (see paragraph 4.1). There are many practical values for k that may be chosen for RS-170 synchronization. With the proper choice of k , complete RS-170 video synchronization waveforms as well as additional useful waveforms or features can be generated by counting and stating detection in a Field Programmable Logic Array (FPLA). When additional waveforms are required, the allowed choices for k diminish rapidly. The most common synchronization features desired are

1. RS-170 synchronization waveform generation
2. NTSC RS-170A synchronization waveform generation
3. CERS 170A/B synchronization waveform generation

5. A rate of four times the color subcarrier frequency for use of off-the-shelf integrated circuits to produce video functions
6. 200fps/100Fps high-speed video synchronization waveform generation
7. 180fps/90fps high-speed video and film camera synchronization waveform generation
8. 120fps/60fps high-speed video and film camera synchronization waveform generation
9. European PAL/SECAM synchronization waveform generation
10. RCC/OSG DIV Scan Line Encoding bit clock rate

4.4 Appendix A, Numerical Relations, explains how to find the lowest frequency to generate any desired set or list of output frequencies and lists some versatile frequencies. For instance, a VCXO frequency of 28.665 MHz ($k = 455$) will support items 1, 3, 4, 5, 6, 8, and 10 from the previous list. Figure 4.2 depicts a block diagram of a practical synchronizer, using 28.665 MHz, in which the phase frequency and fine scale are set by a PLL. The large scale of the phase is set by decoding the 1 pps IRIG epoch and loading the video generation counter/decoder with the desired offset value. This system block diagram described in paragraph 6.0 will show the generation of CERS-170A/B. Chapter 8 describes the details needed for generation of video synchronization waveforms by a PLL system and talks about using some other versatile frequencies, and lists the example sequence of an RS-170 video camera synchronized to IRIG timing.

Example sequence: Phase set at zero at 1 Hz rate

<u>DDD:HH:SS.DF</u>	<u>Event/Events</u>
XXX:XX:X0.0000	video exposure, raster phase set to beginning of field 1.
XXX:XX:X0.0166...	video exposure, beginning of field 2
XXX:XX:X0.0333...	video exposure, beginning of field 1
XXX:XX:X0.0500...	video exposure, beginning of field 2
XXX:XX:X0.0666...	video exposure, beginning of field 1
XXX:XX:X0.0833...	video exposure, beginning of field 2
XXX:XX:X0.1000...	video exposure, beginning of field 1
XXX:XX:X0.1166...	video exposure, beginning of field 2
XXX:XX:X0.1333...	video exposure, beginning of field 1
XXX:XX:X0.1500...	video exposure, beginning of field 2
. . . .	
. . . .	
. . . .	
XXX:XX:X0.9883	video exposure, beginning of field 2
XXX:XX:X1.0000	video exposure, raster phase set to beginning of field 1.
. . . .	
. . . .	
. . . .	

NOTES: DF stands for decimal fraction.
X indicates don't care or irrelevant.
... indicates a truncated number.

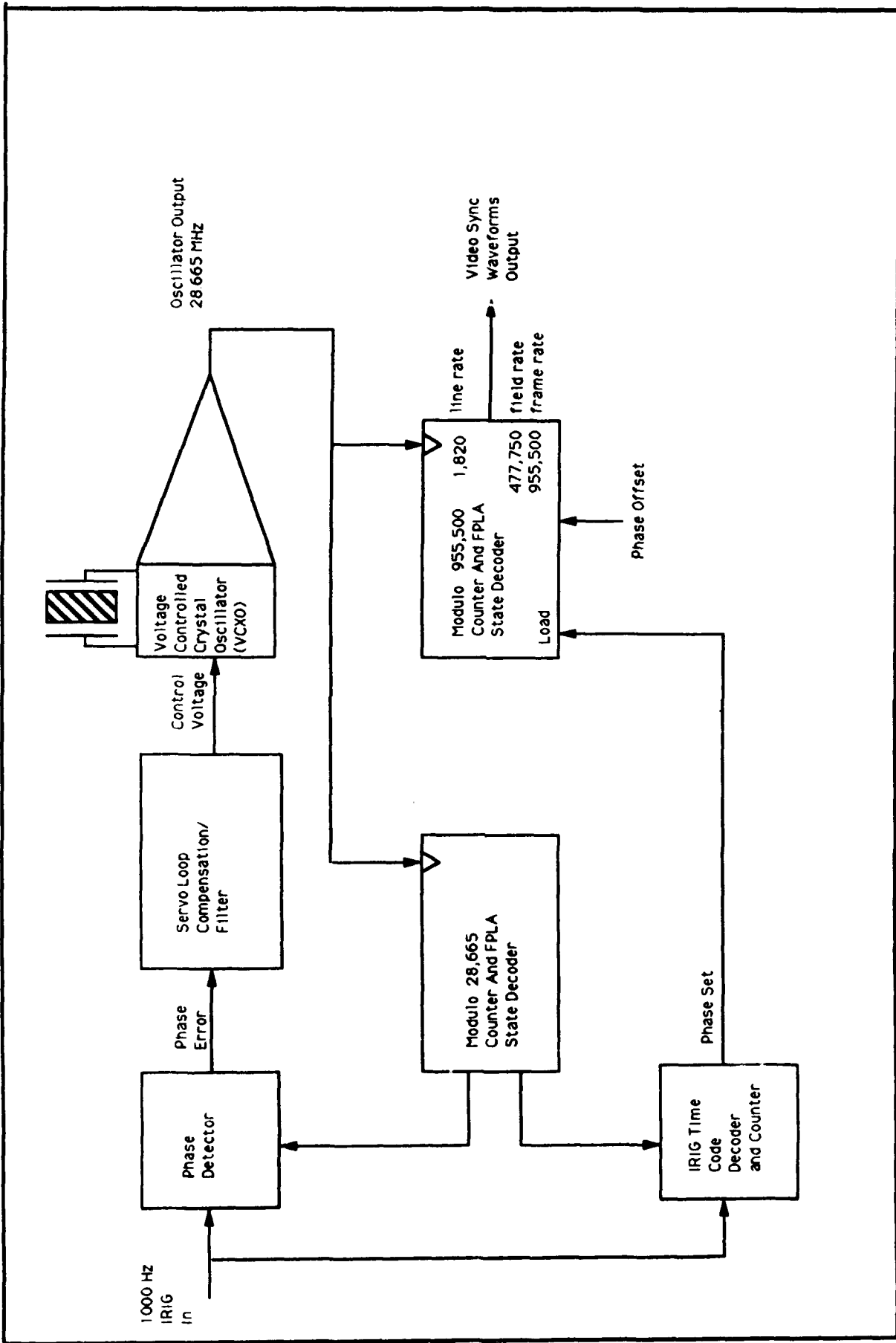


Figure 4-2. Practical RS-170 video synchronization phase locked loop.

CHAPTER 5

NTSC AND EIA RS-170A COLOR VIDEO SYNCHRONIZATION

The NTSC and RS-170A specifications require that there must be exactly 525 lines per video frame, 262.5 lines per video field, and two fields per frame. Further, the frequency ratio between the color subcarrier frequency and video-line rate must be exactly 227.5:1. The NTSC specifies the video line; field and frame rates are derived from the specified color subcarrier frequency (63/88)(5 MHz). This numerical relationship allows the NTSC rates to be derived from a standard 5 MHz atomic clock. The NTSC tolerance on the color subcarrier frequency is ± 10 Hz. When the foregoing rules are applied to the specified color subcarrier frequency to derive the line, field, and frame rate, it turns out that the exact values can only be expressed as rational numbers. Table 5-1 below lists the exact value and a decimal approximation for the NTSC parameters of interest for synchronization.

<u>NTSC Parameters</u>	<u>Exact</u>	<u>Decimal Approx</u>
Color Subcarrier Frequency	39,375,000/11	3579545.454545...
Video Line Rate	2,250,000/143	15,734.26573...
Video Field Rate	60,000/1001	59.94005994...
Video Frame Rate	30,000/1001	29.97002997...

5.1 Applying equation (4-1) to the field rate given in the above table

$$mP_v = n P_T \quad (4-1)$$

$$m(1001/30,000) = n(1/1000)$$

$$m/n = 30/1001$$

The smallest integer values for n and m that satisfy this expression are

$$m = 30$$

$$n = 1001$$

leading to a subrate frame repetition period of 1.001 seconds and

a subrate field repetition period of 0.5005 seconds.

True (exact) NTSC color video synchronization to IRIG timing, derived previously, has the following attributes.

1. The period of field coincidence $30(1001/60,000) = 0.5005$ seconds and the period of frame coincidence $(301001/30,000) = 1.001$ seconds are reasonably short. The 1.001 seconds period leads to nonrepeating epochs.
2. This method generates exact, fully compatible, NTSC values.
3. There are practical circuits for implementation. One circuit is commercially available.

5.2 The exact relationship of NTSC RS-170A rates to RS-170 rates is $RS-170 \text{ rates} = (1001/1000)(NTSC \text{ Rates})$.

5.3 As shown in appendix A, only members of the sequence: 4.5 MHz, 9.0 MHz, 13.5 MHz, 18.0 MHz, ... generated by $n(4.5)$ MHz (where $n = 1, 2, 3, 4, 5 \dots$) will give a VCO frequency capable of generating the 1000 Hz phase detector feedback frequency, the NTSC line rate, the NTSC field rate, and the NTSC frame rate. However, to generate the color subcarrier by direct synthesis, the 35th member of the sequence, 157.5 MHz, must be used. This high frequency makes implementation quite difficult. As explained in appendix A, there is an alternate approach to color subcarrier generation using a second PLL which is simpler to implement.

Figure 5-1 shows the block diagram of an NTSC/IRIG-timing synchronizer using PLL techniques. The diagram has a second PLL for subcarrier generation. Although the block diagram appears to be about the same complexity as the previous video synchronization PLLs, the decoding of the IRIG phase setting epochs is considerably more complicated. To set the video counter-phase, IRIG epochs based on a period of n (1.001 seconds), (where $n = 1, 2, 3, 4, \dots 100$) must be used. Values of n greater than 100 lead to undesirably long delays in start up or interrupt recovery. The period of 1.001 second (or its integer multiples) is not contained evenly in a minute, hour, day, or year, so a jump discontinuity will occur at the end of the repetition period chosen. To minimize jump discontinuities, the year period is chosen. The result is a phase jump between the very end of one year and the very beginning of the next. The phase of video raster is based on the first epoch being the first instant of the new year, following the sequence whose interval is n (1.001) seconds, making it is necessary to decode the full IRIG time code and count the 1000 Hz rate. An example sequence of IRIG-NTSC video phase setting epochs with a period of 10.01 seconds is given in table 5-2.

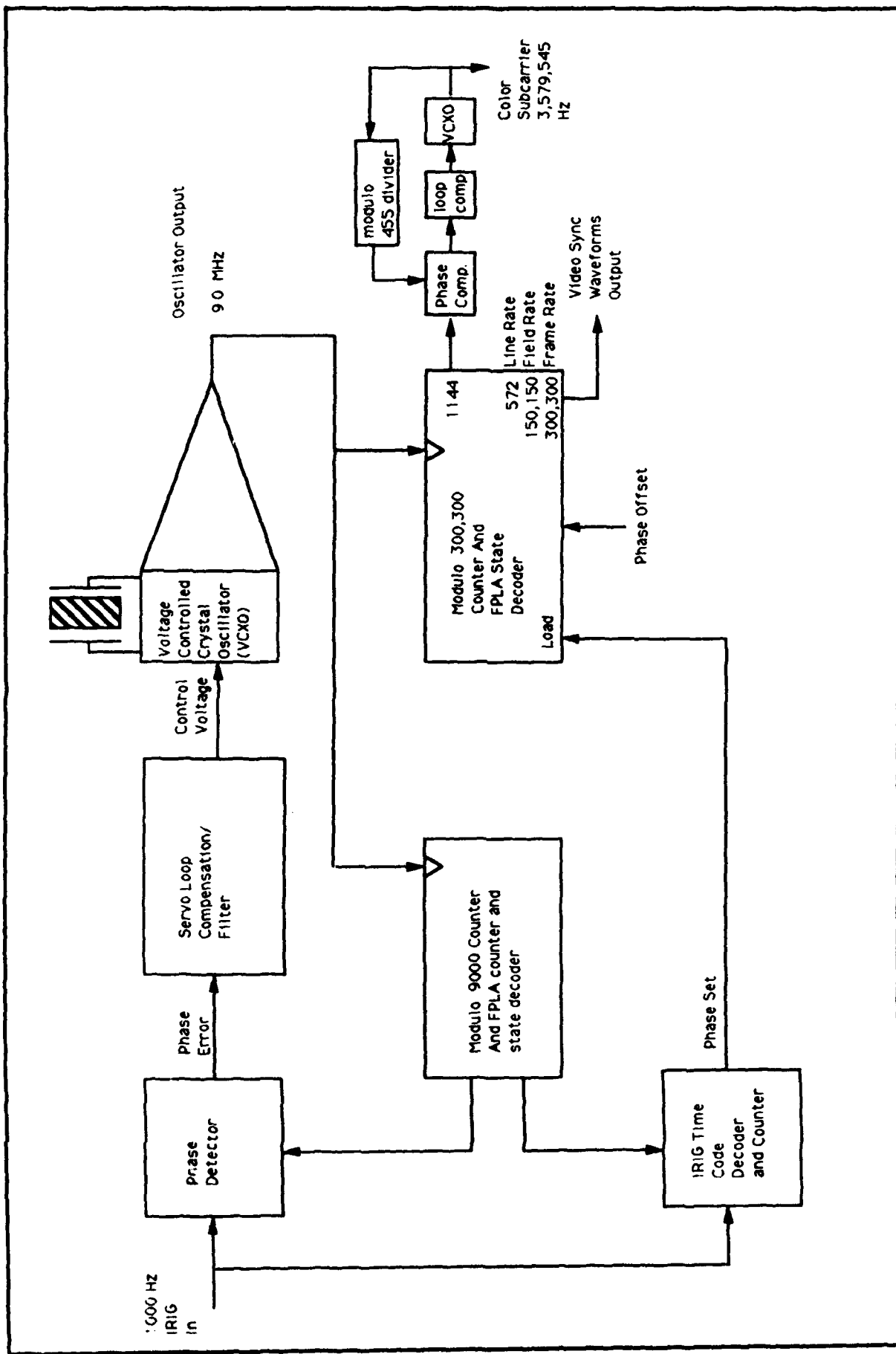


Figure 5-1. NTSC/RS-170A video synchronization phase locked loop.

TABLE 5-2. EXAMPLE PHASE SETTING EPOCHS IN IRIG-NTSC SYNCHRONIZATION

<u>Field Number</u>	<u>DDD:HH:MM:SS.DF</u>
1	000:00:00:00.000
600	000:00:00:10.010
1,200	000:00:00:20.020
1,800	000:00:00:30.030

3,600	000:00:01:00.060
4,200	000:00:01:10.070
4,800	000:00:01:20.080
5,400	000:00:01:30.090
6,000	000:00:01:40.100
6,600	000:00:01:50.110
7,200	000:00:02:00.120

214,400	000:00:59:53.590
216,000	000:01:00:03.600

5,178,600	000:23:59:56.310
5,179,200	001:00:00:06.320

10,357,200	002:23:59:52.620
10,357,800	003:00:00:02.630

1,890,269,400	365:23:59:54.490

1,890,269,730	365:23:59:59.9955
1	000:00:00:00.000

Note: DF = decimal fraction
 The Phase Set Period is 10.01 seconds in this example.

Table 5-3 7is an example sequence of IRIG-timing synchronized NTSC video and shows that there are no repeating coincidence epochs in IRIG-timing synchronized NTSC video. Appendix A describes several VCO frequencies that can be chosen to generate NTSC and additional timing-rate features.

TABLE 5-3. EXAMPLE EXPOSURE TIME SEQUENCE FOR IRIG-NTSC

<u>Field Number</u>	<u>DDD:HH:MM:SS.DF</u>
1	000:00:00:00.0000
2	000:00:00:00.01668....
3	000:00:00:00.03336...
4	000:00:00:00.06673...

30	000:00:00:00.5005

59	000:00:00:00.98431....
60	000:00:00:01.00100
61	000:00:00:01.01768...

90	000:00:00:01.5015

119	000:00:00:01.98531...
120	000:00:00:02.00200
121	000:00:00:02.01868...

3,596	000:00:00:59.99326..
3,597	000:00:01:00.00995
3,598	000:00:01:00.02663...

215,784	000:00:59:59.964...
215,785	000:01:00:00.01308...
215,786	000:01:00:00.02976..

1,890,269,730	365:23:59:59.9955...
1	000:00:00:00.0000

Notes: DF = decimal fraction
 ... implies truncation phase offset = 02

CHAPTER 6

HYBRID COLOR SYNCHRONIZATION

One aspect of NTSC synchronization not suitable for T&E range application is that NTSC-synchronized video cameras may be all synchronized together but not to anything else such as telemetry or radar. One solution is to modify the NTSC-color standard so that it synchronizes better with the rest of the range systems. A straightforward approach is to use the RS-170 monochrome-video line, field, and frame timing, because it synchronizes well to IRIG timing. Four methods are outlined in paragraphs 6.1, 6.2, 6.3, and 6.4. The first two approaches are closely based on the RS-170 standard and are designated CERS-170A and CERS-170B for color extended RS-170A and RS-170B. Both methods use the RS-170 video line, field, and frame rate which is compatible with all standard video equipment. However, some aspect of the color subcarrier specification has to be violated or not complied with, because the NTSC specification demands that the color subcarrier rate be 227.5 times the video line rate and that it be 3,579,545.4545 Hz ± 10 Hz. Satisfying both of these conditions while running at the RS-170 video line rate of 15,750 is not possible. Consequently, the color modulation of the video signal is out of the NTSC specification and may not be compatible with some equipment.

6.1 The synchronized-color subcarrier CERS-170A is made equal to 227.5 times the video line rate, which produces a color subcarrier frequency of 3,583,125 Hz.

6.2 The color subcarrier CERS-170B is set to 3,579,545.4545 Hz. The color subcarrier is not exactly 227.5 times the video line rate and is not synchronized to the line rate. Figure 6-1 shows a system that generates both CERS-170A and CERS-170B.

6.3 The Truncated Raster Synchronization method uses

- RS-170A/NTSC line rate (15734.265....)
- RS-170A/NTSC color subcarrier (3,579,545.4545 Hz)
- RS-170 field and frame rates (60/30)
- 262.2378 lines per field (one line truncated). (Standard is 262.5 lines per field.)
- 524.4755 lines per frame (two lines truncated, one in each field). (Standard is 525 lines per frame.)

6.3.1 Truncated raster synchronization uses step jumps of the video-line period somewhere in the vertical-retrace period. During this time, the video signal is not forming any part of the image on a display monitor, and a step jump in the video-line period is compatible with some display monitors as well as other

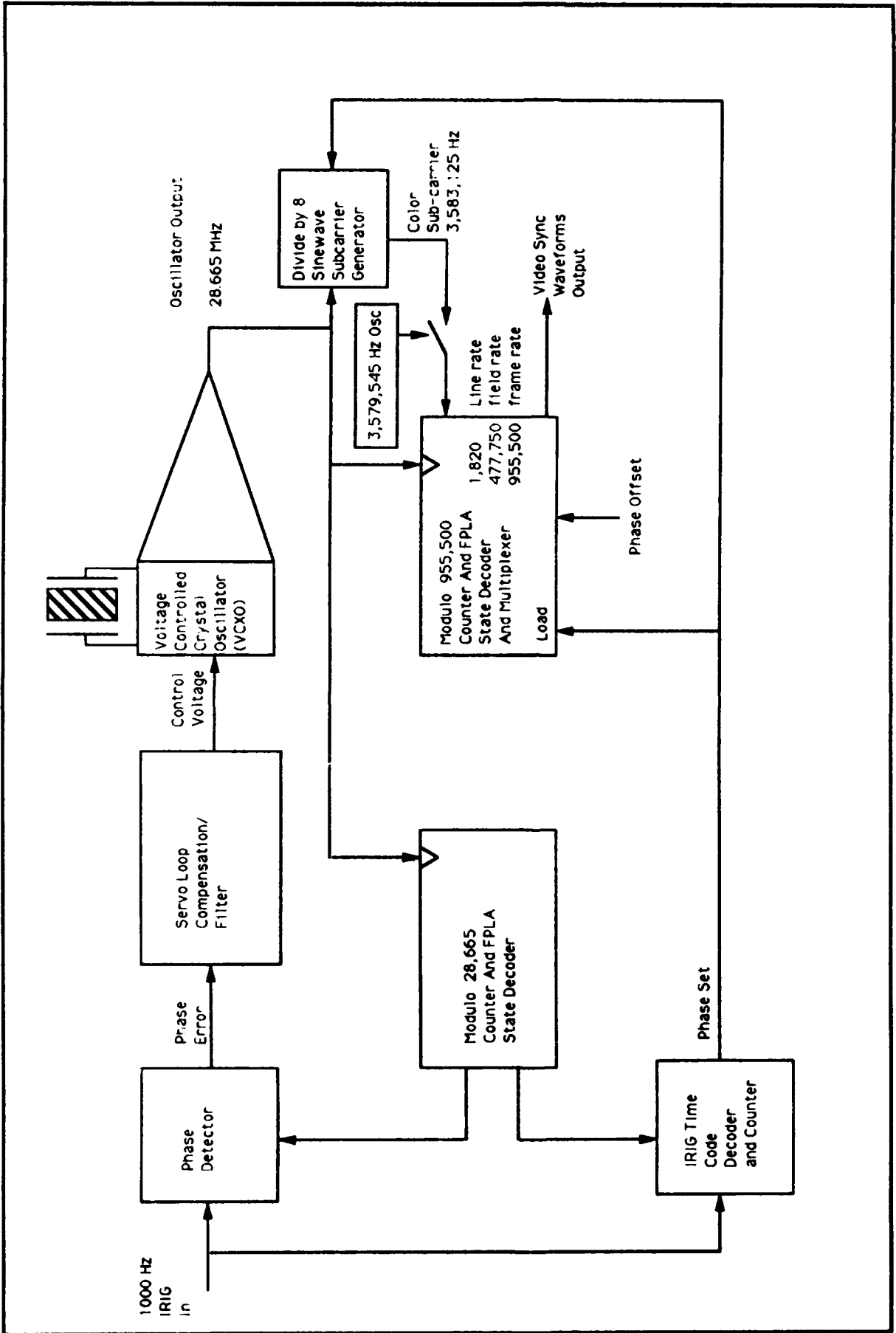


Figure 6-1. CERS-170A/B video synchronization phase locked loop.

video equipment. The step jump is 16.667 microseconds and may occur in one video line or be spread out over several video lines.

6.3.2 Chapter 8 gives the fundamental aspects of generating truncated raster RS-170A (TRRS-170A) video synchronization signals. An IRIG synchronized TRRS-170A generator prototype unit has been built at Naval Air Warfare Center, Weapons Division, (NAWC-WPNS) China Lake (formerly Naval Weapons Center). (See appendix C for results). Although the sample size of the video equipment tested is rather small, it does not appear that TRRS-170A is widely compatible with standard color video equipment.

6.4 Truncated frame RS-170A (TFRS-170A) synchronization method uses the standard NTSC/RS-170A line rate and color subcarrier frequency but uses a step jump in the number of video lines in some video frames to achieve an average rate of 60 fields/30 frames per second. To achieve an average rate of 60 fields/30 frames with the standard NTSC line rates, exactly one video line is truncated (omitted) out of approximately every other video frame. Truncating a video line may seem like a severe step; however, most video equipment have a large tolerance in the field/frame rate timing. This field/frame rate timing also appears to be the only place there is enough tolerance in NTSC equipment to allow it to function at 60 fields/30 frames per second without modification. The TFRS-170A IRIG synchronization also has the character of approximately 50 microseconds of dither in the video exposure time, which is not a problem for most applications.

6.4.1 Several commercially available color video cameras generate a form of truncated raster synchronization when given IRIG synchronized RS-170 monochrome synchronization signals. Examples are Sony DXC M-7 camera, Panasonic 300CLE, and NEC NC-120. When synchronization is accomplished in this manner, the video-signal output from the camera does not conform to the RS-170A vertical interval waveform standard; however, all video monitors and video recorders tested accepted the nonstandard signal. On the other hand, the nature of the waveform distortion is such that most video geometric position reading systems will experience one vertical count (line) of dither in the vertical measurement.

6.4.2 An IRIG Synchronized TFRS-170A generator prototype unit has been built at NAWC-WPNS, China Lake and tested with color video equipment (see appendix C) for results. Although the sample size of the video equipment tested is rather small, it does appear that TFRS-170A is widely compatible with standard color video equipment. It is believed that most video geometric position reading systems will not experience one video-line count dither in the vertical measurement.

6.4.3 The approach in constructing a TFRS-170A synchronizer used a comparison of the phase of the second field between an IRIG synchronized monochrome system and an RS-170A (NTSC) system. A check is made on the last line of the odd field. When the RS-170A phase lags the IRIG synchronized RS-170 by one video line, that field/frame is truncated by exactly one video line. The truncation in effect jumps the field/frame timing ahead by one line (approximately 63.5 microseconds). As mentioned in paragraph 6.4, truncation usually occurs every other video frame; however, occasionally it occurs on two successive video frames to achieve the long term 60 field/30 frame per second rate.

6.5 These hybrid color synchronization methods behave essentially the same with respect to image exposure time versus IRIG timing. They differ in their compatibility with standard NTSC color-video equipment. Table 6-1 summarizes the hybrid color synchronization methods discussed previously. Appendix C lists the behavior of video equipment with respect to these hybrid color video synchronization standards. Equipment compatibility will usually be the predominant factor when choosing a hybrid color synchronization method.

6.6 A full-frame Time Base Corrector (TBC) may be used as a real-time translator between any of the hybrid color video signals and the true NTSC-video signals. Translation to true NTSC by the TBC will achieve 100 percent equipment compatibility. However, when translating any of the hybrid video signals with a 60/30 Hz field/frame rate to NTSC video with a 59.94/29.92 Hz field/frame rate, one video frame in 1001 frames will be lost by the TBC.

6.7 If a VCR will accept a hybrid color video signal, it will act as nonreal-time translators between hybrid color and NTSC. No loss of fields will occur in the VCR as opposed to the TBC. See appendix C for a list of compatibility.

Table 6.1 Hybrid Sync Comparison

	RS-170	CERS-170A	CERS-170B	TRRS-170A	NTSC/RS-170A
Field/Frame Rate	60/30	60/30	60/30	60/30	59.94/29.92
Line Rate	15750	15750	15750	15734.26	15734.26
Color Subcarrier Frequency	N/A	3,583,325	3,579,545.45...	3,579,545.45...	3,579,545.45...
227.5 Ratio Rule	N/A	YES	NO	YES	YES
Raster Format Field/frame	262.5/525	262.5/525	262.5/525	262.2372446	262.5/525



Primary Aspect Causing Incompatibility With Some Video Equipment

CHAPTER 7

HIGH-SPEED VIDEO SYNCHRONIZATION

7.1 The phrase high-speed video is used here to mean a video system that has an image exposure and image-transfer rate that is some multiple of the standard 60 field/seconds-30 frame/seconds video system. Standard monochrome video equipment is only guaranteed to work with video rates within a few parts per thousand of the nominal value. Color video equipment, as shown in chapter 6, is even more sensitive to rate changes. Thus, standard video equipment cannot be expected to work directly with a high-speed video signal. A whole new equipment suite must be considered. The primary consideration for image rate is how many images per second are needed to get the necessary information about the event under study. For a general purpose camera, however, things are not so definite. Discussed in the subsequent paragraphs are reasons for choosing particular values for the high-speed video rates.

7.1.1 Integer multiples of 60 have the advantage a high coincidence rate with 60 fps video. Playback can translate down to exactly 60 fps video raster for equipment compatibility.

7.1.2 A 200-fields-per-second video with a line rate 52,500 Hz has the advantage of simple synchronization to IRIG timing with a IRIG coincidence rate of 200/seconds, which is very high. The image interval period and the IRIG coincidence period are 5.0 milliseconds, which is very good. The coincidence rate with 60 Hz video is 20 Hz, which is quite good. Playback can translate down exactly to 60 fps video raster for equipment compatibility. Commercial system are marketed by NAC, SFAT, and J.C Laboratories.

7.2 The field rate of high-speed color can be made an exact multiple of 60, can be 200, or can be an exact multiple of 59.94. The determination of the video rate which is the most advantageous for a given application, depends on the same considerations as for monochrome systems. Because none of the high-speed color-video signals will be directly compatible with standard color-video equipment, there is no equipment compatibility issue.

7.3 An example block diagram of a system that will produce IRIG-timing synchronized, video synchronization signals for standard, and high-speed video synchronization is shown in figure 7-1. Combinations of high-speed rates that can be produced by the particular master oscillator frequencies are shown in appendix A, Numerical Relationships. The lowest frequency, shown in appendix B, that can generate all of the necessary rates to produce synchronization for 60/120/180/200 field-rate systems is

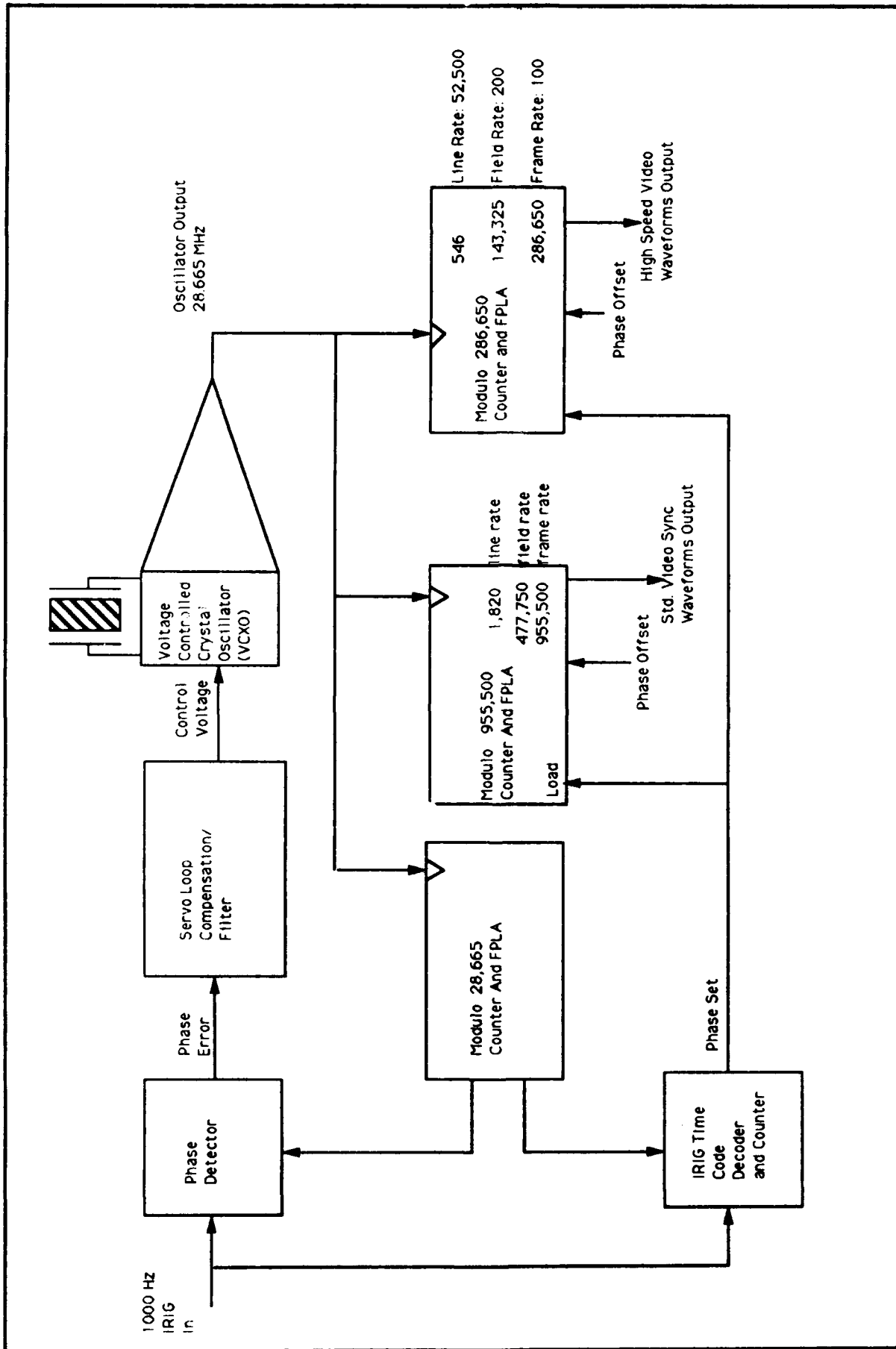


Figure 7-1. Standard and high-speed video synchronization generator.

945,000 Hz. Table 8-1 in chapter 8 lists a number of practical master frequencies that can be chosen. Some frequencies can produce true NTSC rates as well as some multiples of 60. The lowest frequency that can produce 60/120/180/200 fields/seconds, the color hybrid synchronization, and the true NTSC/RS-170 rate is 94.5 MHz.

CHAPTER 8

VIDEO SYNCHRONIZATION WAVEFORMS

8.1 Video synchronization waveforms are shown in figures 8-1, 8-2, and 8-3, together with the numerical data in table 8-1. The video field and frame rate aspects, which are the tip level, of the signals are shown in figure 8-1. The vertical interval details, shown in figure 8-2, can be considered medium or mid-level detail. The line-rate details in figure 8-3 are the low-level or fine-scale detail. Table 8-1 gives time and number-of-clock cycles required to generate all of the synchronization rates discussed in the preceding chapters.

8.2 Prior to the 1980s, video equipment synchronization usually required separate horizontal synchronization and vertical drive signals (see figures 8-1, 8-2, and table 8-1.) That norm has changed, and now it is much more common for equipment to require composite signals for synchronization. For monochrome equipment, composite synchronization or composite video work well, and for color equipment, black burst or composite video is used. Again, prior to the 1980s, synchronization signals were typically -4 volts into 75 ohms. Today, most equipment works best with a -0.4 to -1.0 volt signal into 75 ohms. The synchronization input on much of the modern equipment is ac coupled, so the dc value of the synchronization signal is not important as long as it is constant and below what the termination resistor can handle which is typically 4 volts.

8.3 In reference to the video line timing detail, shown in figure 8-3, the following rules apply. These rules were used in the preparation of table 8-1.

$$A = B+C = 2G$$

$$G = j+F$$

$$B = D+E$$

$$E = 2F$$

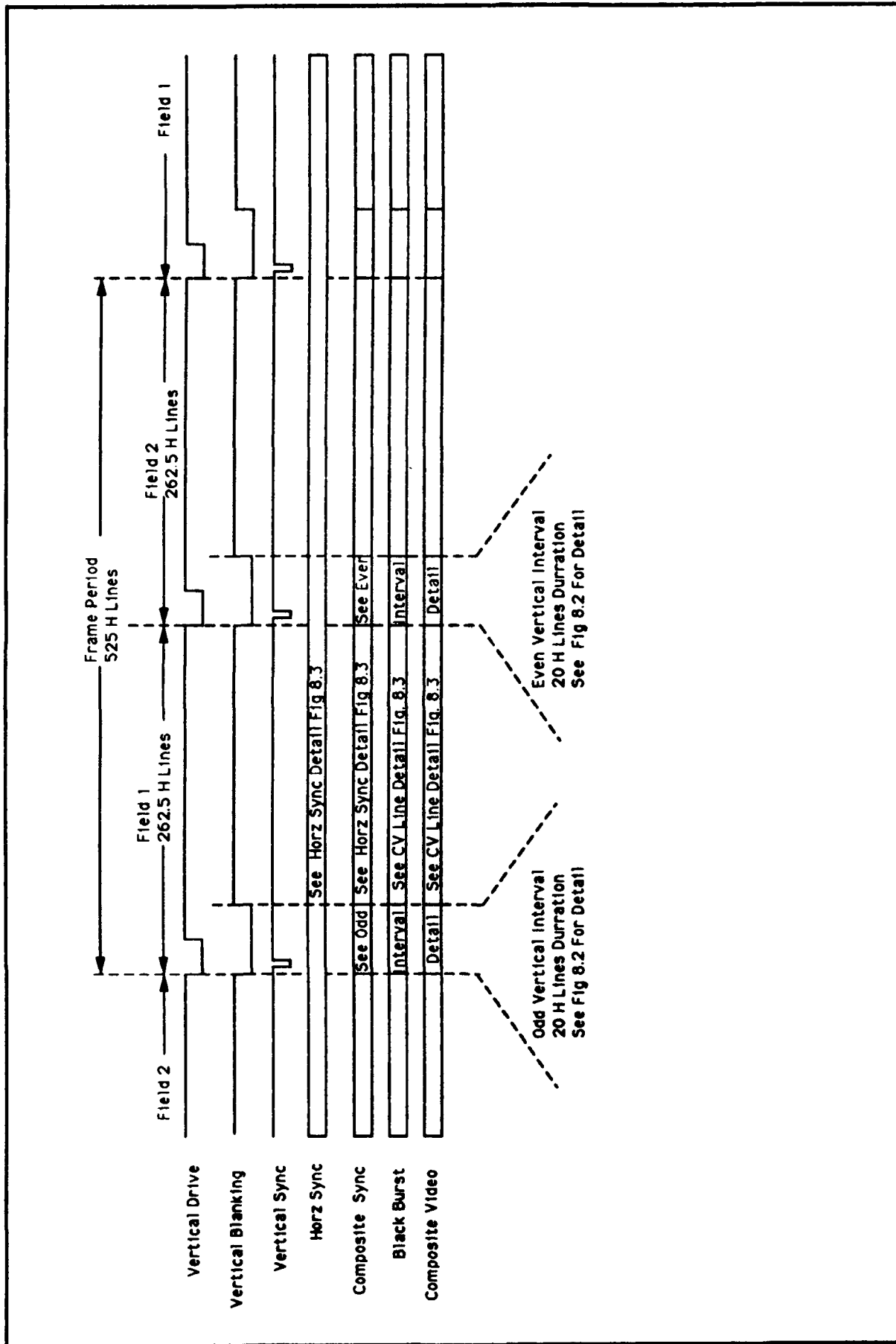


Figure 8-1. Video synchronization waveforms.

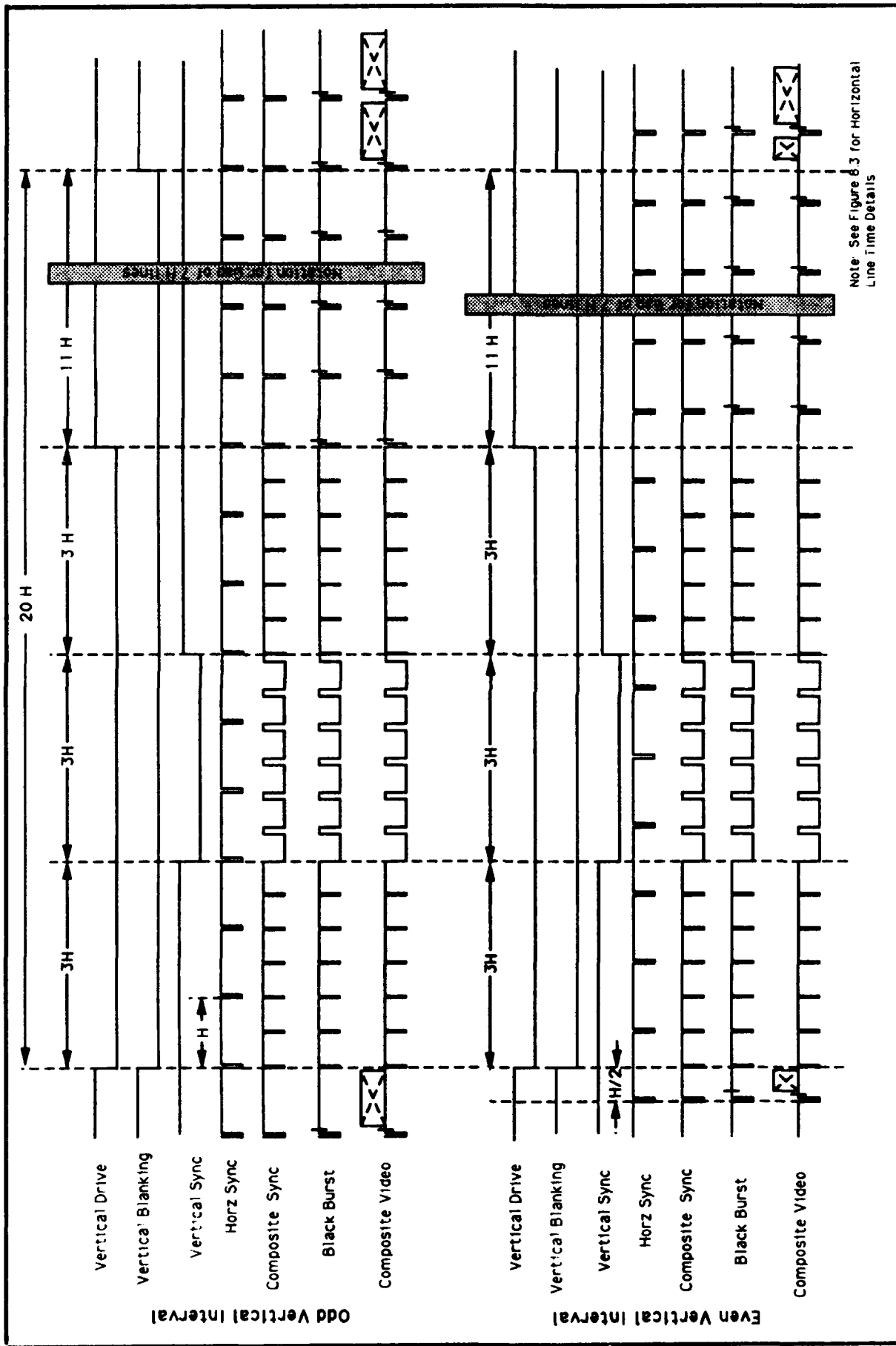


Figure 8-2. Vertical interval detail.

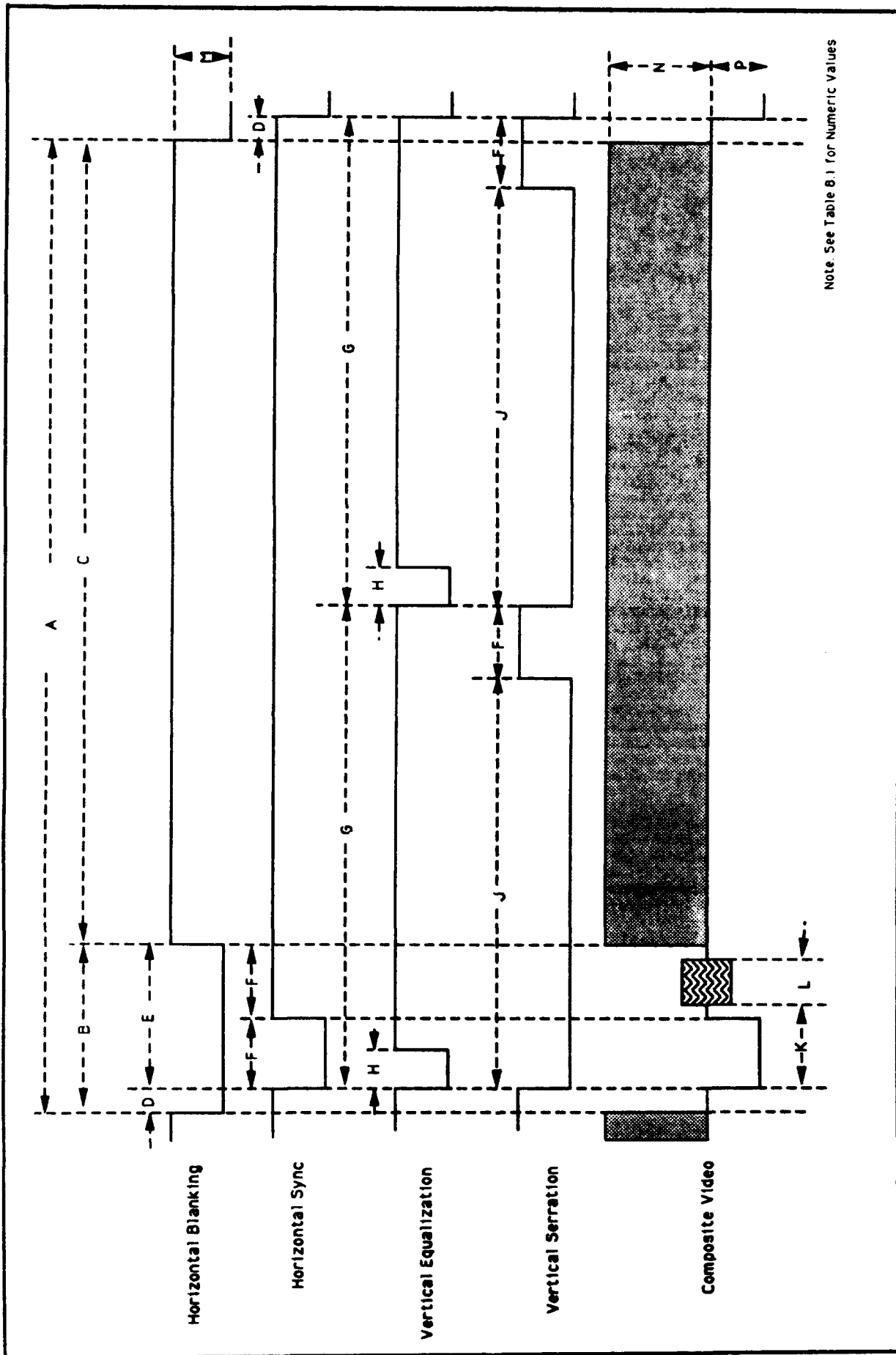


Figure 8-3. Video line timing detail.

TABLE 8-1. VIDEO LINE TIMING DETAIL

	Video Description FLD Rate/Frm Rate Master VCO Freq	RS-170 60/30 16.065 MHz	2XRS-170 120/60 16.065 MHz	3XRS-170 180/90 16.065 MHz	3.3XRS-170 200/100 16.065 MHz	CERS-170A 60/30 16.065 MHz	CERS-170B 60/30 16.065 MHz	TRRS-170A 60/30 16.065 MHz
A	Time Clock Cycles	63.492 1020	31.746 510	21.164 340	19.0476 306	63.492 1020	63.492 1020	63.556 1021
B	Time Clock Cycles	10.9±.2 175	5.45 87	3.63 58	3.27 53	10.9 175	10.9 175	10.9 175
C	Time Clock Cycles	52.6±.1 845	26.3 423	17.53 282	15.78 253	52.6 845	52.6 845	52.6 846
D	Time Clock Cycles	1.50±.1 23	0.75 11	0.5 8	0.45 7	1.5 23	1.5 23	1.5 23
E	Time Clock Cycles	9.4±.1 152	4.7 76	3.1 50	2.82 46	9.4 152	9.4 152	9.4 152
F	Time Clock Cycles	4.7±.1 76	2.35 38	1.57 25	1.41 23	4.7 76	4.7 76	4.7 76
G	Time Clock Cycles	31.75±.1 510	15.875 255	10.58 170	9.525 153	31.75 510	31.75 510	31.75 510.5 (2)
H	Time Clock Cycles	2.3±.1 38	1.15 19	0.767 13	0.69 12	2.3 38	2.3 38	2.3 38
J	Time Clock Cycles	27.05 434	13.525 217	9.02 145	8.115 130	27.05 434	27.05 434	27.05 434.5 (2)
K	Time Clock Cycles	5.3±.1 85	2.65±.05 42	1.77±.03 28	1.6±.03 26	5.3±.1 85	5.3±.1 85	5.3±.1 85
L	Time Clock Cycles	2.514±.1 40	1.26±.05 20	0.84±.03 13	0.755±.03 12	2.5143 40	2.5143 23	2.5143 40
	Notes	(1)	(1)	(1)	(1)	(1)	(1)	(2)

Time in microseconds. (1) Color burst not truly applicable. (2) Not possible by simple division.

TABLE 8-1. VIDEO LINE TIMING DETAIL (continued)

	Video Description FLD Rate/Frm Rate Master VCO Freq	RS-170 60/30 32.13MHz	2XRS-170 120/60 32.13MHz	3XRS-170 180/90 32.13MHz	3.3XRS-170 200/100 32.13MHz	CERS-170A 60/30 32.13MHz	CERS-170B 60/30 32.13MHz	TRRS-170A 60/30 32.13MHz	RS170A/NTSC 59.94/29.97 32.13MHz
A	Time Clock Cycles	63.492 2040	31.746 1020	21.164 680	19.0476 612	63.492 2040	63.492 2040	63.556 2042 (1)	63.556 2042 (1)
B	Time Clock Cycles	10.9±.2 350	5.45 175	3.63 117	3.27 105	10.9 350	10.9 350	10.9 350	10.9 350
C	Time Clock Cycles	52.6±.1 1690	26.3 845	17.53 563	15.78 507	52.6 1690	52.6 1690	52.6 1692	52.6 1692
D	Time Clock Cycles	1.5±.1 48	0.75 25	0.5 17	0.45 15	1.5 48	1.5 48	1.5 48	1.5 48
E	Time Clock Cycles	9.4±.1 302	4.7 150	3.1 100	2.82 90	9.4 302	9.4 302	9.4 302	9.4 302
F	Time Clock Cycles	4.7±.1 151	2.35 75	1.57 50	1.41 45	4.7±.1 151	4.7±.1 151	4.7±.1 151	4.7±.1 151
G	Time Clock Cycles	31.75±.1 1020	15.875 510	10.58 340	9.525 306	31.75 1020	31.75 1020	31.75 1020	31.75 1020
H	Time Clock Cycles	2.3±.1 76	1.15 38	0.767 25	0.69 46	2.3 76	2.3 76	2.3 76	2.3 76
J	Time Clock Cycles	27.05 869	13.525 435	9.02 315	8.115 261	27.05 869	27.05 869	27.05 871	27.05 871
K	Time Clock Cycles	(2) (2)	(2) (2)	(2) (2)	(2) (2)	5.3 170	5.3 170	5.3 170	5.3 170
L	Time Clock Cycles	(2) (2)	(2) (2)	(2) (2)	(2) (2)	2.5143 81	2.5143 81	2.5143 81	2.5143 81
	Notes							3,4	4

Time in microseconds. (1) Closest approximation. (2) Not applicable. (3) One line in each field is truncated to 1517 clock cycles. (4) Approximate NTSC Rates.

TABLE 8-1. VIDEO LINE TIMING DETAIL (continued)

	Video Description FLD Rate/Frm Rate Master VCO Freq	RS-170 60/30 31.5MHz	2XRS-170 120/60 31.5MHz	3XRS-170 180/90 31.5MHz	3.3XRS-170 200/100 31.5MHz	CERS-170A 60/30 31.5MHz	CERS-170B 60/30 31.5MHz	TRRS-170A 60/30 31.5MHz	RS170A/NTSC 59.94/29.97 31.5MHz
A	Time Clock Cycles	63.492 2000	31.746 1000	21.164 666.67(1)	19.0476 600	63.492 2000	63.556 2002	63.556 2002	63.556 2002
B	Time Clock Cycles	10.9±.2 343	5.45 172	3.63 Note (1)	3.27 103	10.9 343	10.9 344	10.9 344	10.9 344
C	Time Clock Cycles	52.6±.1 1657	26.3 828	17.53 Note (1)	15.78 497	52.6 1657	52.6 1658	52.6 1658	52.6 1658
D	Time Clock Cycles	1.5±.1 47	0.75 23	0.5 Note (1)	0.45 15	1.5 47	1.5 48	1.5 48	1.5 48
E	Time Clock Cycles	9.4±.1 296	4.7 148	3.1 Note (1)	2.82 88	9.4 296	9.4 296	9.4 296	9.4 296
F	Time Clock Cycles	4.7±.1 148	2.35 74	1.57 Note (1)	1.41 44	4.7 148	4.7 148	4.7 148	4.7 148
G	Time Clock Cycles	31.75±.1 1000	15.875 500	10.58 Note (1)	9.525 300	31.75 1000	31.75 1001	31.75 1001	31.75 1001
H	Time Clock Cycles	2.3±.1 74	1.15 37	0.767 Note (1)	0.69 22	2.3 74	2.3 74	2.3 74	2.3 74
J	Time Clock Cycles	27.05 852	13.525 426	9.02 Note (1)	8.115 256	27.05 852	27.05 852	27.05 852	27.05 852
K	Time Clock Cycles	5.3±.1 167	2.65 84	1.77 Note (1)	1.6 50	5.3 167	5.3 167	5.3 167	5.3 167
L	Time Clock Cycles	2.5143 79	1.26 40	0.84 Note (1)	0.755 24	2.51 79	2.51 79	2.51 79	2.51 79
	Notes	(3)	(3)	(3)	(3)			(2)	(2)

time in microseconds. (1) Cannot be achieved by simple division. (2) One line in each field is truncated to 1477 clock cycles. 3 Color burst not truly applicable.

TABLE 8-1. VIDEO LINE TIMING DETAIL (continued)

	Video Description FLD Rate/Frm Rate Master VCO Freq	RS-170 60/30 28.665MHz	2XRS-170 120/60 28.665MHz	3XRS-170 180/90 28.665MHz	3.3XRS-170 200/100 28.665MHz	CERS-170A 60/30 28.665MHz	CERS-170B 60/30 28.665MHz	TRRS-170A 60/30 28.665MHz
A	Time Clock Cycles	63.492 1820	31.476 910	21.164 Note (1)	19.0476 546	63.492 1820	63.492 1820	63.556 1822
B	Time Clock Cycles	10.9 312	5.45 156	3.63 Note (1)	3.27 94	10.9 312	10.9 312	10.9 312
C	Time Clock Cycles	52.6 1508	26.3 754	17.53 Note (1)	15.78 452	52.6 1508	52.6 1508	52.6 1510
D	Time Clock Cycles	1.5 42	0.75 22	0.5 Note (1)	0.45 12	1.5 42	1.5 42	1.5 42
E	Time Clock Cycles	9.4 270	4.7 134	3.1 Note (1)	2.82 82	9.4 270	9.4 270	9.4 270
F	Time Clock Cycles	4.7 135	2.35 67	1.57 Note (1)	1.41 41	4.7 135	4.7 135	4.7 135
G	Time Clock Cycles	31.75 910	15.875 455	10.58 Note (1)	9.525 273	31.75 910	31.75 910	31.75 911
H	Time Clock Cycles	2.3 78	1.15 39	0.767 Note (1)	0.69 20	2.3 78	2.3 78	2.3 78
J	Time Clock Cycles	27.05 775	13.525 388	9.02 Note (1)	8.115 232	27.05 775	27.05 775	27.05 776
K	Time Clock Cycles	5.3 135	2.65 76	1.767 Note (1)	1.59 46	5.3 135	5.3 135	5.3 135
L	Time Clock Cycles	2.51 72	1.26 36	0.838 Note (1)	0.754 22	2.5143 72	2.5143 72	2.5143 72
	Notes						(2)	

Time in microseconds. (1) Cannot be achieved by simple division. (2) One line in each field is truncated to 1297 clock cycles.

TABLE 8-1. VIDEO LINE TIMING DETAIL (continued)

	Video Description FLD Rate/FRM Rate Master VOO Freq	RS-170 60/30 0.945MHz	RS170A/NTSC 59.94/29.97 14.38318MHz	RS170A/NTSC 59.94/29.97 9.0MHz
A	Time Clock Cycles	63.492 60	63.556 910	63.556 572
B	Time Clock Cycles	10.9±.2 10	10.9±.2 156	10.9±.2 98
C	Time Clock Cycles	52.6±.1 50	52.6±.1 754	52.6±.1 474
D	Time Clock Cycles	1.5±.1 1	1.5±.1 22	1.5±.1 12
E	Time Clock Cycles	9.4±.1 9	9.4±.1 134	9.4±.1 86
F	Time Clock Cycles	4.7±.1 4.5	4.7±.1 67	4.7±.1 43
G	Time Clock Cycles	31.75±.1 30	31.75±.1 455	31.75±.1 286
H	Time Clock Cycles	2.3±.1 2	2.3±.1 33	2.3±.1 22
J	Time Clock Cycles	27.05 25.6	27.05 388	27.05 243
K	Time Clock Cycles	5.3±.1 5	5.3±.1 76	5.3±.1 48
L	Time Clock Cycles	2.5143 2	2.5143 36	2.5143 23
	Notes		Four times NTSC CS (1)	

APPENDIX A
NUMERICAL RELATIONSHIPS

NUMERICAL RELATIONSHIPS

Procedure for finding the lowest oscillator frequency that will generate a required set (list) of subrates:

1. List the frequencies required.
2. Factor each of the required frequencies into primes. For clarity and convenience, rank these prime factors from the smallest to the largest.
3. Form the lowest oscillator frequency by constructing a product from the above list of prime factors according to the following procedure. The first term of the product is the smallest prime to the highest power where it appears in any of the factors of the required frequencies. The second term of the product is the next larger prime to the highest power where it appears in any of the factors. Proceed through the list of primes to the largest prime of the highest power where it appears in any of the factors. It will be the final term of the product. If a subrate can only be expressed precisely as a rational number, consider only the factors in the numerator. The resulting product will be the smallest number that is evenly divisible by all the original numbers, and will represent the lowest frequency from which all of the subrates can be derived by simple division.

Example: Find the lowest frequency from which standard RS-170 video can be derived.

RS-170 line rate: $15.750 = 2 \cdot 3^2 \cdot 5^3 \cdot 7$
RS-170 field rate: $60 = 2^2 \cdot 3 \cdot 5$
RS-170 frame rate: $30 = 2 \cdot 3 \cdot 5$

$$LP = 2^2 \cdot 3^2 \cdot 5^3 \cdot 7 = 31,500 \text{ Hz}$$

Example: Find the lowest frequency from which standard RS-170 video can be derived from 1000 Hz IRIG signal.

RS-170 line rate: $15,750 = 2 \cdot 3^2 \cdot 5^3 \cdot 7$
RS-170 field rate: $60 = 2^2 \cdot 3 \cdot 5$
RS-170 frame rate: $30 = 2 \cdot 3 \cdot 5$
IRIG rate: $1000 = 2^3 \cdot 5^3$
LP = $2^3 \cdot 3^2 \cdot 5^3 \cdot 7 = 63,000 \text{ Hz}$

List of video rates, IRIG rates, and telecommunications rates expressed as primes.

RS-170

Line Rate: 15,750 = $2 \cdot 3^2 \cdot 5^3 \cdot 7$
 Field Rate: 60 = $2^2 \cdot 3 \cdot 5$
 Frame Rate: 30 = $2 \cdot 3 \cdot 5$

2XRS-170

Line Rate: 31,500 = $2^2 \cdot 3^2 \cdot 5^3 \cdot 7$
 Field Rate: 120 = $2^3 \cdot 3 \cdot 5$
 Frame Rate: 60 = $2^2 \cdot 3 \cdot 5$

3XRS-170

Line Rate: 47,250 = $2 \cdot 3^3 \cdot 5^3 \cdot 7$
 Field Rate: 180 = $2^2 \cdot 3^2 \cdot 5$
 Frame Rate: 90 = $2 \cdot 3^2 \cdot 5$

3.3XRS-170

Line Rate: 52,500 = $2^2 \cdot 3 \cdot 5^4 \cdot 7$
 Field Rate: 200 = $2^3 \cdot 5^2$
 Frame Rate: 100 = $2^2 \cdot 5^2$

NTSC/RS-170A

Line Rate: $2,250,000/143 = (2^4 \cdot 3^2 \cdot 5^6) / 11 \cdot 13$
 Field Rate: $60,000/1001 = (2^5 \cdot 3 \cdot 5^4) / 7 \cdot 11 \cdot 13$
 Frame Rate: $30,000/1001 = (2^4 \cdot 3 \cdot 5^4) / 7 \cdot 11 \cdot 13$
 Color Sub.: $39,375,000/11 = (2^3 \cdot 3^2 \cdot 5^7 \cdot 7) / 11$

CERS-170A

Line Rate: 15,750 = $2 \cdot 3^2 \cdot 5^3 \cdot 7$
 Field Rate: 60 = $2^2 \cdot 3 \cdot 5$
 Frame Rate: 30 = $2 \cdot 3 \cdot 5$
 Color Sub.: 3,583,125 = $3^2 \cdot 5^4 \cdot 7^2 \cdot 13$

CERS-170B

Line Rate: 15,750 = $2 \cdot 3^2 \cdot 5^3 \cdot 7$
 Field Rate: 60 = $2^2 \cdot 3 \cdot 5$
 Frame Rate: 30 = $2 \cdot 3 \cdot 5$
 Color Sub.: $39,375,000/11 = (2^3 \cdot 3^2 \cdot 5^7 \cdot 7) / 11$

TRRS-170A

Line Rate: $2,250,000/143 = (2^4 \cdot 3^2 \cdot 5^6) / 11 \cdot 13$
 Field Rate: 60 = $2^2 \cdot 3 \cdot 5$
 Frame Rate: 30 = $2 \cdot 3 \cdot 5$
 Color Sub.: $39,375,000/11 = (2^3 \cdot 3^2 \cdot 5^7 \cdot 7) / 11$

PAL

Line Rate: 15,625 = 5^6
Field Rate: 50 = $2 \cdot 5^2$
Frame Rate: 25 = 5^2
Color Sub.: 4,430,000 = $2^4 \cdot 5^4 \cdot 443$

SECAM

Line Rate: 15,625 = 5^6
Field Rate: 50 = $2 \cdot 5^2$
Frame Rate: 25 = 5^2
Color Sub.: 4,430,000 = $2^4 \cdot 5^4 \cdot 443$

IRIG- Timing

$$1000 \text{ Hz} = 2^3 \cdot 5^3$$

Telecommunications Rates.

$$\begin{aligned} 600 &= 2^3 \cdot 3 \cdot 5^2 \\ 1,200 &= 2^4 \cdot 3 \cdot 5^2 \\ 2,400 &= 2^5 \cdot 3 \cdot 5^2 \\ 4,800 &= 2^6 \cdot 3 \cdot 5^2 \\ 9,600 &= 2^7 \cdot 3 \cdot 5^2 \\ 19,200 &= 2^8 \cdot 3 \cdot 5^2 \\ 56,000 &= 2^6 \cdot 5^3 \cdot 7 \\ 64,000 &= 2^9 \cdot 5^3 \end{aligned}$$

Lowest master oscillator frequencies for some common applications.

1. RS-170, 2XRS-170 3XRS-170, 3.3XRS-170, IRIG (1000 Hz)

$$2^3 \cdot 3^3 \cdot 5^4 \cdot 7 = 945,000 \text{ Hz}$$

2. CERS-170 without (without) direct color subcarrier (CS) and IRIG (1000 Hz)

$$2^3 \cdot 3^2 \cdot 5^3 \cdot 7 = 63,000 \text{ Hz}$$

3. CERS-170A (with direct SC), CERS-170B, 2XRS-170, 3.3XRS-170 and IRIG (1000 Hz)

$$23 \cdot 3^2 \cdot 5^4 \cdot 7^2 \cdot 13 = 28.665 \text{ MHz}$$

4. NTSC (without direct CS), IRIG (1000 Hz)

$$2^5 \cdot 3^2 \cdot 5^6 = 4.5 \text{ MHz}$$

5. NTSC with direct CS

$$2^5 \cdot 3^2 \cdot 5^7 \cdot 7 = 157.5 \text{ MHz}$$

6. CERS-170A, (without direct CS) CERS-170B, TRRS-170A, 2XRS-170, 3.3XRS-170, RS-170A/NTSC, IRIG(1000Hz), PAL

$$2^5 * 3^2 * 5^6 * 7 = 31.5 \text{ MHz}$$

7. CERS-170A(without direct CS), CERS-170B(without direct SC), TRRS-170A(without direct CS), 2XRS-170, 3XRS-170, 3.3XRS-170, RS-170A/NTSC, IRIG(1000Hz), PAL

$$2^5 * 3^3 * 5^6 * 7 = 94.5 \text{ MHz}$$

8. The lowest frequency providing everything under 7, plus direct color subcarrier (CS)

$$2^5 * 3^3 * 5^7 * 7^2 * 13 = 42.9975 \text{ GHz.}$$

NOTE: Unfortunately, this frequency is too high to have any practical application.

COLOR SUBCARRIER GENERATION

1. As shown under the previous section on the lowest master oscillator frequencies, direct color subcarrier (CS) generation often leads to a very high master oscillator frequency. In many cases, the frequency is too high to be practical. To form a black burst or composite video signal, a sine wave CS is needed as opposed to the square waves which are provided by digital circuitry. Further, the phase of the color subcarrier needs to be precisely controlled, relative to the digital waveforms. These three factors favor the use of a secondary PLL with a sine-wave oscillator to generate the CS in most cases.

2. When using a secondary PLL to generate the CS, it is desirable to minimize the ratio between the loop input frequency and the CS generated. In other words, the feedback loop count (division) should be minimized. Minimizing the feedback count will tighten the loop control and provide for a more closely coupled CS and video horizontal synchronization. To minimize the feedback loop division, the factors of the counter/divider used to generate the line count need to be factors contained in 455 which are $5^7 \cdot 9$.

3. An example of a tightly coupled CS loop using a master oscillator of 31.5 Mhz is to divide 31,500,000 Hz by 44 and then multiply by 5 to get 3,579,545.26 Hz. In this case, the CS loop feedback division is 5.

4. An example of a loosely coupled CS loop using a master oscillator of 31.5 MHz is to divide 31,500,000 Hz by 2002 to get the video line rate, then divide the line rate by 2 to get

7,867.13286 Hz. Finally, multiply 7,867.13286 by 455 to get
3,579,545.26 Hz. In this case, the CS loop feedback division is
455.

APPENDIX B
IMPLEMENTATION EXAMPLES

IMPLEMENTATION EXAMPLE

List the systems that all T&E Ranges would like to propose or make available. List the major characteristics, block diagram (if available), and fabrication/procurement route.

Synchronizing Equipment Available

1. ITS System.

IRIG Timing Input Format:

Video Outputs: NTSC/RS-170A Synchronization Systems:

Other Features: Decoded IRIG time is provided VIA the UME Bus

Phase offset adjustment: Unkown

Physical characteristics: VME card implementation

Comments: Compatible with methods outlined here.

Approximate Cost: \$1650.00

Status: Off the shelf. Data sheet available from ITS Inc.,
19360 Business Center Drive, Chatsworth, CA.
91329-3547

2. NWC CERS-170A/B System.

IRIG Timing Input Format: IRIG-A dc-level shift, 5 volt logic levels

Video Synchronization and Timing Outputs: Vertical drive, horizontal drive, composite synchronization, CERS-170 Black Burst, 60 pps TTL level.

Other Features and Comments

Phase Offset Adjustment: Adjustable to one full video frame with approximately 180 nanosecond resolution.

Physical Characteristics: 19-inch rack mountable box with 3.25 inch vertical panel spacing

Comments: Compatible with method outlined here.

Approximate Cost: \$4000.00

Status: Construction documentation available from NAWC-WPNS, China Lake.

3. NAC/ITS system: High Speed Video Synchronization Systems

IRIG Timing Input Format:

Video Synchronization and Timing Outputs:

Other Features:

Phase Offset Adjustment:

Physical Characteristics:

Comments: Compatible with method outlined here. VME card implementation.

Approximate Cost: Unknown

Status: Off the shelf. Data sheet available from

4. NADC System

IRIG Timing Input Format:

Video Synchronization and Timing Outputs:

Other Features:

Phase Offset Adjustment:

Physical Characteristics:

Comments: Compatible with method outlined here. VME card implementation.

Approximate Cost: Unknown

Status: Off the shelf. Data sheet available from

5. NATC System

IRIG Timing Input Format:

Other Features:

Phase Offset Adjustment:

Physical Characteristics:

Comments: Compatible with method outlined here. VME card implementation.

Approximate Cost:

Status: Off the shelf. Data sheet available from HEI Inc System

IRIG Timing Input Format:

Video Synchronization and Timing Outputs:

Other Features:

Phase Offset Adjustment:

Physical Characteristics:

Comments: Compatible with method outlined here. VME card implementation.

Approximate Cost: Unknown

Status: Off the shelf. Data sheet available from

6. Omega Video System

IRIG Timing Input Format:

Video Synchronization and Timing Outputs:

Other Features:

Phase Offset Adjustment:

Physical Characteristics:

Comments: Compatible with method outlined here.

Approximate Cost: Unknown

Status: Off the shelf. Data sheet available from

7. **NAWC-WPNS, China Lake. Video Synchronization System 2
(In Development).**

IRIG Timing Input Format: IRIG-B

Video Synchronization and Timing Outputs: Firmware can be loaded into PALS to simultaneously produce two of the following: RS-170, CERS-170A, CERS-170B, TRRS-170, 2XRS-170, 3XRS-170, 3.3XRS170(200FPS), 60 pps, 120 pps, 180 pps and 200 pps.

Other Features:

Phase Offset Adjustment:

Physical Characteristics: VME card implementation.

Comments: Compatible with method outlined here.

Approximate Cost: Unknown

Status: Off the shelf. Data sheet available from

APPENDIX C

**SYSTEM AND EQUIPMENT COMPATIBILITY WITH VIDEO
SYNCHRONIZATION STANDARD, (STANDARD AND
COLOR SYNCHRONIZATION)**

**SYSTEM AND EQUIPMENT COMPATIBILITY WITH VIDEO SYNCHRONIZATION
STANDARD, (STANDARD AND HYBRID COLOR SYNCHRONIZATION)**

System and equipment compatibility is listed and discussed according to video synchronization format. The synchronization formats are listed in the following order:

1. IRIG Synchronized NTSC/RS-170A Color Video
2. IRIG Synchronized CERS-170A Color Video
3. IRIG Synchronized CERS-170B Color Video
4. IRIG Synchronized TRRS-170A Color Video
5. IRIG Synchronized TFRS-170A Color Video

IRIG Synchronized NTSC/RS-170A Color Video

1. Monochrome Monitors: Compatible. The display is the luminance portion of the video signal with a color subcarrier sinewave superimposed which produces small moving dots on the monochrome monitor. The color subcarrier dots can be eliminated with a color trap filter, but horizontal resolutions will be also lost.
2. Color Monitors: Compatible. Synchronization has no effect.
3. Monochrome Cameras: Most monochrome cameras will synchronize to a NTSC signal.
4. Color Cameras: Compatible if the camera has synchronization input.
5. IR Cameras: Most IR cameras are not synchronizable.
6. Video Recorders
 - 6.1 NTSC video works with all NTSC color video recorders. Synchronization of NTSC to IRIG timing produces true NTSC and does not change the compatibility of NTSC.
 - 6.2 Sony D-2 Recorder: Compatible
 - 6.3 Ampex VPR-II with TBC: Compatible
7. Time Base Correctors: Compatible
8. Processing Amplifiers: Compatible
9. Analog Video Transmission System: Compatible
10. Digital Video Transmission (with compression): Compatible with color video-transmission systems. Not compatible with

monochrome systems. Color trap filter must be used to eliminate the color subcarrier on monochrome digital video coded systems.

11. Video Trackers

11.1 Monochrome Trackers: Generally, a color video signal moderately or severely degrades monochrome video trackers ability to track. Usually, if the color subcarrier is removed from the color video signal with a color trap, the performance of the monochrome tracker is improved to be comparable with its performance with a monochrome input.

11.2 Color Trackers: NAWC-WPNS, China Lake color tracker. Compatible

12. TSPI Data System

12.1 Asynchronous Systems: Compatible

12.2 IRIG Synchronous Systems TPS Data System: Generally not compatible.

13. DIV Encoders: Compatible

13.1 Left Edge Encoders: Compatible

13.2 Scan Line Encoders: Compatible

14. Video Readers/Video Data Reduction Systems: Generally, a composite color video is not very compatible with digital image processing. The color subcarrier must be removed by a color trap filter or by using S-VHS signal format and inputting only the luminance signal to the image processor.

IRIG Synchronized CERS-170A Color Video

1. Monochrome Monitors: Compatible. The display is the luminance portion of the video signal with a color subcarrier sine wave superimposed which produces small moving dots on the monochrome monitor. The color subcarrier can be eliminated with a color trap filter, but horizontal resolution will also be lost.

2. Color Monitors: Display of luminance only. Attempting to display color will either have no effect or will produce a rainbow effect of color from left to right across the display. Color monitors can be modified to display CERS-170A by replacing the color crystal with a 3,583,125 Hz crystal.

3. Monochrome Cameras: Compatible if external synchronization option exists.

4. Color Cameras: The following three effects have been observed depending on the make and model of the camera.

- 4.1 The normal camera operation is completely disrupted and unusable.
- 4.2 The camera vertical interval is synchronized, but the line rate and color subcarrier remain at NTSC rates. Examples: Sony DSC M7, Panasonic 300 CLE, NEC NC-120, NEC SP3.
- 4.3 The camera completely synchronizes to the CERS-170A signal. Example: NEC NX-18.
- 5. IR Cameras: Compatible with IR cameras that have external synchronization capability.
- 6. Video Recorders
 - 6.1 General: Records luminance information only. Chrominance information is lost and may even disrupt the recording.
 - 6.2 Ampex VPR-II with TBC will record luminance and chrominance.
- 7. Time Base Correctors
- 8. Processing Amplifiers (proc amps): Generally processes luminance information only. The nonstandard color subcarrier may disrupt some proc amps.
- 9. Analog Video Transmission System: Generally compatible.
- 10. Digital Video Transmission (with compression): Generally processes luminance information only.
- 11. Video Trackers
 - 11.1 Monochrome Trackers: Generally compatible, however, for best results, the color subcarrier should be stripped with a color trap filter.
 - 11.2 Color Trackers: Compatible with NAWC-WPNS, China Lake developed color tracker.
- 12. TSPI Data System
 - 12.1 Asynchronous Systems: Compatible.
 - 12.2 IRIG Synchronous Systems: Compatible.
- 13. DIV Encoders:
 - 13.1 Left Edge Encoders: Compatible.
 - 13.2 Scan Line Encoders: Compatible.
- 14. Video Readers/Video Data: Generally a composite color video is not very compatible with digital image processing. The color subcarrier must be removed by a color trap filter or by using S-VHS signal format and inputting only the luminance signal to the image processor.

IRIG Synchronized CERS-170B Color Video

- 1. Monochrome Monitors: The display is the luminance portion of the video signal with a color subcarrier sine wave

superimposed which produces small moving dots on the monochrome monitor. The color subcarrier dots can be eliminated with color trap filter, but horizontal resolution will be lost also.

2. Color Monitors: Generally compatible.
3. Monochrome Cameras: Compatible.
4. Color Cameras: The following three effects have been observed depending on the make and model of the camera.
 - 4.1 The normal camera operation is completely disrupted and unusable.
 - 4.2 The camera vertical interval is synchronized, but the line rate and color subcarrier remain at NTSC rates.
 - 4.3 The camera completely synchronizes to the CERS-170A signal.
Example: NEC NX-18.
5. IR Cameras: If the camera has an external synchronization capability, it will synchronize to CERS-170B.
6. Video Recorders
 - 6.1 General. The CERS-170B video works with all common video recorders.
 - 6.2 Ampex VPR-II with TBC: Not compatible.
 - 6.3 Sony D-2 recorder: Not compatible.
7. Time Base Correctors: Unknown
8. Processing Amplifiers: Generally processes luminance and chrominance information.
9. Analog Video Transmission System: Compatible
10. Digital Video Transmission (with compression): Unknown.
11. Video Trackers
 - 11.1 Monochrome Trackers: Generally compatible, however, for best results, the color subcarrier should be stripped with a color trap filter.
 - 11.2 Color Trackers: Compatible with NAWC-WPNS, China Lake developed color tracker.
12. TSPI Data System
 - 12.1 Asynchronous Systems: Compatible.
 - 12.2 IRIG Synchronous Systems: Compatible.
13. DIV Encoders
 - 13.1 Left Edge Encoders: Compatible.
 - 13.2 Scan Line Encoders: Compatible.

14. Video Readers/Video Data Reduction Systems: Generally, a composite color video is not very compatible with digital image processing. The color subcarrier must be removed by a color trap filter or by using S-HVS signal format and inputting only the luminance signal to the image processor.

IRIG Synchronized TRRS-170A Color Video

1. Monochrome Monitors: Monitor make and model dependent. The display is the luminance portion of the video signal with a color subcarrier sinewave superimposed which produces small moving dots on a monochrome monitor. The color subcarrier dots can be eliminated with a color trap filter, but horizontal resolution will be also lost.
2. Color Monitors: Make and model dependent.
3. Monochrome Cameras: Make and model dependent but generally not compatible.
4. Color Cameras: Make and model dependent but generally not compatible.
5. IR Cameras: Make and model dependent but generally not compatible.
6. Video Recorders
 - 6.1 General. TRRS-170A video works with all common video recorders.
 - 6.2 Sony D-2: Not compatible.
 - 6.3 Ampex VPR-II with TBC: Not compatible.
7. Time Base Correctors: Unknown.
8. Processing Amplifiers: Unknown.
9. Analog Video Transmission System: Compatible.
10. Digital Video Transmission (with compression): Make and model dependent but generally not compatible.
11. Video Trackers
 - 11.1 Monochrome Trackers
 - 11.2 Color Trackers
12. TSPI Data System
 - 12.1 Asynchronous Systems
 - 12.2 IRIG Synchronous Systems
13. DIV Encoders
 - 13.1 Left Edge Encoders

13.2 Scan Line Encoders

14. Video Readers/Video Data Reduction Systems

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