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Final Report
4 November 1963 to 19 December 1963

AEROSPACE GROUP

HUGHES

HUGHES AIRCRAFT COMPANY
CULVER CITY, CALIFORNIA

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PREFACE

This report summarizes the study of methods of information bandwidth reduction for analog television signals under NASA contract NAS 9-1564 during the period from 19 June 1963 through 19 December 1963. This final report summarizes some of the results previously reported in the Phase I and Phase II reports. In addition, it includes a detailed description of the multiple interlace system, which was selected for further study during the third phase.

A list of participants is listed below.

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APPENDIX

1. INTRODUCTION

The use of television information from space vehicles is vital in achieving the objectives of many space missions. Conventional television systems, which provide what is usually considered excellent verisimilitude, are not appropriate because of vehicle limitations of size, weight, and power capacity. Since economy in these factors is vital, the mission and vehicle limitations must be considered.

Throughout the history of movies and TV, audiences have accepted with equanimity unrealistic presentations of real scenes. Flicker, jump, and noise were once commonplace; detail, brightness and contrast have been inadequate; field of view has been minuscule. Even the best techniques of both movies and TV still suffer from deficiencies that are perceptible to a critical eye. The realism of today's commercial TV has been achieved at the expense of considerable equipment complexity and through generous power and bandwidth allocations. Where these provisions have been contra-indicated, picture quality has suffered a setback, and viewers have been forced to accept presentations that are reminiscent of those of much earlier days. Currently, in many situations, slow scan TV or a series of still photos are quite adequate media for the communication of changing visual data.

An objective of this study has been the investigation of television bandwidth compression systems with the goal of determining the characteristics and performance of one which offers the potential of greatest compression ratio while imposing a minimum sacrifice of realism, and requiring minimum complexity of spaceborne equipment. At the completion of the second phase of the program, the multiple interlace system was selected, for reasons set forth in the Phase II Report, as most appropriate for meeting the requirements of manned spacecraft missions.

The multiple interlace TV Bandwidth Reduction system, with relatively simple encoding equipment, provides an impressively high bandwidth compression ratio. At high compression ratios however, image breakup of moving objects is quite apparent, even for moderate motion rates. The same statements are true for a conventional slow scan system, where the manifestation of the breakup is quite different and, for a wide range of frame rates, more objectionable.

Regardless of the method employed to reduce television bandwidth, the magnitude of motion breakup is determined by the motion occurring during a frame period. For systems with equal frame rates (the reciprocal of the period during which complete renewal of changing pictorial information is accomplished) the dimensions of breakup are equal. The feature of interest is the nature of the breakup and its acceptability to the viewer.

For techniques which provide an adequately shuttered mode of operation, moving objects progress across the display in a series of jumps, with all picture components retaining the original spatial and contrast resolutions. If movement greater than the minimum spatial resolution dimension occurs during the shutter-open period, blur, tilt, and/or other breakup of the moving components result. For example, in the presentation of an unshuttered slow scan mode, blur, tilt and jump are all apparent. For techniques in which information is renewed gradually, general blurring or changes of distributed groups of lines or picture elements occur throughout the area swept by the picture component motion during a frame period.

Some degree of blurring of moving objects is a natural consequence of the limitations of human vision. The multiple interlace technique exploits this characteristic of vision to a considerable degree. The success of a bandwidth compression technique which discards information depends on the types of information discarded and the manner in which it is accomplished. Tests have established that the full resolution potentially available in moving or changing objects is not assimilable via the visual channel. It is information of this type which is discarded in a multiple interlace system, in a manner which causes moving edges to tend to blur in the direction of motion.

It is certainly true that large compression ratios (very low frame rates) result in obvious breakup which does not seem natural, for example: dark objects moving across a light background appear to lose their substance, and actually disappear under extreme conditions; light objects moving across a dark background appear to project a distributed array of bright spots in the direction of motion. In comparison with slow scan of the same frame rate* however, the breakup is not as remote from reality, and the appearance of course improves rapidly as the compression ratio is reduced. In addition, the variable storage feature available in the multiple interlace mechanization offers the option of improving the presentation of moving components at the expense of spatial resolution of the stationary components.** The ability to select, at the ground terminal, a storage ratio which is optimum for a particular set of picture characteristics and viewing requirements can greatly extend the usefulness of a space TV system.

Other candidate techniques, among them edge detection and frame correlation have been tentatively set aside at this time. While they offer the potential of moderate to high compression ratios without significant picture degradation, they do not, in their current status of development, provide a satisfactory answer to the space mission television requirement.

It is concluded that for equal transmission bandwidths in the region where an attempt is made to provide some illusion of motion, the multiple interlace technique provides the most acceptable presentation.

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*Except at extremely low frame rates where scan-converted shuttered slow scan is superior.

**Phase II report paragraph 3. 5. 2.

2. FUNDAMENTAL FACTORS OF BANDWIDTH COMPRESSION

In the first phase of this study program, the literature was studied to locate and classify all of the techniques which might be used to reduce the information bandwidth required for a television video signal. This study has been concerned with analog processing techniques and has had as a goal the selection of that technique, suitable for manned space missions, which would allow the best combination of viewability, reduction in bandwidth, minimum required signal to noise ratio, and minimum spacecraft complexity.

During the evaluation of these methods of bandwidth reduction, the significant factors affecting bandwidth requirement have become apparent.

2.1 GENERAL BANDWIDTH REQUIREMENTS

To review briefly those factors determining bandwidth requirement, consider a television frame with N elements per line and L lines per frame. Thus there are NL elements per frame. If frames are scanned at the rate of R frames per second, the highest frequency video signal F_{max}', (occurring when alternate elements are black and white) would be

$$F_{max}' = \frac{NLR}{2} \tag{1}$$

Since, in the scanning procedure, some time is required for return of the scan at the end of each line and at the end of each frame, the active elements must be scanned more rapidly to allow for the retrace time. This in turn raises the maximum frequency (and hence the information bandwidth)

$$Fmax = \frac{F'max}{\left(1 - \frac{T_h}{T_H}\right)\left(1 - \frac{T_v}{T_V}\right)}$$

where F'max = maximum frequency with zero retrace time

T_h = Horizontal retrace time

T_H = Total time per line

T_v = Vertical retrace time

T_V = Total time per frame (2)

This maximum frequency is not determined by the average nature of the material being televised but only by the maximum rate at which changes in signal may occur. Usually, the limiting frequency components are generated by only a very small portion of a scene. Consequently, even if the maximum rate of scanning* significant elements is as indicated by equation (2), the average number of significant elements scanned per second may be less by more than an order of magnitude.

Many adjacent elements on a scan line have identical values and are therefore redundant. Similar redundancy exists from line to line and frame to frame. Elimination of all redundancy would reduce to a minimum the number of elements which must be scanned to convey information about a scene.

Another major factor to be considered in evaluating bandwidth requirements is that of a priori knowledge of the signal to be transmitted. For example, if the scanning format is known and the element scan rate, line rate and frame rate are constant, then in principle no position information need be transmitted. In conventional television, the stability of the scan equipment is not generally sufficient to provide adequate pictures with no position information. However, since the element, line and frame rates are constant, the position information consists only of a system of synchronizing pulses on a line and frame basis.

Since vertical and horizontal retrace time can be used for transmitting sync pulses, no increase in scanning rate is required to accommodate this information. Therefore, the bandwidth required for conventional television is not altered by the addition of sync information.

In contrast to this condition, consider a system in which amplitude or brightness signals, adjacent in time, are generated by elements which are not directly spatially related. In order to assign an amplitude signal to a corresponding element position at the receiving equipment, a position signal must now be associated with each amplitude signal. It is obvious that the bandwidth required by this composite signal of amplitude

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*By significant elements, we mean those differing in brightness from adjacent elements by a noticeable amount.

and position information will be greater than the signal bandwidth required for amplitude information only.

Systems, which eliminate redundant elements, and therefore utilize a variable scan rate, may still provide a bandwidth saving regardless of the added position information required, provided that the number of elements which can be eliminated from the transmission is sufficient to compensate for the increased amount of information required per element.

2.2 INFORMATION BANDWIDTH VERSUS LINE NUMBER AND FRAME RATE

As noted, the information bandwidth requirement for television is determined by the amount of information needed to describe each sampled resolution element and by the maximum rate at which the elements are sampled. For conventional TV, where the element sequences and rates are constant, the family of hyperbolic curves shown in Figure 2.1 indicates the relationship between resolution, frame rate and bandwidth.

For systems which operate by elimination of redundancy, the curve shown in Figure 2.2 indicates bandwidth ratio (relative to that shown in Figure 2.1) versus minimum redundancy capability. Minimum redundancy capability defines the picture with the least amount of redundancy that can be completely transmitted within one frame period. This curve is based on transmission of position information and amplitude information for each non-redundant element.

As discussed in section 4.4 of the phase two report, for the Edge Detection technique of redundancy removal, the probability of position error increases as the run length increases. For a maximum run length of eight elements, Figure 2.2 would be redrawn as in Figure 2.3. For the system described by Figure 2.3, the position error is cumulative on an element to element basis within a line. In contrast, where a constant element rate is preserved, position error is independent of elemer position and virtually independent of noise.

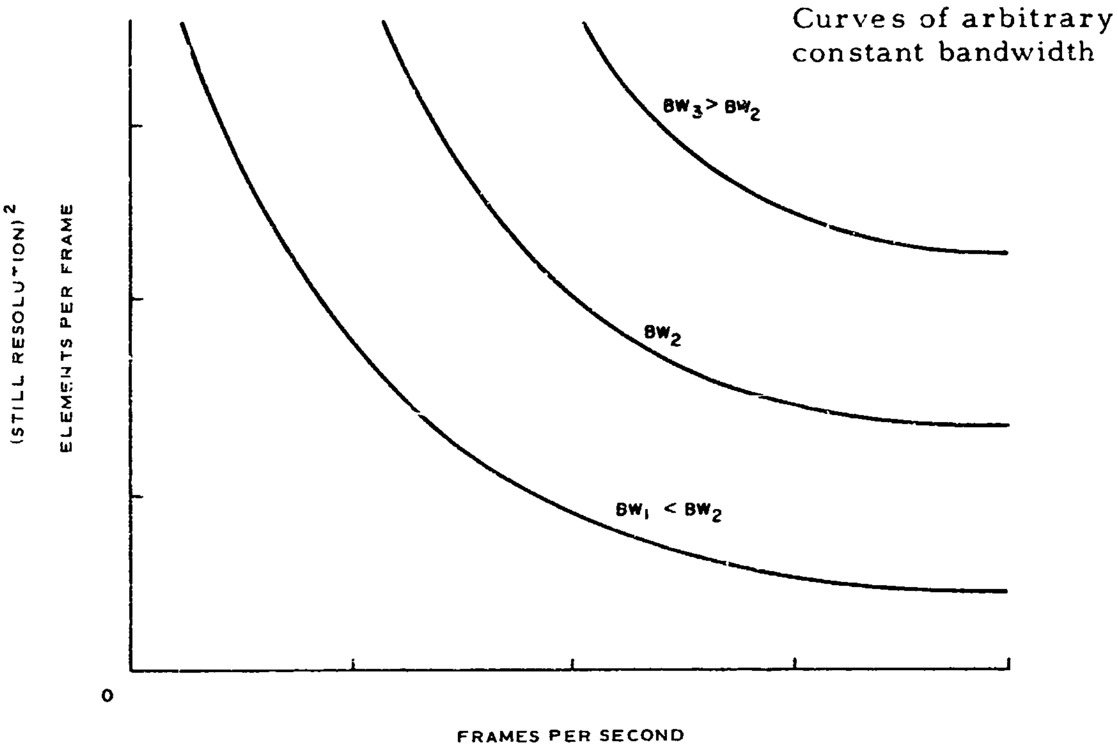


Figure 2.1. Resolution, bandwidth and frame rate relationship - conventional TV.

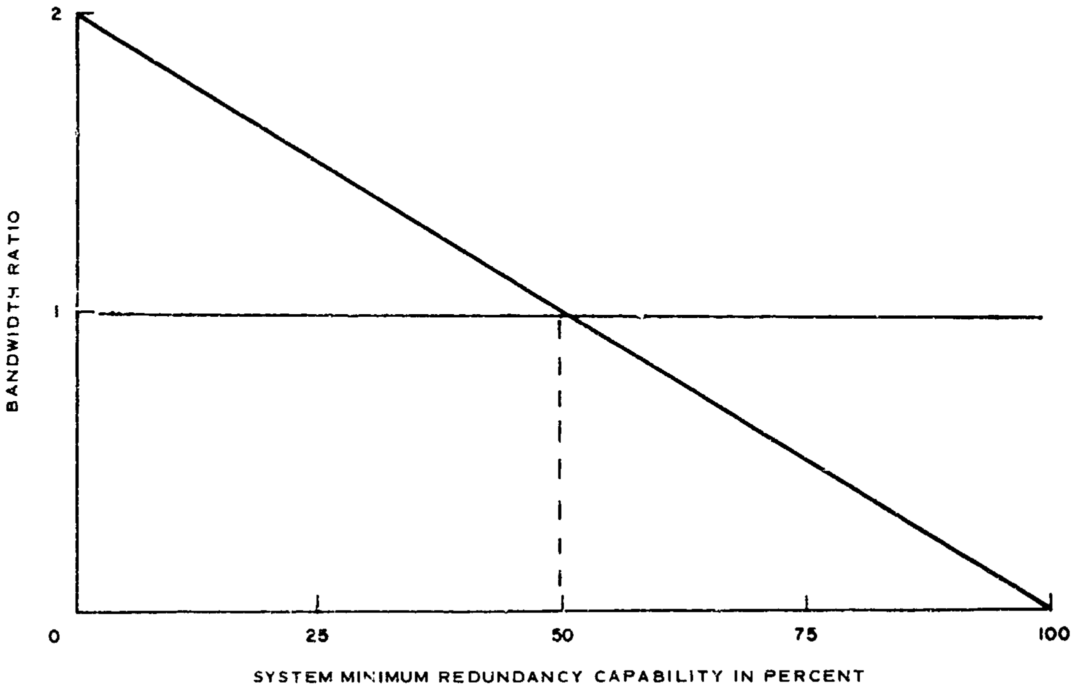


Figure 2.2. System redundancy capability.

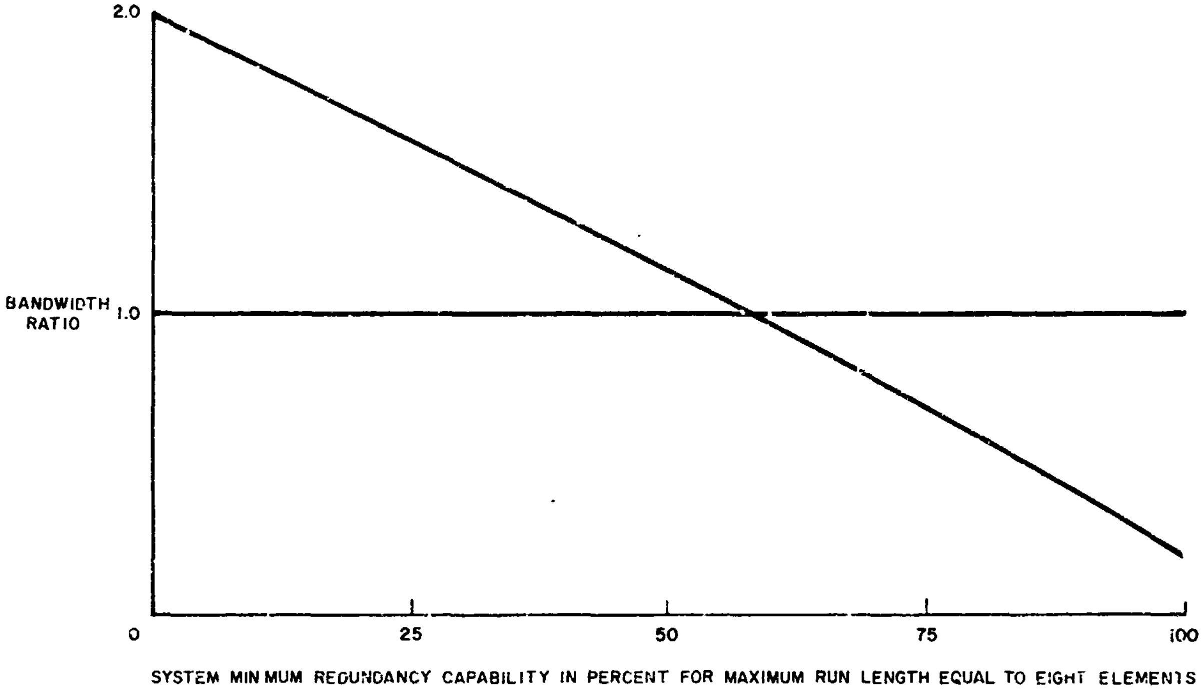


Figure 2.3. Bandwidth ratio versus system redundancy capability.

2.3 VIEWABILITY

Another factor to be considered in bandwidth requirements is the viewability associated with various types of picture degradation. For example, the eye has a different resolution capability for still scenes as contrasted to scenes which move relative to the eye's field of view, as discussed in section three of the Phase II report. In principle, one could degrade the resolution of an area by a factor proportional to the velocity of that area relative to the general scene with little loss of viewability.

Viewability degradation is different for amplitude error versus position error. Tests conducted at Hughes Aircraft Company (Reference 1207) on the effect of noise on television viewability, indicate a large difference in viewing of amplitude error versus position error. The tests were conducted by inserting noise into the if amplifier of a fm receiver having a fm improvement factor of 23 db. The following figures are all extracted from the above reference. It would appear that the viewability of the picture shown in Figure 2.4 is comparable to that of Figure 2.5. The degradation present in Figure 2.4 is predominantly position error, while the degradation in Figure 2.5, at 10 db greater noise level, is predominantly amplitude error. Likewise in Figures 2.6 and 2.7, the difference in noise level is 10 db, Figure 2.6 exhibiting largely position error and Figure 2.7 primarily amplitude error. It is obvious that position errors are more objectionable than amplitude errors. This phenomenon is common to those in fringe TV areas where "snow" is readily acceptable in television pictures so long as solid sync is retained. A possible explanation of this difference in viewability degradation may be in the ability of the eye to provide area interpolation or pattern recognition so long as the position location of reproduced element is correct. It should also be noted that superimposing successive frames having noncoherent amplitude errors will improve resolution while erroneous position information which is noncoherent will contribute to blur and fuzziness.

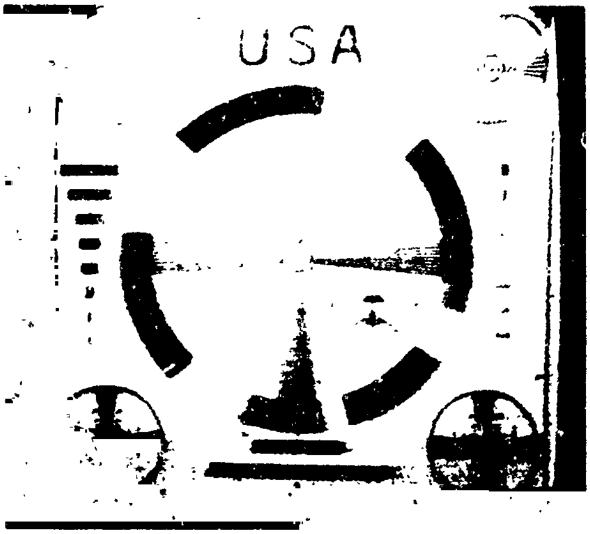


Figure 2.4. Position error 10 db carrier/noise ratio.

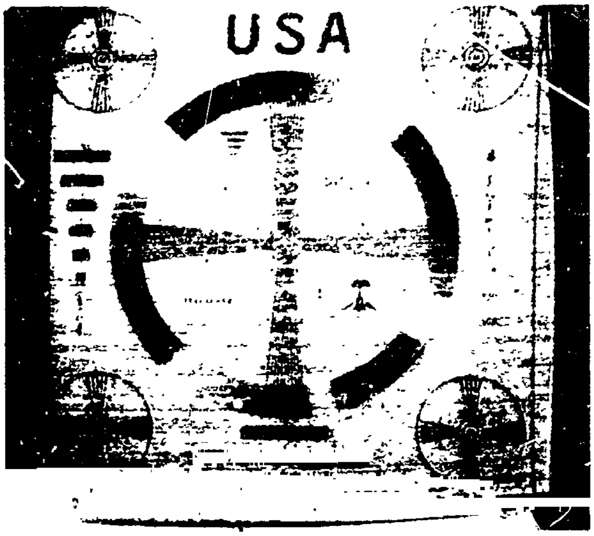


Figure 2.5. Amplitude error only 0 db carrier/noise ratio.

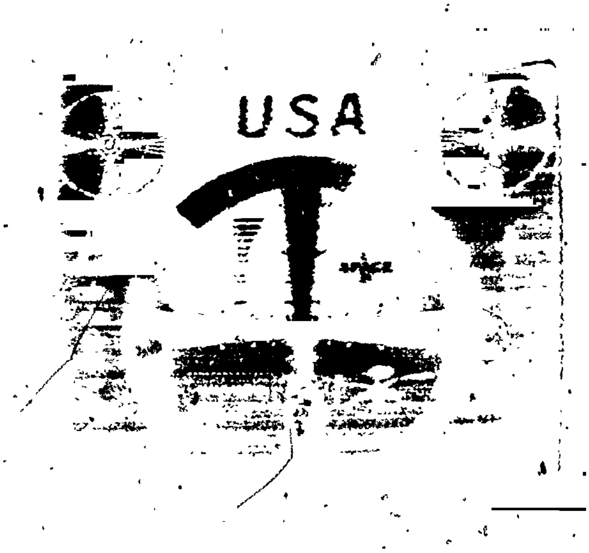


Figure 2.6. Position error +7 db carrier/noise ratio.

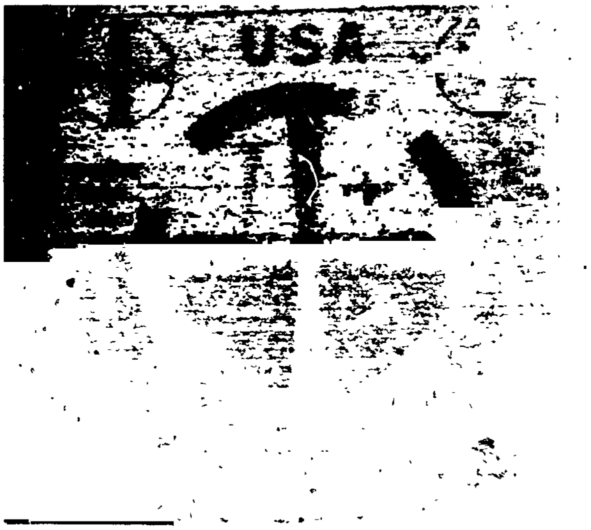


Figure 2.7. Amplitude error only -3 db carrier/noise ratio.

To illustrate the relationship more fully refer to Figure 2. 8. Here the information shown in Figure 4 2 of the Phase II report is combined with the information expressed in Figure 2. 4 through 2. 7 of this section.

It should be noted that at very high signal to noise ratios, position errors and amplitude errors are equally small, and both systems will yield high picture quality. As the signal to noise ratio drops, position error rates increase rapidly (see Figure 4. 2 of the Phase II report) causing rapid degradation of those systems where a priori position information has been eliminated.

2. 4 BANDWIDTH REDUCTION

One can reduce the information bandwidth required for TV video only by reducing the maximum rate of information elements to be transmitted. The obvious initial methods of compression as pointed out in the Phase I report (section 2. 1) include:

a. Reduce frame rate
b. Reduce horizontal and vertical resolution
c. Reduce retrace or flyback time

The next step would be to encode the picture by some technique which would minimize the information required to describe significant elements while minimizing the peak rate at which this information must be transmitted. The necessity of retaining a priori position information for all but the most highly redundant scenes implies a requirement for maintaining constant frame, line, and element rates at the camera. To minimize the peak information rate while meeting this requirement without lowering the frame rate or resolution below an acceptable level, requires a technique which processes only a portion of the total frame information during a frame period.

Such a system would result from a dot sampling technique in which each frame consists of a low resolution dot pattern. In addition the dot patterns of successive low resolution frames can be so ordered that they can be interlaced at the receiver to generate a high resolution low

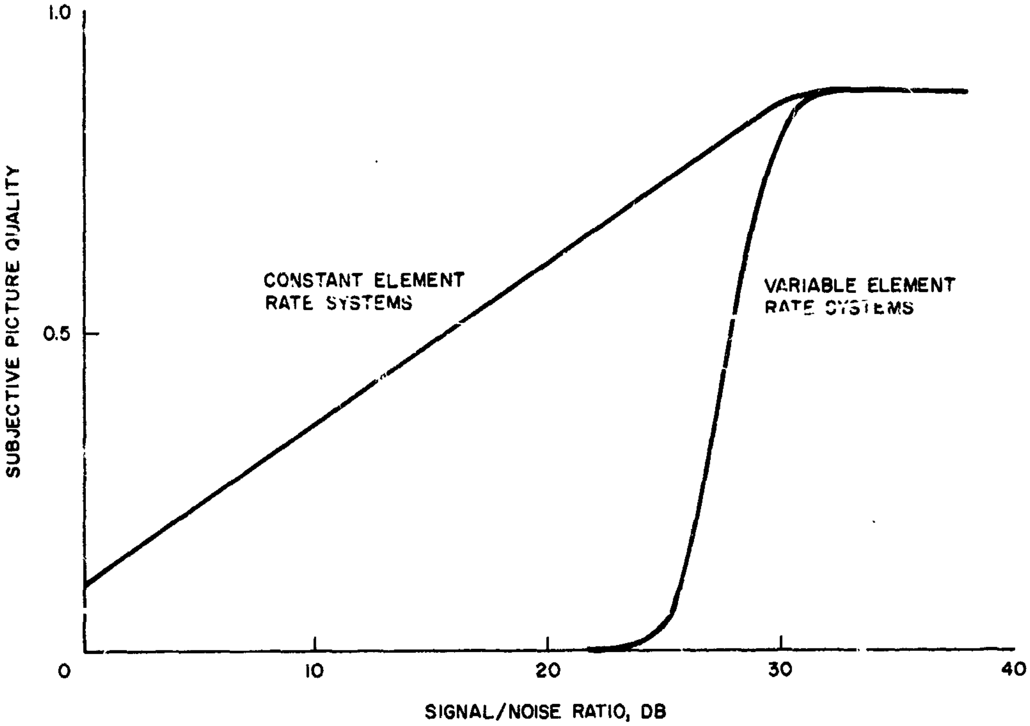


Figure 2.8. Picture quality versus signal to noise ratio.

frame rate picture. The system developed at Hughes Aircraft, called "Multiple Interlace," incorporates these concepts and appears to be the best overall system for obtaining large information bandwidth reduction for use in deep space television.

3. MULTIPLE INTERLACE SYSTEM

The multiple interlace system is an analog television system for reducing the bandwidth required for transmission of picture information. The system takes advantage of the reduced resolution of the human visual system when viewing objects which are moving with respect to the field of view. The bandwidth required by a high resolution - high scan rate system can be reduced, with little decrease in viewer acceptance, by using low resolution and high frame rate for objects moving relative to the field of view and high resolution at low frame rate for objects stationary relative to the field of view.

3.1 GENERAL DESCRIPTION

The system utilizes a "pseudo-random" multiple interlace technique in which the high resolution, low frame rate picture is composed of a number of superimposed low resolution, high frame rate pictures. Instead of a variable intensity line for the reproduced picture, the elements are variable intensity dots. The "coarse" dot structures of the superimposed low resolution frames become the multiple interlaced fields which compose the high resolution picture.

A "wide-band" video signal from a conventional television camera is fed to a video encoder. The encoder selects different parts of the picture from successive fields in a pseudo-random sequence and processes the information for transmission over a narrow bandwidth link. No storage devices are needed at the camera or transmitter since the information desired from each frame is selected in real time by gating circuits. The resulting picture information can be reconstructed into a regular TV format at the receiver by means of a decoder, a storage device, and a scan converter.

3.1.1 Camera

The block diagram of the basic camera required for the multiple interlace system is shown in Figure 3.1. The camera is a complete unit whose operation is independent from the encoder. The output video from the camera is fed to the encoder for processing. The video can also be used for direct viewing, near the location of the camera, by using a conventional TV monitor.

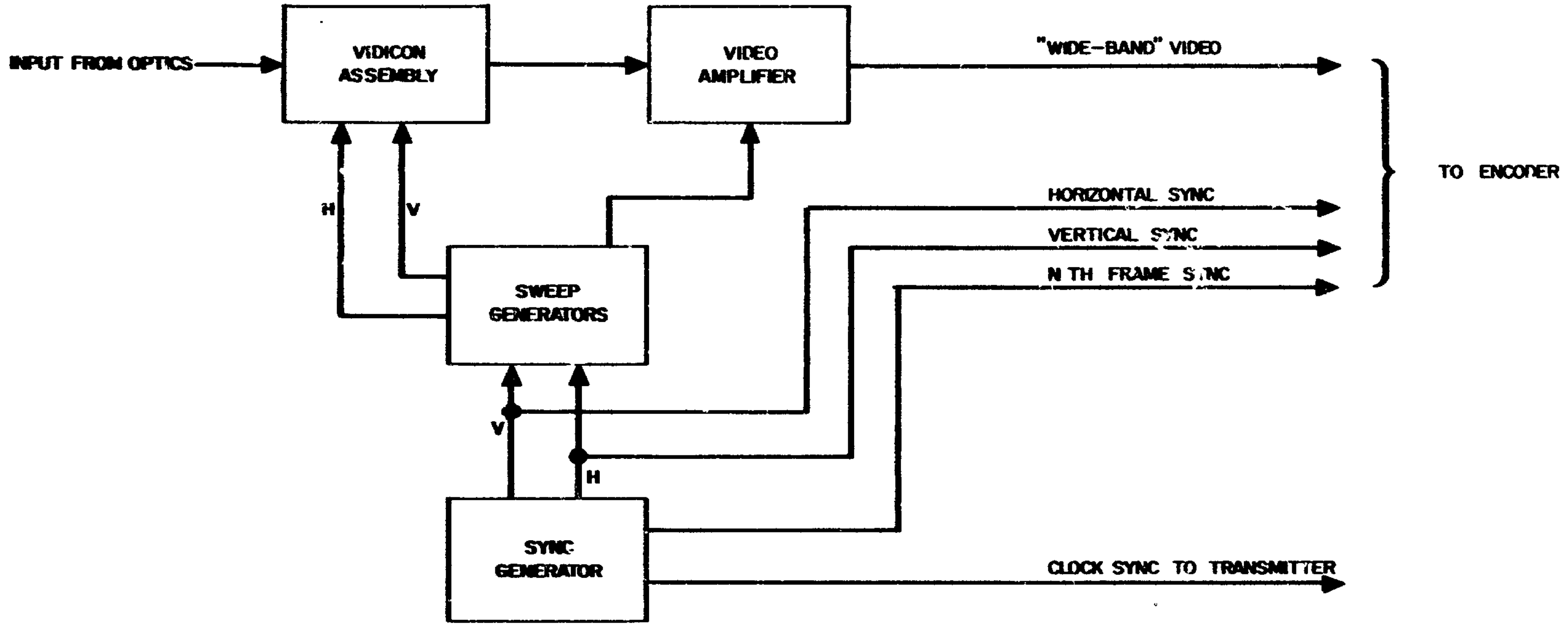


Figure 3.1. Basic camera.

The camera consists of a vidicon assembly, a video amplifier, sweep generators and sync generators. The camera is essentially "standard" in design and operation except for the Nth frame sync signal (where N is equal to the multiple interlace ratio). The video, horizontal sync, vertical sync and Nth frame sync are fed directly to the encoder. The clock sync, which is the basic frequency reference for the entire system, is fed directly to the transmitter. The clock sync is used at the decoder for generating horizontal and vertical sync.

3.1.2 Encoder

The multiple interlace system is implemented by the encoder shown in Figure 3.2. The encoder consists of four major parts; a gating pulse train generator, a gating pulse train sequence selector, a video gate and box car detector, and a low pass filter.

The video gate samples the video information at discrete points and produces an output consisting of narrow pulses. This gated video signal is fed to a box-car detector which enhances the signal-to-noise ratio by stretching the pulses. The stretched pulses are fed through a low pass filter and modulate the transmitter.

The gating pulses are produced in the gating pulse train (GPT) generator. The number of different pulse trains required is equal to the multiple interlace ratio (N). The pulse trains are synchronized with the horizontal sweep.

The required sequence selection of the N number of gating pulse trains is accomplished by the gating pulse train (GPT) sequence selector. The GPT sequence selector is synchronized with the vertical and horizontal sweeps and is reset by the Nth frame sync signal.

The encoder, therefore, generates a signal which represents a sequence of N different low resolution frames. Each frame contains 1/N of the picture elements of the original scene.

3.1.3 Decoder and Storage

A decoder is required at the receiver to process the encoded video signal for display and/or scan conversion. The decoder basically consists of a GPT generator, a GPT sequence selector and a video gate.

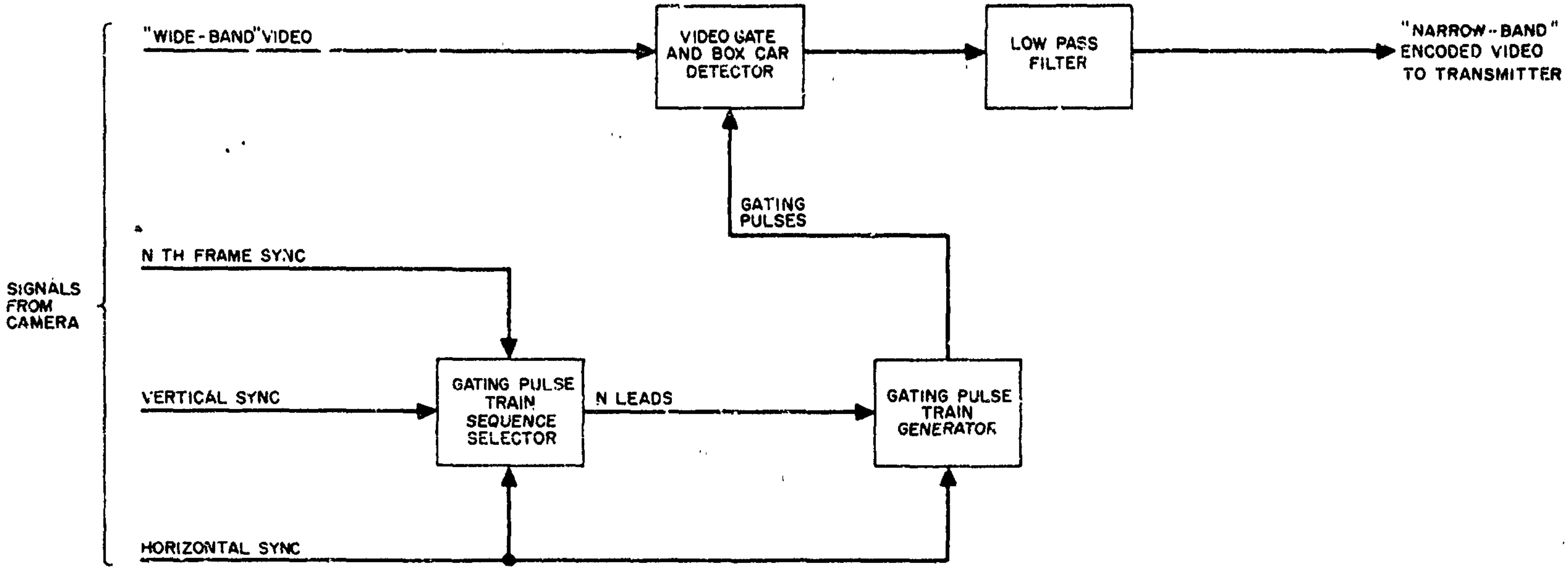


Figure 3.2. Multiple interlace encoder.

The decoder functions essentially the same as the encoder except that the box-car detector and filter are not required. A time delay in the decoder compensates for the delay through the low pass filter in the encoder.

The full capabilities of the multiple interlace system are obtained when the decoder is used in conjunction with a storage device. N channels of recording are required. The decoder must also have N channels. One recorder channel is used for each low resolution frame to be used in the high resolution format. The information in each recorder channel is replaced periodically at the encoder cyclic rate; each low resolution frame is stored, sampled up to N times and replaced. The high resolution frames are reconstructed by the N channel decoder by sampling elements in stored low resolution frames in the required sequence. The output signal from the decoder can be fed to a monitor as normal wideband video.

3.2 DESIGN DETAILS FOR TYPICAL SYSTEM

The design details for a typical multiple interlace system are presented in this section. A camera, encoder, and decoder with magnetic drum storage are described. The encoder is described in the greatest detail.

3.2.1 System Parameters

The television system performance and key parameters are shown in Table 3.1.

Video Bandwidth Required for Transmission	92	kcps
Video Bandwidth in Camera	1.47	mcps
Low Resolution Frames per second	30	
High Resolution Frames per second	1.875	
Horizontal Resolution in TV lines	172	
Vertical Resolution in TV lines	169	
Aspect Ratio	4:3	
Total Horizontal Lines per frame	256	
Total Horizontal Elements per line	384	
Factors in number of line per frame	2^8	
Factors in number of horizontal elements per line	3×2^7	
Multiple Interlace Ratio of Encoder	16:1	
Kell Factor	0.71	

Table 3.1. System performance and parameters.

Vertical Interlace Ratio	1:1
Vertical Blanking	0.07V
Horizontal Blanking	0.16H
Clock Oscillator Frequency (16 f_H)	122.88 kcps
Horizontal Frequency (f_H)	7.68 kcps
Vertical Frequency (f_V)	30 cps

Table 3.1. System performance and parameters (continued).

3.2.2 Camera

The detailed block diagram of a typical camera for use with the multiple interlace system is shown in Figure 3.3. The camera consists of a vidicon assembly, a video amplifier, a line-to-line keyed clamp, a sync-blanking adder, a horizontal and vertical sweep generator, a blanking generator, a crystal controlled clock oscillator, a frequency divider and horizontal and vertical sync generator, and a 16th frame counter and sync generator.

The vidicon assembly converts an optical image into an electrical signal and consists basically of a vidicon and a magnetic deflection yoke. For applications where size and weight is critical, a one-half inch vidicon with magnetic deflection and electrostatic focus should be used. The one-half inch vidicon has a resolution capability in excess of 400 lines.

The electrical signal from the vidicon is amplified and d-c restored on a line-to-line basis by a clamp keyed with the horizontal sync pulses. The video amplifier has a bandwidth greater than 1.5 mcps.

The system blanking pulses generated in the blanking generator are added to the video in the sync-blanking adder. The system blanking pulses are slightly wider than the vidicon blanking pulses.

The 16th frame sync signal is also added to the video in the sync-blanking adder. The block diagram of the 16th frame counter and sync generator is shown in Figure 3.4. The circuit is the main addition to a "conventional" type TV camera to make it operate in conjunction with a multiple interlace system. A four stage counter, triggered by the vertical sync, feeds a trigger pulse to a delay monostable multivibrator at the leading edge of every 16th vertical sync pulse.

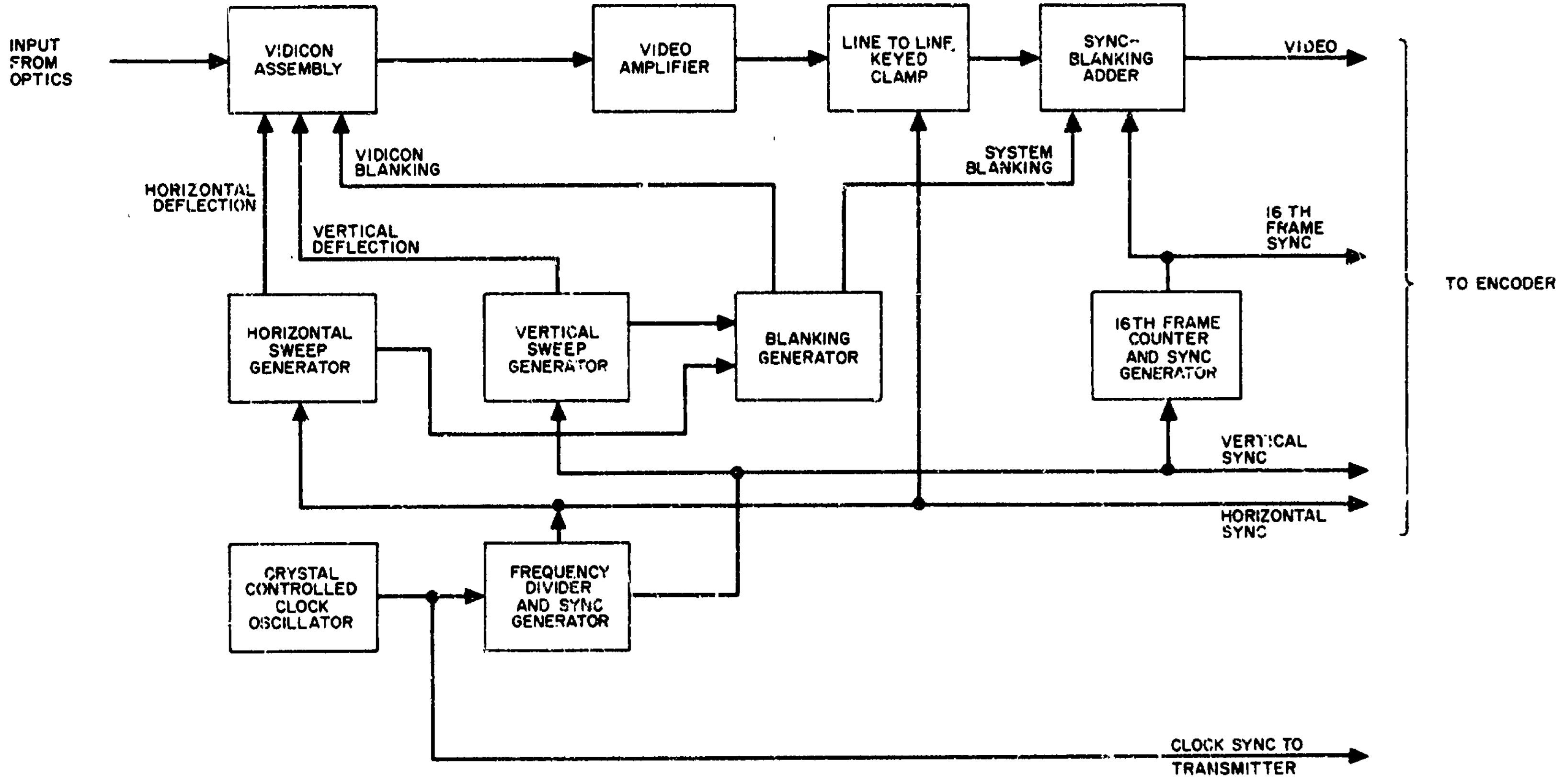


Figure 3.3. Typical camera for use with multiple interlace TV system.

Figure 3.4. 16th frame counter and sync generator.

The delay time is approximately equal to the time required for six horizontal lines. At the end of the delay time the sync pulse generator is triggered and produces a negative pulse approximately six horizontal lines wide. The resulting 16th frame sync is added to the vertical sync resulting in a composite vertical sync waveform as shown in Figure 3.5.

A crystal controlled oscillator operating at a frequency of 122.88 kcps provides a stable frequency reference for the multiple interlace system horizontal and vertical sync. The horizontal sync pulses are generated by dividing the clock frequency by 16 (2^4) to obtain a frequency of 7.68 kcps. The vertical sync pulses are generated by dividing the horizontal frequency by 256 (2^8) to obtain a frequency of 30 cps.

The horizontal and vertical deflection signals are obtained by conventional sweep generators which are synchronized with the stable horizontal and vertical sync pulses. The sweep generators also feed synchronizing signals to the blanking generator. The blanking generator creates pulses that are used for blanking the vidicon during horizontal and vertical retrace, and for providing system blanking.

3.2.3 Encoder

The functions of the encoder, as explained in section 3.1.2, are implemented by a video gate and box car detector, a low pass filter, a gating pulse train generator, and a gating pulse train sequence selector.

3.2.3.1 Video Gate, Box Car Detector and Low Pass Filter. A schematic diagram of a typical video gate, box car detector and low pass filter is shown in Figure 3.6. The video gate consists of resistors R1 thru R4 and diodes CR1 thru CR6. The circuit acts as a bi-directional switch with a very small pedestal or offset. The gate is open during the interval between gating pulses (diodes CR1 thru CR4 are back biased). When the gating pulses occur, diodes CR5 and CR6 are back biased thereby allowing current thru resistors R1 and R2 to turn on diodes CR1 through CR4. During the time the gate is closed, capacitor C1 charges

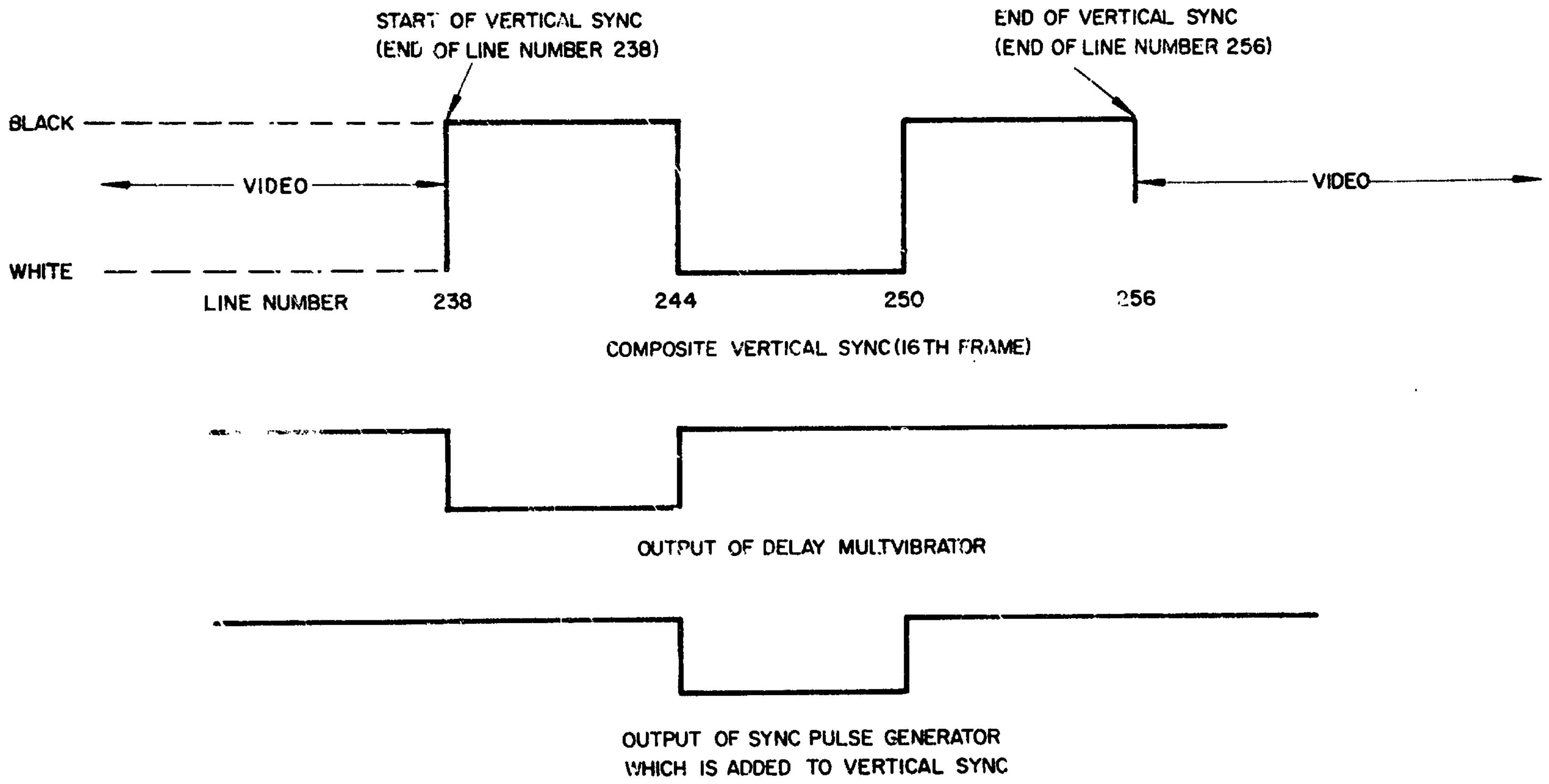


Figure 3.5. Waveforms of composite vertical sync for 16th frame and 16th frame sync generator.

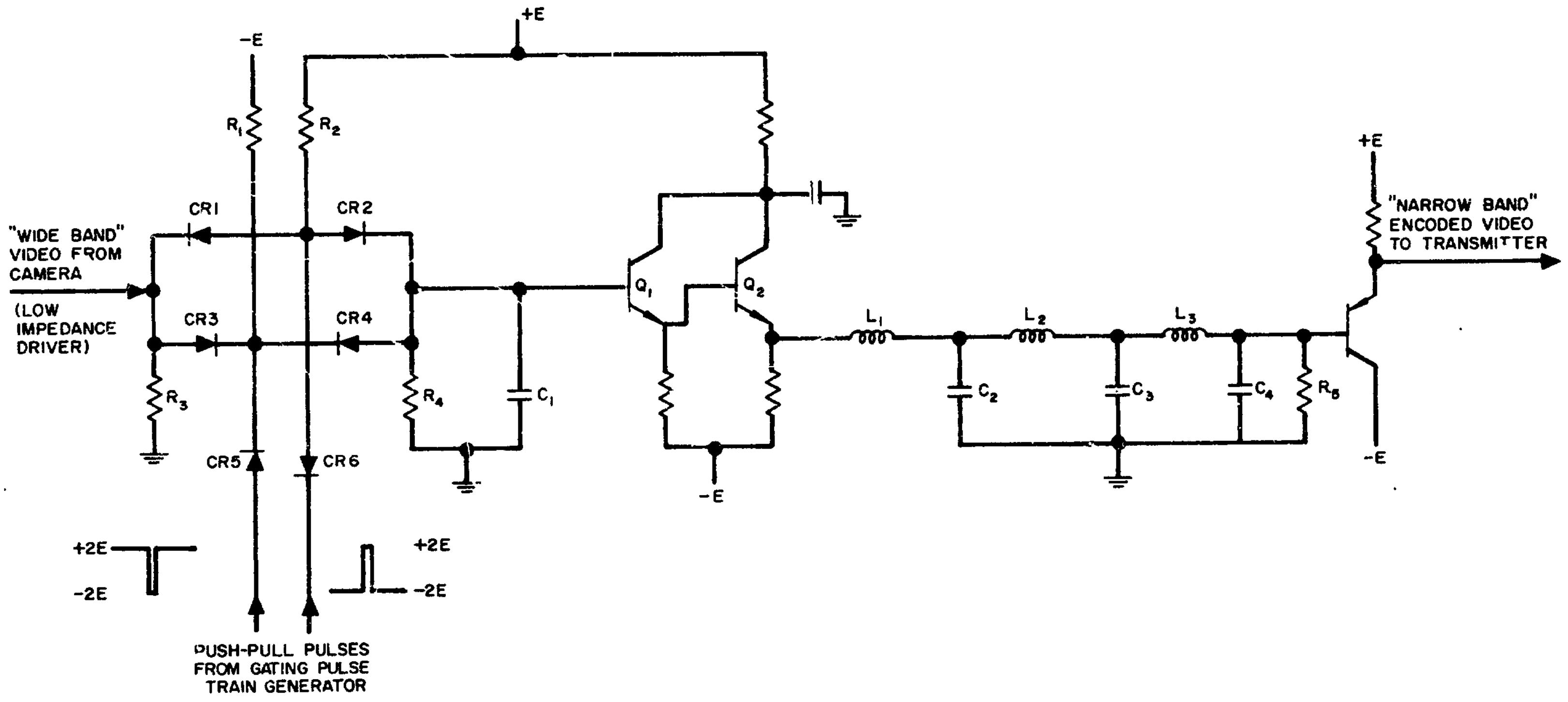


Figure 3.6. Typical video gate, box car detector and low pass filter.

to the peak value of the "wide band" video from the camera. When the gate opens the voltage on the capacitor remains essentially constant until the gate closes again. Therefore, the bi-directional switch (video gate) in conjunction with capacitor C1 acts as a pulse stretching circuit or box car detector. The circuit is designed so that the time constant $(R_T)(C1)$ is very long compared to the time interval (5.4 μsec) between pulses. R_T is equal to the parallel combinations of R_4, the input impedance of Q1, and the impedance of the video gate when open.

The video from the box car detector is fed through a 92 kcps low pass filter (L1 thru L3, C2 thru C4, and R5) and then to the transmitter. The filter is a 6-pole no-overshoot filter with a 36 db/octave asymptotic roll-off. The filter is designed for no overshoot or ringing in response to a step change in input, and for a nearly linear phase vs. frequency characteristic to minimize video signal distortion.

3.2.3.2 Gating Pulse Train Generator. The gating pulse trains are produced in the gating pulse train (GPT) generator as shown in Figure 3.7. Sixteen different pulse trains are required. The pulse trains (designated A through P) are produced by a special eight stage counter (that has very small propagation delay) and a pulse generator. The pulse trains are selected, one at a time, by sixteen pulse train selection "AND" gates that receive selection signals from the GPT sequence selector.

The pulse trains are accurately synchronized with the horizontal sync pulses by a phase locked loop consisting of a voltage controlled oscillator (VCO), a phase detector, a lag-lead network, an eight stage pulse train counter that divides by 16, and a conventional counter that divides by 24. The design problems of the phase locked loop are similar to those encountered in commercial television horizontal synchronization. The phase locked loop must provide a high repetitive phase accuracy with acceptable immunity to noise and acceptable pull-in capability. Line-to-line timing errors reduce the horizontal resolution. The maximum tolerable timing error is assumed to be one-half picture element, or approximately 0.17 μsec. This results in a maximum repetitive phase error of approximately 0.5 degrees.

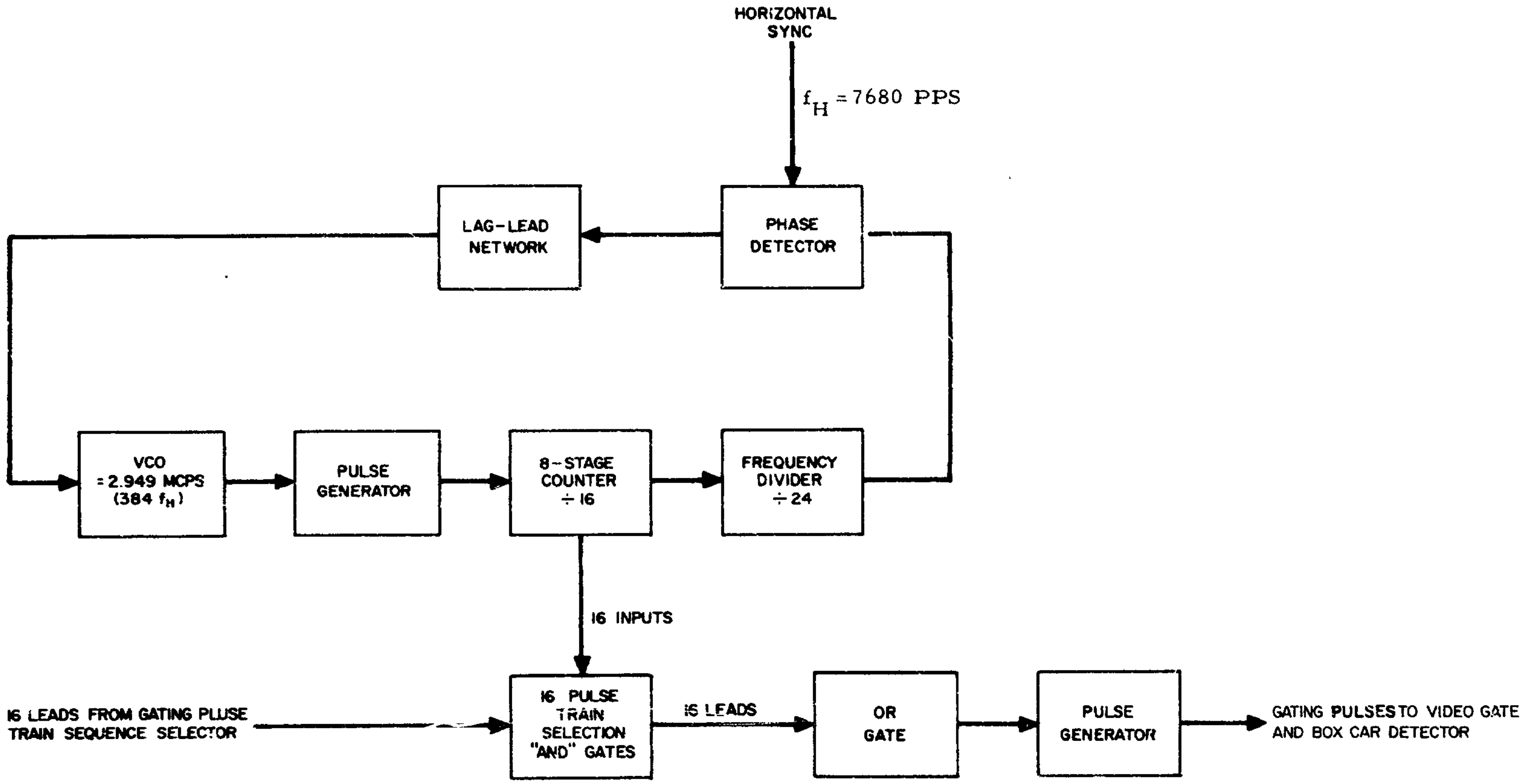


Figure 3.7. Gating pulse train generator.

The voltage controlled oscillator operates at a frequency of 2.94912 mcps, which is 384 times the horizontal frequency (f_H). The VCO frequency is changed by varying the d-c voltage on two silicon voltage variable capacitors. The lag-lead network is designed to optimize the servo response.

The block diagram of the eight stage pulse train counter is shown in Figure 3.8. The two outputs from each of the eight flip-flops are fed to separate AND gates. The selected flip-flop output signal triggers a pulse generator thereby producing the desired gating pulse train.

The states of the flip-flops in the eight stage counter are shown in Figure 3.9. The counter is wired so that once every cycle (every 16th input pulse) all of the flip-flops are simultaneously in the "0" state. This feature insures proper sequencing of the counter. Each flip-flop in the counter operates at one-sixteenth the frequency of the VCO and is triggered only upon occurrence of a VCO pulse. Therefore, propagation delay in the counter is essentially nonexistent.

Existing circuit techniques can be used to generate accurate gating pulse trains that easily meet the needs of the system. The width of individual pulses is approximately 0.34 μsec with a period of approximately 5.4 μsec. Rise and fall times of less than 0.015 μsec and timing errors between pulse trains of less than 0.01 μsec can be obtained with relatively straightforward circuitry.

3.2.3.3 Gating Pulse Train Sequence Selector. The block diagram of the gating pulse train (GPT) sequence selector is shown in Figure 3.10. The sequence logic and location of dots in two low resolution frames is shown in Figure 3.11.

The pulse train sequence (AGMC ....FL) is generated by the four stage pulse train sequence counter and sixteen AND gates. The states of the flip-flops in the counter are shown in Figure 3.12. The counter is triggered by each horizontal sync pulse and, therefore, a different pulse train is selected for adjacent horizontal lines. Every sixteenth horizontal line (for a given frame number) uses the same gating

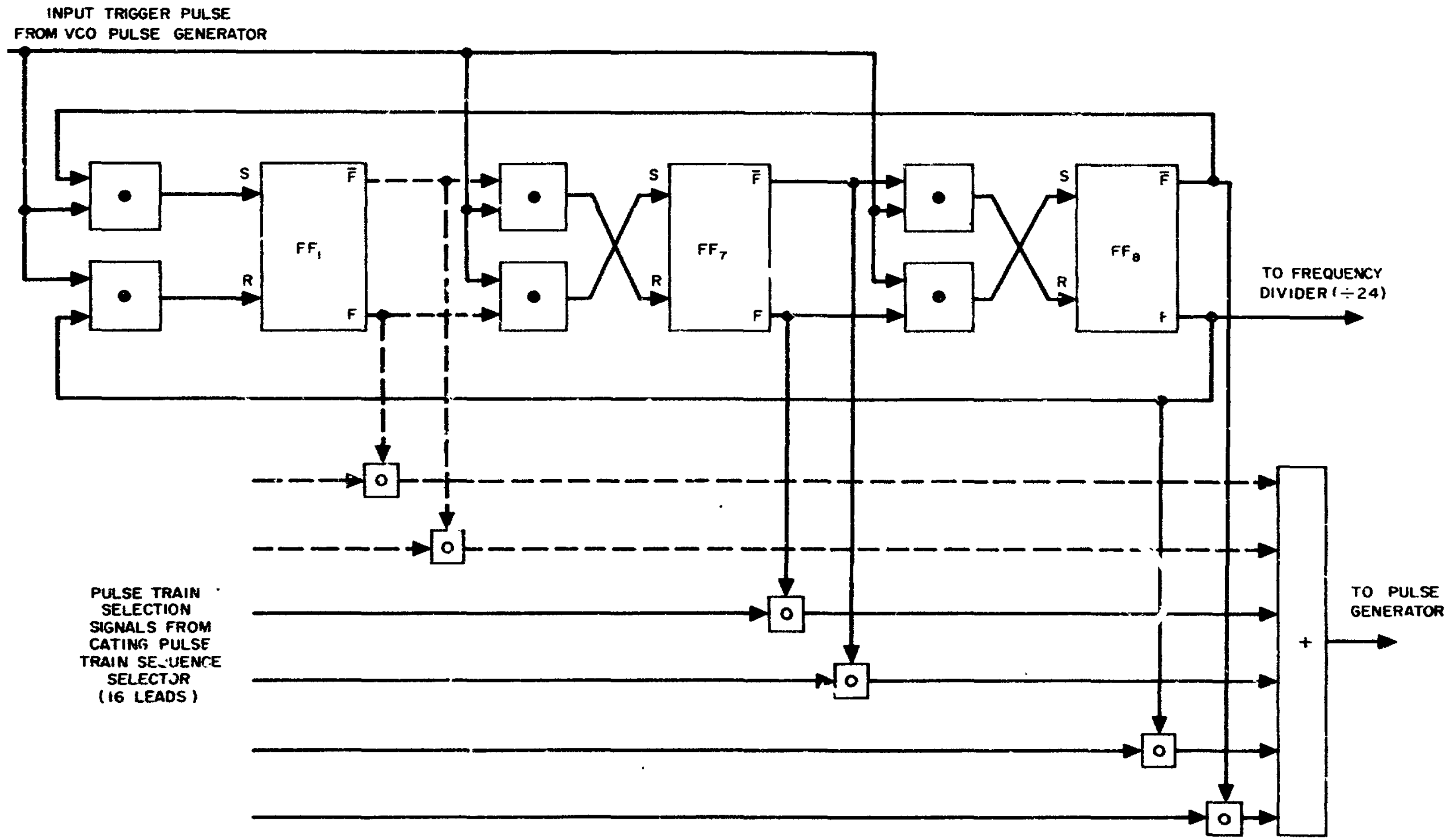


Figure 3.8. Eight stage pulse train counter and sixteen pulse train selection gates.

Input Pulse	State of Flip Flop							
	FF$_8$	FF$_7$	FF$_6$	FF$_5$	FF$_4$	FF$_3$	FF$_2$	FF$_1$
1	0	0	0	0	0	0	0	1
2	0	0	0	0	0	0	1	1
3	0	0	0	0	0	1	1	1
4	0	0	0	0	1	1	1	1
5	0	0	0	1	1	1	1	1
6	0	0	1	1	1	1	1	1
7	0	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	0
10	1	1	1	1	1	1	0	0
11	1	1	1	1	1	0	0	0
12	1	1	1	1	0	0	0	0
13	1	1	1	0	0	0	0	0
14	1	1	0	0	0	0	0	0
15	1	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0

Figure 3.9. States of the flip flops in the eight stage pulse train counter.

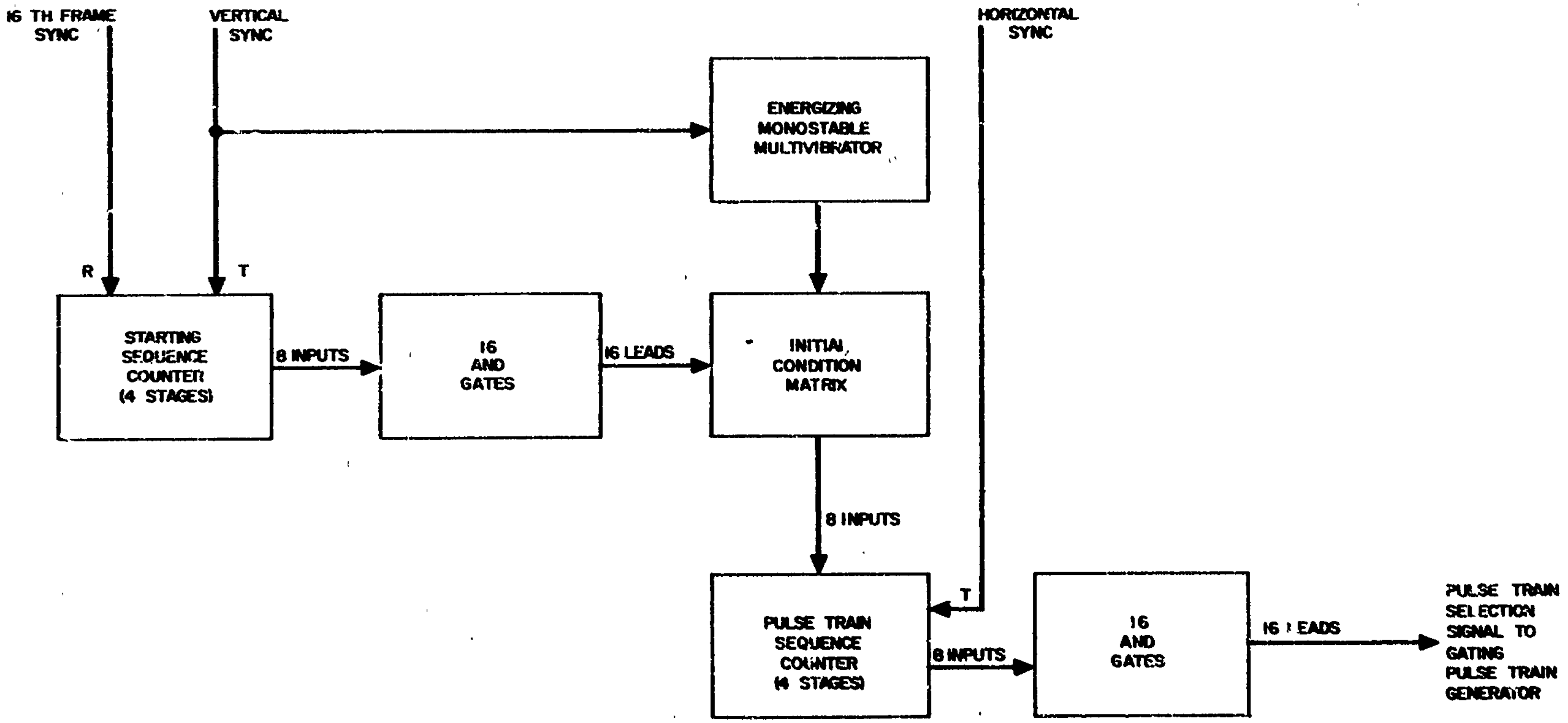


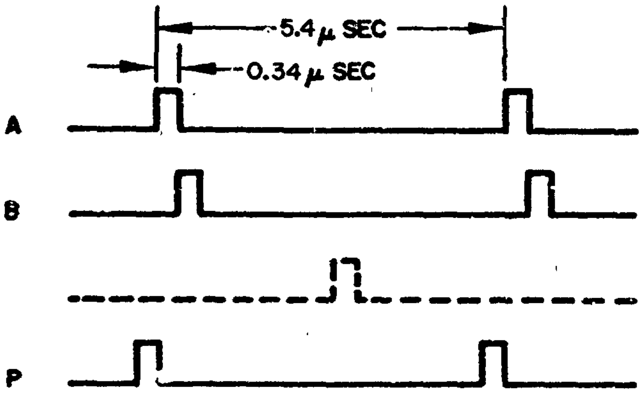
Figure 3.10. Gating pulse train sequence selector.

PULSE TRAIN SEQUENCE

A G M C I O E K B H N D J P F L

STARTING SEQUENCE

FRAME	PULSE TRAIN	FRAME	PULSE TRAIN
1	A	9	I
2	D	10	L
3	G	11	O
4	J	12	B
5	M	13	E
6	P	14	H
7	C	15	K
8	F	16	N



GATING PULSE TRAINS

PULSE TRAINS

LINE NUMBER	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	1			2												
2							1			2						
3													1			2
4			1			2										
5									1			2				
6	2														1	
7					1		2									
8											1		2			
9		1	2													
10								1	2							
11														1	2	
12				1	2											
13										1	2					
14		2														1
15						1		2								
16												1		2		

DOT LOCATIONS FOR LOW RESOLUTION
FRAMES NO.1 AND NO.2
(BASIC BLOCK OF DOTS)

Figure 3.11. Gating pulses trains and sequence logic of encoder.

State of Flip-Flop				Pulse Train Sequence	Line Number of Basic Block
FF_4	FF_3	FF_2	FF_1		
0	0	0	0	A	1
0	0	0	1	G	2
0	0	1	0	M	3
0	0	1	1	C	4
0	1	0	0	I	5
0	1	0	1	O	6
0	1	1	0	E	7
0	1	1	1	K	8
1	0	0	0	B	9
1	0	0	1	H	10
1	0	1	0	N	11
1	0	1	1	D	12
1	1	0	0	J	13
1	1	0	1	P	14
1	1	1	0	F	15
1	1	1	1	L	16

Figure 3.12. States of the flip-flops in the pulse train sequence counter.

pulse train. Since there are sixteen different gating pulse trains, the basic block of dots shown in Figure 3.11 consists of sixteen rows of dots by sixteen columns of dots. A basic block of dots is defined as the largest grouping of dots, that is non-repetitive.

Since the pulse train sequence remains the same for all frames, the starting point (the pulse train for the first line) is changed from frame to frame so that all of the dots in each basic block are presented after sixteen frames. The pulse train starting sequence (Frame 1 - Pulse Train A, Frame 2 - Pulse Train D, ---- Frame 16 - Pulse Train N) is generated by the four stage starting sequence counter and sixteen AND gates. The states of the flip-flops in the counter are shown in Figure 3.13.

At the start of each frame, the pulse train sequence counter is set by the initial condition matrix (shown in detail in Figure 3.14) to provide the selected pulse train starting sequence. A power "ON" pulse is applied to the initial condition matrix when the energizing monostable multivibrator is triggered by the trailing edge of the vertical sync pulse. The signal input from the starting sequence counter designates a pulse train that is to be set into the pulse train sequence counter. For example, assume that pulse train D is selected by the starting sequence counter. The power "ON" pulse activates the AND gates and amplifiers (in Figure 3.14), and four signals are formed that will set the proper initial condition in the pulse train sequence counter (FF1 to 1, FF2 to 1, FF3 to 0, and FF4 to 1). These four signals are fed through OR gates, are amplified and then force the counter into the selected initial condition. The duration of the power "ON" pulse is ≈ 65 µsec (≈ one-half a horizontal line), and the pulse train counter is sequenced by all following horizontal sync pulses.

Some electrical characteristics of the gating pulse train sequence selector are:

Starting Sequence Counter

Maximum counter rate	30 cps
Rise and Fall Times	<1 msec

State of Flip-Flop				Starting Sequence of Pulse Trains	Frame Number
FF_4	FF_3	FF_2	FF_1		
0	0	0	0	A	1
0	0	0	1	D	2
0	0	1	0	G	3
0	0	1	1	J	4
0	1	0	0	M	5
0	1	0	1	P	6
0	1	1	0	C	7
0	1	1	1	F	8
1	0	0	0	I	9
1	0	0	1	L	10
1	0	1	0	O	11
1	0	1	1	B	12
1	1	0	0	E	13
1	1	0	1	H	14
1	1	1	0	K	15
1	1	1	1	N	16

Figure 3.13. States of the flip-flops in the starting sequence counter.

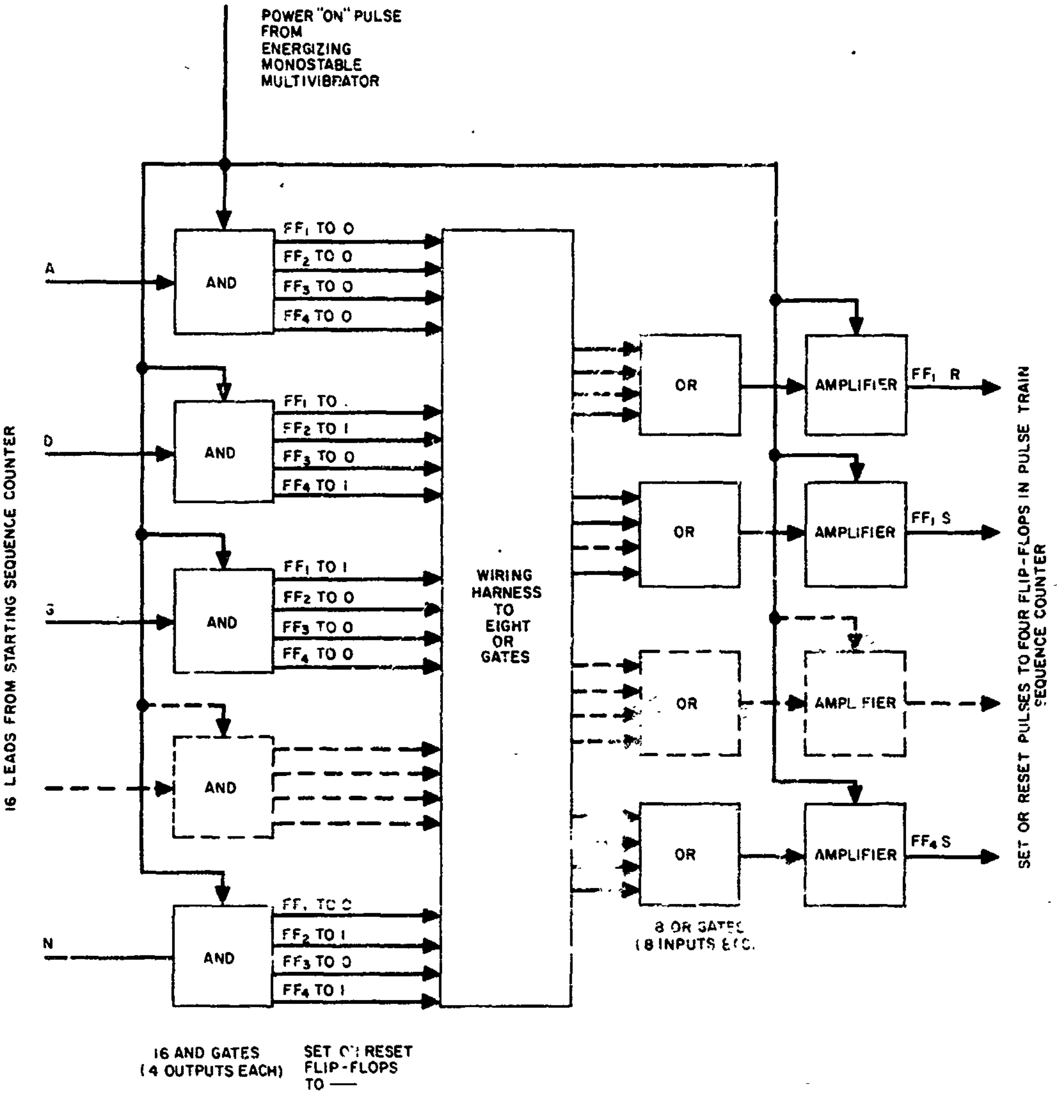


Figure 3.14. Initial condition matrix.

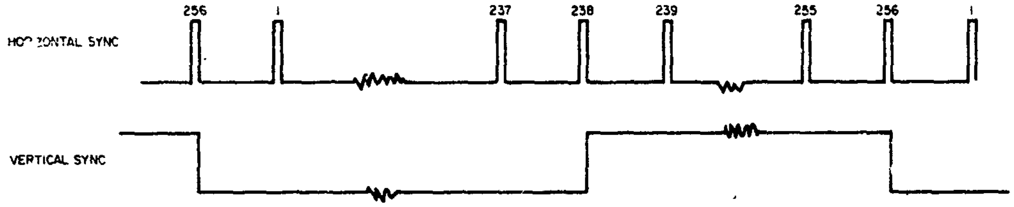
Pulse Train Sequence Counter		
Maximum counting rate	7.68	kcps
Rise and Fall Times	<1	μsec
Energizing Monostable Multivibrator		
Pulse Width	65	μsec ± 20%
Rise and Fall Times	<1	μsec

These requirements are easily met with modern transistors in conventional flip-flops and multivibrators.

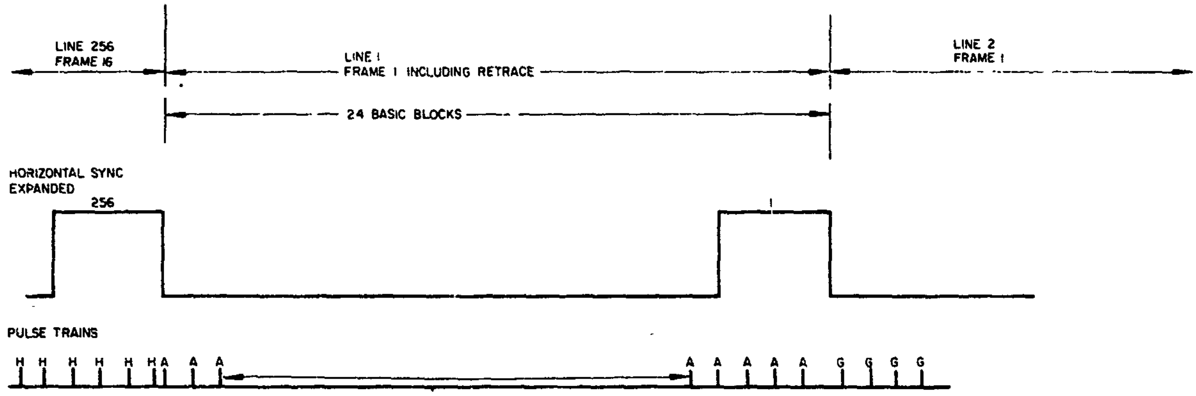
3.2.3.4 Typical System Timing. The typical timing relationships of the multiple interlace system are shown in Figures 3.15 and 3.16. Individual lines end with a horizontal sync pulse and individual frames end with a vertical sync pulse. Vertical sync pulses start and end at the trailing edge of horizontal pulses. Part (A) of Figure 3.15 shows the time relationship between horizontal and vertical sync pulses. The vertical sync starts at the trailing edge of the 238th horizontal sync and ends at the trailing edge of the 256th horizontal sync. Part (B) of Figure 3.15 shows the time relationship between horizontal sync pulses and gating pulse trains. The beginning of Line 1 of Frame 1 occurs at the trailing edge of the 256th horizontal sync, and the end occurs at the trailing edge of the 1st horizontal sync. Gating pulse train A is used during line 1 to place a variable intensity dot in each of the 24 basic blocks of dots.

The timing diagram in Figure 3.16 shows the relationship between the 16th frame vertical sync and the horizontal sync. The leading edge of the vertical sync triggers the starting sequence counter. The leading edge of the 16th vertical sync triggers the counter to 0 0 0 0 (Pulse train A). The trailing edge of the 16th frame sync always resets the sequence counter to 0 0 0 0 (Pulse train A) thereby assuring proper synchronization.

The trailing edge of the vertical sync triggers the energizing monostable multivibrator. This causes the pulse train designated in the sequence counter to be set into the pulse train sequence counter. For example, pulse train N occurs during the first line of the 16th frame and pulse train A occurs during the first line of the 1st frame.



(A) RELATIONSHIP OF VERTICAL AND HORIZONTAL SYNC



(B) RELATIONSHIP OF HORIZONTAL SYNC AND GATING PULSE TRAINS

Figure 3.15. Timing diagram No. 1.

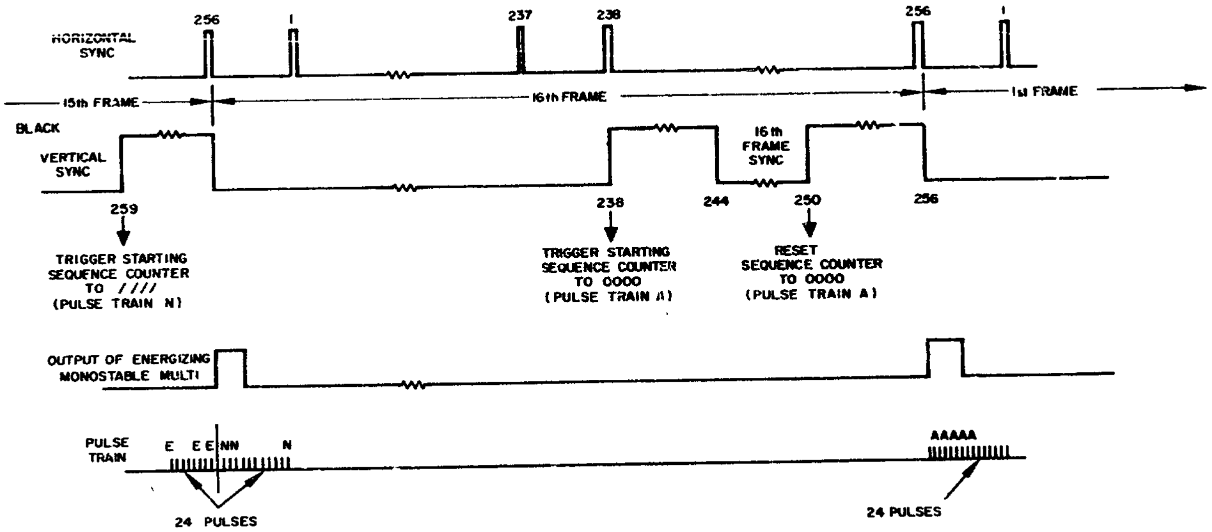


Figure 3.16. Timing diagram No. 2.

3.2.4 Decoder

The block diagram of the multiple interlace decoder with 16 channel magnetic drum storage is shown in Figure 3.17. Incoming low resolution frames are stored in individual channels of the drum as designated by the record channel selector. Speed control of the drum is accomplished by comparing incoming sync with pre-recorded sync marks. Short term timing corrections are applied on a line-to-line basis to the incoming narrow band video to establish correct time relationship with pre-recorded drum sync marks. Information from each of the channels is assembled by the sixteen channel decoder which samples the narrow band data to construct the display video.

3.2.4.1 Decoder Timing. The diagram of Figure 3.18 indicates the format and chronology of the stored frames as well as the sampling sequence and timing. The video waveforms are for the full storage mode with a stationary scene. Each of the 256 lines of the final high resolution display is made up of 24 segments of the 16 picture elements each, which are assembled from samples of narrow band video taken from each of the stored low resolution frames. A portion of the box-car encoder samples and the subsequent narrow-banded video for several low resolution frames is shown for the first horizontal line of a camera and display frame. The decoder sampling points (dictated by the gating pulse trains) progress from top to bottom of the diagram as indicated by the slanted dashed lines. The positions of the channel and frame numbers are varied from line to line because for each line the sampling sequence has a different starting point and a different order. The summation of sampled voltages from the narrow band signals constitute the display video. For clarity of the time relationship between camera and display waveforms, transmission delay and timing errors have been removed, and the delay through the low pass filter is shown as approximately one sample period.

3.2.4.2 Decoder Operation. The following discussion explains the operation of the decoder processing equipment in greater detail. For the 30 frame per second system, the drum speed is nominally 30 rps (1800 rpm); 256 horizontal sync marks per revolution are prerecorded

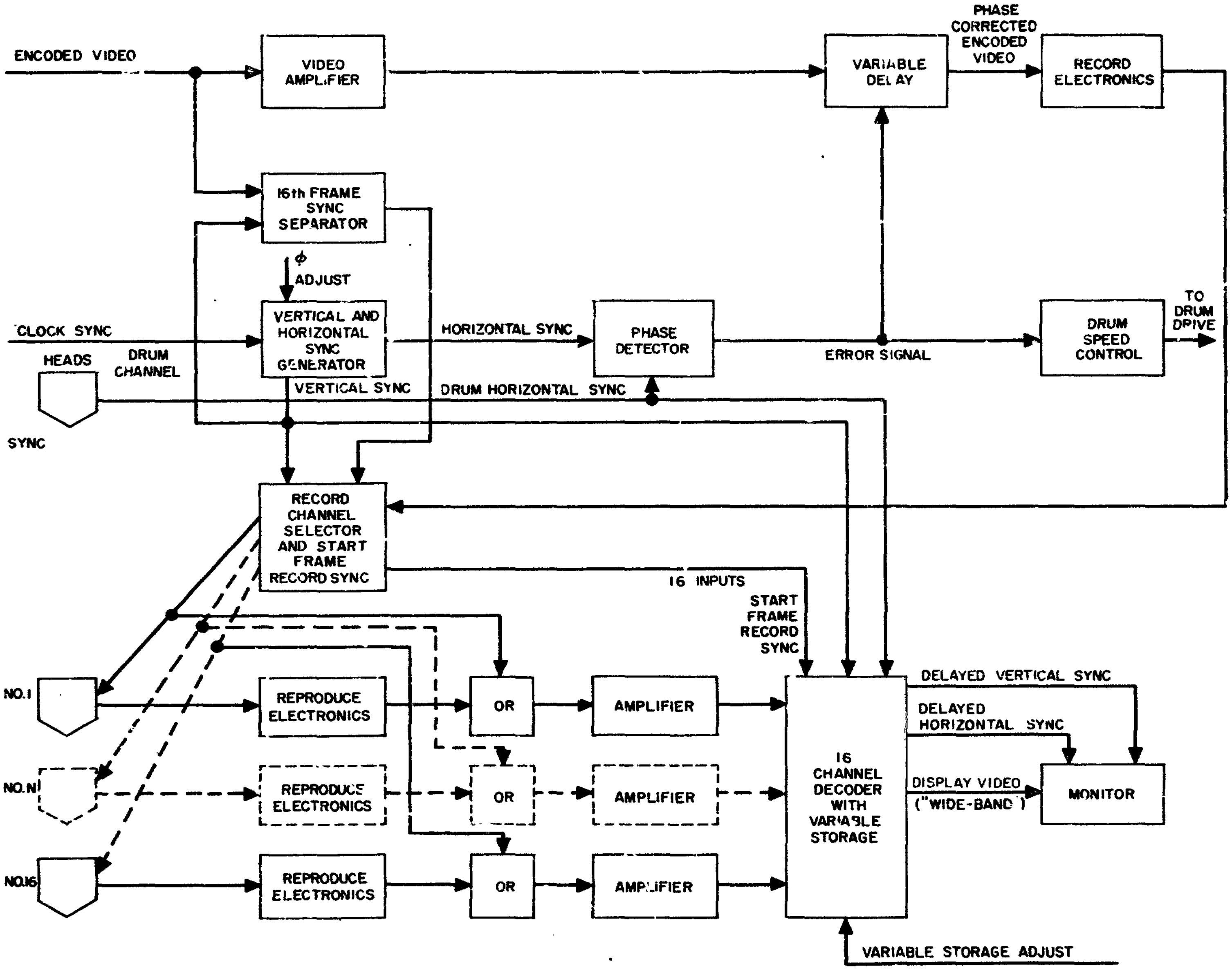


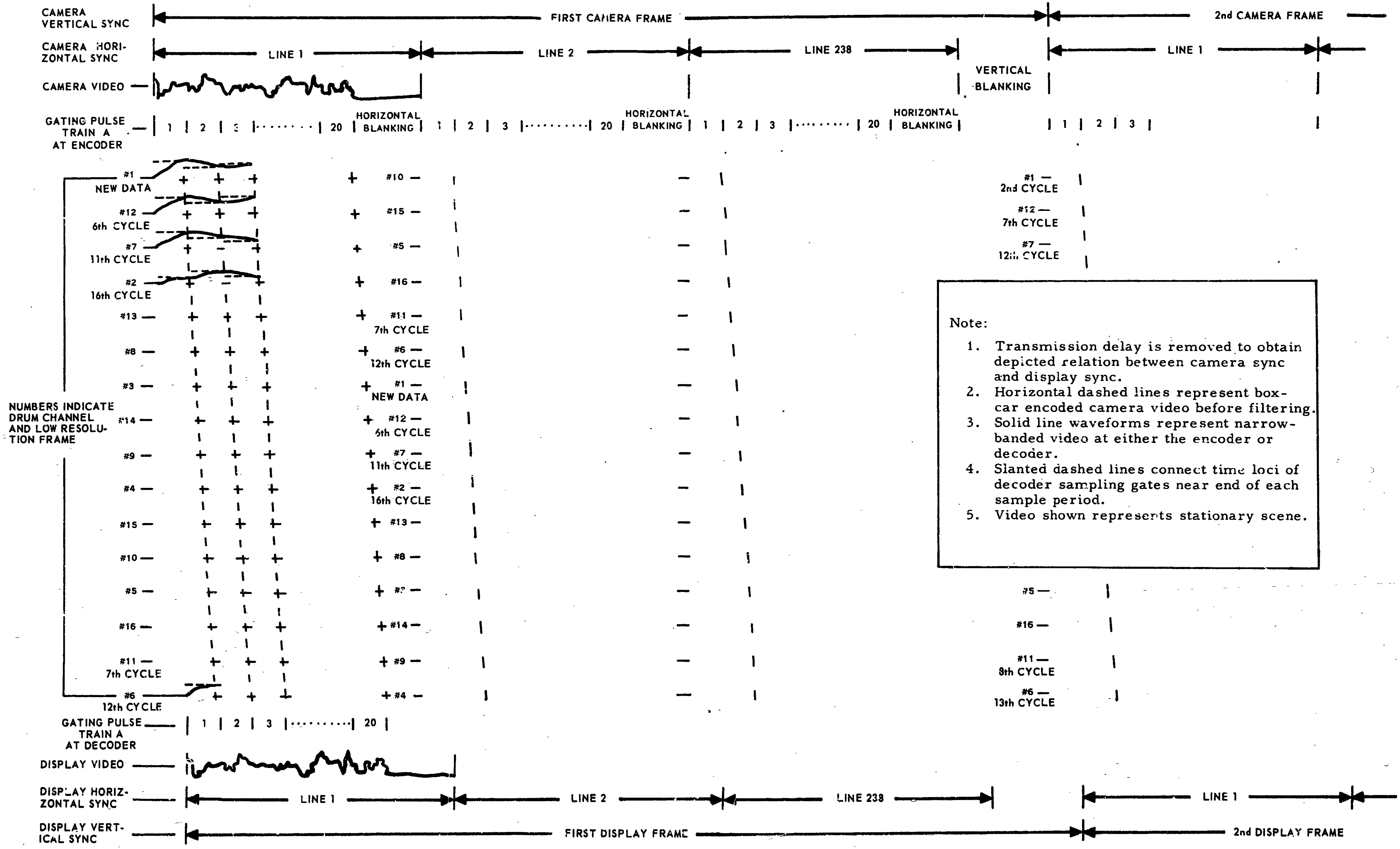
Figure 3.17. Multiple interlace decoder with magnetic drum storage.

in the timing channel; sixteen data channels are used. In operation, the drum rotates at the speed (one revolution per frame) which generates the correct nominal sync rate, and the speed control loop maintains the drum sync in synchronism with the incoming sync. Drum sync is used to control system timing. Incoming sync is compared to drum sync to develop a fast phasing correction which is applied to incoming video to position it on the drum in its required relationship with the drum sync. As each low resolution frame is received, it is written on an individual channel, then it is read from the drum repeatedly until it is replaced by new incoming information. A single revolution of the drum makes available at each of the heads, signals corresponding to the time functions of the original amplitudes of each of the sixteen low resolution frames. In each revolution, the decoder extracts, in the order indicated in Figure 3.18, twenty-four time-spaced samples from each line of each of sixteen low resolution frames. This sampling sequence produces the reconstructed high resolution video which results when the original intensity modulated dot patterns generated by the encoder are properly superimposed.

The vertical and horizontal sync generator provides outputs which are used in the sync comparator to develop timing correction signals, for gating in the 16th frame sync separator, and for timing in the record channel selector and the 16 channel decoder. It separates clock sync, which is derived from a narrow band phase lock loop in the receiver, into horizontal and vertical sync by frequency dividing circuits.

The 16th frame sync separator provides a frame sync signal which synchronizes the frame timing cycle in the Record Channel Selector. It is required to insure that the Record Channel Selector is in phase (proper low resolution frame number) with the incoming signal. Composite encoded video, which contains the 16th frame sync signal, is gated by the vertical sync output of the Vertical and Horizontal Sync Generator to develop the signal which locks in the Record Channel Selector.

Drum characteristic (speed, diameter, packing density), head characteristics (gap width, spacing) and performance (amplitudes and



Note:

1. Transmission delay is removed to obtain depicted relation between camera sync and display sync.
2. Horizontal dashed lines represent boxcar encoded camera video before filtering.
3. Solid line waveforms represent narrow-banded video at either the encoder or decoder.
4. Slanted dashed lines connect time loci of decoder sampling gates near end of each sample period.
5. Video shown represents stationary scene.

Figure 3.18. Decoder timing diagram.

phase perturbations) determine the specifications of a suitable storage unit. The requirements of 30 rps speed and sixteen plus channels are met in drums available from several sources. The same head will both record and reproduce for a given channel, eliminating the problem of precise spacing between heads. The channel selector switches the record electronics from head to head for the recording operation, while simultaneously, the reproduced signals are sampled in the decoder to construct the display video signal. Obsolete information may be erased in a separate operation, possibly using the record-reproduce head when neither of its primary functions is required or alternatively, erasure may be accomplished in the process of storing new information.

To insure adequate recorded wave length a ten inch drum diameter is specified. The narrowband video to be recorded contains a total of 6144 samples taken over any complete low resolution frame period. This number of samples is recorded on one channel in a single revolution of the drum. The drum circumference of 31.4 inches allows approximately .005 inch per sample or 200 storage cells per inch. The necessity of maintaining amplitude fidelity of the analog signal and for minimum timing errors warrant the use of long recorded wave lengths.

In both the recording and reproducing processes, several factors can influence the amplitude fidelity of the signal. Since linear reproduction of stored data is desired these factors are considered. Most important are the recording material magnetic characteristics and the spacing and gap losses. The distortion caused by the non-linear characteristics of the magnetic substance may be minimized by using various types of biasing or coding. Simple high frequency AC biasing may be adequate to achieve acceptable results, but probably a more involved technique such as FM recording will be required, especially since spacing loss effects cannot be overcome by biasing.

The significance of spacing loss is evidenced by the change in reproduction spacing loss for a constant recorded wavelength which is ten times the head to drum spacing. For a spacing range of ± 25 percent the reproduced signal amplitude will vary through a range of about 5 db. Recording spacing loss, which is additive if both are expressed in db, is similar in nature although not as great in range. Both effects increase as the recorded wavelength becomes smaller. The gap loss is a consequence of the nature of the reproducing process which produces, at the head winding terminals, a voltage proportional to the time rate of change of the flux within the gap. If the recording has been linearized, the reproduced signal, for wavelength large compared to gap width, is the time derivative of the recorded signal (if spacing loss is disregarded). This results in a 6 db per octave rise with increasing frequency (and increasing phase lag). As the wave length approaches the gap length, the net flux change in the gap decreases, falling to zero when the two are equal. Because of these factors, FM recording and a nominal drum diameter of ten inches are tentatively specified.

Rotational noise and irregularities in drum angular position as a function of time will result in errors in sampling timing. Since 2,949,120 samples per second are required to reconstruct the final display video at 30 frames per second, the sampling gate mid-point separation, in terms of drum physical dimensions for the ten inch drum is about 300 microinches; time separation is 0.34 microseconds. Control of the gate location with a precision of this order of magnitude is necessary to insure that each sample used in picture reconstruction is taken from the appropriate region in the encoded waveform. Reclocking the gate timing with drum sync for each horizontal line results in a period of 130 microseconds over which this precision must be maintained. Results of tests conducted at Hughes Aircraft Company on production samples of a magnetic drum used in an airborne digital computer indicate that the magnitude of short term timing errors resulting from rotational irregularities does not exceed a few hundred nanoseconds in the course of a complete revolution. Since this performance is substantially better than required, drums which meet commercial standards of performance will be acceptable. One manufacturer of magnetic drums states that the timing error can be kept under one part in 10,000 with relatively simple techniques.

The drum completes one revolution for each transmitted low resolution frame. Drum rotation is locked to camera sync. Short term errors are to be anticipated, hence the necessity for the variable delay to be discussed subsequently, but long term errors must not be permitted to accumulate beyond the dynamic range of the variable delay.

To synchronize drum rotation with camera frame rate, the phase detector develops an error signal proportional to the difference between camera sync and drum sync and the error signal is fed to a controllable oscillator which determines the frequency of the AC voltage supplied to a synchronous or low-slip induction motor connected to the drum. Another method of speed control applies the error signal to a drag-brake which controls the percentage of slip of an induction motor. The free running rpm of the motor, which must be selected to run fast, is reduced the amount required to maintain synchronization.

The phase detector and the variable delay together position the encoded video on the drum in its required relationship with drum sync. Since drum sync does not invariably agree with incoming sync (which will be in the proper time relationship with incoming video) and since sufficiently rapid correction of drum θ and ω is not feasible, the fast phasing correction is applied electrically, on a line-to-line basis, to the incoming signal. The phase detector develops a d-c error signal proportional to the time difference between the incoming video sync and the drum sync. A lumped-constant step-variable delay line is used for the variable delay. The d-c error signal from the phase detector is also used to maintain proper drum speed.

For the 30 frame per second system, the record channel selector in a 16/30 second cycle, switches at 30 steps per second to place each of the encoded low resolution frames on a different drum channel. The channel selector is triggered by the vertical sync and reset by the 16th frame sync. In addition, the channel selector feeds the incoming video to the decoder to allow decoding of the low resolution video frame simultaneously with recording.

The block diagram of the sixteen channel decoder with variable storage is shown in Figure 3.19. The operation of the decoder is similar to the operation of the encoder as described in section 3.2. The major difference is that the decoder has sixteen inputs and simultaneously decodes all sixteen channels. The decoder has a gating pulse train generator that is identical to the one in the encoder. The GPT generator is locked to the delayed horizontal sync from the drum. The delay is required to compensate for the delay and rise time characteristics of the low pass filter in the encoder.

The gating pulse train sequence selector in the decoder is simpler than the one in the encoder. Only a pulse train sequence counter is required since the same frame always has the same starting pulse train for line 1. Therefore, the wiring from the gating pulse train sequence counter to the 16 sets of 16 AND gates provides each of the 16 frames with a different starting pulse train for line 1.

The encoded video from each of the 16 record channels (representing 16 frames) is fed thru a separate video gate. The correct sequence of gating pulse trains is also fed to each video gate. Therefore the output of the 16 video gates represents the full storage picture.

Variable storage is obtained by reducing the number of times a recorded low resolution frame is displayed. This is accomplished using sixteen monostable multivibrators, with variable pulse width control, and 16 AND gates. Each of the sixteen multivibrators are triggered by the designated start frame record sync signal. If the pulse width is set for maximum, each low resolution frame of video is displayed sixteen times. As the pulse width is shortened, each new frame of video is displayed fewer times. Therefore, the storage can be varied from zero (each low resolution frame is displayed only once) to maximum (each low resolution frame is displayed sixteen times).

For operation with less than full storage, variable background brightness control improves the acceptability of the displayed picture. The brightness of the "missing" dots is automatically set to a brightness determined by operator variable controls and/or proportional to the magnitude of the original dot with respect to a reference level.

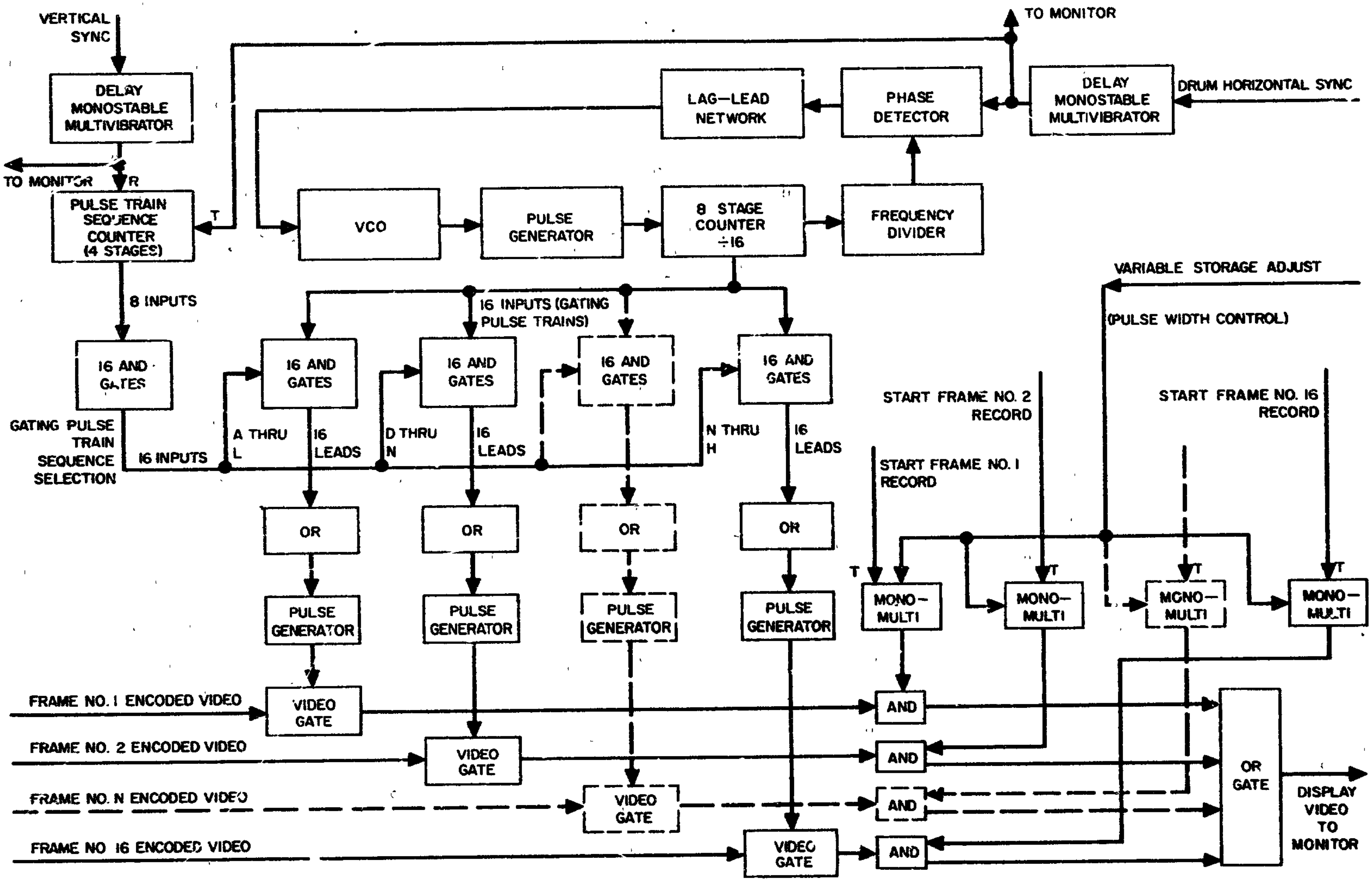


Figure 3.19. Sixteen channel decoder with variable storage.

3.3 INTERFACE WITH COMMERCIAL TELEVISION

Scan conversion equipment is necessary to condition multiple interlace video signals for transmission via conventional TV channels. Because of the differences in system parameters, decoded multiple interlace picture data must be stored temporarily in a form which will accomodate a scanning mode that can generate video signals in the required format.

Several storage media are useful. Photographic film, CRT phosphors and display storage tubes with appropriate decay characteristics, and electrostatic storage tubes can all be employed. The use of film or any of the display tubes permits readout with conventional optical scanning. The electrostatic storage tube provides a direct video voltage output developed by a scanning electron beam which reads out data previously stored as charge density levels on elementary areas of the surface of a dielectric layer.

Multiple gun storage tubes (Figure 3.20) which permit simultaneous read-write operations are marketed by many manufacturers. Basic conversion systems which, in addition to the tube include input and output video amplifiers, read and write deflection yokes and amplifiers and focus coils and controls, are available in the $30,000 price range. Principles of operation and performance characteristics of the tubes are given in manufacturers' technical data sheets. Some of the following is adapted from material in the bulletin describing the Raytheon recording storage tube, type CK7702.

The secondary electron emission characteristic of a dielectric film (Figure 3.21) may be exploited to add or remove electrons from elementary surface areas (of the order of the cross section of the impinging electron beam) thus accomplishing storage of data in analog electrical form. If the velocity of electrons hitting the dielectric film exceeds the critical value, more electrons are emitted than absorbed, and in the area of impact, a positive charge builds up. If the velocity is less than the critical value, the reverse is true. By establishing the correct potential difference between the storage surface and the electron gun (write gun) cathode, (thus establishing electron velocity

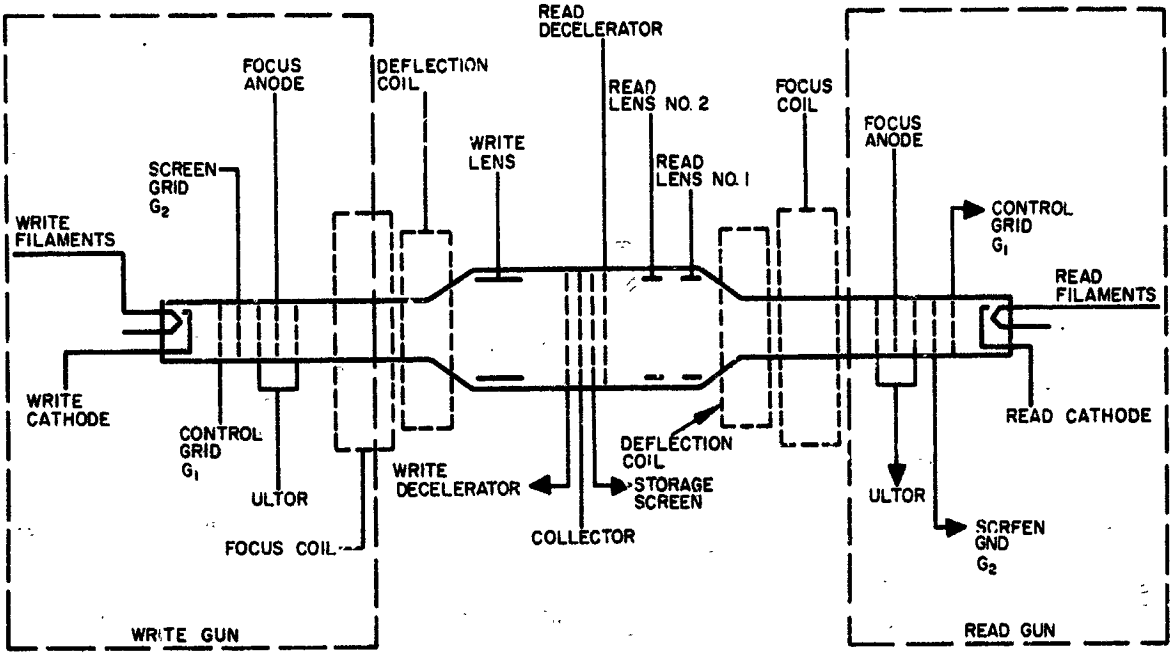


Figure 3.20. Storage tube electrode configuration.

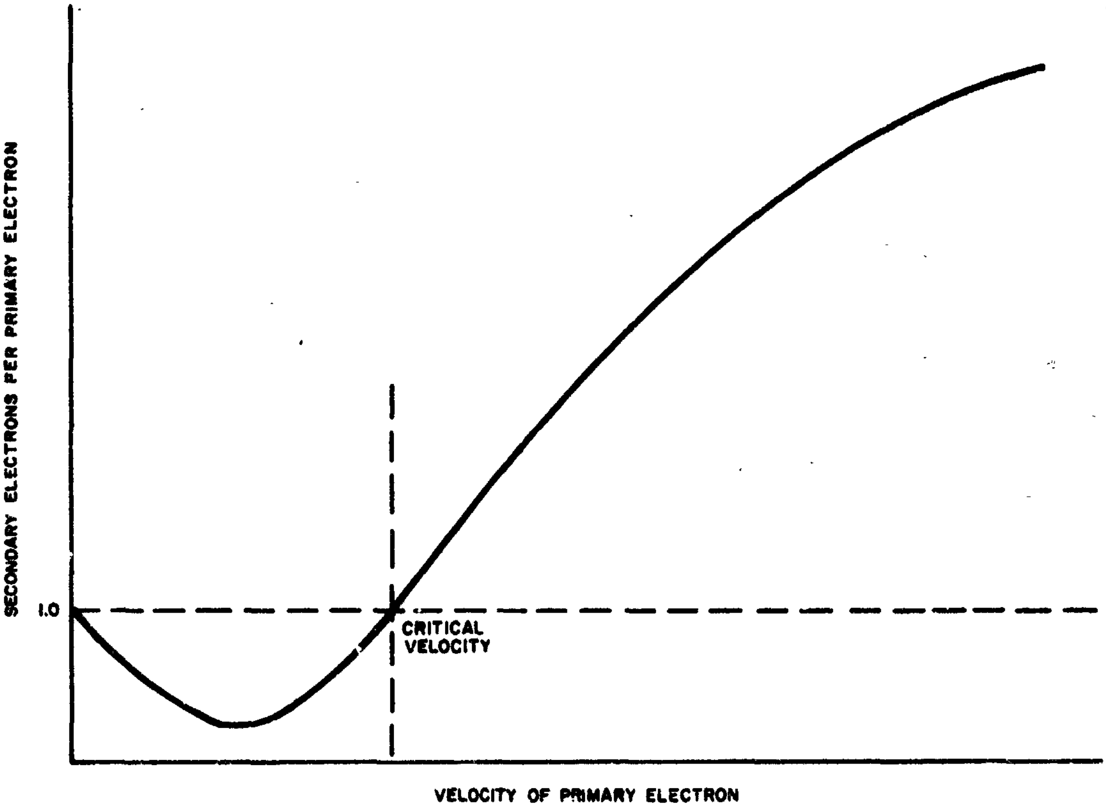


Figure 3.21. Secondary emission characteristic of storage dielectric. (From Raytheon Data Sheet.)

at impact) and then scanning the storage surface with the intensity modulated write beam, a pattern of areas of varying charge (and hence voltage) levels is stored.

In the CK7702, as in most storage tubes, the dielectric storage layer has been deposited on a metal mesh. This assembly can act like a control grid to regulate the magnitude of the current of a second scanning electron beam (read-out beam) passing through it. Depending on the local character of the stored pattern, more or less beam current is transmitted, and information, developed from the pattern established by the write gun, is thus made available at a collector electrode. A satisfactory erase characteristic is achieved by adjusting electrode potentials so that the scanning read-out beam removes the stored charge pattern. In addition to accomplishing readout, this continually restores the storage surface to the potential required for the continuing writing process. Crosstalk or dynamic coupling of the write beam to the output electrode circuit is reduced to an acceptable level by video cancellation or by RF carrier separation techniques. Since both beams may scan independently, simultaneously, and in individual conformity to the requirements of the systems with which they are directly associated, scan conversion from one set of system parameters to another is accomplished. A simplified block diagram of a scan conversion unit using a dual gun recording storage tube is shown in Figure 3.22.

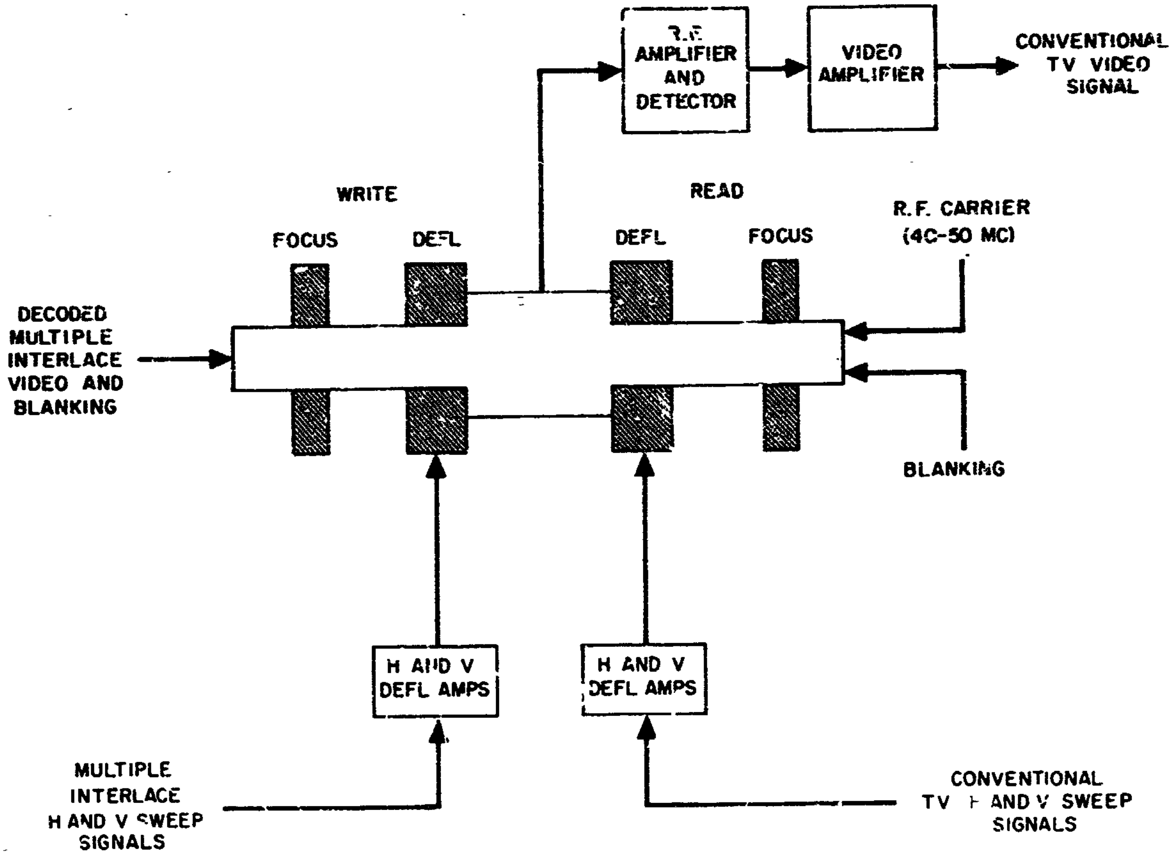


Figure 3.22. Scan conversion unit block diagram.

4. PERFORMANCE EVALUATION

The viewing test program discussed in the Phase II report (Section 3. 5) has been continued in an effort to gain more knowledge of the factors influencing the acceptability of multiple-interlace presentations. Further experiments have been performed using, in addition to the photographic technique discussed, the controlled decay phosphor characteristic of the Tonotron® for variable frame storage. Background brightness level control has been implemented and tested in the laboratory, and dot pattern optimization for partial storage displays has been investigated.

4.1 DISCUSSION OF VIEWING TESTS

All of the viewing tests of the multiple interlace technique were made using the laboratory demonstration system described in the Phase I report. This equipment, incorporating a 16:1 multiple interlace ratio, dictated full-storage high resolution frame rates of 25/16 per second for the photographic technique, and 30/16 per second for the Tonotron®. With this large compression ratio, blurring and spreading of objects with moderate motion rates is quite apparent and somewhat unnatural in appearance. Slow scan at 12:1 compression and even at 5:1 compression (the latter requiring three times the bandwidth employed for the multiple interlace test) manifests image breakup as an objectionable hopping or annoying jerkiness of moving objects. For multiple interlace, as reported in the second phase of this program, decreasing the frame storage period improves the illusion of motion by decreasing the extent of the area of break-up. This however decreases the spatial resolution available in the display. In fractional storage mode operation, a background level control is used to adjust display background level to keep overall brightness constant, to minimize small area flicker, and to decrease the excessive degree of contrast between display elements which are presenting pictorial information and those which are not.

In these tests, both multiple interlace and slow scan exhibit poorer performance than conventional wide band TV where moderate motion rates are encountered. A graphical comparison of resolution versus object motion for a conventional TV system and the variable storage multiple interlace system is shown in Figure 4. 1.

The effect of varying the frame rates can be predicted for these two systems. If both systems were to be set up at 30 frames per second, the slow scan would become, with the inconsequential exception of vertical interlace, identical to conventional TV. Since it has been assumed that appropriate storage eliminates any flicker effects in the slow scan display, the vertical interlace feature is of no significance, and the implied equivalence is therefore valid. Multiple interlace appears to offer no significant improvement in illusion of motion at this frame rate (although it might reduce some stroboscopic effects). Since the multiple interlace dot structure imposes an additional horizontal Kell Factor degradation, it is reasonable to conclude that the "speeded-up-slow-scan" is superior at 30 frames per second.

Figure 4. 2, which illustrates this and subsequent conclusions, presents a graphical interpretation of the argument for a scene involving movement. Details of levels, slopes, and crossover points of the curves shown in Figure 4. 2 will vary with picture content and object motion rate. For example, at zero motion rate, both system characteristics extend horizontally from their Y intercepts. The shape of the curves also depend to some extent on object size, background contrast, and will vary from viewer to viewer.

As the frame rate is decreased, a point is reached where jump becomes evident in the slow-scan display. At this point, its acceptability begins to diminish very rapidly with decreasing frame rate. This can occur at frame rates as high as 15 per second (2:1 compression ratio). On the other hand, the full-storage multiple interlace display will not exhibit jump, and its break-up, because of its distributed nature, will not be discernible until a lower frame rate is reached.

As the frame-rate is further decreased, the multiple interlace display now begins to deteriorate appreciably, eventually falling in acceptability below the shuttered slow-scan display which finally loses its objectionable jerkiness, and assumes the aspect of a sequence of still pictures. Illusion of motion from a physiological point of view is then

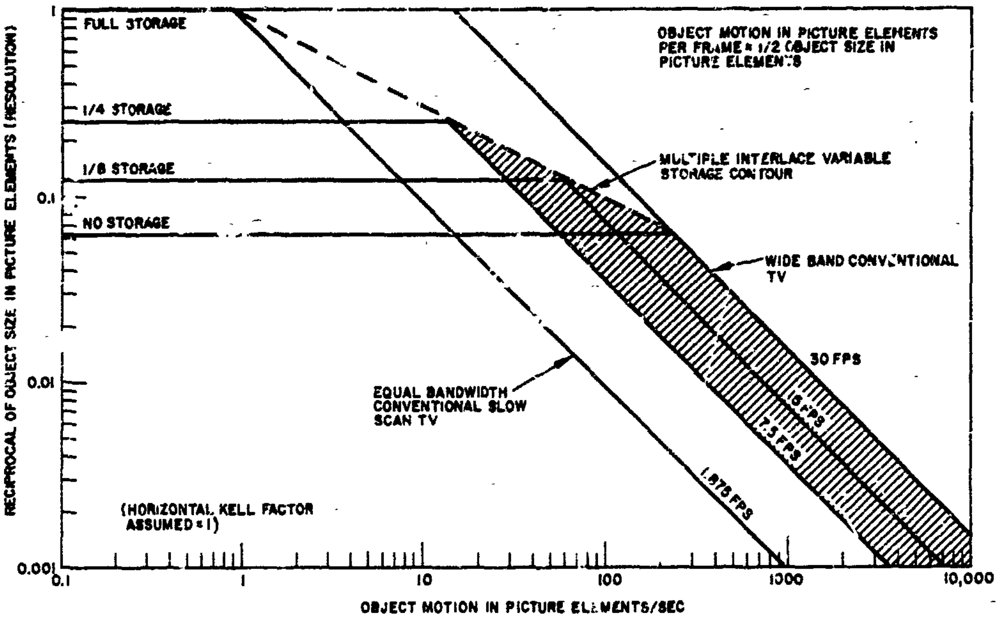


Figure 4.1. Comparison of resolution versus object motion for conventional TV and variable storage multiple interlace.

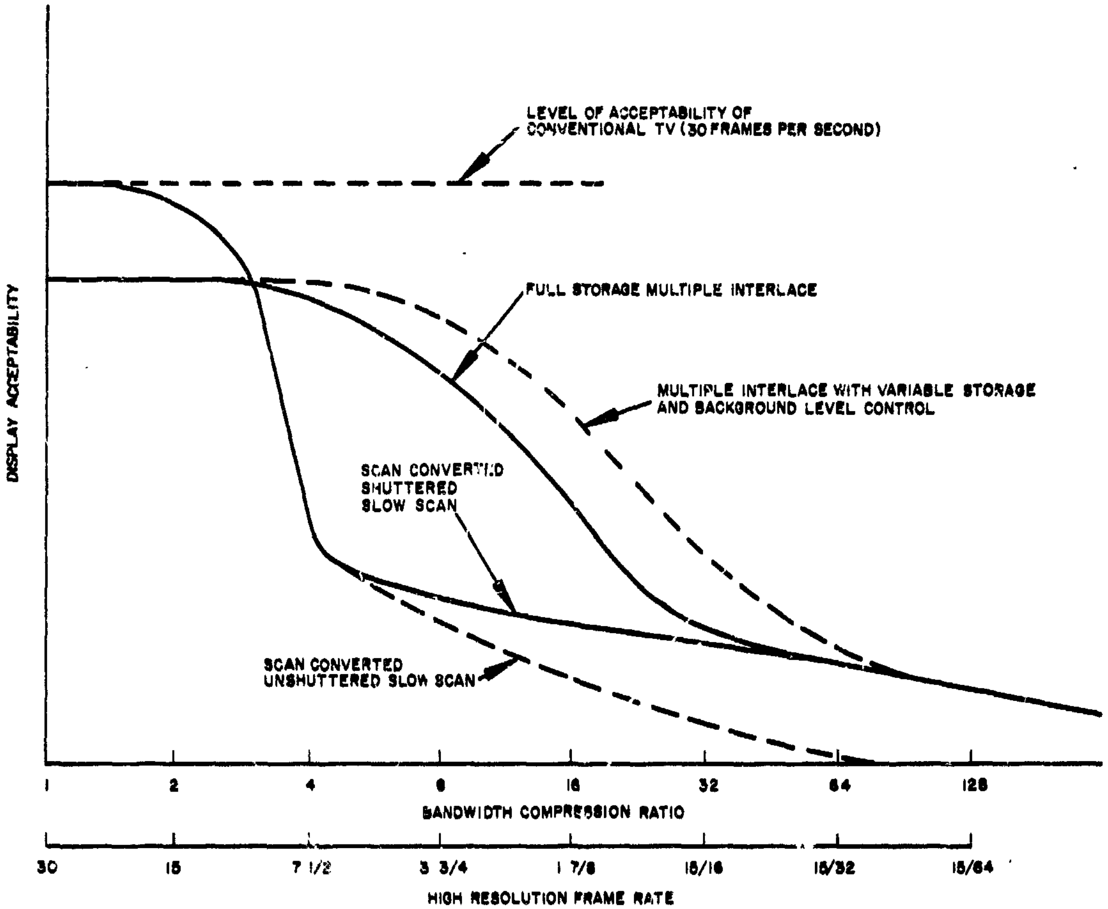


Figure 4.2. Acceptability comparison of slow scan and multiple interlace displays for a scene involving movement.

completely lost and the term "break-up" no longer has its former significance. At these very low frame rates, multiple interlace still manifests break-up, discernible as moving patterns of picture elements, causing any but the slowest moving objects to lose their identity. Here, of course, unshuttered slow scan has the same serious problem, with an equivalent blurring in the area of motion.

Unfortunately, the flexibility of the present laboratory setup is not sufficient to permit complete confirmation of these conclusions. It seems obvious, however, that there exists a range of frame rates over which the full storage multiple interlace is clearly preferable to shuttered slow-scan, and other frame rates where shuttered slow-scan may be preferable to full-storage multiple interlace.

It should be pointed out, however, that Figure 4.2 indicates a flattening of both system characteristics as the bandwidth compression ratio is reduced. This means that beyond a particular value of frame rate (different for each system) no additional improvement in picture quality is achieved by increasing the frame rate. If beyond those points in the direction of decreasing bandwidth compression ratio, the wider bandwidth resulted in an increase in resolution rather than an increase in frame-rate, the acceptance characteristics would continue to rise until limiting resolution is achieved. Under these circumstances, the advantage now apparent for the slow-scan system in the low bandwidth compression region would vanish.

Under many circumstances, at the lower frame rates, the advantage of multiple interlace is greatly increased by using partial frame storage. In those scenes where realistic portrayal of the smooth flow of motion is desired, a degradation in overall spatial resolution is preferable when the alternative is the characteristic break-up of the slow-scan display. At a high resolution frame rate of only 16/30 frames per second, when partial frame storage is used, objects with high motion rates appear to move naturally, even though spatial resolution is considerably decreased. This feature of the multiple interlace technique, which affects the operation of only the ground equipment can greatly extend the usefulness of a space TV system.

4.2 TWO SPECIAL FEATURES OF MULTIPLE INTERLACE

The multiple interlace TV system has two special features that are important for use in space television.

One of these is the availabiltiy of a wide band, high frame rate picture for direct viewing by the astronaut in the spacecraft. The picture video directly from the camera (before being encoded) can be displayed using only a "conventional" monitor. Coding techniques which manipulate scan rate require on board decoding equipment.

The second feature is the higher signal to noise ratio of the video being fed to the transmitter in the multiple interlace system as compared to a "shuttered" slow scan conventional TV system. It is assumed that the shutter time of the slow-scan TV would be made equal to the effective shutter time of the multiple interlace TV (the reciprocal of the low resolution frame rate) to obtain equal blurring of moving objects.

The light transfer characteristics (on a log-log plot) of a typical "storage" vidicon operating at two frame rates is shown in Figure 4.3. The video signal output of the vidicon when scanned at 30 frames/second (for a multiple interlace system) is approximately 16 times the output when scanned at 1.875 frames/second (the frame rate of an equal bandwidth slow-scan TV). Therefore, the video signal to noise ratio of the multiple interlace system is approximately 24 db higher.

The importance of the higher signal to noise ratio is that satisfactory television pictures can be obtained with the multiple interlace system at lower illumination levels (by a factor of approximately 16).

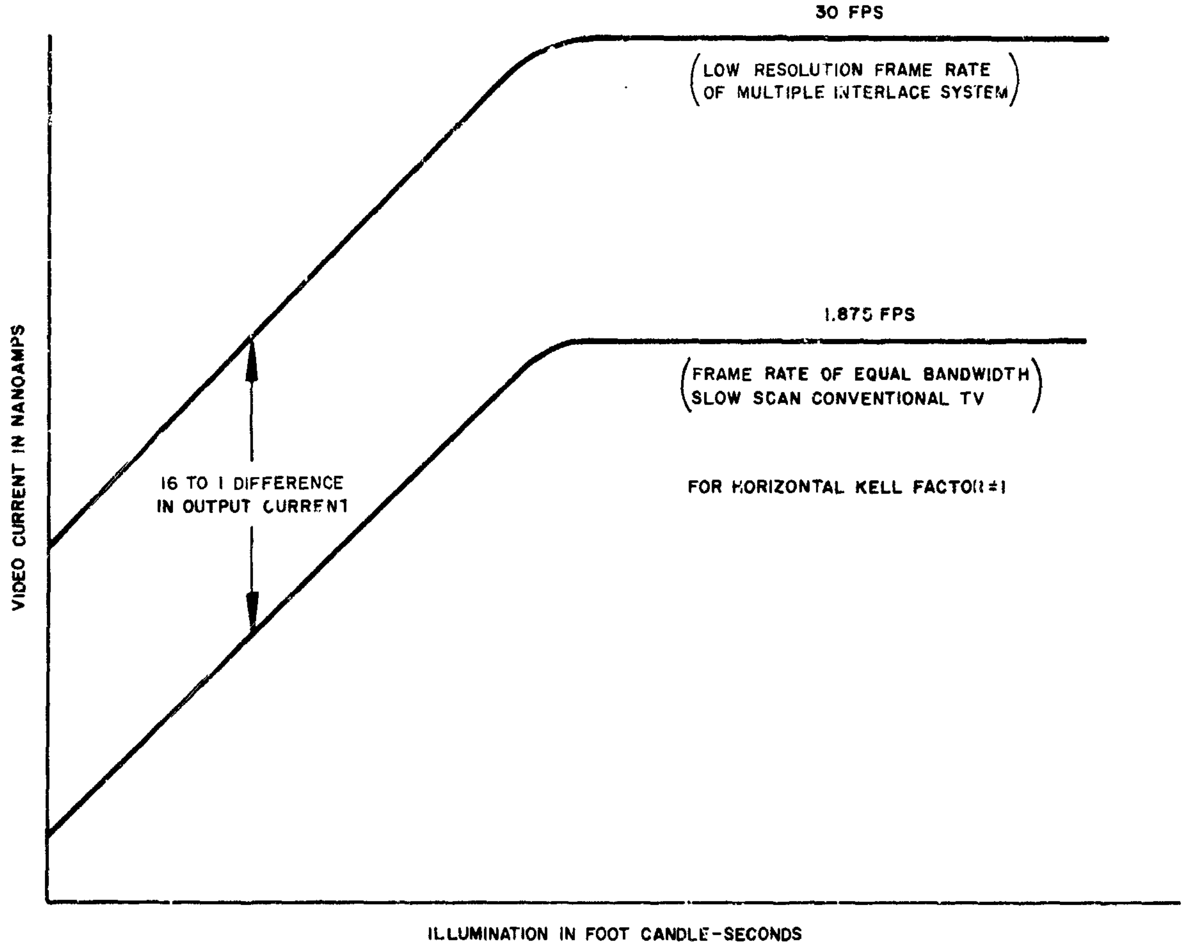


Figure 4.3. Light transfer characteristics (log-log plot) of a typical vidicon at two frame rates.

5. DOT INTERLACE PATTERNING AND DOT CRAWL EFFECTS

The dot interlace system of bandwidth reduction is subject to two types of optical disturbances in the displayed picture -- patterning and dot crawl. Patterning is the optical illusion of a false texture in the picture due to the arrangement of dots within a low resolution frame (LRF). The crawling effect is an optical illusion in which lines or dots of the picture appear to crawl across the display because of stroboscopic effects in the presentation of successive LRF's. It is possible to minimize these effects by properly ordering the successive presentations of LRF's with the content of each LRF judiciously arranged.

A preliminary analysis of these effects was presented in the Phase I report. This discussion will consist of a review and extension of that study.

5.1 DOT INTERLACE TECHNIQUES

The basic 2 to 1 line interlace technique of conventional television can be extended in the horizontal direction of a picture as well as in the vertical direction. In this case the picture is split into picture elements. A single scan covers only 1/Nth the number of dots in a line (where N is the multiple interlace or dot interlace ratio). Figure 5.1 illustrates the dot patterns for several dot interlace systems. Included in the Figure are the dot patterns of noninterlace, line interlace, and dot interlace television. The bandwidth reduction achieved for each system is relative to the noninterlace television system at a fixed scan rate.

For the 2 to 1 dot interlace system there are two ways to arrange the dots in the basic pattern block (shown by heavy lines), but only one dot LRF sequence. The 4 to 1, 8 to 1, and higher order dot interlace systems have many possibilities for dot pattern arrangement and dot LRF sequence. The selection of a dot pattern and LRF presentation sequence for these systems will determine the degree of patterning and dot crawl in a reproduced picture.

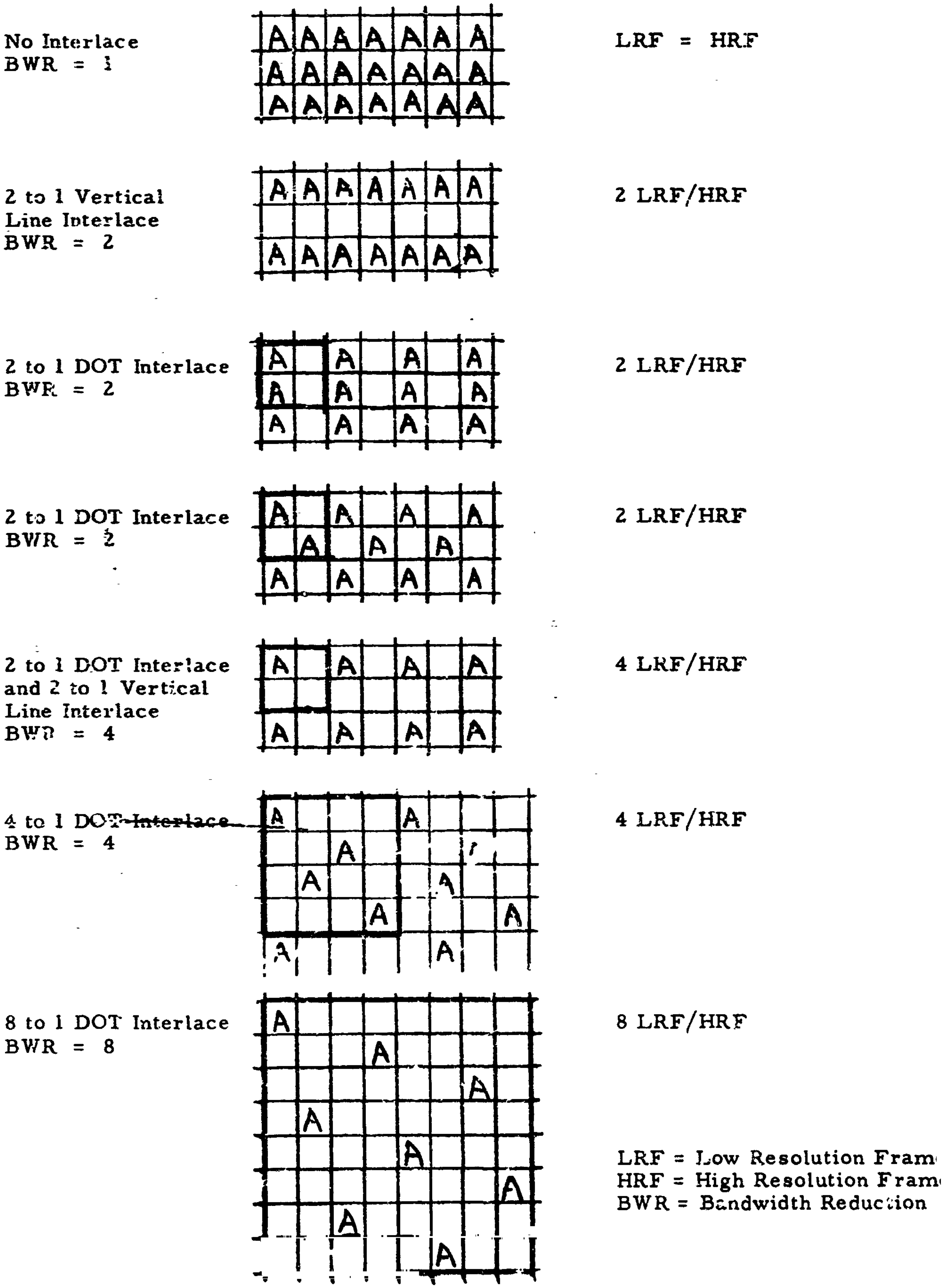


Figure 5.1. Picture interlace techniques.

The only investigation of dot interlace patterning and dot crawl effects that has been reported in the literature is that of Haantjes and Teer (reference 1033) who experimented with a combination 2 to 1 dot interlace and 2 to 1 line interlace system.

In this system, if A, B, C, D are interlaced dots of the two even and two odd lines of four successive LRF's , then the principle of dot interlace requires that dots A are midway between dots C and dots B are midway between dots D. If dots A, B, C, D are located on a straight line, a stroboscopic effect may easily arise, because the four impressions occurring at LRF intervals may easily be interpreted as one moving dot pattern as shown in Figure 5.2.

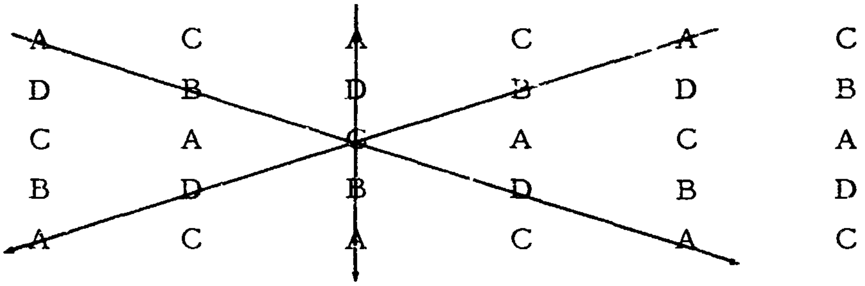


Figure 5.2. Dot fields for 2 to 1 dot interlace, 2 to 1 line interlace system.

In the LRF pattern illustrated by Figure 5.3, the dots on the even lines are staggered by a one half element distance. It is impossible to locate A, B, C and D on a straight line. In this case a stroboscopic effect will not be as noticeable.

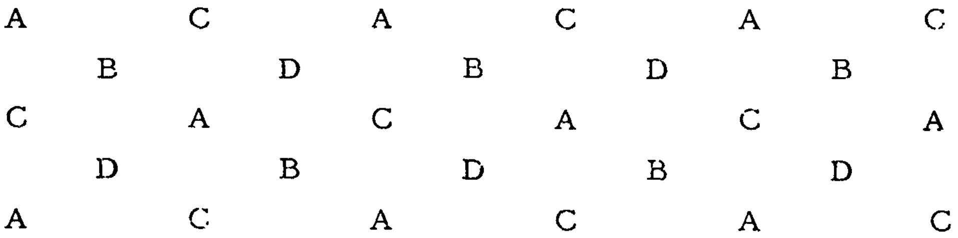


Figure 5.3. Dot fields for staggered 2 to 1 dot interlace, 2 to 1 line interlace system.

However, another second order stroboscopic effect may accompany this configuration (A B, AB e.g.) which will appear vertically and horizontally and which will be equally perceptible in all four directions.

5.2 MULTIPLE INTERLACE SYSTEM

A laboratory demonstration model of the multiple interlace system has been built with a 16 to 1 multiple interlace ratio. The experimental system utilizes 2 to 1 line interlace in addition to 16 to 1 dot interlace because commercial stations broadcast with a 2 to 1 line interlace, and most laboratory equipment is designed to this standard. Thus, for experimental testing purposes it was expedient to apply the multiple interlace encoder to the standard 2 to 1 vertically interlaced picture. As was mentioned in the previous reports, 2 to 1 line interlace in conjunction with dot interlace is usually not worthwhile, and would not be utilized for an operational system. However, the performance of the concept can be evaluated in this form.

The experimental system is not equipped with a ground processing memory at present. With full memory in the receiver the effects of patterning and dot crawl will be eliminated. However, the use of partial storage (i.e., storage of only a number of the most recent LRF's received) may create additional patterning or dot crawl effects. Until a memory is included in the system it is only possible to predict the patterning and dot crawl effects by analytical techniques and photographic simulation.

5.2.1 Dot Pattern and Low Resolution Frame Presentation Sequence of the Experimental System

The basic dot pattern for one LRF of the experimental system is shown in Figure 5.4. This pattern with a dot (called the key dot) occupying the first element position of the first line is defined to be the first LRF of a sequence of 32 LRF's. The basic dot pattern is repeated horizontally and vertically over a picture in blocks of 16 elements and 32 lines as illustrated in Figure 5.5.

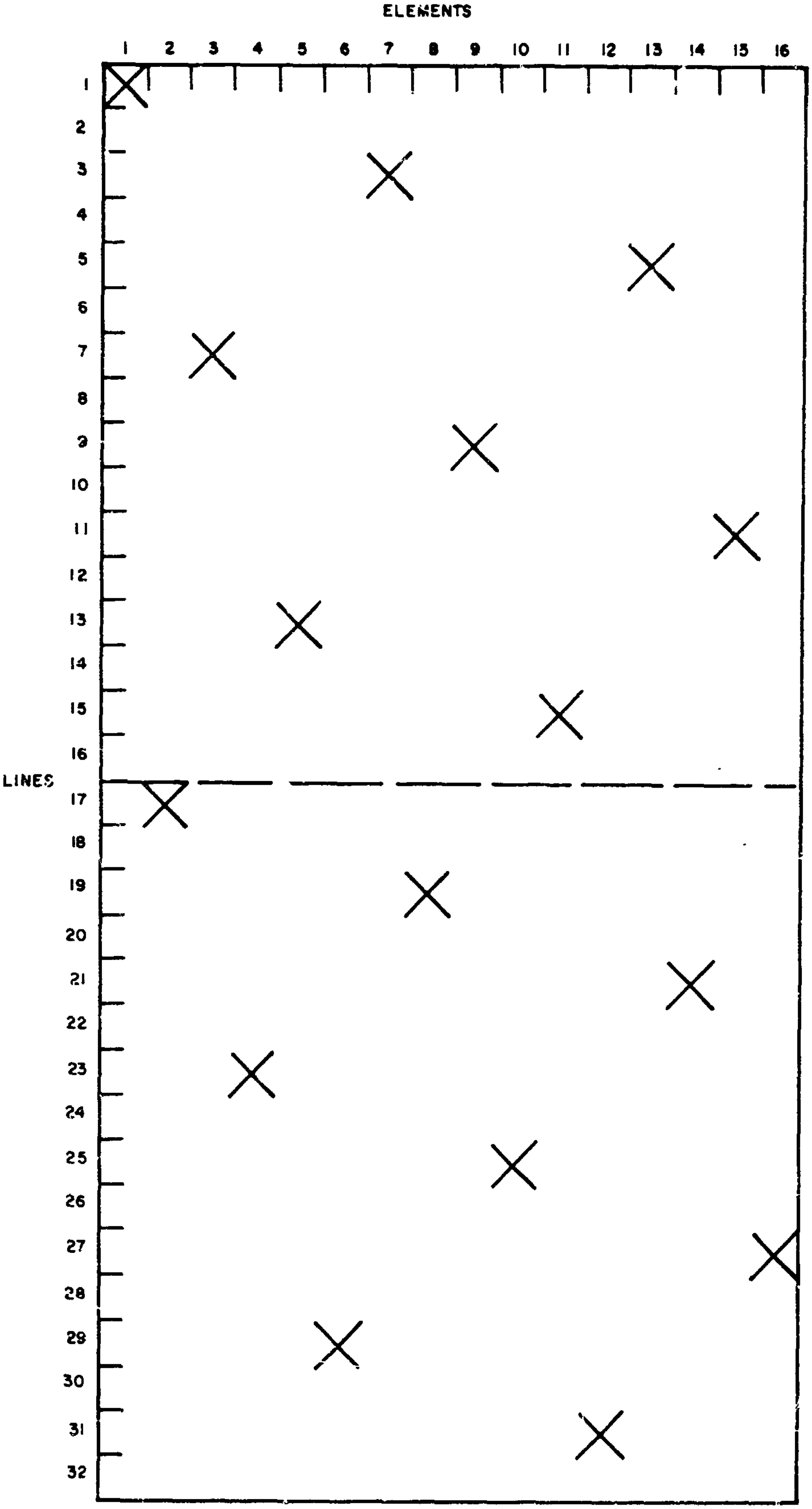


Figure 5.4. Basic dot pattern for the experimental dot interlace system.

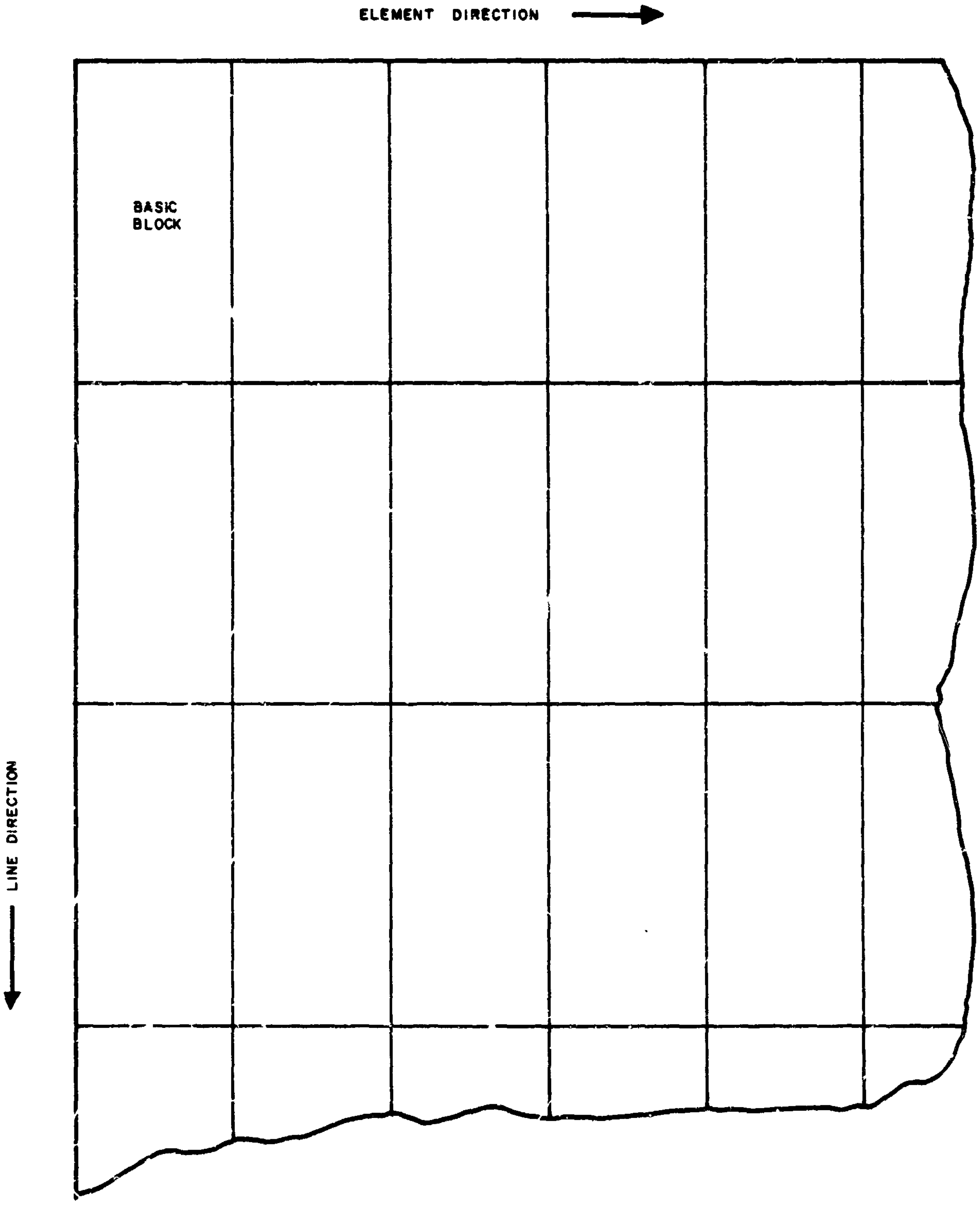


Figure 5.5. Repetition of basic blocks over frame for the experimental system.

The LRF presentation sequence of dots for the experimental system is shown in Figure 5.6. This sequence specifies the placement of the key dot along the first odd and even lines. For example, in LRF number one, dots will be placed in a block with the key dot of the pattern occupying the first element of the first line as indicated in Figure 5.4. In the second field, dots will be placed in the block with the key dot being placed in element position 10 of the second line, etc. The completed block containing the 32 low resolution frames (LRF's) of a high resolution frame (HRF) is shown in Figure 5.7.

The LRF presentation sequence can be illustrated more clearly with the time-spatial dot LRF pattern diagram shown in Figure 5.8. In the figure the horizontal dimension is element spacing along a picture block while the vertical dimension represents a time sequence of LRF placement. The numbers in the boxes indicate the placement of the key dot of the basic dot pattern, both in time and horizontal position. The purpose of such a diagram is to indicate the time-spatial patterns that occur in the reconstruction of a picture.

5.2.2 Patterning in the Experimental System

The patterning in the experimental system is due to the geometric arrangement of dots in a LRF. With full storage all dots will be present in a LRF period and the patterning effect will be absent. As the amount of field storage is decreased patterns of dots will appear. With no storage the patterning will be due to the geometric arrangement of dots in the basic block shown in Figure 5.4. For quarter storage eight dot LRF's will be simultaneously displayed. Figure 5.9 illustrates the dots displayed for the first eight LRF's. In this situation a diagonal type composite pattern of dots will be produced.

5.2.3 Dot Crawl in the Experimental System

It is the basic dot pattern and the time-spatial pattern that determine the degree of patterning and dot crawl. Dot crawl in the experimental system is caused by adjacent LRF's of dots being presented in such a manner that along a vertical line two or more dots are placed

Low Resolution Frame

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
odd line	1		4		7		10		13		16		3		6		9		12		15		2		5		8		11		14	
even line		10		13		16		3		6		9		12		15		2		5		8		11		14		1		4		7

Element Position of Key Dot in First Even and Odd Lines

Figure 5.6. Low resolution frame presentation sequence of dots for the experimental system.

	ELEMENTS															
LINES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1	23	13	3	25	15	5	27	17	7	29	19	9	31	21	11
2	28	18	8	30	20	10	32	22	12	2	24	14	4	26	16	6
3	29	19	9	31	21	11	1	23	13	3	25	15	5	27	17	7
4	24	14	4	26	16	6	28	18	8	30	20	10	32	22	12	2
5	25	15	5	27	17	7	29	19	9	31	21	11	1	23	13	3
6	20	10	32	22	12	2	24	14	4	26	16	6	28	18	8	30
7	21	11	1	23	13	3	25	15	5	27	17	7	29	19	9	31
8	16	6	28	18	8	30	20	10	32	22	12	2	24	14	4	26
9	17	7	29	19	9	31	21	11	1	23	13	3	25	15	5	27
10	12	2	24	14	4	26	16	6	28	13	8	30	20	10	32	22
11	13	3	25	15	5	27	17	7	29	19	9	31	21	11	1	23
12	8	30	20	10	32	22	12	2	24	14	4	26	16	6	28	18
13	9	31	21	11	1	23	13	3	25	15	5	27	17	7	29	19
14	4	26	16	6	28	18	8	30	20	10	3	22	12	2	24	14
15	5	27	17	7	29	19	9	31	21	11	1	23	13	3	25	15
16	32	22	12	2	24	14	4	26	16	6	28	18	8	30	20	10
17	11	1	23	13	3	25	15	5	27	17	7	29	19	9	31	21
18	6	28	18	8	30	20	10	32	22	12	2	24	14	4	26	16
19	7	29	19	9	31	21	11	1	23	13	3	25	15	5	27	17
20	2	24	14	4	26	16	6	28	18	8	30	20	10	32	22	12
21	3	25	15	5	27	17	7	29	19	9	31	21	11	1	23	13
22	30	20	10	32	22	12	2	24	14	4	26	16	6	28	18	8
23	31	21	11	1	23	13	3	25	15	5	27	17	7	29	19	9
24	26	16	6	28	18	8	30	20	10	32	22	12	2	24	14	4
25	27	17	7	29	19	9	31	21	11	1	23	13	3	25	15	5
26	22	12	2	24	14	4	26	16	6	28	18	8	30	20	10	32
27	23	13	3	25	15	5	27	17	7	29	19	9	31	21	11	1
28	18	8	30	20	10	32	22	12	2	24	14	4	26	16	6	28
29	19	9	31	21	11	1	23	13	3	25	15	5	27	17	7	29
30	14	4	26	16	6	28	18	8	30	20	10	3	22	12	2	24
31	15	5	27	17	7	29	19	9	31	21	11	1	23	13	3	25
32	10	32	22	12	2	24	14	4	26	16	6	28	18	8	30	20

Figure 5.7. Full frame of dot patterns for the experimental system.

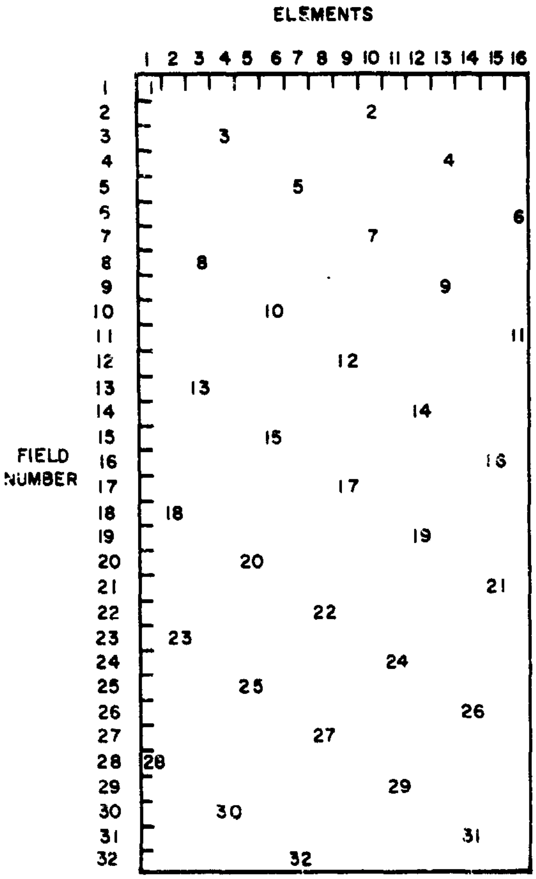


Figure 5.8. Time-spatial dot low resolution frame pattern for the experimental system.

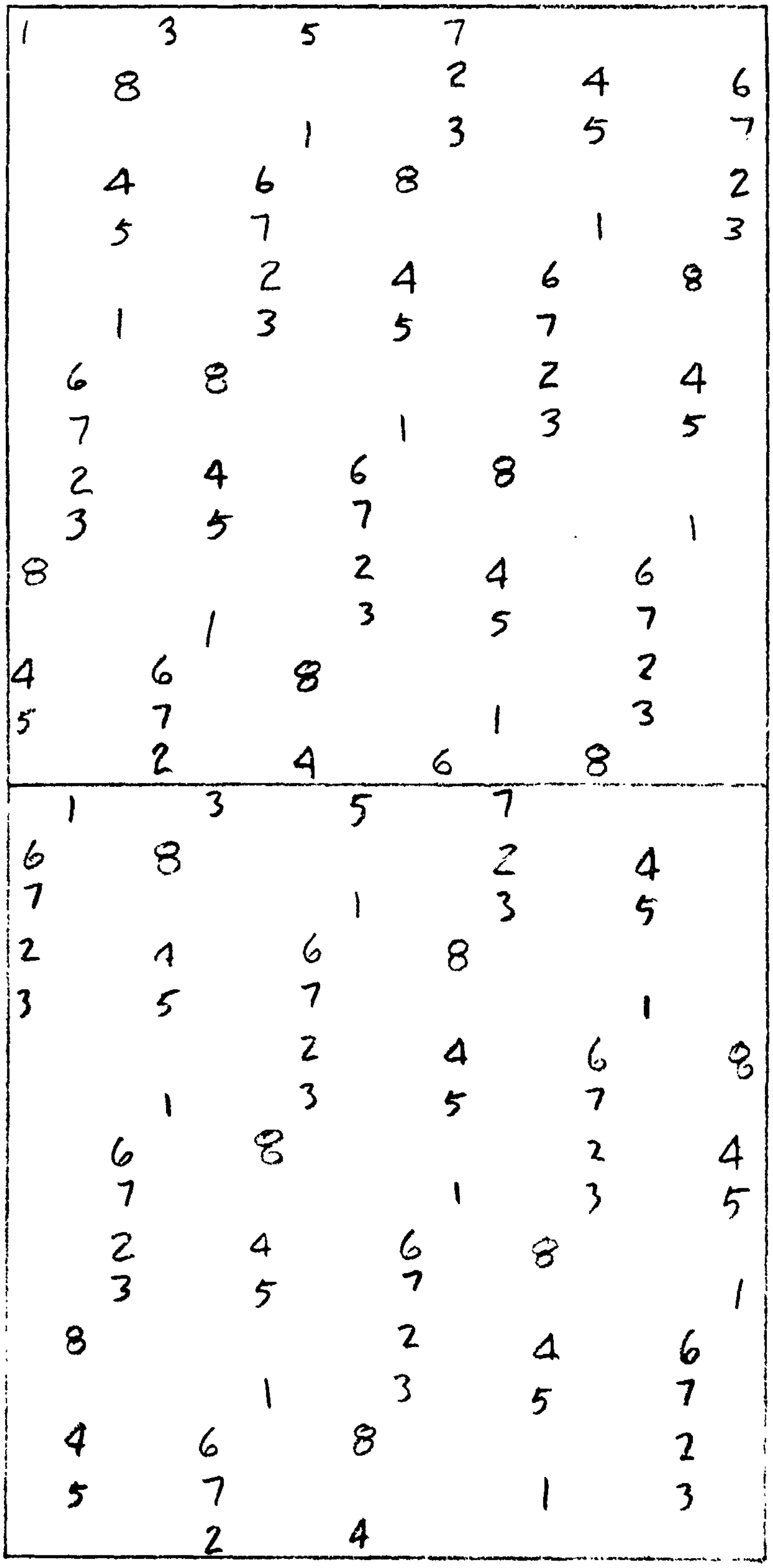


Figure 5.9. First eight frames of dot patterns (quarter storage) for the experimental system.

one next to the other in sequence. Referring to the block of dots of a full frame shown in Figure 5.7 it can be seen that along any vertical line the dots of two adjacent LRF's are placed one above the other in two LRF periods. For example, in the first vertical column of the block, dots of LRF's 28 and 29, 24 and 25, 20 and 21, etc. are placed one above the other. This situation is repeated in all of the columns. Figure 5.10 illustrates the runs of adjacent field dots by arrows. The direction of the arrows indicates the increase in LRF number. The effect of these two element runs is that the eye will notice a dot crawling effect that will appear as waves of brightness moving up or down the displayed picture. In the experimental system with runs of only two elements, the effect is not particularly pronounced, but longer runs or runs of uneven length may cause more serious effects in systems with other dot patterns or pattern sequences.

5.3 DETAILED STUDY OF 16 TO 1 DOT INTERLACE SYSTEM

The 16 to 1 dot interlace system has been selected for detailed study primarily because it affords a high potential bandwidth reduction. Also, the 16 to 1 interlace ratio permits the selection of many combinations of dot patterns and LRF presentation sequences and, therefore, it provides a good indication of the effects of patterning and dot crawl, and the methods for minimizing these effects.

5.3.1 Dot Patterns and Low Resolution Frame Presentation Sequences for 16 to 1 Dot Interlace System

Several basic dot pattern blocks are shown in Figures 5.11 to 5.14. In the blocks labeled modulus 0 to modulus 15 the positions of the dots are cyclically set by counting from the first element in the upper left corner of the block. The only restriction is that not more than one element can be used in any particular row or column. When the cyclic count ends in a column containing a previous dot the next free column is chosen. The black squares indicate the conflicting picture elements. The pattern appearing most evenly distributed is the modulus 6 pattern. It should be noted that this is the basic pattern chosen for the odd and even fields of the experimental system.

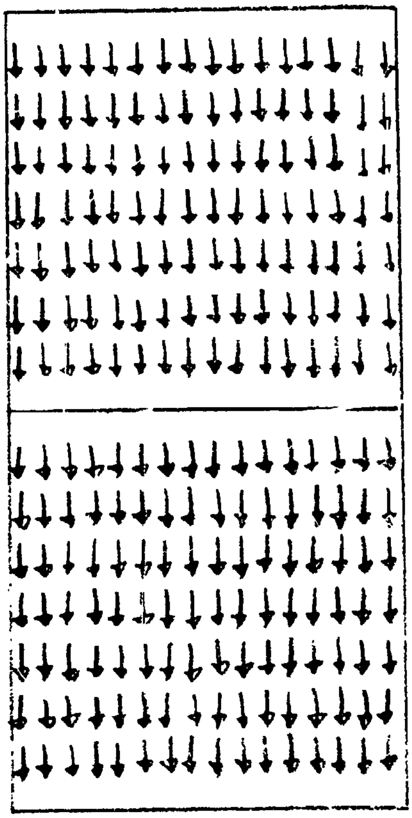


Figure 5.10. Dot field runs for the experimental system.

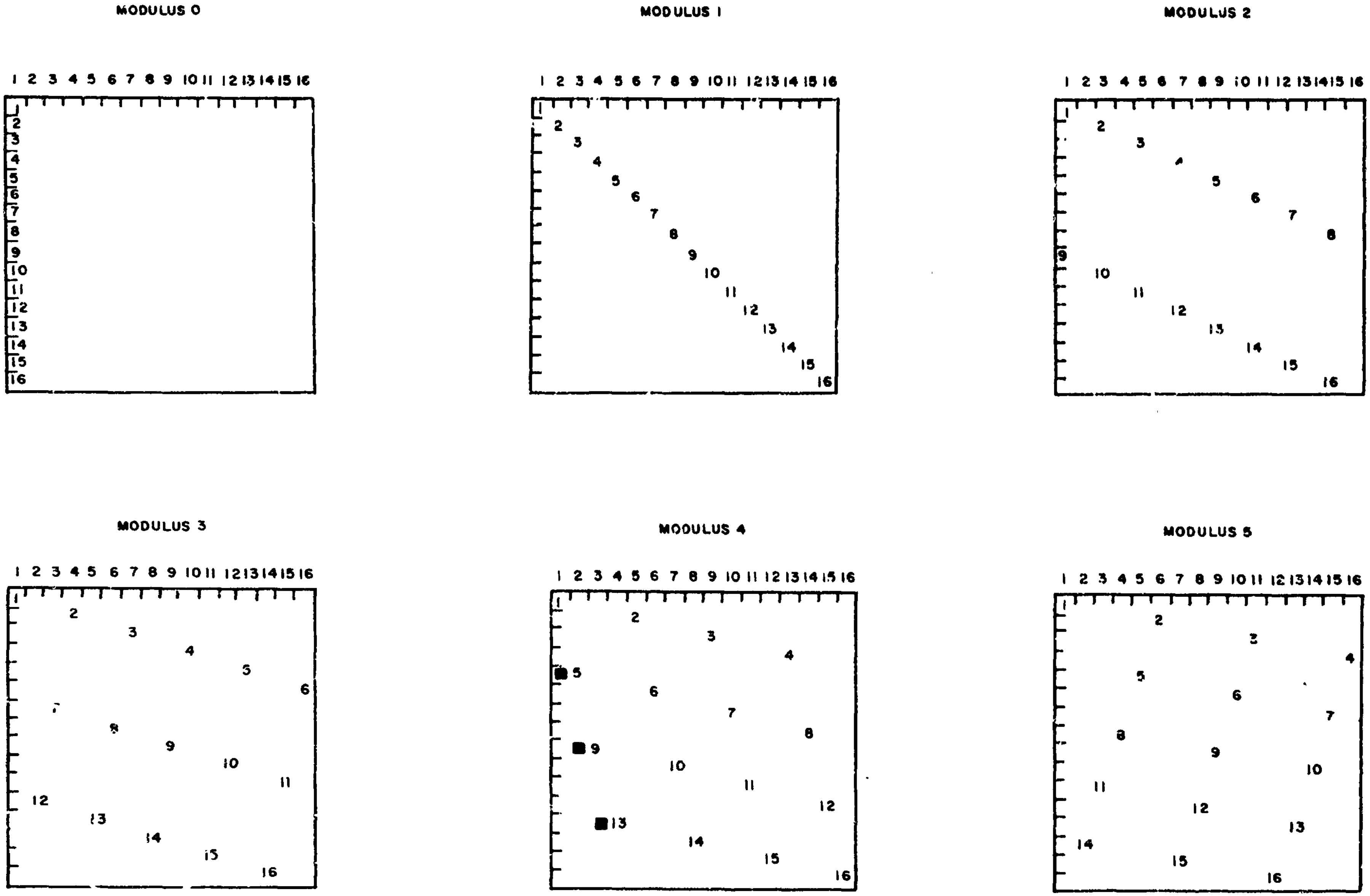


Figure 5.11. Geometric dot patterns.

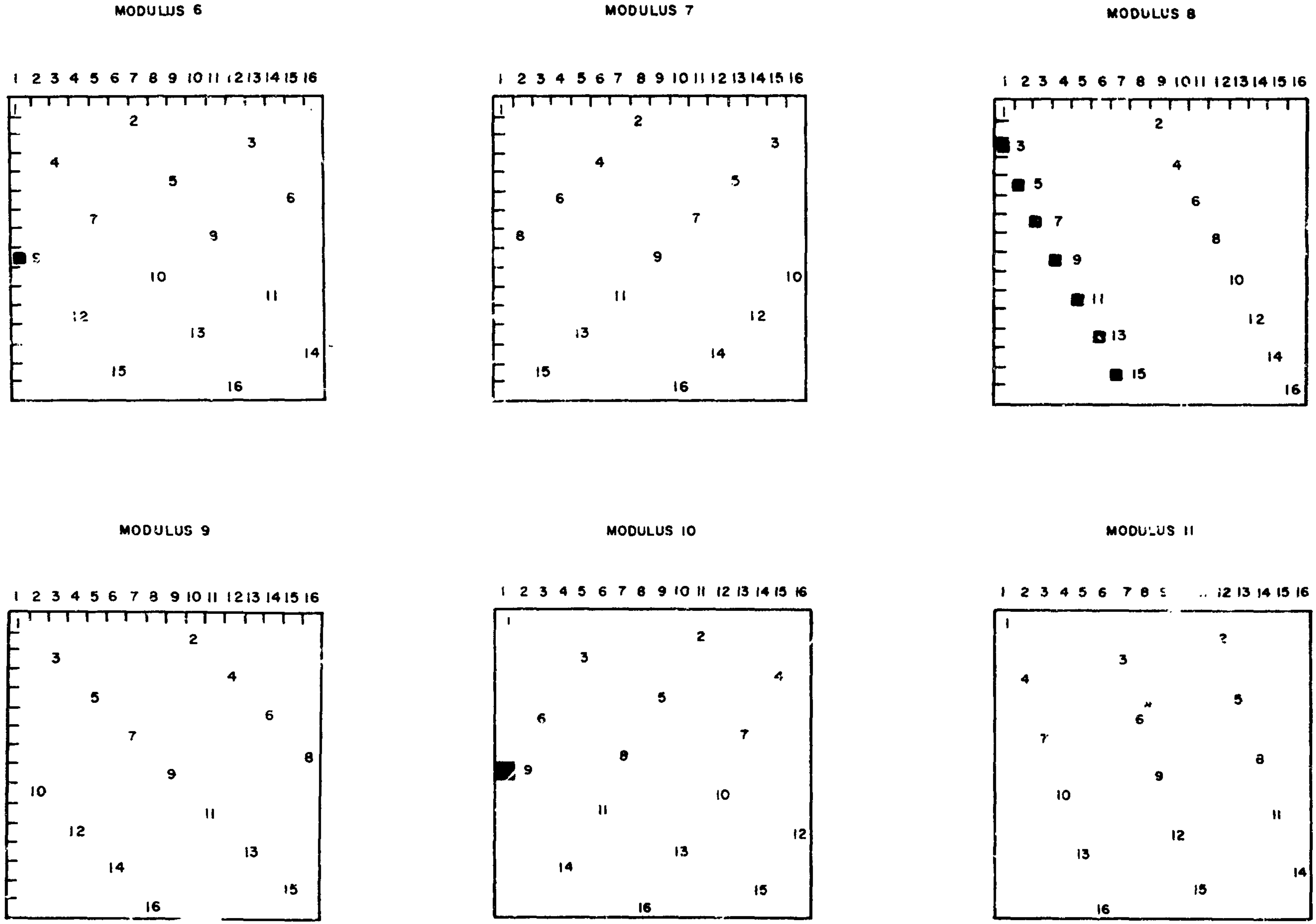
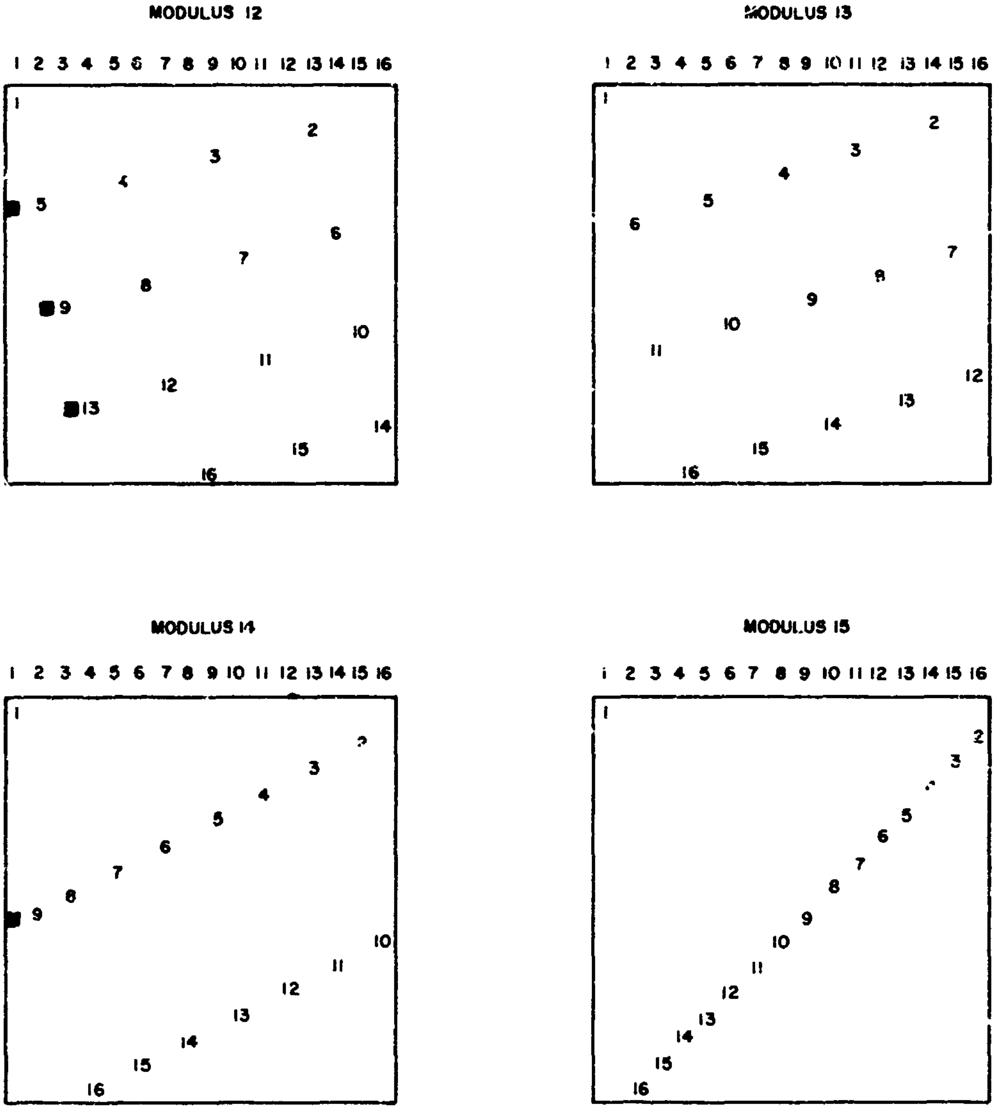


Figure 5.12. Geometric dot field patterns.



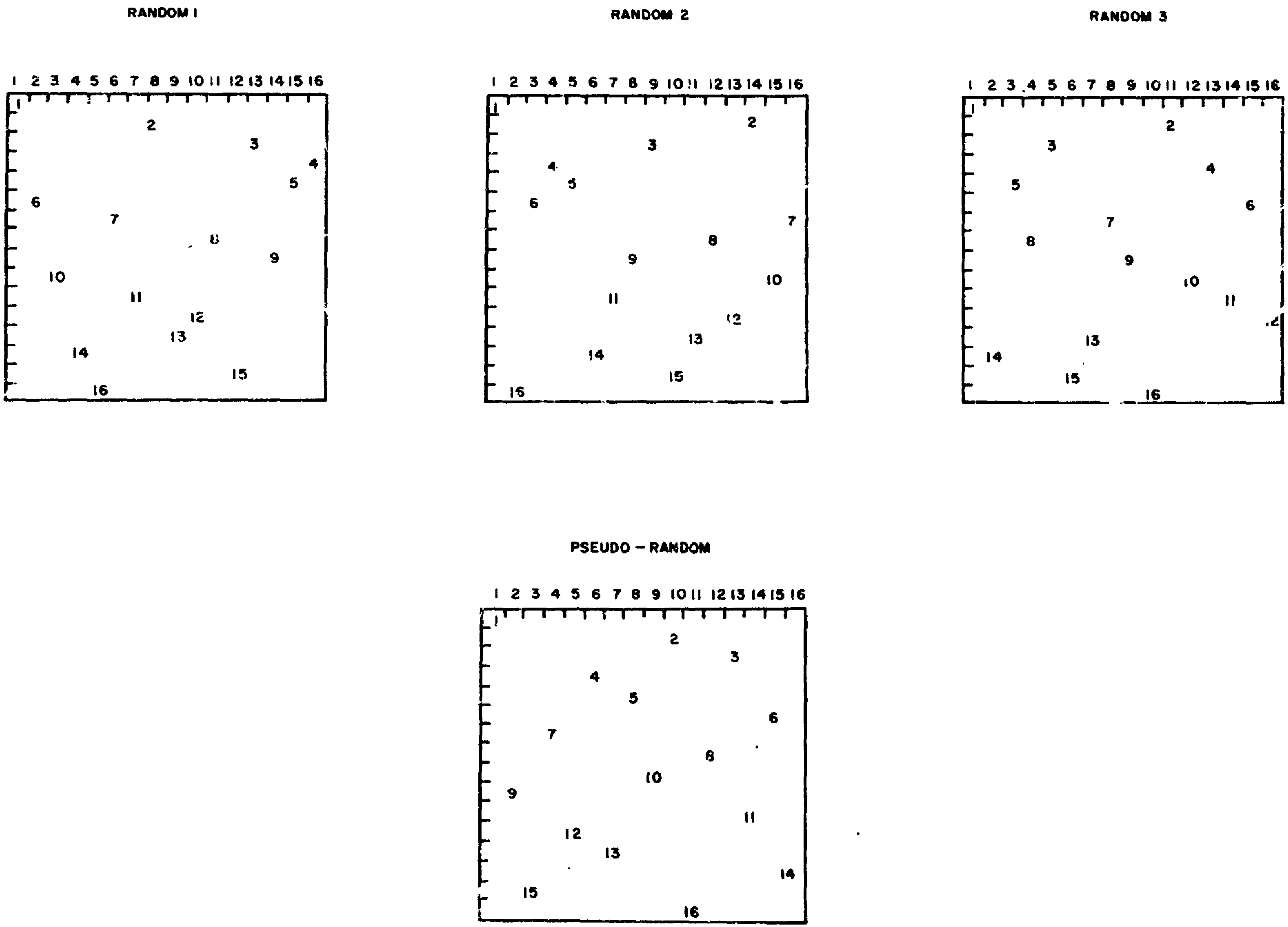
MODULUS 12

MODULUS 13

MODULUS 14

MODULUS 15

Figure 5.13. Geometric dot patterns.



RANDOM 1

RANDOM 2

RANDOM 3

PSEUDO - RANDOM

Figure 5.14. Random and pseudo random dot patterns.

The three blocks designated random 1 to random 3 are developed by placing the dot elements in positions determined from a random number table. The only restriction in the selection is that each row or column cannot contain more than one dot. The block labeled pseudo random contains dots placed to yield a relatively uniform density and to minimize the formation of geometric patterns.

If the time presentation of patterns is geometric, the modulus dot patterns of Figures 5.11, 5.12, and 5.13 can be considered as time-spatial diagrams with the time sequence in the vertical direction.

5.3.2 Patterning in the 16 to 1 Dot Interlace System

Of the geometric patterns, the modulus 6 pattern appears to be the most uniform and free from inherent patterns. When field storage is used, the dot LRF presentation order becomes significant. This fact is illustrated for quarter storage by Figures 5.15 to 5.22 which represent the first four fields displayed for modulus 1 to modulus 15 field presentation sequences. Each dot pattern is the modulus 6 pattern. The blocks displayed according to an LRF presentation sequence of moduli 3, 5, 7, 8, 9, and 11 show a distinct diagonal type pattern. The modulus 1 and 15 field presentation sequence blocks have a horizontal pattern, and the moduli 4, 6, 10, 12, 13 and 14 blocks have a vertical pattern.

The blocks with a horizontal pattern exhibit a distinctly nonuniform composite dot pattern and will not be acceptable. The same situation exists for the blocks with a diagonal pattern. The most acceptable of these blocks are the modulus 6 and modulus 9 LRF presentation sequence blocks, but the composite dot pattern is not as uniform as desired. The most uniform blocks are the modulus 4 and modulus 12 order presentation blocks. These blocks are in effect identical in pattern, and either one may be accepted.

It is necessary not only that the quarter storage blocks do not exhibit patterns for the display of the first four LRF's, but that the blocks also are acceptable for all groups of four LRF's displayed simultaneously. Figures 5.23 and 5.24 illustrate the simultaneous

1	2	3	4												
						1	2	3	4						
												1	2	3	4
		1	2	3	4										
								1	2	3	4				
3	4													1	2
				1	2	3	4								
										1	2	3	4		
	1	2	3	4											
							1	2	3	4					
4													1	2	3
			1	2	3	4									
									1	2	3	4			
2	3	4													1
					1	2	3	4							
											1	2	3	4	

DOT PATTERNS 1-4

MODULUS 6 PATTERN
MODULUS 1 PRESENTATION SEQUENCE

1		2		3		4									
						1		2		3		4			
3		4										1		2	
		1		2		3		4							
								1		2		3		4	
2		3		4										1	
				1		2		3		4					
4										1		2		3	
	1		2		3		4								
							1		2		3		4		
	3		4										1		2
			1		2		3		4						
									1		2		3		4
	2		3		4										1
					1		2		3		4				
	4										1		2		3

DOT PATTERNS 1-4

MODULUS 6 PATTERN
MODULUS 2 PRESENTATION SEQUENCE

Figure 5.15. Quarter storage composite patterning effects.

1			2			3			4						
						1			2			3			4
		3			4							1			2
		1			2			3			4				
	4							1			2			3	
	2			3			4							1	
				1			2			3			4		
			4							1			2		
	1			2			3			4					
4							1			2			3		
2			3			4							1		
			1			2			3			4			
		4							1			2			3
		2			3			4							1
					1			2			3			4	
	3			4							1			2	

DOT PATTERNS 1-4

MODULUS 6 PATTERN
MODULUS 3 PRESENTATION SEQUENCE

1				2				3				4			
		4				1				2				3	
2				3				4				1			
		1				2				3				4	
3				4				1				2			
		2				3				4				1	
4				1				2				3			
		3				4				1				2	
	1				2				3				4		
			4				1				2				3
	2				3				4				1		
			1				2				3				4
	3				4				1				2		
			2				3				4				1
	4				1				2				3		
			3				4				1				2

DOT PATTERNS 1-4

MODULUS 6 PATTERN
MODULUS 4 PRESENTATION SEQUENCE

Figure 5.16. Quarter storage composite patterning effects.

1					2					3					4
3					4	1					2				
	2					3					4	1			
	4	1					2					3			
		3					4	1					2		
			2					3					4	1	
			4	1					2					3	
				3					4	1					2
4	1					2					3				
	3					4	1					2			
		2					3					4	1		
		4	1					2					3		
			3					4	1					2	
				2					3					4	1
				4	1					2					3
2					3					4	1				

DOT PATTERNS 1-4

MODULUS 6 PATTERN
MODULUS 5 PRESENTATION SEQUENCE

1		4				2						3			
		3				1		4				2			
		2						3				1		4	
		1		4				2						3	
				3				1		4				2	
4				2						3				1	
3				1		4				2					
2						3				1		4			
	1		4				2						3		
			3				1		[illegible]				[illegible]		
			2						3				1		4
			1		4				2						3
					3				1		4				2
	4				2						3				1
	3				1		4				2				
	2						3				1		4		

DOT PATTERNS 1-4

MODULUS 6 PATTERN
MODULUS 6 PRESENTATION SEQUENCE

Figure 5.17. Quarter storage composite patterning effects.

1					4		2							3	
				3		1					4		2		
	4		2							3		1			
3		1					4		2						
						3		1					4		2
			4		2							3		1	
		3		1					4		2				
	2							3		1					4
	1					4		2							3
					3		1					4		2	
		4		2							3		1		
	3		1					4		2					
2							3		1					4	
				4		2							3		1
			3		1					4		2			
4		2							3		1				

DOT PATTERN 1-4

MODULUS 6 PATTERN
MODULUS 7 PRESENTATION SEQUENCE

1	3							2	4						
						1	3							2	4
				2	4							1	3		
		1	3							2	4				
2	4							1	3						
						2	4							1	3
				1	3							2	4		
		2	4							1	3				
	1	3							2	4					
4							1	3							2
					2	4							1	3	
			1	3							2	4			
	2	4							1	3					
3							2	4							1
					1	3							2	4	
			2	4							1	3			

DOT PATTERNS 1-4

MODULUS 6 PATTERN
MODULUS 8 PRESENTATION SEQUENCE

Figure 5.18. Quarter storage composite patterning effects.

1		3							2		4				
	4					1		3							2
					2		4					1		3	
		1		3							2		4		
	2		4					1		3					
3							2		4					1	
				1		3							2		4
			2		4					1		3			
	1		3							2		4			
2		4					1		3						
						2		4					1		3
			1		3							2		4	
		2		4					1		3				
	3							2		4					1
4					1		3							2	
				2		4					1		3		

DOT PATTERN 1-4

MODULUS 6 PATTERN
MODULUS 9 FIELD PRESENTATION
SEQUENCE

1				3						2				4	
2				4		1				3					
3						2				4		1			
4		1				3						2			
		2				4		1				3			
		3						2				4		1	
		4		1				3						2	
				2				4		1				3	
	1				3						2				4
	2				4		1				3				
	3						2				4		1		
	4		1				3						2		
			2				4		1				3		
			3						2				4		1
			4		1				3						2
					2				4		1				3

DOT PATTERNS 1-4
QUARTER STORAGE
MODULUS 6 PATTERN
MODULUS 10 FIELD PRESENTATION
SEQUENCE

Figure 5.19. Quarter storage composite patterning effects.

1	4					3					2				
	2					1	4					3			
		3					2					1	4		
		1	4					3					2		
			2					1	4					3	
				3					2					1	4
				1	4					3					2
3					2					1	4				
	1	4					3					2			
		2					1	4					3		
			3					2					1	4	
			1	4					3					2	
				2					1	4					3
4					3					2					1
2					1	4					3				
	3					2					1	4			

DOT PATTERNS 1-4

MODULUS 6 PATTERN
MODULUS 11 PRESENTATION SEQUENCE

1				4				3				2			
		2				1				4				3	
4				3				2				1			
		1				4				3				2	
3				2				1				4			
		4				3				2				1	
2				1				4				3			
		3				2				1				4	
	1				4				3				2		
			2				1				4				3
	4				3				2				1		
			1				4				3				
	3				2				1				4		
			4				3				2				1
	2				1				4				3		
			3				2				1				4

DOT PATTERNS 1-4

MODULUS 6 PATTERN
MODULUS 12 PRESENTATION SEQUENCE

Figure 5.20. Quarter storage composite patterning effects.

1							4			3			2		
3			2			1							4		
			4			3			2			1			
		1							4			3			2
		3			2			1							4
					4			3			2			1	
	2			1							4			3	
	4			3			2			1					
	1							4			3			2	
	3			2			1							4	
				4			3			2			1		
2			1							4			3		
4			3			2			1						
						4			3			2			1
		2			1							4			3
		4			3			2			1				

DOT PATTERNS 1-4

MODULUS 6 PATTERN
MODULUS 13 PRESENTATION SEQUENCE

1										4		3		2	
4		3		2		1									
						4		3		2		1			
2		1										4		3	
		4		3		2		1							
								4		3		2		1	
3		2		1										4	
				4		3		2		1					
	1										4		3		2
	4		3		2		1								
							4		3		2		1		
	2		1										4		3
			4		3		2		1						
									4		3		2		1
	3		2		1										4
					4		3		2		1				

DOT PATTERNS 1· 4

MODULUS 6 PATTERN
MODULUS 14 PRESENTATION SEQUENCE

Figure 5.21. Quarter storage composite patterning effects.

1													4	3	2
			4	3	2	1									
									4	3	2	1			
3	2	1													4
					4	3	2	1							
											4	3	2	1	
	4	3	2	1											
							4	3	2	1					
2	1													4	3
				4	3	2	1								
										4	3	2	1		
4	3	2	1												
						4	3	2	1						
												4	3	2	1
		4	3	2	1										
								4	3	2	1				

DOT PATTERNS 1-4

MODULUS 6 PATTERN
MODULUS 15 PRESENTATION SEQUENCE

Figure 5.22. Quarter storage composite patterning effects.

	5			2				3				4			
		4					5			2				3	
2				3				4					5		
			5			2				3				4	
3				4					5			2			
		2				3				4					5
4					5			2				3			
		3				4					5			2	
		5			2				3				4		
			4					5			2				3
	2				3				4					5	
			/	5			2				3				4
	3				4					5			2		
5			2				3				4				
	4					5			2				3		
			3				4					5			2

DOT PATTERNS 2-5

MODULUS 6 PATTERN
MODULUS 4 PRESENTATION SEQUENCE

	5				6			3				4			
		4					5				6			3	
	6			3				4					5		
			5				6			3				4	
3				4					5				6		
			6			3				4					5
4					5				6			3			
		3				4					5				6
		5				6			3				4		
			4					5				6			3
		6			3				4					5	
				5				6			3				4
	3				4					5				6	
5				6			3				4				
	4					5				6			3		
6			3				4					5			

DOT PATTERNS 3-6

MODULUS 6 PATTERN
MODULUS 4 PRESENTATION SEQUENCE

Figure 5.23. Quarter storage composite patterning effects.

	5				6				7			4			
		4					5				6				7
	6				7			4					5		
			5				6				7			4	
	7			4					5				6		
			6				7			4					5
4					5				6				7		
			7			4					5				6
		5				6				7			4		
7			4					5				6			
		6				7			4					5	
				5				6				7			4
		7			4					5				6	
5				6				7			4				
	4					5				6				7	
6				7			4					5			

DOT PATTERNS 4-7

MODULUS 6 PATTERN
MODULUS 4 PRESENTATION SEQUENCE

	5				6				7				8		
			8				5				6				7
	6				7				8				5		
			5				6				7				
	7				8				5				6		
			6				7				8				5
	8				5				6				7		
			7				8				5				6
		5				6				7				8	
7				8				5				6			
		6				7				8				5	
8				5				6				7			
		7				8				5				6	
5				6				7				8			
		8				5				6				7	
6				7				8				5			

DOT PATTERNS 5-8

MODULUS 6 PATTERN
MODULUS 4 PRESENTATION SEQUENCE

Figure 5.24. Quarter storage composite patterning effects.

display of LRF's 2-5, 3-6, 4-7 and 5-8 for a modulus 6 pattern and a modulus 4 LRF presentation sequence. Each of the blocks exhibits the same type of composite patterning as the block of the first four LRF's.

Another check that must be made on the acceptance of a method of order presentation is the patterning effect for a greater amount of storage. Figures 5.25 and 5.26 illustrate the composite patterning effects for half storage for the modulus 6 pattern and the modulus 4 order presentation format. None of the half storage blocks examined showed any serious composite patterning effects.

5.3.3 Dot Crawl in the 16 to 1 Dot Interlace System

The other major consideration in the selection of a field presentation sequence is that of dot crawl. There will be dot crawl in a reproduced picture if the sequence of LRF display is such that dots of adjacent LRF numbers are located in a spatial numerical order. This situation can be discovered for a particular basic dot pattern and LRF order presentation sequence by developing a complete frame of dot patterns. Figure 5.27 shows the full frame of dot patterns for a modulus 6 dot pattern and a modulus 4 order presentation sequence. Examination of the block shows that only one run of adjacent LRF numbers exists horizontally or vertically. This is the LRF number 16 to LRF number 1 transistion that occurs on every line as shown in Figure 5.28. The uniform placement of these short runs should not produce a serious amount of dot crawl.

As an example of a situation where dot crawl would be more bothersome, consider the case of a modulus 6 dot pattern and a modulus 6 LRF presentation sequence. The full frame of dot patterns is shown in Figure 5.29 for this case. It will be noticed that the block is composed of many runs of varying length. Figure 5.30 illustrates the run lengths and positions for this case.

5.4 SUMMARY OF PATTERNING AND DOT CRAWL STUDY

From this study of composite patterning effects it appears that the modulus 6 dot pattern and a modulus 4 low resolution frame presentation sequence are the best choices for the 16 to 1 dot interlace system. For a final evaluation of the patterning and dot crawl effects of this system it will be necessary to implement the system and conduct viewer acceptability tests. If this pattern and presentation sequence does not prove to be completely acceptable, further minimization of the patterning and dot crawl effects should be possible by using a pseudo random dot pattern and LRF presentation sequence. This can easily be accomplished with the system described in section 3.2.

1	5			2	6			3	7			4	8		
		9	8			1	5			2	6			3	7
2	6			3	7			4	8			1	5		
		1	5			2	6			3	7			4	8
3	7			4	8			1	5			2	6		
		2	6			3	7			4	8			1	5
4	8			1	5			2	6			3	7		
		3	7			4	8			1	5			2	6
	1	5			2	6			3	7			4	8	
7			4	8			1	5			2	6			3
	2	6			3	7			4	8			1	5	
8			1	5			2	6			3	7			4
	3	7			4	8			1	5			2	6	
5			2	6			3	7			4	8			1
	4	8			1	5			2	6			3	7	
6			3	7			4	8			1	5			2

DOT PATTERNS 1-8

MODULUS 6 PATTERN
MODULUS 4 PRESENTATION SEQUENCE

	5	9		2	6			3	7			4	8		
		4	8				5	9		2	6			3	7
2	6			3	7			4	8				5	9	
			5	9		2	6			3	7			4	8
3	7			4	8				5	9		2	6		
9		2	6			3	7			4	8				5
4	8				5	9		2	6			3	7		
		3	7			4	8				5	9		2	6
		5	9		2	6			3	7			4	8	
7			4	8				5	9		2	6			3
	2	6			3	7			4	8				5	9
8				5	9		2	6			3	7			4
	3	7			4	8				5	9		2	6	
5	9		2	6			3	7			4	8			
	4	8				5	9		2	6			3	7	
6			3	7			4	8				5	9		2

DOT PATTERNS 2-9

MODULUS 6 PATTERN
MODULUS 4 PRESENTATION SEQUENCE

Figure 5.25. Half storage composite patterning effects.

	5	9			6	10		3	7			4	8		
		4	8				5	9			6	10		3	7
	6	10		3	7			4	8				5	9	
			5	9			6	10		3	7			4	8
3	7			4	8				5	9			6	10	
9			6	10		3	7			4	8				5
4	8				5	9			6	[illegible]		3	7		
10		3	7			4	8				5	9			6
		5	9						3	7			4	8	
7			4	8				5	[illegible]			6	10		3
		6	10		3	7			4	8				5	9
8				5	9			6	10		3	7			4
	3	7			4	8				5	9			6	10
5	9			6	10		3	7			4	8			
	4	8				5	9			6	10		3	7	
6	10		3	7			4	8				5	9		

DOT PATTERNS 3-10

MODULUS 6 PATTERN
MODULUS 4 PRESENTATION SEQUENCE

	5	9			6	0			7	1		4	8		
11		4	8				5	9			6	0			7
	6	10			9	1		4	8				5	9	
			5	9			6	10			7			4	8
	7	11		4	8				5	9			6	10	
9			6	10			7	11		4	8				5
4	8				5	9			6	10			7	11	
10			7	11		4	8				5	9			6
		5	9			6	10			7	11		4	8	
7	11		4	8				5	9			6	10		
		6	10			7	11		4	8				5	9
8				5	9			6	10			7			4
		7	11		4	8				5	9		2	6	10
5	9			6	10			7	11		4	8			
	4	8				5	9			6	10			7	11
6	10			7	11		4	8				5	9		

DOT PATTERNS 4-11

MODULUS 6 PATTERN
MODULUS 4 PRESENTATION SEQUENCE

Figure 5.26. Half storage composite patterning effects.

1	5	9	13	2	6	10	14	3	7	11	15	4	8	12	16
11	15	4	8	12	16	1	5	9	13	2	6	10	14	3	7
2	6	10	14	3	7	11	15	4	8	12	16	1	5	9	13
12	16	1	5	9	13	2	6	10	14	3	7	11	15	4	8
3	7	11	15	4	8	12	16	1	5	9	13	2	6	10	14
9	13	2	6	10	14	3	7	11	15	4	8	12	16	1	5
4	8	12	16	1	5	9	13	2	6	10	14	3	7	11	15
10	14	3	7	11	15	4	8	12	16	1	5	9	13	2	6
16	1	5	9	13	2	6	10	14	3	7	11	15	4	8	12
7	11	15	4	8	12	16	1	5	9	13	2	6	10	4	3
13	2	6	10	14	3	7	11	15	4	8	12	16	1	5	9
8	12	16	1	5	9	13	2	6	10	14	3	7	11	15	4
14	3	7	11	15	4	8	12	16	1	5	9	13	2	6	10
5	9	13	2	6	10	14	3	7	11	15	4	8	12	16	1
15	4	8	12	16	1	5	9	13	2	6	10	14	3	7	11
6	10	14	3	7	11	15	4	8	12	16	1	5	9	13	2

Figure 5.27. Full frame of dot patterns Modulus 6 pattern, Modulus 4 presentation sequence.

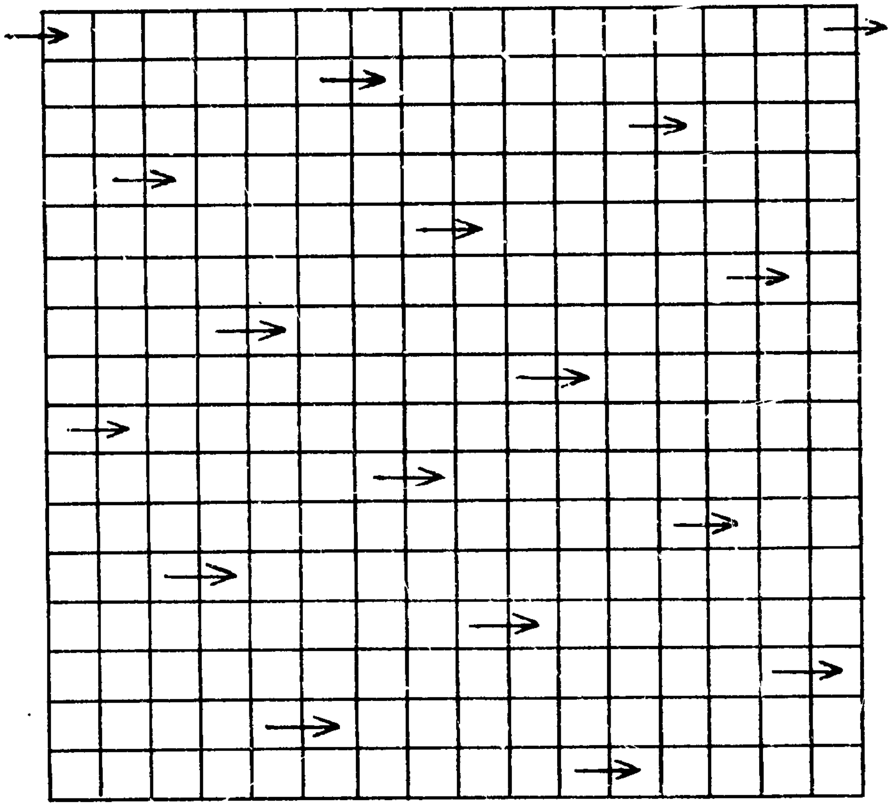


Figure 5.28. Dot fields runs Modulus 6 pattern, Modulus 4 presentation sequence.

1	9	4	12	7	15	2	10	5	13	8	16	3	11	6	14
8	16	3	11	6	14	1	9	4	12	7	15	2	10	5	13
7	15	2	10	5	13	8	16	3	11	6	14	1	9	4	12
6	14	1	9	4	12	7	15	2	10	5	13	8	16	3	11
5	13	8	16	3	11	6	14	1	9	4	12	7	15	2	10
4	12	7	15	2	10	5	13	8	16	3	11	6	14	1	9
3	11	6	14	1	9	4	12	7	15	2	10	5	13	8	16
2	10	5	13	8	16	3	11	6	14	1	9	4	12	7	5
14	1	9	4	12	7	15	2	10	5	13	8	16	3	1	6
13	8	16	3	11	6	14	1	9	4	12	7	15	2	10	5
12	7	15	2	10	5	13	8	16	3	11	6	14	1	9	4
11	6	14	1	9	4	12	7	15	2	10	5	13	8	16	3
10	5	13	8	16	3	11	6	14	1	9	4	12	7	15	2
9	4	12	7	15	2	10	5	13	8	16	3	11	6	14	1
16	3	11	6	14	1	9	4	12	7	15	2	10	5	13	8
15	2	10	5	13	8	6	3	11	6	14	1	9	4	12	7

Figure 5.29. Full frame of dot patterns Modulus 6 pattern, Modulus 6 presentation sequence.

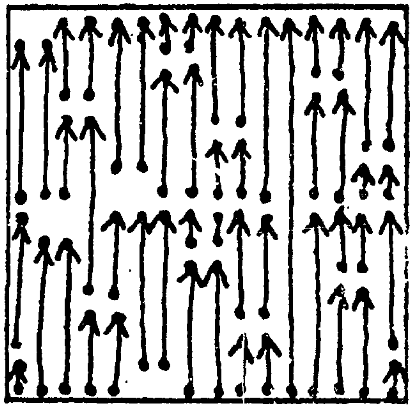


Figure 5.30. Dot field runs Modulus 6 pattern, Modulus 6 presentation sequence.

6. CONCLUSIONS

There are two major parts to the problem of obtaining television information from deep space. The first part has to do with changing an optical presentation into an electrical signal while the second part relates to conveying that electrical signal to earth with the least degradation. In approaching the task of converting an optical display into an electrical signal both the encoding and decoding equipment must be considered, since the goal of such a task is to obtain the best tradeoff among picture quality, information bandwidth restriction, and immunity to noise effects. A comparison of various processing schemes might properly be done by connecting a camera utilizing a technique under consideration, and monitor mated to that camera system. To compare two systems, two identical low pass filters could be placed between camera and monitor of each of the two systems under test. Noise could also be added in the same degree to the outputs of the two filters and the picture quality on the two monitors compared. Regardless of the means used to transmit the signal to ground, i.e. AM, FM, or digital coding, it is obvious that the less video bandwidth required as well as the lower the video signal to noise ratio required, the better the overall system will be if all else is equal.

The present study has considered various analog techniques which might be used to convert a visual presentation into a minimum bandwidth video signal having a minimum susceptibility to video noise. In as much as all such schemes have some effect on picture quality, the relative effect on viewability of many types of degradion have been analyzed. The ability of various television systems to convey the appearance of motion has been studied, along with an evaluation of various types of moving image breakup.

It is a conclusion of this study that, although additional effort in the area of frame storage mechanization is needed to demonstrate its full capability, the multiple interlace system offers decided advantages over other techniques evaluated for use on manned space missions. In order to evaluate the subjective acceptability of this and other systems, it appears to be advisable to construct camera and encoders as well as ground processing decoders. Efforts to simulate frame storage by use of cathode ray tubes or by film storage techniques have not been satisfactory, and should be supplemented by design and fabrication of experimental models of portions of the proposed system as part of any future work.

The advantages of the multiple interlace system include the following:

a. High frame rate low resolution pictures available for viewing rapid motion.

b. High resolution low frame rate pictures available where motion rate is low.

c. Effective frame rate selectable at the receiver over a 16:1 range.

d. Constant element rate makes full use of a priori information.

e. Spacecraft equipment of minimum complexity and size.

f. Wide band video available for monitor in S/C for Astronaut viewing.

g. Scanning vidicon in S/C camera occurs at 16 times the equipment bandwidth conventional TV scan rate. This results in increased signal available for equal foot-candle-second exposure resulting in higher video signal to noise ratio at the camera.

APPENDIX A

ADDITIONS TO BIBLIOGRAPHY OF TELEVISION BANDWIDTH COMPRESSION TECHNIQUES

The phase one report of the Advanced Analog Television Study contained an extensive bibliography of television bandwidth compression techniques and related topics. Since the publication of the phase two additions to the bibliography the following additional papers and reports have been discovered.

1207 H. J. Romanowicz, "Effect on Surveyor TV Picture Quality of Sync Degradation Due to Noise" IDC 2729.10/288 Hughes Aircraft Company.

1208 Colin Cherry, M. H. Kubba, D. E. Pearson, M. P. Barton, "An Experimental Study of the Possible Bandwidth Compression of Visual Image Signals," Proc. IEEE, November 1963, pg 1507-1517.

1209 M. H. Kubba, "Automatic Picture Detail Detection in the Presence of Random Noise," Proc. IEEE, November 1963, pg 1518-1523.