Nasa CR-65226

Report 10173

STUDY REPORT FOR THE MANNED SPACECRAFT VIDEO MONITOR

CONTRACT NO. NAS 9-4551

prepared for

NASA MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

HAZELTINE ®

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HAZELTINE CORPORATION
HAZELTINE ELECTRONICS DIVISION

REPORT 10173

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Contract No. NAS9-4551

November 12, 1965

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SUMMARY

This report describes the preliminary study work on the Manned Spacecraft Video Monitor performed under Contract NAS 9-4551. The study was conducted to develop a design and construction philosophy, hardware, and display techniques for the spacecraft video monitor consistent with the space system requirements. State of the arts displays have been evaluated and compared. A cathode ray tube display system was selected. A preliminary design for the display electronics was developed, tested, and evaluated under laboratory conditions. The electronic design provides for minimum power consumption, extreme flexibility of operation, and high reliability. The packaging philosophy of the Video Monitor components was established and provides for system compactness, ruggedness, minimum weight, and maximum simplicity. Several cathode ray tube screen phosphors were tested and evaluated under simulated spacecraft conditions and the phosphor best suited to the wide range of display repetition rates was selected.

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SECTION I

INTRODUCTION

A. GENERAL

The purpose of this report is to describe the work ~~accomplished~~ on NASA contract NAS9-4551 during the period from July 7 1965 to November 7, 1965. The objective of this contract is to study, design and develop an engineering model of the Video Monitor for a manned spacecraft.

The program is divided into two phases. The first phase is a design study whose purpose is to investigate various display techniques and select the system concept best suited to the manned spacecraft requirements. The investigation work is supported by breadboard experimentation to check feasibility, evaluate performance, and confirm theoretical analyses. The second phase is a design and development phase whose objective is to construct and test the engineering model of the video monitor based on the results of the study.

This report describes the work performed in the first phase of the program, reports the results of the study, and recommends the design approach and packaging configuration for the engineering model.

B. STUDY PHASE

The study phase began with an investigation of the state-of-the-art of display techniques in order to determine the basic design concept that will achieve maximum compliance with the spacecraft requirements of system compactness, minimum weight, low power consumption, extreme flexibility, high reliability, maximum simplicity, and environmental ruggedization.

Electroluminescent display techniques were studied for feasibility of adaptation to the intended spacecraft usage. It was determined that the performance of existing electroluminescent displays is inferior in practically all respects to the performance obtainable from cathode ray tubes. Conservative estimates predict that the quality of large image, electroluminescent displays will not equal the quality of CRT displays for at least ten years. Furthermore, the stringent requirements of the spacecraft monitor application for high resolution and controlled storage further increase the gap between electroluminescence and CRT technology. All the problems associated with electroluminescent displays have not yet been solved experimentally in the laboratory, let alone on a practical basis.

An investigation was conducted into the state-of-the-art of cathode ray tubes to evaluate and define the tube parameters and the deflection method best suited to the video monitor performance requirements.

It was determined that a CRT display utilizing the rectangular 6-inch diagonal faceplate provides an optimum size display. Gun designs which provide adequate resolution and other features of the herein recommended system arrangement are available for this bulb size.

Various CRT phosphors were investigated and evaluated to determine the persistence characteristics required to display the wide range of image frame rates.

In order to provide frame rate display flexibility the phosphor must have multiple persistence characteristics which can be separated by using appropriate color filters. Both cascaded and mixed phosphors were considered and evaluated. Because of the human factors involved, such as flicker, the final selection of the phosphor was made after experimentally simulating the viewing conditions and subjectively evaluating the display under all frame rates.

Results of the deflection circuit study show that, theoretically, minimum power requirements are achieved by a system having a hybrid vertical (Y) axis deflection comprising a low frequency electromagnetic component and a high frequency electrostatic component. They are operated simultaneously for both the signal and image display modes over the dc to 1 Mc range by means of a crossover network. This eliminates the necessity for input signal switching and for dc coupling at high voltage of the electrostatic signals or, alternately, of the video intensity signal. It also provides extended off-center and low frequency deflection of the signal display. The horizontal (X) axis deflection is provided by a high efficiency direct coupled magnetic circuit.

The electronic circuits for the Video Monitor were designed, breadboarded, and tested to verify the design parameters and establish the most efficient configuration.

The resultant power requirements of the recommended system are: X deflection 5.40 watts, Y deflection low frequency 1.20 watts, Y deflection high frequency 3.33 watts, filament 1.8 watts. The total is 21.14 watts for the complete unit. The low power consumption simplifies heat removal, reduces size and weight of the completed unit and reduces reliability problems.

The mechanical design study was based on the results of the electrical design study, the spacecraft requirements, and human factors considerations. The cathode ray tube support fixture was designed and the Video Monitor chassis laid out to meet the electrical and environmental requirements. Various circuit packaging methods were considered and evaluated for minimum volume, minimum weight, maximum rigidity, optimum heat transfer, and ease of repair. The recommended mechanical design of the Video Monitor is a single unit construction combining all the system functions into one package. This approach offers minimum volume, weight and complexity with maximum rigidity, ease of installation, and operation.

C. REPORT CONTENTS

The theoretical design considerations and analyses of the Manned Spacecraft Video Monitor are presented in Section II of this report. The functional system requirements are considered one at a time, and the desired operating parameters and design concepts are established to satisfy the requirements with minimum weight, volume and power consumption.

The results of the electroluminscent display study are presented in Section III. A brief qualitative description of what electroluminescence is and how it works is given. Supplementing this is as much state-of-the-art information regarding its capabilities that is available and pertinent to the Manned Spacecraft Video monitor application.

A detailed electrical circuit design description is given in Section IV. The electrical design concepts and the resulting performance characteristics are described. The functional operation of each circuit and the various system operating modes are described.

A detailed description of the mechanical design concept is presented in Section V.

Section VI reports the display performance characteristics obtained with the breadboard of the Video Monitor.

SECTION II

SYSTEM PERFORMANCE CONSIDERATIONS

A. GENERAL

The objective of this section is to analyze the basic philosophy and system concept of the Manned Spacecraft Video Monitor and to establish those parameters which will provide the desired performance in an optimized package of minimum size, weight and power consumption.

Those system specifications outlined in the statement of work, Exhibit "A", of contract NAS9-4551, which are of specific interest in establishing an optimized basic design include operation in two modes - either as an image display or as a signal display - and include max. -min. limits on certain parameters as listed below.

a. Ambient illumination -- 2 to 1 ft. -lambert

b. Gray scale -- 6 uniform steps min.

c. Resolution -- 1000 TV lines at 20% modulation max.

d. Resolution -- 1200 lines min. with 40% overlap max.

e. Deflection (X) -- 20 Kc to 0.5 cps, 1% linearity

f. Deflection (Y-image) -- 60 cps to 0.625 cps, 2% linearity

g. Deflection (Y-signal) -- 1 Mc to dc, 1% linearity

h. Display storage (image) -- 1.6 sec. min.

i. Power -- 10 watts max.

j. Weight -- 10 pounds max.

k. Volume -- 600 cu. in. max.

The CRT is the major component which influences display performance and establishes package size. The associated deflection circuitry is the principal source of power consumption. High power dissipation requires complex heat conduction and radiation means, increases size and weight, and introduces reliability problems. Major emphasis is therefore placed on the CRT and on selection of deflection components and circuits which achieve the desired performance at theoretical minimum power consumption and which provide over-all system simplification. In the following sections each of the display parameters is considered separately and its effect on meeting the above specifications and objectives is analyzed.

B. CATHODE RAY TUBE

1. Viewing Conditions

Determination of the optimum display characteristics of the CRT screen is dependent on the solution of a complex relationship of several independent variables. The principle variables involved are the display highlight brightness, persistence, contrast, and the resolution. These variables must be optimized for the visual characteristics of image perception of the human eye under the ambient illumination of 2 ft. -lambert, and for the various display modes.

From a viewer standpoint, the modes of operation, whether image or signal, may be considered in three distinct ranges dependent on the display repetition rate. These ranges center about the frequencies of the three image displays, that is, 60 cps, 10 cps and 0.625 cps.

a. 60 CPS Display

The screen viewing area is 17.3 square inches. A variety of short persistence phosphors having relatively high efficiency including the blue component of P7 would be suitable. At 6 KV accelerating potential a nominal figure for efficiency is 0.03 μa per ft. -lambert X square inch. The display beam current at 20 ft. -lamberts highlight is then 10 μa - a value attainable at the required resolution (Section B.2). Flicker is below the perceptible limit and storage is not a problem.

b. 10 CPS Display

At 10 cps the display light output is limited by the amount of flicker which can be tolerated by the viewer. Image retention or storage characteristics of the eye cease at about this frequency. Flicker perception (fc) vs brightness (B) is given by the Ferry-Porter law

$$fc = 37 + 12.6 \log_{10} B$$

At 10 cps the value of B is less than 0.01 ft. -lambert - a value on the boundary of scotopic vision where eye resolution is degraded. However, the illumination level acceptable will be determined by the amount of flicker which can be tolerated by the observer rather than the point at which flicker becomes perceptible. This latter value is dependent on many factors; the general illumination level, angle subtended by the display, length of time that continuous viewing is required, phosphor time constant and decay characteristic, etc. The useable brightness may be expected to fall in the range of approximately 0.2 to 2 ft. -lambert.

Beam current will depend on the phosphor efficiency which may be lower than the typical range for a suitable phosphor. To achieve minimum flicker the phosphor decay characteristic should be as long as possible without introducing intolerable smear. For this purpose the decay should hold for the 0.1 second interval, then terminate rapidly rather than have a long tail as characterized by the P7 yellow component. A phosphor of this type is P12. A longer time constant is, however, desired. Possible phosphors in the desired range include Ferranti type L3, or the Thomas type E.

To achieve the gray scale requirement for low display light levels as compared to the ambient level, a limiting angle filter may be required if conventional CRT screens are employed.

c. 0.625 CPS Display

In order to provide an optimum display over the range from 1 - 2 seconds it is necessary that the phosphor decay slowly over this interval. To eliminate smear it should terminate quickly thereafter. Even for a slow decay phosphor, however, the difference in brightness of the line being scanned and the rest of the image will cause some glare and fade out of the decayed image. The decrease in brightness of P7.1 second after excitation is about 25 times. Retention by the observer of a one to two second image is possible, but the average light level will be low. Another good phosphor for this range is Thomas type E. Such a phosphor might provide suitable performance for both the 10 and 1 - 2 cps ranges. This phosphor decays only 10% in 0.1 second and 90% in 1.6 seconds.

d. Possible Phosphor Arrangement

In order to overcome the above noted difficulties if P7 phosphor is found inadequate, another approach to a more satisfactory screen arrangement is the use of a screen comprising a mixture of two or three phosphors with appropriate decay characteristics and adequate color separation so that the undesired components could be filtered out. Two component versions would include a short time constant green P1 and a long persistence orange type E.

2. Resolution Vs Gun Requirements

The resolution specifications are not fully defined. However, assuming a Gaussian spot distribution, the relationship between 1/2 axis mean spot width (σ) and percent modulation (F = 0.20) is

$$F = e^{-2\pi^2 f^2 \sigma^2}$$

f is the inverse of the spacing for which the modulation is specified or 1/4.8 mils for the proposed faceplate. The resultant mean spot width (2σ) is 2.74 mils. 1200 lines vertical gives a line spacing of 3.0 mils. 40% overlap is here assumed to apply to 4 σ width, thereby resulting in a specified 2σ spot width of 2.5 mils. The above values provide a display in which the degradation due to spot size is rather small and may result in severe gun design requirements under adverse conditions discussed under screen section B. 1.

In order to assure optimum center to edge focus with minimum spot degradation and without the use of complex dynamic focus modulation, it is desirable to use a "zero" focus electrostatic gun. It has a large depth of field but is limited in beam current. Available gun designs were discussed with Thomas Electronics personnel. They quote a 4 mil spot size at 25 μa and 6 KV for a zero focus gun designed for a 3/4 inch neck tube and estimate max. beam current before blooming, at 50 μa. If a higher beam current and/or smaller spot size is required, Thomas can supply a hi-electrostatic gun capable of considerably higher beam current vs spot size. This gun substantially retains the depth of focus feature and would require a focus adjustment at relatively high voltage. The high performance of this type gun is unique with Thomas. Such a gun is estimated to provide a 100 μa spot in a 3/4 inch neck tube and could go considerably higher in a 1 and 1/8 inch neck tube (all based on 4 mil spot size).

3. Electrostatic Deflection Vs CRT Size

From the magnetic deflection energy standpoint a minimum (3/4 inch) neck diameter is desired. In view of packaging, shock, and vibration requirements this neck should be as short as possible. It will be shown that electrostatic deflection at high frequencies (Y signal) provides a large saving in power. The zero focus gun is available with electrostatic (Y) plates. They do not add appreciably to neck length. The deflection sensitivity is approximately 200 volts per inch, the capacity 7 pf max. per plate. Over-all tube length is 10-3/4 inch of which 5-1/4 inch is the bulb faceplate to reference line dimension. A hi-electrostatic gun would be 1/2 inch to 1 inch longer.

The zero focus electrostatic tube with electrostatic (Y) plates will therefore meet all the display requirements provided screen requirements are limited to 20 μa max. Above this value a hi-electrostatic gun of increased size is recommended.

4. Heater Power

The principal problem associated with reduced heater power is reliability. The low power heaters developed for commercial application (per Thomas) are not adaptable to high reliability performance. They, however, have developed high reliability 1.8 watt heaters and have done some work on a similar 1 watt heater. In view of the requirement for both reliability and low total power, it is recommended that the 1.8 watt heater be used in preliminary design.

C. DEFLECTION YOKE

The prime requisites of the deflection yoke are that it does not introduce spot size degradation with deflection and that it provide the required deflection with minimum energy. Since large energy requirements occur during high speed deflection, the LI^2 constant of the yoke is the principal criterion of interest. However, where reactance energy recovery can be achieved as will be proposed the yoke Q (including core losses) is of interest. In this application additional factors to be considered are size, weight and means for adequately conducting the heat out of the yoke to its mounting support.

Commercially available 3/4 inch neck diameter yokes with low LI^2 products include Celco type MY514, Syntronic type Y59 and Syntronic dwg. #C3020. The LI^2 products at 6 KV and 55 degree total deflection for these yokes are:

MY514:	1 mhy 6.5 ohms,	I = 1.194A,	$LI^2 = 1.43$ mj
Y59:	1.15mhy 1.8 ohms,	I = 1.13A,	$LI^2 = 1.47$ mj
Dwg. 3020:	R = 3 x L	------------------	$LI^2 = 1.30$ mj

Type Y59 is the only yoke with a high Q core. It also provides good heat removal and is provided with pin-cushion correction magnets. They are recommended to reduce geometric distortions in order that linearity specifications may be met without requiring deflection circuit linearity corrections. See Section D.

In deflection circuit power calculations which follow, the value of 1.47×10^{-3} for LI^2 (type Y59) will be used. Final choice of yoke will depend on an experimental evaluation of the yoke.

D. DEFLECTION CIRCUITS

1. General

The peak and average (dc power supply drain - W) inductive power requirements of any type magnetic deflection circuit under repetitive operating conditions of a specified waveform can be expressed as a function of the yoke LI^2 constant, the repetitive frequency (f) and an operating duty ratio (r) of the waveform. The general form is

$$W = kLI^2 f \times f(r)$$

The yoke current waveforms vs time of interest are linear (constant slope) and sinusoidal. The equations are listed below for a variety of circuit configurations and waveforms.

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a. Single ended - class A - inductive coupled - retrace pulse nonlimited.

sine wave: $W = 1.57LI^2f$; linear: $W = LI^2f/2(1 - r)$

b. Push-pull, complementary-symmetry, quasi-complementary - class B - retrace pulse nonlimited - *symmetrical power supply

sine wave: $W = LI^2f$; linear: $W = LI^2f/4r$

*Complementary-symmetry and quasi-complementary circuits with linear input and a (nonsymmetrical power supply ratio coresponding to the value of r)

$$W = LI^2f/8r(1 - r)$$

c. Circuits per b above with auxiliary retrace pulse drive circuitry.

sine wave: same as b; linear: $W = LI^2f/4$ (when r is small)

d. Complementary-symmetry, quasi-complementary - dc coupled-class B - reactance energy (resonant flyback) circuit*.

linear: $W = LI^2f/8$

*The equation is independent of duty ratio(r). However yoke Q, as previously stated is not considered in above equations. For low values of r, high Q is essential.

e. Horizontal scan diode boost circuit.

linear trace: $W = LI^2f/32$ (typical for high Q yokes)

2. X Deflection

In view of the wide sweep rate requirements of this circuit (20 Kc to 0.5 cps) and the necessity for positioning adjustment, it is essential that it be dc coupled and yet be able to accommodate a fast retrace, high amplitude voltage pulse waveform. The high efficiency boost circuit (e of D. 1) will not meet the slow speed (dc) requirement. Circuit d meets the requirements with a minimum amount of power. It will also provide continuous operation at the zero trace (left side) position without drawing appreciable power. The X deflection current required (nom) is 0.8 I, therefore the required X power for worst scanning condition is

$$W = \frac{0.64\ LI^2f}{8} = \frac{0.64 \times 1.47 \times 10^{-3} \times 20K}{8} = 2.35 \text{ watt}$$

The X yoke resistive loss for a linear symmetrical waveform is

$$W_R = 0.64\, I^2R/12 = 0.123 \text{ watt}$$

The power supply drain required for the yoke resistance is

$$W_R = 0.64\, I^2R/4 = 0.369 \text{ watt}$$

The total theoretical min. X power is 2.72 watts for the worst waveform condition. An arbitrary value of 75% efficiency will be assumed on all power calculations. The gross total power for X is then 3.6 watts. It should be noted this value may be reached only by optimum choice of circuit configuration and matching power supply voltages.

3. Y Deflection

a. Magnetic Vs Electrostatic Signal Display

Power requirements of the Y deflection will be determined by the max. required frequency of 1 Mc in the signal display mode. Investigations of a variety of circuit arrangements - both magnetic and electrostatic - have been made. In order to reduce power and transistor voltages Y signal amplitude has been compromised. An optimum value is approximately 5 centimeters or 2 inches on the screen.

For magnetic deflection, since I corresponds to 6 inches, the scale factor is 1/3. Of available circuit configurations as outlined in D. 1 only those listed in b are suitable for random input waveforms at frequencies to 1 Mc. Circuits which attempt to reduce power do so at the expense of circuit complexity and do not work well under high frequency random signal conditions.

For a 2 inch peak to peak deflection

$$W = L(I/3)^2f = 1.47 \times 10^3/9 = 163 \text{ watts}$$

For electrostatic deflection a general power formula may be derived for driving a capacitive (C) circuit load. For a theoretically perfect drive circuit this formula is

$$W = CV^2f$$

The circuit requirements are achieved by means of an inverted complementary-symmetry configuration in which the collectors form a common output terminal. In the present application each transistor loading capacity is comparable to the deflection plate load. In addition a push-pull arrangement is required to provide balanced drive to the deflection plates. Based on a total load of 30 pf per side and 200 volts peak to peak per side, to give ± 1 inch of deflection, the power is

$$W = 2 \times 25 \times 200^2 \times 10^{-6} = 2.4 \text{ watt}$$

For a conventional resistive (R) load push-pull video stage, the power is constant, independently of signal frequency, but determined by the reference frequency (f_0) of the peaking network selected to provide the required output frequency. A minimum f_0 is 0.5 Mc and with only one output transistor required per side a load C of 20 pf is assumed.

$$R = \frac{1}{2\pi f_0 C} = 16 \text{ K}$$

$$W = V^2/R = 2.5 \text{ watts min.}$$

In view of its equivalent power, fewer active components and simpler circuit, the electrostatic circuit appears preferable.

The power requirement for a reasonable amplitude with magnetic deflection is far beyond the specification requirements. Conversely, a suitable electrostatic CRT is available. Its deflection voltage requirements are within the range of available transistors. Electrostatic deflection for the Y signal display should therefore be used.

b. Y Image Display

In order to achieve full deflection and adequate resolution, magnetic deflection is necessary for the Y image display. A complementary-symmetry driver circuit is optimum for this low frequency requirement. Referring to D.1.b the vertical (Y) deflection power for a 0.6 scale factor and 4% duty ratio at 60 cps is

$$W = 0.36\ LI^2 f/4r = 0.36 \times 0.00147 \times 60/4 \times 0.04 = 0.2 \text{ watt}$$

It may be noted, by comparing in D.1.b the equations for a sine wave signal to that for the low duty ratio linear signal, for a given voltage output and current (I) the sine wave frequency capability of the circuit is higher than the linear waveform frequency by the ratio $1/4r = 6.25$. Therefore a $60 \times 6.25 =$ 375 cycle sine wave at full amplitude may be accommodated by the amplifier without increasing the power requirement. In actual practice, to achieve the calculated power with a ± 12v power supply, would require an excessively high yoke coil inductance. A practical coil in the range of 100 mhy will require approximately 0.35 watt and the circuit will provide full drive to 650 cps.

Advantage may be taken of the above noted capability in arriving at an optimum solution to the Y-driver circuit arrangement. In order to achieve electrostatic deflection at low frequencies in the signal display mode it is necessary either to maintain the deflection plates at low voltage and provide dc restoration to the Z-axis signal at a large negative potential as well as provide filament power isolation or to provide dc restoration for the Y-deflection plate signals at a large positive potential. Both alternatives may be avoided by using the low frequency image mode magnetic deflection circuits to provide deflection of the signal mode components for frequencies below the above noted 650 cycle limit. It is then only necessary to provide capacitive coupling at high voltage for the high frequency signal mode components. Signal separation can be achieved by a variety of crossover circuit arrangements. The two amplifiers may then be operated simultaneously as a single unit for either mode of operation and only input signal switching is required.

Based on 1-megohm coupling resistors and a crossover frequency of 650 cps the required high voltage coupling capacitors are 250 pf each - values small enough to be readily obtainable and not require appreciable volume.

4. Display Distortions

Figure 2-1 is a curve showing the radial error distortion ($\Delta\theta$) in radians vs the deflection (θ) for a flat face tube. Without deflection linearity correction the horizontal displacement error is $\pm$ 0.0035 radian. Referenced to picture height this is a linearity error of $\pm$ 0.0035/0.75 x 0.70 = $\pm$ 0.67%. The X and Y pincushion distortions are in the range of 3% each. It is recommended that permanent magnet pincushion correction be employed to eliminate the most obvious geometric distortions. Since linearity distortions are within specified limits and correction would be complex for this application none should be made.

E. GENERAL CIRCUIT CONSIDERATIONS

The circuits discussed are all within the design range of available transistors, and where applicable, integrated circuits. They approach in operation the theoretical minimum attainable power consumption without introducing appreciable circuit complexity.

In order to achieve minimum size and weight it is essential to select the simplest circuit configuration for each function. This section contains some general comments with regard to circuit functions not specifically covered above.

1. Time Base Circuits

The display unit is required to provide a wide range of deflection speeds and triggering frequencies. The amplitudes required are, however, of constant

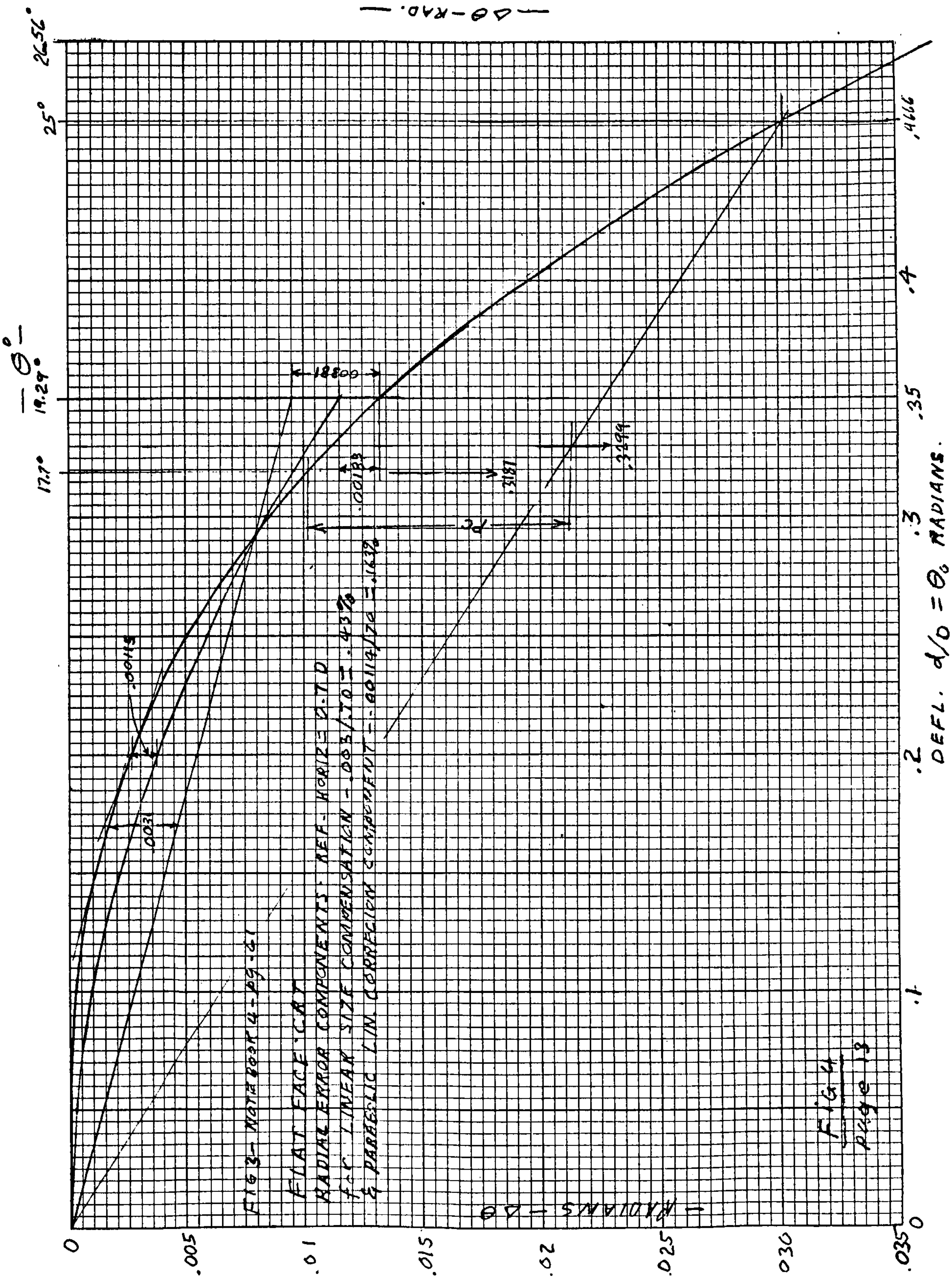


Figure 2-1. Flat Face CRT Radial Error Components

value as determined by the CRT size. The time base waveform generators should take advantage of the above by use of automatic amplitude cutoff circuitry in order to minimize the number of control switching functions. The circuit arrangement selected should also provide an output square wave equal to the trace interval to be used as a blanking pulse. This eliminates the necessity for subsequent blanking circuits which operate from the deflection output.

2. Switching Circuits

It is recommended that insofar as possible the circuit functions which require switching be designed integral with or adjacent to the control panel switches in order to simplify over-all circuit requirements. This approach is believed feasible in view of the use of integrated circuits and the small space requirements of the circuits involved.

3. Video Circuits

a. Sync Separation

To recover the burst frequency sync pulse signals from the 10 and 0.625 frames per record image video signals, the use of a combination of a narrow bandpass filter and an integrator is recommended. This combination will strip the sync signal from the video with the maximum signal to noise ratio and will thus provide a stable, jitter-free image display even under poor signal to noise ratio conditions. The rise time of the resulting horizontal and vertical sync pulses is degraded by this method, but this is of little importance since these pulses need not trigger the horizontal and vertical sweeps directly. Instead, the horizontal and vertical sweeps can be generated in a free-running mode and a phase comparator can be used to lock the frequency of the sweeps to the stripped sync pulses. This technique provides the maximum noise immunity. The bandpass filter reduces the noise bandwidth to 80 Kc. The demodulator-integrator further reduces the noise bandwidth to 16 Kc. Following the integrator is a level discriminator which eliminates all spurious signals whose amplitude is less than 25% of the lowest sync amplitude. The resulting sync pulse is further filtered by the phase comparator which reduces the effective noise bandwidth to 300 cycles.

b. Video Driver

In order to reduce the peak-to-peak video drive signal to the grid of the CRT and minimize the power dissipation in the drive circuitry, a separate blanking signal is applied to the cathode of the CRT. This arrangement reduces the video drive amplitude two to one while retaining full blanking during retrace.

4. Power Consumption

Total power consumption of the system based on the circuits discussed is summarized below:

Electronics	3.75 watts	
CRT Heater	1.80	
HV Power	0.84	
X Deflection	5.40	
Y Defl. Magnetic	1.20	
Y Def. Electrostatic	3.33	
Circuit Total	15.32	
DC to DC Converter	3.06	(80% efficiency)
Power Preregulator	2.76	(85% efficiency)
Unit Total	21.14 watts	

This power dissipation is the maximum anticipated under the worst operating condition. This condition occurs only in the A-scan mode of operation with the short time base horizontal sweep. In the image mode of operation the power can be reduced 3.33 watts by turning off the power to the electrostatic deflection above. Other power reduction schemes can be applied to the basic design and will be investigated during the development phase of the Video Monitor program.

F. MECHANICAL DESIGN CONSIDERATIONS

1. Design Objectives

The mechanical design objective is to provide structural support to the electronic components for reliable operation in the specified environment. This is achieved by constraining the transmission of dynamic loading within safe limits in a minimum weight and volume package.

The minimum volume for packaging the CRT and the electronics is established by the following constraints:

a. Length - CRT tube 11 inches

b. Width - CRT tube 6 inches

c. Height - CRT tube and controls 9 inches

The main considerations in establishing the packaging arrangement are as follows:

a. Rigid support of printed circuit boards to minimize deflections

b. Heat transfer by conduction to the base in contact with the Spacecraft Display Console heat sink plate (cold plate).

c. Directly mount high power dissipation electronic components to the structural support members to minimize thermal resistance.

d. Minimum weight.

e. Minimum volume.

f. Accessibility.

g. Retaining electronic circuits together in the same region.

h. Meet electrical requirements, i.e. circuit location, R.F.I. shielding.

The design goals in mounting the CRT are as follows:

a. Mount CRT and support structure independent of the electronics, electronics structure, and optical filters.

b. Mount CRT and support structure from the front panel, rather than at both front and back of the chassis.

c. Mount CRT from the flared glass bottle. Do not restrain free movement of the CRT neck.

d. Provide high resonant frequency to reduce the shock loading amplification factor, but lower than the resonant frequency of the glass neck or electron gun structure.

e. Tubular structure for weight reduction.

f. Stiffen tubular structure against lateral and torsional deflection.

g. Provide an adjustment device for applying preload to the bottle section of the CRT.

h. Mount CRT deflection yoke.

2. Packaging Trade-Off Analysis

The initial concept of the Manned Spacecraft Video Monitor housed within two packages, as described in the Hazeltine Report 1-5479, has been reviewed in light of both electrical and mechanical design studies. The two main considerations in establishing the mechanical packaging philosophy are minimum weight and minimum volume. Other considerations are front panel area, ease of operation (human factors), power allocation and density, ease of assembly, maintenance, and reliability. Each of the above factors were considered in detail in establishing each of the packaging concepts.

The results of the investigation are summarized briefly in Table 2-1 which compares weight, volume, and power density for each design concept. As shown in the table, efficient packaging of all components and devices into a one package design decreases the weight from 21.5 pounds to 19.5 pounds, a saving of 10 per cent. Similarily, the volume is reduced from 913 cubic inches to 805 cubic inches, which results in a savings of 13 per cent. Estimates indicate that there is not a substantial difference in front panel area for either design. Calculations of power density, a parameter which is proportional to temperature rise, show that the one package design has a slightly higher power density than its counterpart. This is mainly due to a decrease in volume.

In addition to the 10% saving in weight and 13% saving in volume the problem associated with the additional cables, connectors and shielding is eliminated by the use of a one package design.

Because of the factors enumerated above the Video Monitor has been established as a one package design concept.

3. Design Flexibility

The design constraints and objectives discussed in Section A1 are satisfied by the one-package design concept and are discussed in detail in Chapter V., "Mechanical Design Configuration." There are, however, several other constraints that could influence the design resulting in a possible weight and volume saving. Other packaging concepts could be investigated considering the following:

a. Aspect Ratio

A trade-off analysis based on available room in the spacecraft.

b. Volume

Based on the desired aspect described above, the volume of the one-package design could be reduced from a rectangular package to a truncated pyramid shape. The r‧ .uction of the number of primary and secondary controls from the .ront panel would reduce front panel aread and thereby reduce volume.

TABLE 2-1.

TWO PACKAGE/ONE PACKAGE COMPARISON

Two Package System *

Design	Size	Weight (Pounds)	Volume (Cu. In.)	Power (Watts)	Power Density (Watts/cu. in.)
Display Unit	7" x 7" x 11.5"	12.5	563	15.8	.028
Control Unit	7" x 4" x 12.5"	9.0	350	5.6	.016
System Total		21.5	913	21.4	.023 (ave.)

One Package System

Design	Size	Weight (Pounds)	Volume (Cu. In.)	Power (Watts)	Power Density (Watts/cu. in.)
Display and Control Unit	7" x 10" x 11.5"	19.5	805	21.4	.027

* This two package design is based on latest circuit definition and updates information presented in the proposal (HED Technical Proposal, Report No. 1-5479, dated 14 April 1965). This estimate considers minimum design weight, volume, and front panel area.

c. Weight

The use of integrated and cordwood circuits for many of the electronic circuits would reduce printed circuit board area and therefore the supporting structure. This would result in a weight and possibly a volume saving. This change in a feasibility model is not advisable since it would reduce the possibility of adapting design changes during evaluation and at the same time increase cost of changes. This change could be adapted in the flight hardware.

SECTION III

ELECTROLUMINESCENT DISPLAY STUDY

A. INTRODUCTION

This section presents some of the major difficulties which makes an electroluminescent display unsuitable for application in the Manned Spacecraft Video Monitor. A brief description of what electroluminescent is and how it works is given first. Many references in Appendix I give a more detailed explanation of the principles involved. The basic methods of excitation are discussed in regard to characteristics such as resolution, storage, gray shades, gamma, contrast, writing rate and erasure. One method of excitation is through photoconductive material and is commonly referred to as a "light-to-light" amplifier. Although a "light-to-light" amplifier by definition is not a TV monitor, a discussion of it gives information on some of the possibilities of photoconductive-electroluminescent techniques.

The electroluminescent display performance parameters must meet the following specifications. The display surface is to be 3.6 inches by 4.8 inches and have a resolution capability of 300 lines per inch. The scans vary from approximately one-half frame per second to the normal TV scan. The slow frame rate requires a storage of 1.6 seconds and the maximum writing rate is 0.2 microseconds per resolution element. Six gray shades are required with a maximum intensity of 20 foot-lamberts. These specifications are discussed below with respect to the state-of-the-art of electroluminescent panels.

The electronics associated with putting the information on the display is not discussed. It is complex and difficult but by no means outside the state-of-the-art. Several of the references suggest possible schemes for addressing the display. Since the circuitry takes the form of a fair sized computer this in itself is a disadvantage to the over-all system reliability, size, and weight.

B. GENERAL DESCRIPTION

Electroluminescente (EL) is the conversion of electricity into light within a phosphor. A typical EL lamp consists of a base sheet of glass substrate upon which is applied a thin transparent conductive film. The next layer contains an electroluminescent phosphor embedded in a ceramic dielectric. Upon this is applied the final layer of either transparent conductive or metallic film. The sum of the thicknesses of all of the coatings applied to the glass substrate is less than 0.01 inches.

The device acts as a flat plate luminous capacitor which emits visible radiation from the phosphor when activated by an alternating current. The light output of an EL lamp is approximately proportional to the frequency and to the square of the applied voltage, although these characteristics are interrelated and vary somewhat with different combinations of phosphors. Excitation voltages range from 100 to 800 volts and frequency is usually in the 200 to 500 cycle range. Driving voltage is limited by the breakdown potential of the lamp and frequency is limited by the capacitance of the film structure and leakage excitation considerations.

Initially EL cells were not overly bright or efficient. Ten to 50 foot-lamberts is a brightness range usually mentioned. There has been much effort to achieve higher brightnesses for EL lamps. A high figure recently quoted is upward of 4000 foot-lamberts for a green cell operated at 20,000 cycles. However, it must be pointed out that these figures apply to experimental models operated at high voltages and frequencies which may result in a lifetime of a few minutes or so.

Recently much effort has gone into improving the life of these cells. Apparently a high humidity will decrease their usable life. Consequently, even though phosphors embedded in plastic resin generally give higher brightness than phosphors embedded in ceramics, the latter are continually being investigated because they are less affected by humidity and are generally more durable.

Other advantages for the ceramic cell are its ability to withstand impact, its resistance to chemical attack and a greater resistance of its dielectric to temperature and voltage breakdown.

In addition to the properties of the EL lamps listed above a novel feature that they have is that their color can be changed by a shift in the applied frequency. This is brought about because these phosphors produce one or more light bands in a specific wavelength region. The effect of frequency change is to alter the relative amount of light emitted in each band and in this way produce a color change. Different colors can also be achieved by painting the cell with luminescent paint.

In addition to brightness and color, the efficiency of EL cells has received a good deal of attention. While, as mentioned above, brightness increases with both frequency and voltage, efficiency in general does not. Optimum efficiencies so far have usually been achieved at intermediate voltages. For example, plastic embedded cells with brightnesses of 50 foot-lamberts operating at 200 to 300 volts and between 500 to 1000 cycles and with efficiencies of 8 to 14 lumens per watt are being produced.

C. DISCRETE ELEMENT EXCITATION

If each cell is considered a discrete resolution element it can be combined with other cells in rows and columns to form a display panel. When information is to be displayed those cells which correspond to the pattern of information are excited. Each resolution element would have its own input, and for the display raster required for the spacecraft monitor there would be approximately 200,000 inputs (normal TV scan). This is derived by multiplying the number of horizontal resolution elements by the number of vertical lines. Because of the increased resolution requirement on the slow scan the number of inputs, for this mode of operation, would have to be increased by an order of magnitude.

Since high resolution displays utilizing this method of excitation have not been developed to any great extent, little is known of their characteristics and capabilities. It is doubtful that a resolution in excess of 20 lines per inch is available. Since the EL material has a transient response in the neighborhood of microseconds, the writing rate and erasure are primarily a function of the drive circuitry. Likewise the contrast ratio, gray shades and gamma are primarily dependent upon the electronics and the overall system requirements as discussed in Section B. Storage on the other hand presents a serious problem.

Sampling techniques or buffer memories in the associated circuitry offer a means of storing the information. However, the electronic approach is outside the scope of this study and will not be discussed. Modification of the phosphor or integrating the phosphor with other materials in a sandwich-type construction offers another means for storing the information. The two most common approaches employ a series combination of either ferroelectric or photoconductive (PC) material with the electroluminescent phosphor layer. Both of these methods are explained in detail in Section D. There it is also shown that these approaches seriously limit the resolution and tone rendition capabilities.

Fifteen lines per inch is about the maximum resolution obtainable using the ferroelectric approach. Since the panel has resolution in this neighborhood the addition of discrete ferroelectric capacitors doesn't lead to further degradation of the resolution. Although some reports verify that both storage and gamma capabilities can be achieved with ferroelectric capacitors, it is doubtful that both these properties can be met simultaneously on a practical basis. Because the photoconductive electroluminescent panel has a well defined hysteresis characteristic it operates in an on-off manner and prohibits any gray shades from existing. Depositing PC material on an EL layer lends itself to higher resolution than the ferroelectric material. Therefore, resolution is primarily limited to the density to which the individual electrodes can be packed.

The main disadvantages with this method of excitation are:

1. the complexity of the drive circuitry
2. the low resolution capabilities
3. the loss of gamma due to the information storage technique

D. CROSS GRID OR MATRIX EXCITATION

An alternate method of excitation is known as the XY Matrix Input. The idea is to place an EL phosphor between an orthogonal (XY) array of grids. If a voltage is applied to one line of X and one line of Y grids the voltage drop across the area where the grids overlapped would be twice as great as across either grid. If the total voltage drop is of the proper magnitude the EL phosphor will luminesce at that area.

In a typical design the panel is constructed of three layers (see figure 3.-1). A horizontal or X array layer of parallel conductors, an EL layer, and a vertical or Y array layer of conductors. By using a suitable frequency and establishing the proper voltage at a selected X line and Y line, light will be emitted from that particular area of the EL phosphor between the crossed elements. This cuts the number of electrical inputs down to the sum of the required horizontal resolution elements and vertical lines. On the normal TV scan this is approximately 900 inputs.

One serious problem encountered with an unmodified XY matrix panel is that of crosstalk. In general, when a voltage is applied to an X and Y line an attenuated light signal appears across a whole line of the X grid as well as the whole line of the Y grid. Of course, at the point of intersection of the two grids the brightness is much greater than along each line, but the spurious light signal that gets through adversely affects the wanted signal.

There are several possible ways to overcome these difficulties and in general they employ two methods of approach: 1) the modification of the EL material in such a way that its brightness voltage curve has an exponential slope so that with half the applied voltage the brightness of the phosphor is so low that the contrast ratio is satisfactory, 2) use of nonlinear elements in series with the phosphor so that the voltage across the EL phosphor can be easily modified. While approach (1) is not being neglected, a great deal of interest is centered on approach (2).

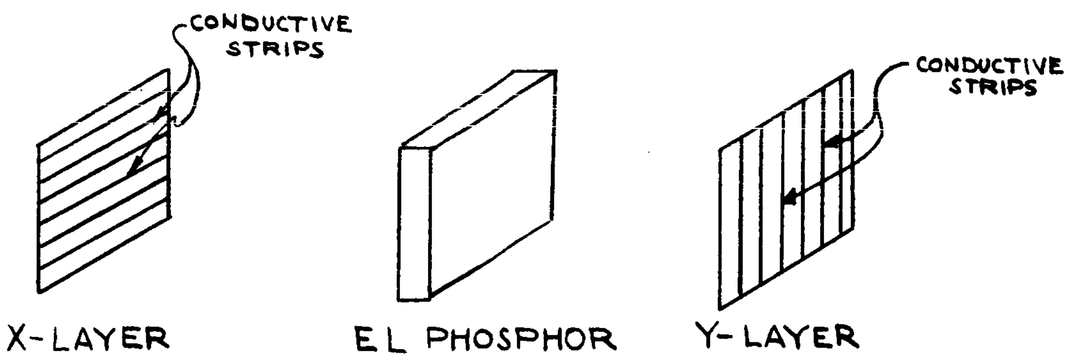


Figure 3-1. Matrix Electroluminescent Display

One system which employs approach (2) uses ferroelectric nonlinear capacitors in conjunction with the EL cell (ELF). Ferroelectric controls are basically ceramic capacitors built in a metal-ceramic-metal sandwich for ease of adaptation to the reading of electroluminescent display panels.

Ferroelectric capacitors, unlike ordinary capacitors, change capacitance as a function of the bias voltage applied to them. By changing the bias voltage the circuit capacitance changes and presents the power supply with a different capacitive load (see figure 3-2). The voltage now is divided according to the value of the capacitors and the circuit thus causing the voltage across the electroluminescent panel to change. Ferroelectric capacitors also have a high dielectric resistivity. Once a bias voltage is applied and has established a charge pattern this pattern will remain even with the bias removed until it is modified by the application of the different bias voltage. Slight deterioration of the display does result with storage times greater than several minutes. Much research is being done to develop the storage of information while still maintaining gray shade capability, but to date nothing successful has been accomplished on a practical basis. Another major drawback is the difficulty in developing a uniform response from all the capacitors, and achieving high density of the capacitors per unit area.

One ELF unit has featured an illumination of 25 foot-lamberts with contrast ratios of 50:1 and a resolution of 10 lines per inch. Panel voltage typically was about 200 volts at 10,000 cycles.

Another method of minimizing crosstalk and improving contrast ratio is to place a thin film of nonlinear resistance in series with the EL material. This is a popular approach and has met with good success. The nonlinear resistance causes the light output vs. voltage excitation to have a relationship such that the line excitation is suppressed while the line intersection excitation is not. Although overall brightness is diminished with this approach intensities in the neighborhood of 20 foot-lamberts can be achieved without much difficulty. An existing thin-film electroluminescent panel exhibits a 150 hour life time at 300 foot-lambert brightness and provides resolution up to 150 lines per inch, 0.05% reflectivity for good contrast, and brightness uniformity within 3%.

Since the resistive layer is homogeneous and continuous it gives better resolution and more uniform characteristics over the entire panel than the ferroelectric capacitors. However, there are no storage capabilities associated with the nonlinear resistance, and the gamma characteristic does not accommodate displays requiring gray shade capability.

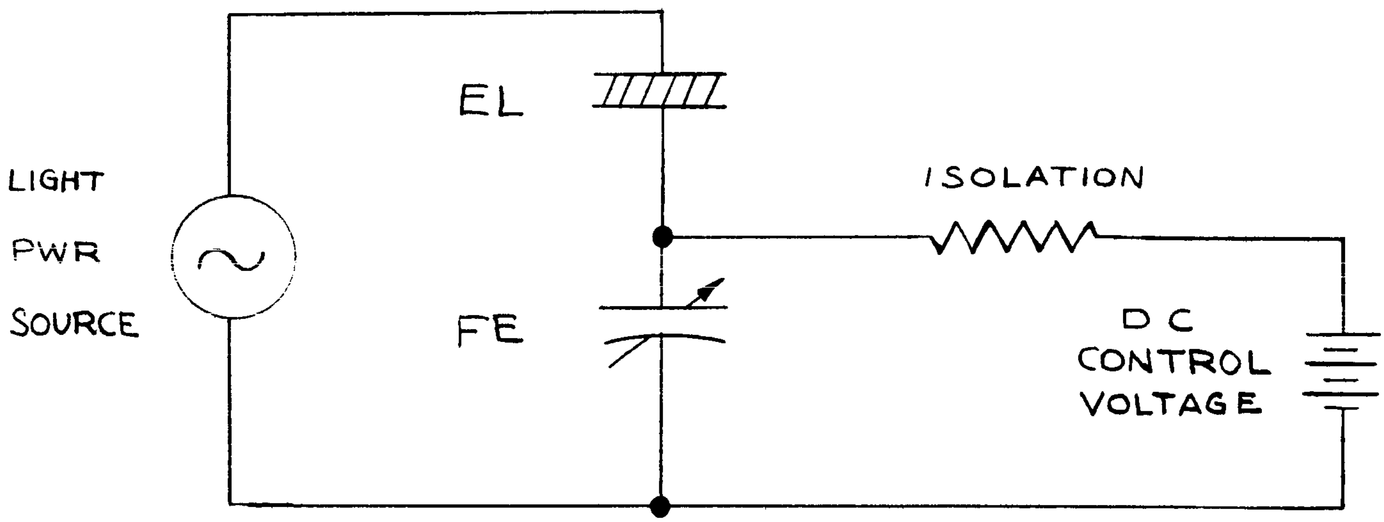


Figure 3-2. Ferroelectric Electroluminescent Display

Although the ferroelectric approach to contrast and suppressed cross-talk has an added feature in the storage capability it is by no means the only method for storage. The series combination of EL material and photoconductive (PC) material in a sandwich construction possesses storage capabilities for display of information and for binary computer logic. This approach has been more successful than the ferroelectric capacitor approach in obtaining better resolution. The voltage excitation causes the EL phosphor to emit light which in turn strikes the PC material. When this happens the PC material lowers its resistivity causing more voltage to be applied across the phosphor. This is positive feedback and results in a hysteresis characteristic which enables storage. This type of storage, however, prohibits gray shades.

Bistable storing of the display information is not what is needed, but rather a time variable or dynamic persistence of the light. Since EL phosphor has a brightness decay rate to 1% in the order of magnitude of microseconds, other storage techniques must be sought. For example, PC material has a much longer decay rate. To eliminate the feedback an opaque film must be placed between the EL and the PC. However, the PC must now be excited by a light source. When light shines on the photoconductive material its resistance decreases thus less voltage will be dropped across the photoconductor and the voltage across the panel will increase. The greater the intensity of the input light the lower the resistance of the photoconductor and the brighter the electroluminescent panel output. This light output and the image input is called a light amplifier.

When an input image is applied to a light amplifier the output signal does not appear simultaneously. A few milliseconds time lag results because of the time required to decrease the resistance of the photoconductor. The decay time is longer than the rise time. Several seconds are required for the output to fall to one-tenth of its initial value.

Light amplifiers are capable of intensifying any image input including the presentations of gray tones as well as black and white. Resolutions about 40 lines per inch have been obtained.

If direct optical focusing of the image is not used, the information must be converted from electrical signals to light signals as in a crt. This light amplifier is no longer the primary display, but would then be used in conjunction with the CRT to utilize its slow decay characteristics.

A third method is to use partial feedback. This permits the panel to be excited by a voltage source and yet does not contain the bistable storage characteristic. It gives a fairly good gamma but is extremely sensitive to environment and has met with only little success in the laboratory.

Although the number of inputs has been reduced in the cross grid method of excitation the drive circuitry is still a problem for a high resolution display. The disadvantage lies in the great amount of circuitry required to energize the display panel in order to meet the resolution and storage requirements. The problem here is similar to that discussed in the previous section.

In a "light-to-light" amplifier the storage property has met with the best success as far as maintaining gamma is concerned. However, there is difficulty in controlling both the writing rate and erasure.

E. PIEZOELECTRIC EXCITATION

To avoid the switching problem of the cross-grid technique described above, EL Piezoelectric panels have been proposed. In the construction of these panels electroluminescent phosphor is deposited on small cylinders of piezoelectric material and the cylinders are placed in parallel across a variable frequency generator. The cylinders are made slightly different so as to have their own unique resonant frequency. When the generator is tuned to one of the resonant frequencies the cylinder responds in its vibrational mode and a strong polarization field is generated across its end surfaces. The intensity of the field is dependent on the voltage output of the generator and the phosphor deposited on the end surface lights up with proportional intensity. Since piezoelectric materials exhibit voltage amplification, a potential across the phosphor layer may be several times that of the frequency generator. By arranging the cylinders according to resonant frequency the light spot can be made to sweep across the cylinder ends with the intensity ~~and position~~ controlled by the magnitude and frequency of the applied voltage. The same effect can be achieved by using a piezoelectric wedge except that a continuous light movement would be obtained. Localized resonances are obtained in a wedge since the resonant frequency is a sharp function of geometry. The spot of light would then be moved by varying the generator frequency. Resolution would be determined by the width and slope of the wedge. Ideally, if bandwidth requirements permitted, all wedges could be placed electrically in parallel and by one sweep through the frequency range the light spot could be made to move over the whole panel consisting of rows of these thin wedges. More likely the rows of wedges would have to be swept sequentially utilizing switching devices, but the switching problem would be less severe than in the cross grid case.

Another piezoelectric design approach creates localized areas of high field intensity by strobing an acoustically generated voltage pulse as it travels along the length of an electroluminescent strip. A raster scan is accomplished by a combination of phase-modulated strobing and channel strip switching.

In order to observe the electroluminescent output, it is necessary to stop the acoustic image as it progresses down the length of the ceramic strip. This is accomplished readily by generating a strobe pulse across the layers. By appropriate timing of the strobe pulse, a thin illuminated line can be made to appear at any selected point along the strip. Voltage amplitudes are chosen so that visible output is obtained only at points of coincidence of the piezoelectrically generated pulses, and the applied strobe pulses. Repeated pulses at constant intervals will reinforce the original input. This results in a visible output at any selected distance from the input electrode.

An important advantage in using this electric field type of sweep is that a light spot is generated without the need for the electrodes to be placed in proximity of it. The feasibility of such a display panel has been proved, but, in order for it to be developed for TV-tape displays, extensive research must be done.

In this device, image resolution depends on the effective pulse width and on how close the strips can be packed. One millimeter images require pulses of approximately 0.3 μsec. Voltage-brightness relationships were verified in the short pulse excitation region of operation. Using a 0.3 μsec pulse at 13.5 kc repetition rate, a 700 volt amplitude, corresponding to a sum of strobe peaks and piezoelectric generated voltages, was needed to produce a brightness of 20 foot-lamberts. No information is available on how close the strips can be packed.

The burden of the drive circuitry in this approach is in its ability to create and maintain critical timing. Again, resolution is nowhere in the neighborhood of the spacecraft monitor requirements, and the simultaneous property of controlled storage and gamma is absent.

F. CONCLUSIONS

EL has certain advantages which makes it especially attractive for spacecraft applications. Power requirements are normally in the milliwatt range for each square inch of illuminated panel. The device is basically free of catastrophic failure since a filament or vacuum is not required. This enables EL reliability to exceed that of any other readout device. Since EL panels are flat and the lighted area is directly behind a thin glass substrate, no parallax problems exist and the device can be viewed over extremely wide angles.

However, the disadvantages of an EL display are so severe, that it will not offer any competition to a CRT for close to ten years. Most of the material investigated in the study is the product of laboratory investigation. To reduce any of these devices to practice would require an enormous development program.

Even if all the problems concerning resolution, storage, gray shades and gamma could be solved, there would still remain the problem of uniformity. Each resolution element in the display would have to possess identical characteristics. Not only is this complex, but is also very costly as has been demonstrated in the "ELF" program which was suspended several years ago for the above reasons.

In its basic principle a "light-to-light" amplifier is contrary to the results being sought, although it comes closest to meeting all of the requirements. The primary factor here is the flat panel being the sole display.

Perhaps it is in the piezoelectric approach, an entirely new approach, or a combination of all the approaches discussed, that electroluminescence will some day replace the CRT.

SECTION IV

DETAILED CIRCUIT DESIGN DESCRIPTION AND ELECTRICAL PERFORMANCE SPECIFICATION

A. GENERAL

A block diagram of the Video Monitor is shown in figure 4-1. Basically the system has two modes of operation, an image display and a signal display mode. In the image display mode, TV type information is displayed at three different scanning rates, a normal scan of 30 frames per second, 2 to 1 interlaced, and two slower scanning rates of 10 and 0.625 frames per second non-interlaced. The composite image video signal is amplified to intensity modulate the grid of the CRT. Horizontal and vertical sync signals are derived from the composite video by the sync separator. At the normal scanning rate the sync separator can extract amplitude coded sync from the video signal or external sync. At the 10 frames per second rate sync pulses can be recovered from either video amplitude, or burst coding of the video signal or from an external sync. At the slowest scan rate, 0.625 frames per second the sync separator works only on burst or external sync. The outputs of the sync separator are used to synchronize the horizontal and vertical sweep generators which drive the deflection amplifiers. Diode matrix logic, controlled by the Mode Selector switch, is used to perform the switching required for the change from one scan to the next.

In the signal display mode, the Video Monitor is converted into an A-scope type of display. Signal video enters a calibrated attenuator corresponding to a vertical deflection sensitivity of 0.02 to 10.0 volts per centimeter. Its output is amplified in the following stage to drive the vertical deflection amplifier. In the vertical deflection amplifier the video signal is divided into two components by a crossover network. The two components are a low frequency signal which is fed to the magnetic vertical deflection amplifier, the other the high frequency component which is amplified and used to deflect the beam electrostatically. This method achieves a dc to 1 mc vertical bandwidth at low power consumption. The Y axis sweep calibrated from 0.5 cps to 20 kc is triggered in synchronization with the signal video by either an external trigger or from the video signal itself.

The entire Video Monitor is transistorized with the exception of the cathode ray tube. The circuits are designed for minimum power consumption and each component is sufficiently derated so that a high degree of reliability is achieved when the system is operated in a space environment. Some of the circuits utilize microelectronic integrated circuits to reduce the size,

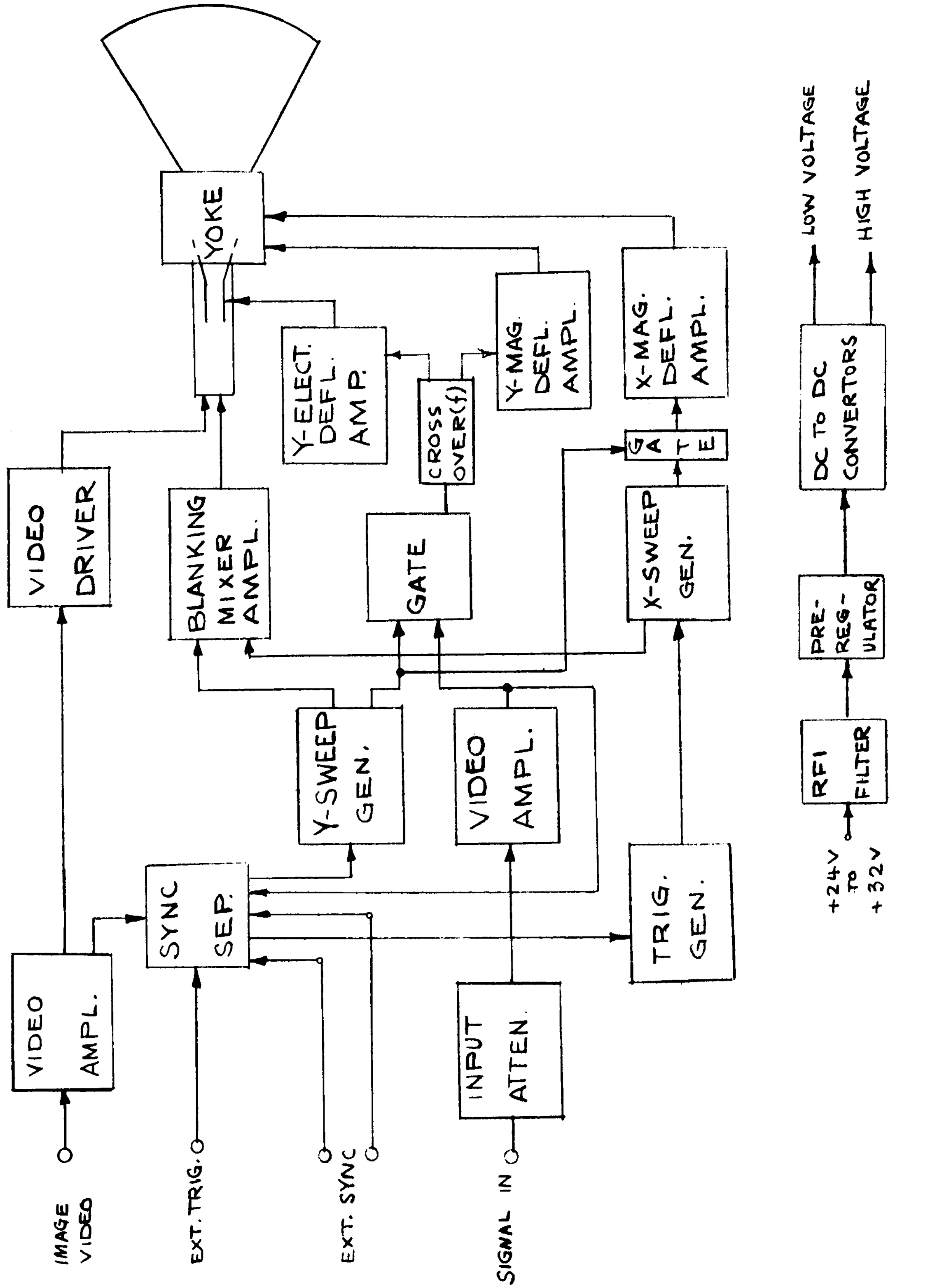


Figure 4-1. Video Monitor Block Diagram

weight and power of the monitor. Most of the remaining circuits can easily be converted to the microelectronic integrated type directly either by off-the-shelf components or custom integrated circuits. In the study phase of this program discrete components are used instead of integrated circuits until the design of the monitor is proven. The following sections contain detailed circuit descriptions.

B. VIDEO AMPLIFIER

The video amplifier shown in figure 4-2 and 4-3 accepts information from one of two inputs, an amplitude sync composite video input which is terminated in 100 ohms and a burst sync composite video input terminated in 51 ohms. Either input is remotely selected by the display mode selector located on the front panel. The input stage of the video amplifier is a current summing feedback amplifier. Its input impedance is low due to feedback and is biased at zero dc potential. This allows either input to be grounded without disturbing the gain of the other channel. This stage has a gain of nine with inversion and a bandwidth of 7 Mc. Instead of a single transistor, two transistors are used in cascode to increase the over-all gain - bandwidth product. Two outputs are supplied, one with fixed gain for use in the sync separation circuits, the second is continuously variable by the contrast control on the front panel. The variable gain output is ac coupled and dc restored at the input to the CRT driver stage. The CRT driver stage has a gain of four and is capable of supplying 35 volts video to intensity modulate the control grid of the CRT. Its bandwidth of 6.5 Mc, which combined with the input stage yields an over-all bandwidth of 5 Mc. The driver stage utilizes cascoded transistors with split feedback. The split feedback is used to evenly divide the power dissipated in the two transistors. The Video Amplifier's Power Dissipation is less than 1 watt.

C. CATHODE BLANKING AMPLIFIER

The blanking amplifier, figure 4-3, performs two functions; one to turn off the CRT beam current during the inactive portion of the scan and to control the amount of beam current (brightness) during the active trace. During the active trace the cathode sits at an adjustable negative voltage controlled by the brightness control on the front panel. This control sets the amount of grid to cathode potential. To blank off the tube during retrace the cathode potential is raised to a positive supply voltage cutting off the beam current. In order to conserve power while maintaining high bandwidth the following two stage amplifier was developed. The first stage is an ordinary saturated switching amplifier with a high resistance (100K) collector load. This stage is normally biased off, allowing the CRT cathode to sit at an adjustable negative voltage which determines the CRT

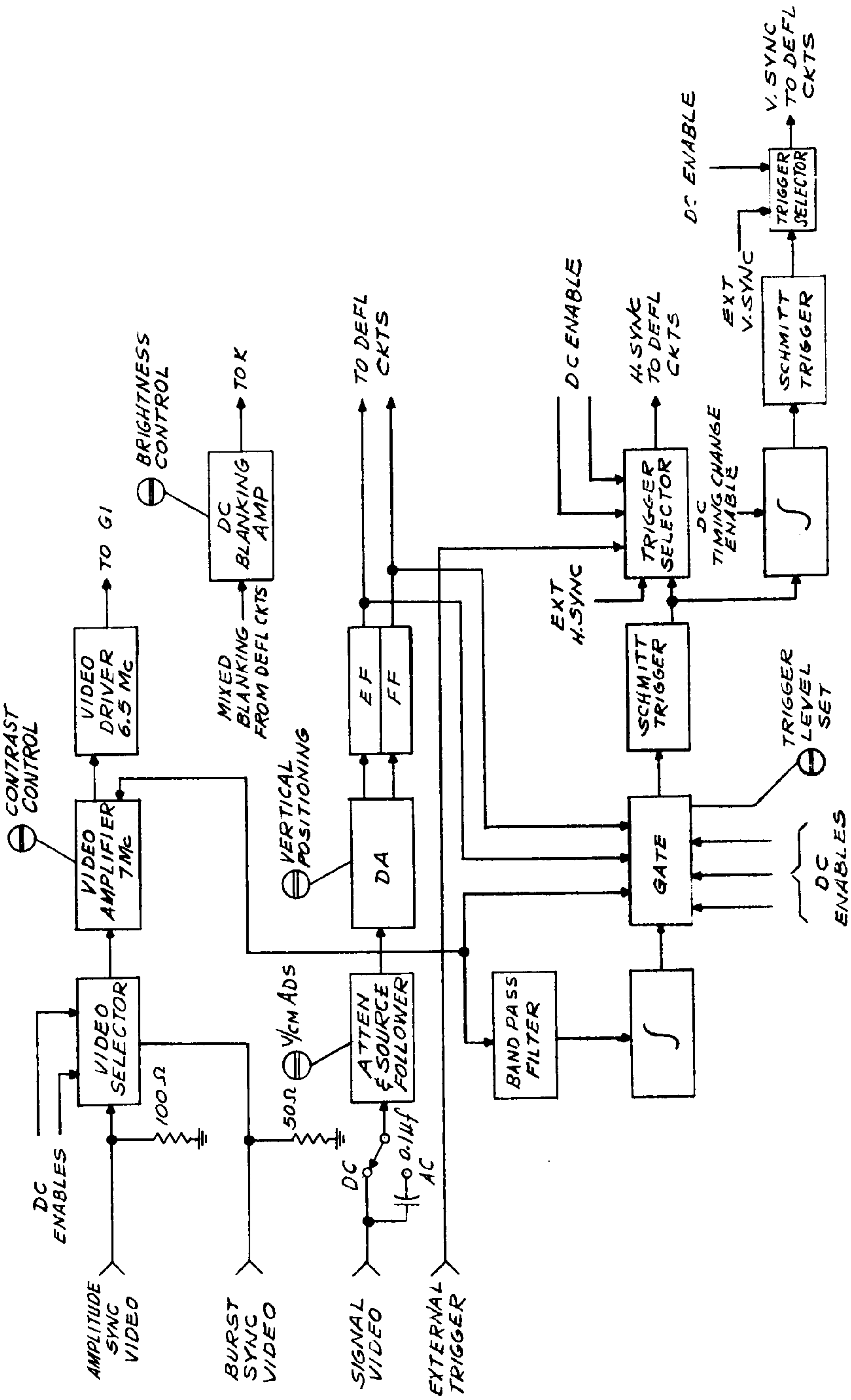


Figure 4-2. Video Amplifier & Sync Separator Block Diagram

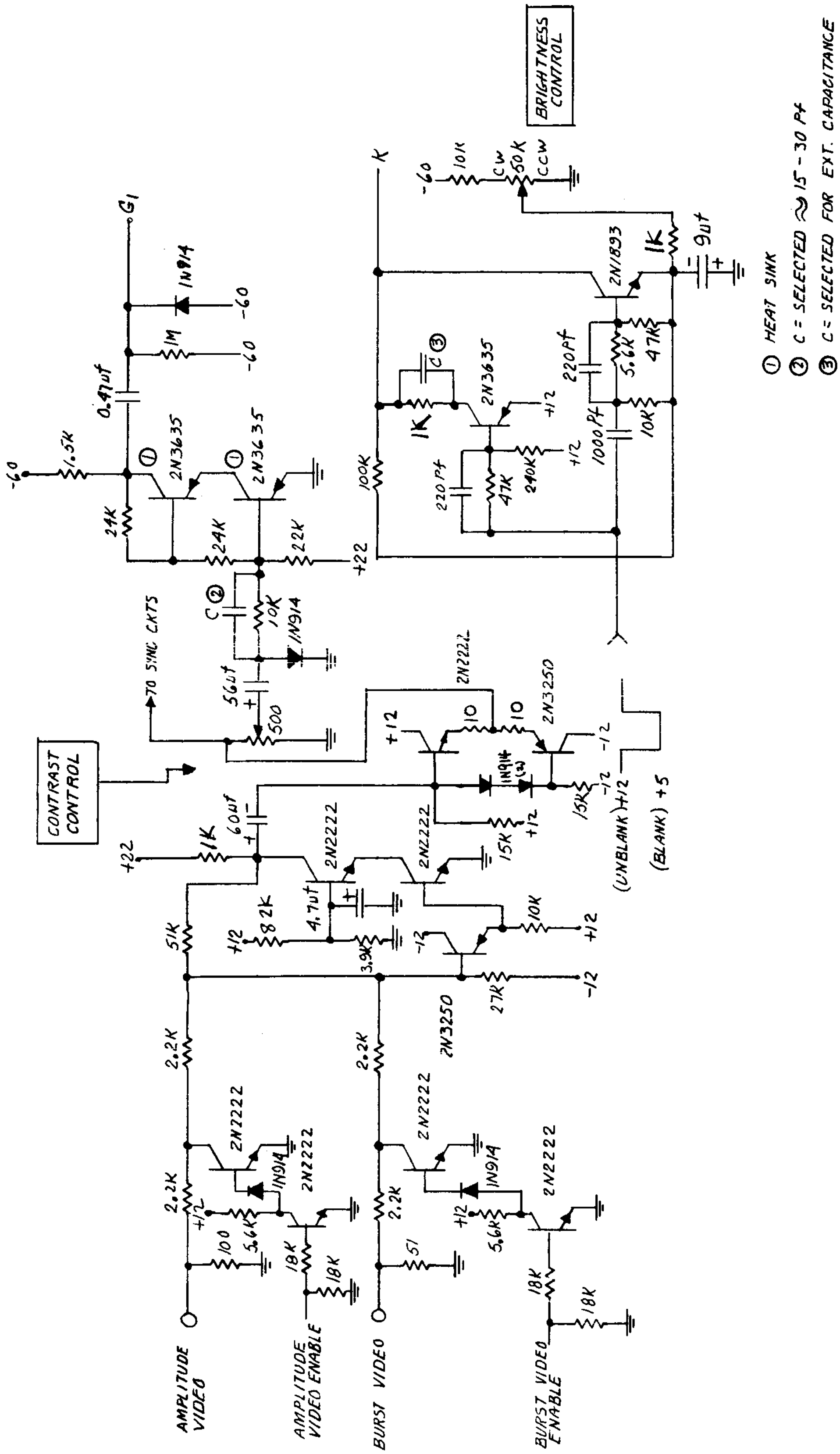


Figure 4-3. Image Video Amp

brightness. At the start of the inactive portion of the scan the mixed blanking signal from the deflection amplifier turns on the transistor producing a sharp leading edge. At the end of the retrace period this transistor turns off. The trailing edge of the blanking pulse is differentiated and ac coupled into the second stage, turning it on and clamping the output to the negative supply voltage. This stage turns off after the transient of the differentiated blanking pulse decays to zero. This produces very fast rise and fall times at the cathode while consuming less than 0.1 watts.

D. SYNC SEPARATOR

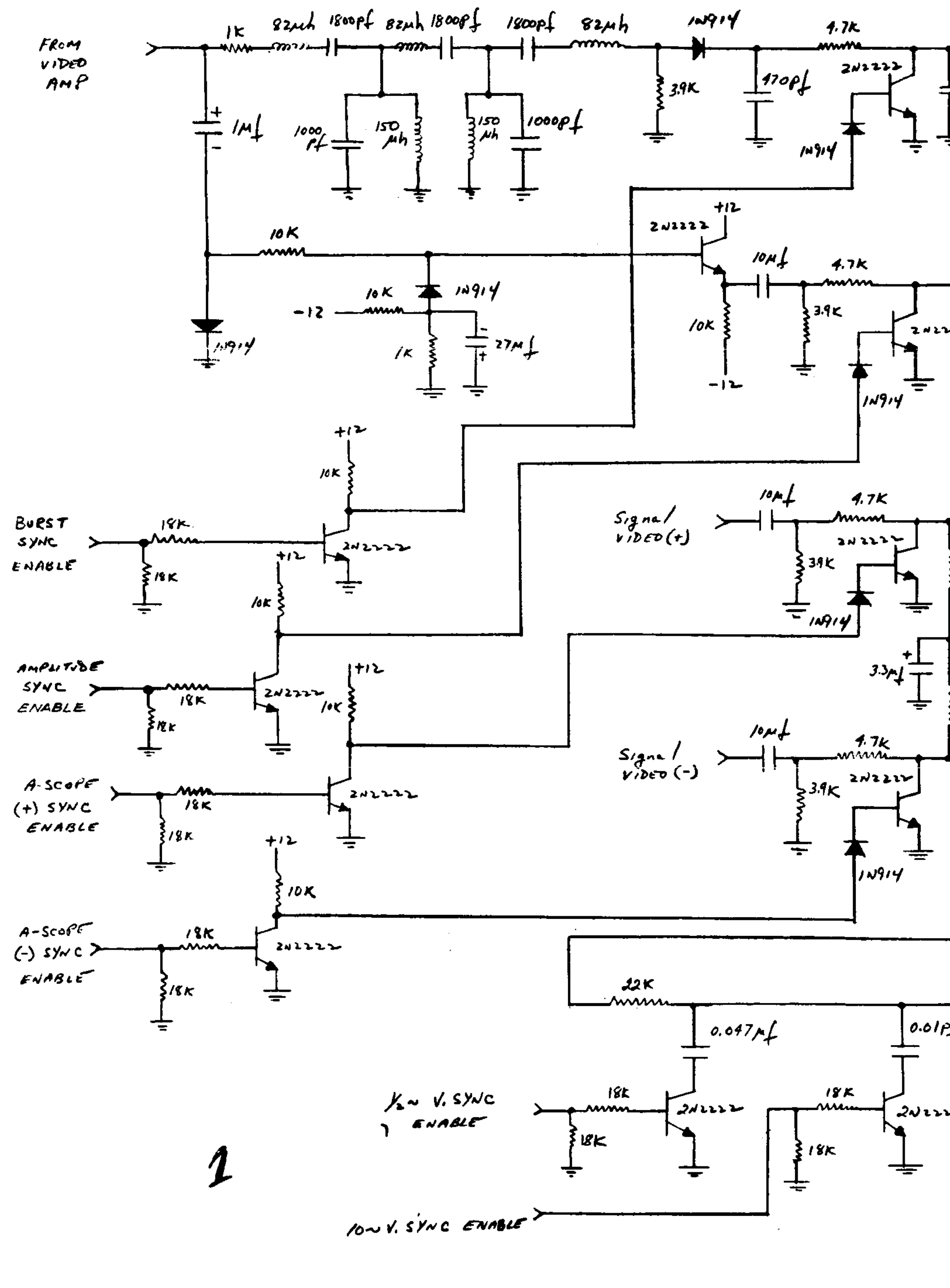
The composite video from the fixed gain output of the video amplifier is fed into two sync separators. See figure 4-4. One is designed to extract amplitude sync information at the 60 and 10 cycle frame rates, the other to extract burst sync information at the 10 and 0.625 cycle frame rates. Another sync separator is used to generate a sync trigger when the monitor is used as an A-scope. The above sync generators are resistively combined to trigger a voltage level detector amplifier. The output of the proper sync separator is gated on by an enable signal from the Mode Selector switch located on the front panel.

The burst sync separator consists of a bandpass filter with a 80 Kc bandwidth centered at 409.6 Kc. The output of the filter is demodulated, clamped, and filtered before it is combined with the other sync separators.

In the amplitude sync separator the video is clamped to the sync tips and the video portion of the signal is then removed by clipping anything below a preset level. The remaining portion of the signal is combined with the other sync separators.

In A-scope operation the output of the signal display amplifier is used to generate the horizontal sync trigger. Either output of the signal display amplifier is used (one for positive sync, the other for negative sync). These signals are ac coupled, and combined with a variable dc level controlled by the trigger level pot located on the front panel. By varying this control the level detector amplifier will trigger on any portion of the video desired.

The combined output of the sync separator is used to trigger an integrated level detector amplifier. This level detector is a high gain zero crossing detector which when triggered forms the horizontal sync pulse. This pulse enters a diode selection gate along with any horizontal external sync pulses. The proper output of the gate is selected and controlled by the mode select switch on the front panel.


FROM VIDEO AMP
1K
82μh
1800pf
82μh
1800pf
1800pf
82μh
1N914
4.7K
2N2222
1μf
1000 pf
150 μh
150 μh
1000pf
3.9K
470pf
1N914
+12
2N2222
10K
1N914
10μf
4.7K
10K
-12
1K
27μf
10K
3.9K
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1N914
BURST SYNC ENABLE
18K
18K
10K
2N2222
Signal/ VIDEO(+)
10μf
4.7K
3.9K
2N2222
AMPLITUDE SYNC ENABLE
18K
18K
2N2222
10K
3.3μf
A-SCOPE (+) SYNC ENABLE
18K
18K
2N2222
Signal/ VIDEO(-)
10μf
4.7K
3.9K
2N2222
A-SCOPE (-) SYNC ENABLE
18K
18K
10K
2N2222
22K
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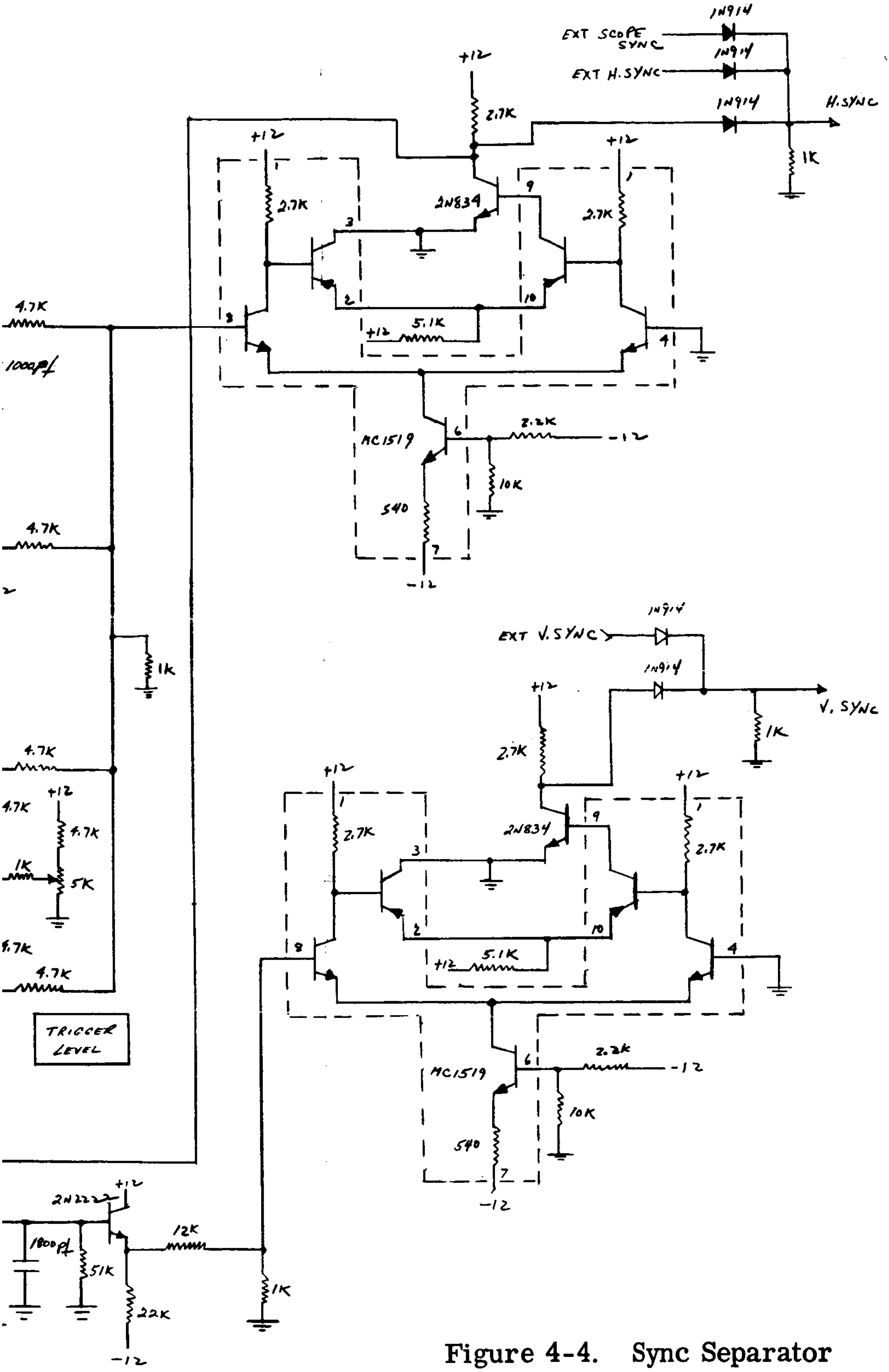


Figure 4-4. Sync Separator

The vertical sync is formed by integrating the horizontal sync pulse. The output of the integrator is the input to a second level detector circuit whose output forms the vertical syhc pulse. This pulse is also diode gated with any external vertical sync pulses in the same manner as the horizontal sync pulse.

Two time constants are used in the vertical integration, a fast time constant for 60 cps separation and a longer time constant for 10 and 0.625 cps. The time constant is electronically switched and controlled by the mode select switch.

The complete sync separator consumes approximately 400 milliwatts.

E. SIGNAL VIDEO AMPLIFIER

When the video monitor is used as an A-scope, the Video Signal Amplifier figure 4-5 is used to amplify the signal to a level sufficient to drive the Y-axis deflection amplifiers. The input to the amplifier is AC or DC coupled, determined by a front panel switch. Before the video is amplified it enters a 10 position attenuator. The input impedance of the attenuator is 1 megohm at all switch positions and it is frequency compensated to preserve the overall bandwidth of 1 Mc. The output of the attenuator enters a field effect source follower. This stage has a 10 Meg input impedance to prevent loading the attenuator. The output of the source follower drvies one input of an integrated differential dc feedback amplifier. The open loop gain of the amplifier is 66 db at 1 Mc, while the close loop gain is 100. The other input to the differential amplifier is a varying dc voltage controlled by the vertical positioning pot located on the front panel. This dc voltage is fed to the amplifier through source follower identical to the signal input source follower for temperature compensation. The differential outputs of the amplifier are buffered with emitter followers to drive the deflection amplifiers. The signal display amplifier consumes 175 milliwatts of power.

F. DEFLECTION CIRCUITS

1. Design Philosophy (see block diagram figure 4-6)

The monitor deflection circuits are required to perform two different modes of operation. For the video image displays two sweep generators and their associated orthogonal deflection amplifiers are required. For the signal display a signal video input and a single sweep generator with their associated orthogonal deflection amplifiers are required. In order to maintain simplicity in circuit design and switching, the same deflection amplifiers were used for both operating modes.

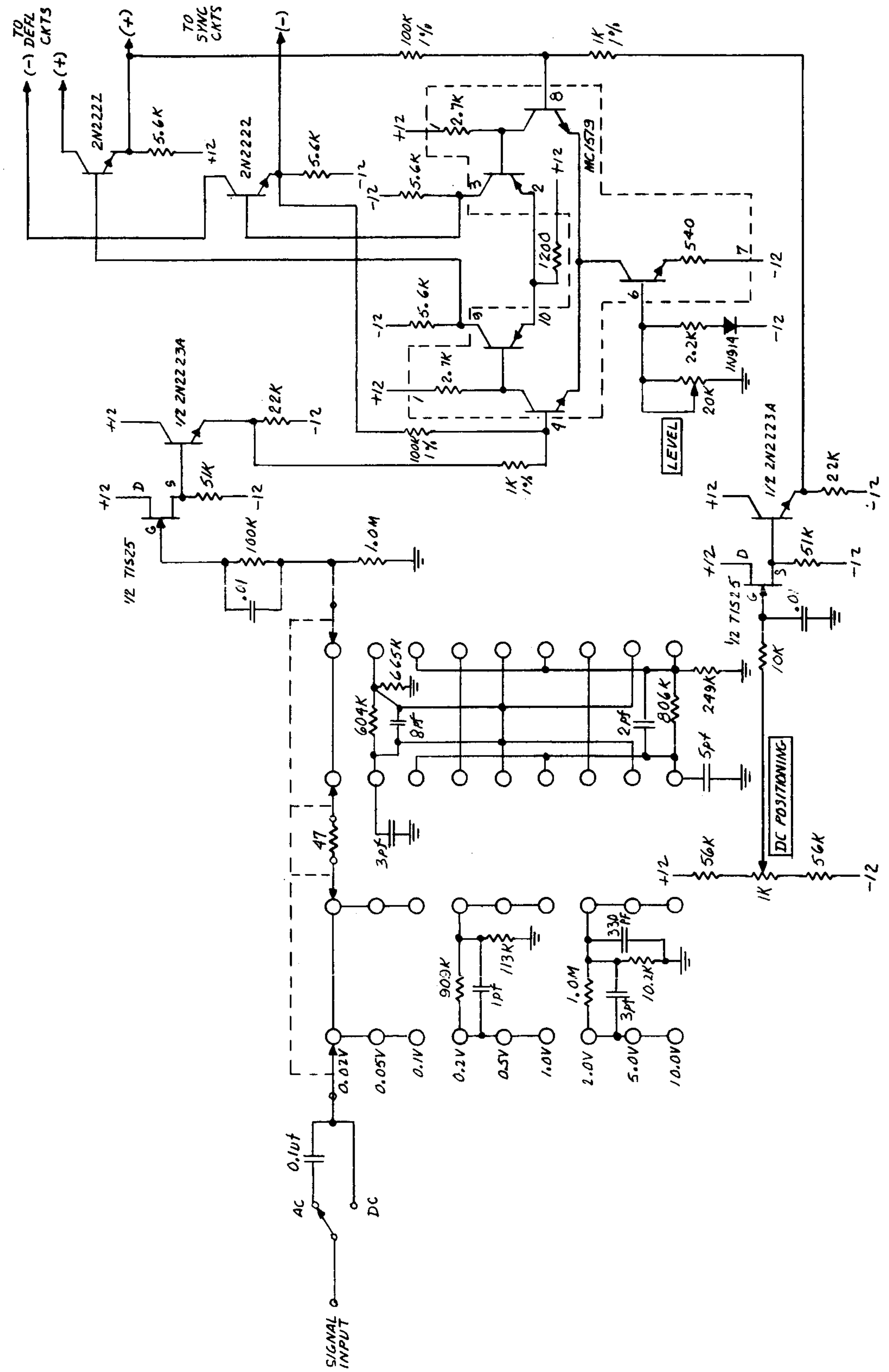


Figure 4-5. Signal Video Amp

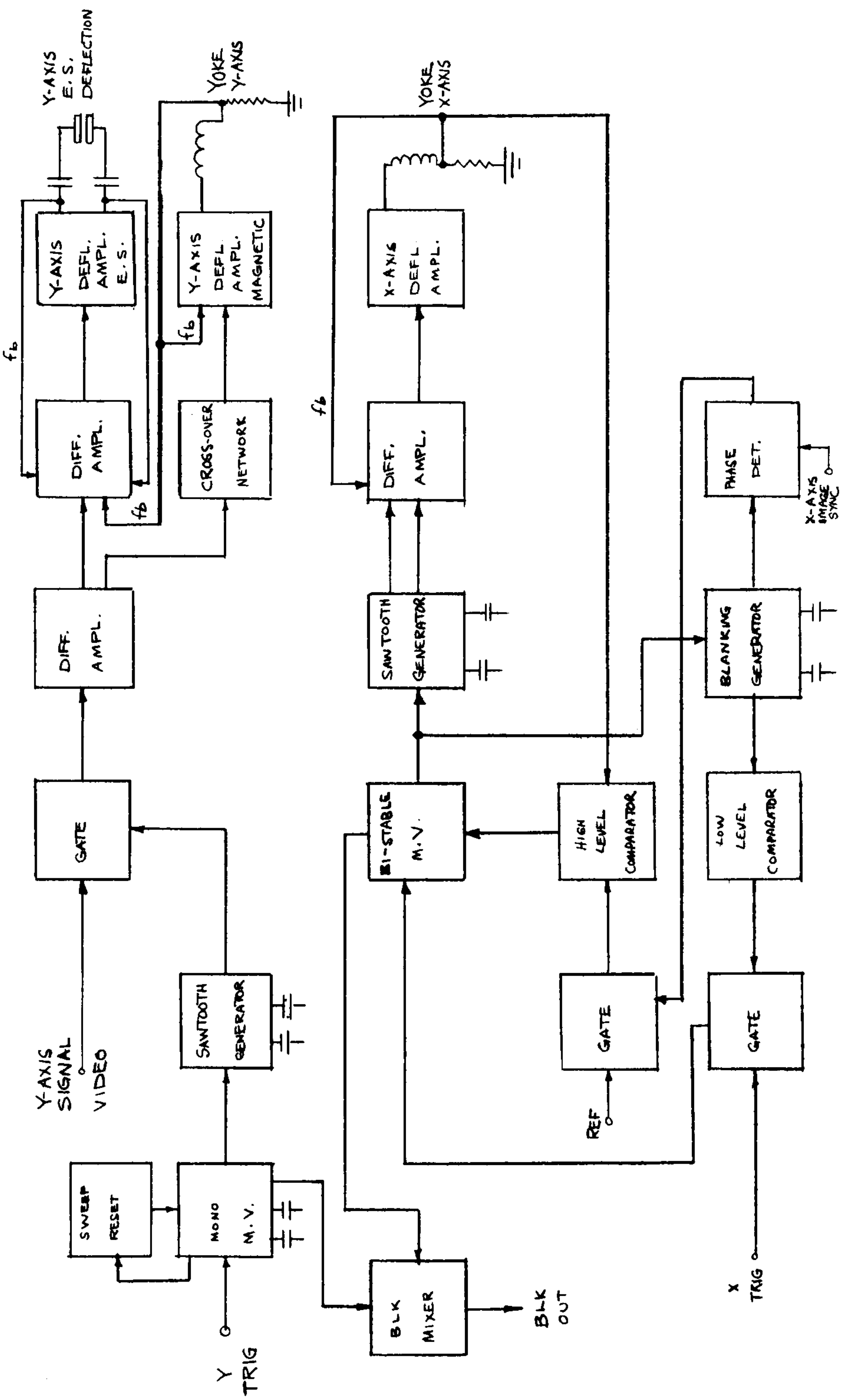


Figure 4-6. Block Diagram Deflection Circuits

Further simplification was obtained by using the same method of sensing and controlling the X-axis sweep generation in both modes. This was accomplished by controlling the peak-to-peak amplitude of the output yoke current. The active trace amplitude is controlled by a high level comparator. The time allowed for the sweep to retrace, stabilize and be retriggered is established by a low level comparator.

During image display it is desirable to provide noise immunity for the X-axis triggering circuit. An additional requirement is to insure that the X-axis blanking on the CRT start before the X-trigger pulse in order to avoid a bright vertical line on the left side of the raster. This requirement is met by permitting the low level comparator to retrigger the sweep, making the deflection circuit free running. The frequency of operation is controlled by a phase detector sensing the phase difference between the synchronizing signal and the sweep signal, and translating it to a DC bias to control the triggering level on the high level comparator. The phase difference offset between the synchronizing signal and the output pulse of the high level comparator permits the comparator output signal to lead the synchronizing signal. The comparator output is used to initiate the start of the blanking interval. An integrator circuit in the phase comparator provides the required immunity to noise.

For signal display the frequency control circuit is not used. The low level comparator instead of retriggering the sweep is used to develop a gating signal. The gating signal permits the next subsequent trigger signal to initiate the start of the X-axis sweep.

Another simplifying consideration, which results from changing from image to signal display, is the duplication in components which occurs in the low frequency sweeps. In signal position, a 1/2 cycle sweep is required in the X-axis. In the image position the low frequency sweep in the Y-axis is 0.625 cycles. The capacitors required for each sweep are the same, requiring a pair of 8 μfd capacitors, occupying 1.7 cubic inches and weighing 80 grams. The size and weight resulting from circuit duplication would be prohibitive. A more practical approach was to switch a sawtooth generator and its associated input differential amplifier from the Y-axis in image display, to the X-axis in signal display.

In order to maintain the required stability in the output deflection currents under variations of temperature, voltage and aging, differential circuits were used wherever practical. Furthermore, the differential circuit technique can easily be transformed to microelectronic integrated circuit configuration. Where single ended circuits were used, as in the magnetic deflection amplifiers, considerable feedback was used to stabilize their operation.

A further consideration which influenced the choice of circuits was the need to provide many switching functions, yet being limited to the amount of front panel space that was available. This problem was resolved by resorting to transistor switching, the transistor being activated by a simple switch on the front panel in conjunction with a diode logic matrix. The sawtooth and pulse generation circuits selected were those which lent themselves readily to transistor switching.

In order to provide a Y-axis response from DC to 1 Mc for the signal display, the CRT deflection consists of a combination of electrostatic deflection for high frequency signals and magnetic deflection for low frequency signal. This approach permits AC coupling to the electrostatic deflection plates, avoiding the problem of amplifier circuits being maintained at a high potential. The problem of obtaining the proper cross-over relationship between the two deflection systems was resolved by providing a difference signal to the electrostatic amplifier. The difference signal was composed of the normal sawtooth signal and a sampling of the output yoke current of the magnetic amplifier.

2. Video Image Display

a. Y-axis Deflection Circuit (figure 4-7 and figure 4-8)

The Y-trigger pulse from the sync separator triggers the monostable multivibrator. The resulting change in state causes a RC network to start charging. When a critical voltage is reached the associated unijunction transistor becomes conductive, producing a pulse which resets the multivibrator. The resulting output of the monostable multivibrator provides the required Y-axis blanking signal and the required clamp pulse for the sawtooth generator. A second unijunction circuit permits the circuit to be free running when no trigger pulse is available.

During the blanking period the clamp pulse driving the sawtooth generator charges a capacitor to +12 volts and discharges it through a current source during the sweep period, thereby generating a linear sawtooth signal. The sawtooth generation circuit is duplicated in order to provide two signals to a differential amplifier. The various required sweep rates are generated by changing capacitors or altering the bias voltage on the constant current generator.

Two field effect transistors connected as differential source followers are used to provide high impedance pick-off of the sawtooth voltage. The output signal is then DC offset to provide the proper DC level input to a differential amplifier. The output of the differential amplifier provides a single ended drive to the magnetic and electrostatic deflection amplifiers.

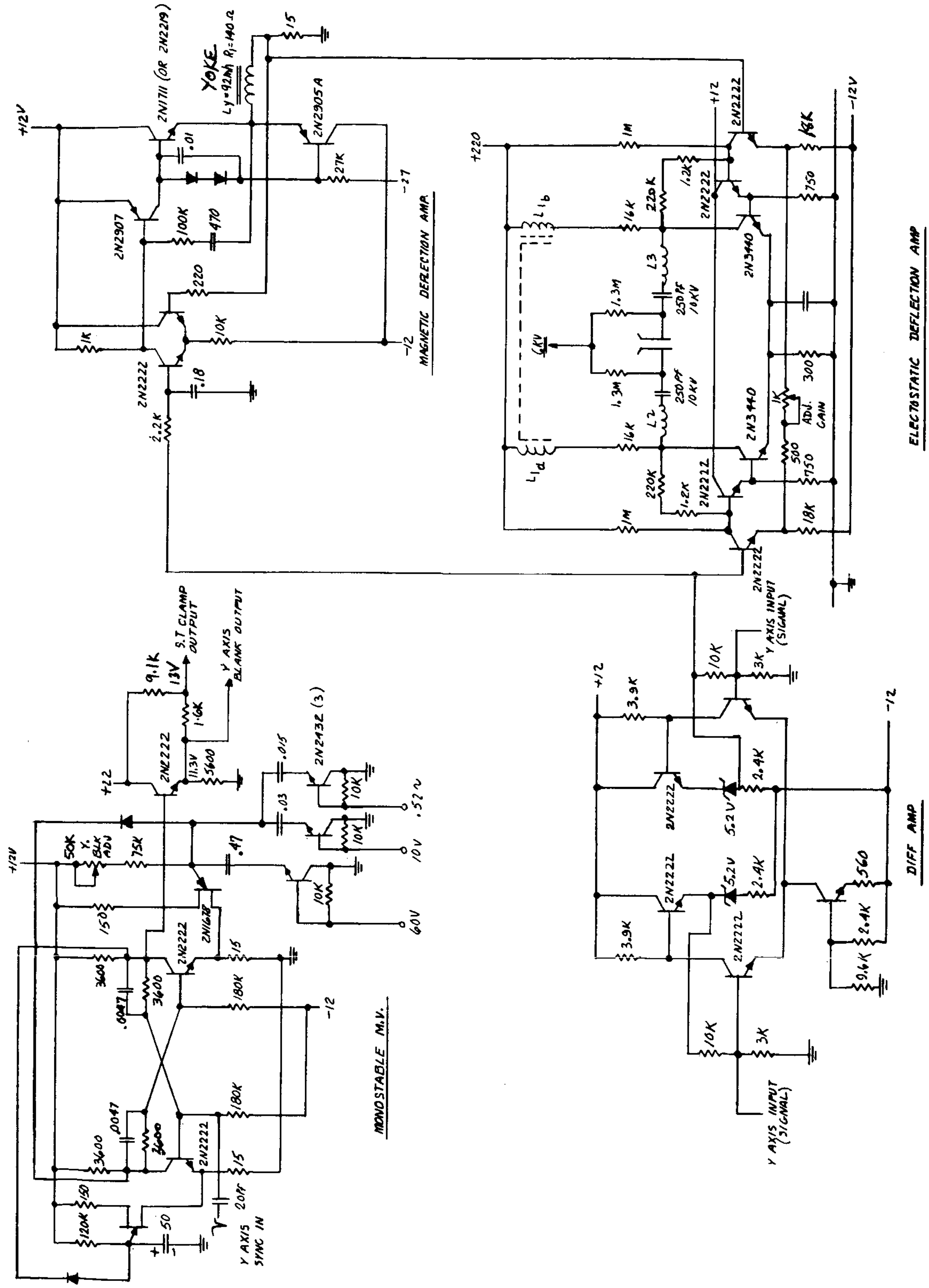


Figure 4-7. Y-Axis Deflection Amp

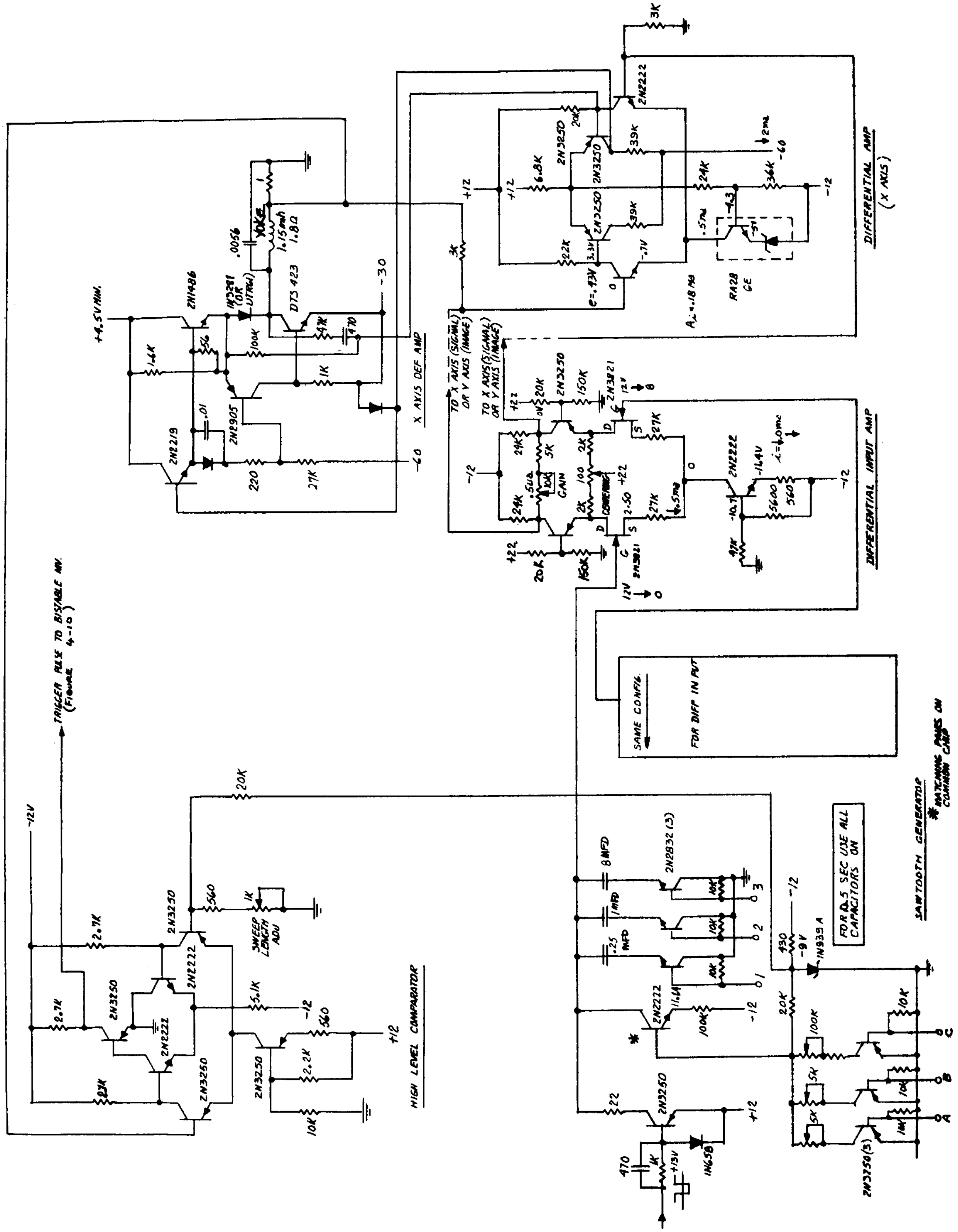


Figure 4-8. X-Axis Deflection Amp (Signal Mode)

The magnetic deflection amplifier input stage contains a low pass filter which establishes the frequency crossover at 250 cycles. The input stage consists of a differential amplifier which provides a high input impedance and the proper mixing of the feedback and input signal. This is followed by an amplifier which drives the complementary push-pull output transistors. The yoke winding is DC coupled to the output. A 15 ohm resistor in series with the yoke which samples the yoke current, provides the feedback signal. The Y-axis electrostatic amplifier input is differential, one input being connected to the signal before the low pass filter and the second input connected to the 15 ohm resistor sensing the yoke current. The electrostatic amplifier output therefore represents the difference signal, which is the high frequency portion of the signal which is not present in the magnetic amplifier output.

The electrostatic deflection amplifier consists of the differential input stage which is coupled by emitter followers to the output transistors. A series shunt peaking network in the output stage provides a bandwidth of 1 Mc. The output is RC coupled to the electrostatic deflection plates by a high pass filter which crosses over at 250 cycles. Feedback of 22db is used to stabilize the amplifier.

b. X-axis Deflection Circuit (figure 4-9 and figure 4-10)

The X-axis deflection circuit is best explained by assuming an X-axis trigger pulse from the sync separator initially triggers the bistable multivibrator upon start up. This resulting change in state of the bistable multivibrator initiates the start of the generation of the sawtooth current in the yoke.

This current is sampled by a high level comparator circuit sensing the current in a 1 ohm resistor in series with the yoke winding. When the maximum current amplitude has been attained in the yoke the comparator which consists of a two stage complimentary differential amplifier, changes state. The comparator provides an accurate level comparison, having a transition width of 2 millivolts and an offset of less than 3 millivolts.

The comparator signal causes the bistable multivibrator to reset to the initial state, thus terminating the sweep. The multivibrator starts the blanking interval by unclamping a capacitor in the blanking generator which has been charged to +12 volts during the sweep interval. The capacitor is discharged toward -12 volts by a resistor. The point at which the voltage reaches zero is accurately detected by a low level comparator which is similar in design to the high level comparator. The comparator output triggers the bistable multivibrator to initiate the start of the sweep.

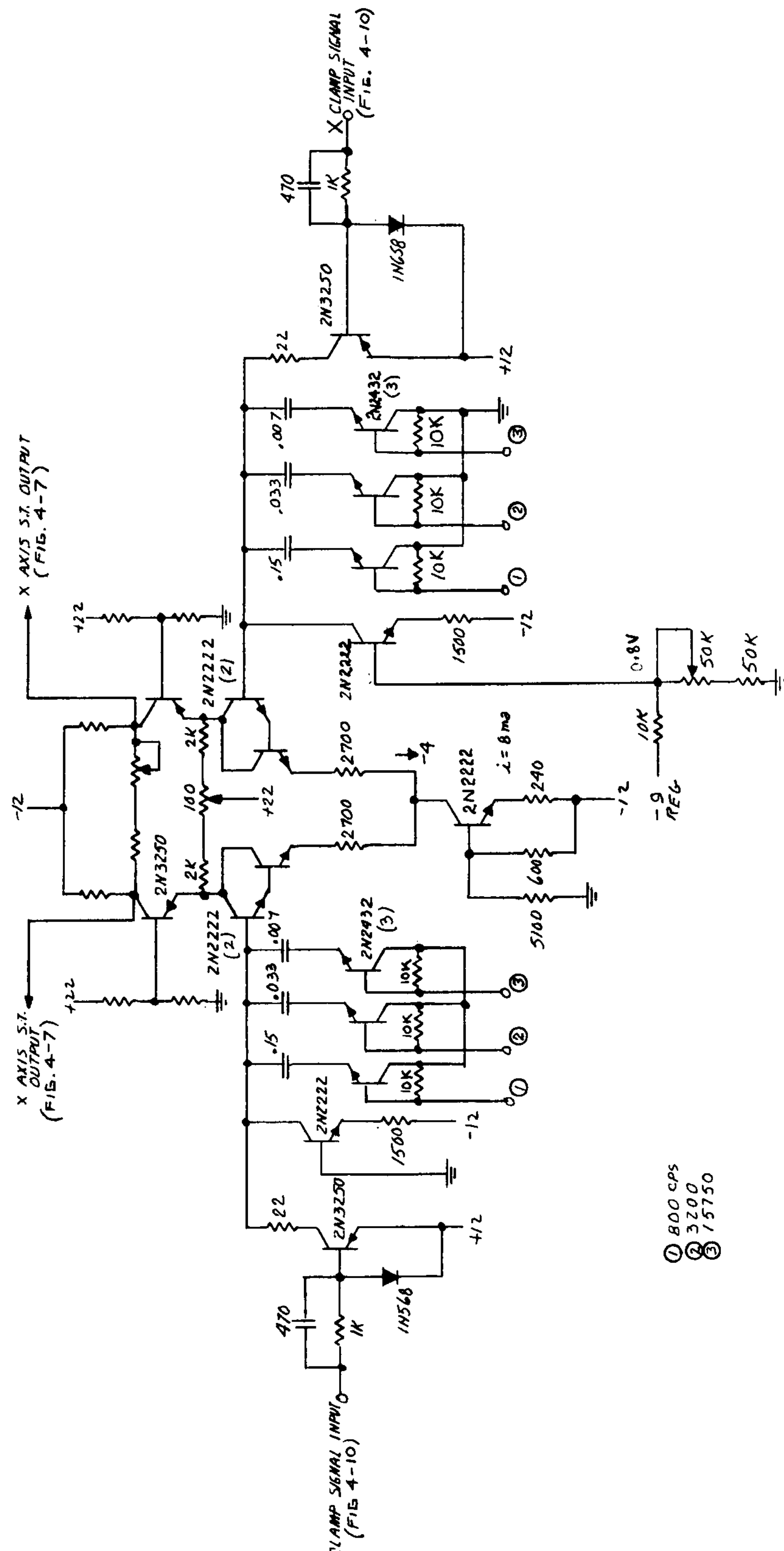


Figure 4-9. X-Axis Sawtooth Generator (Image Mode)

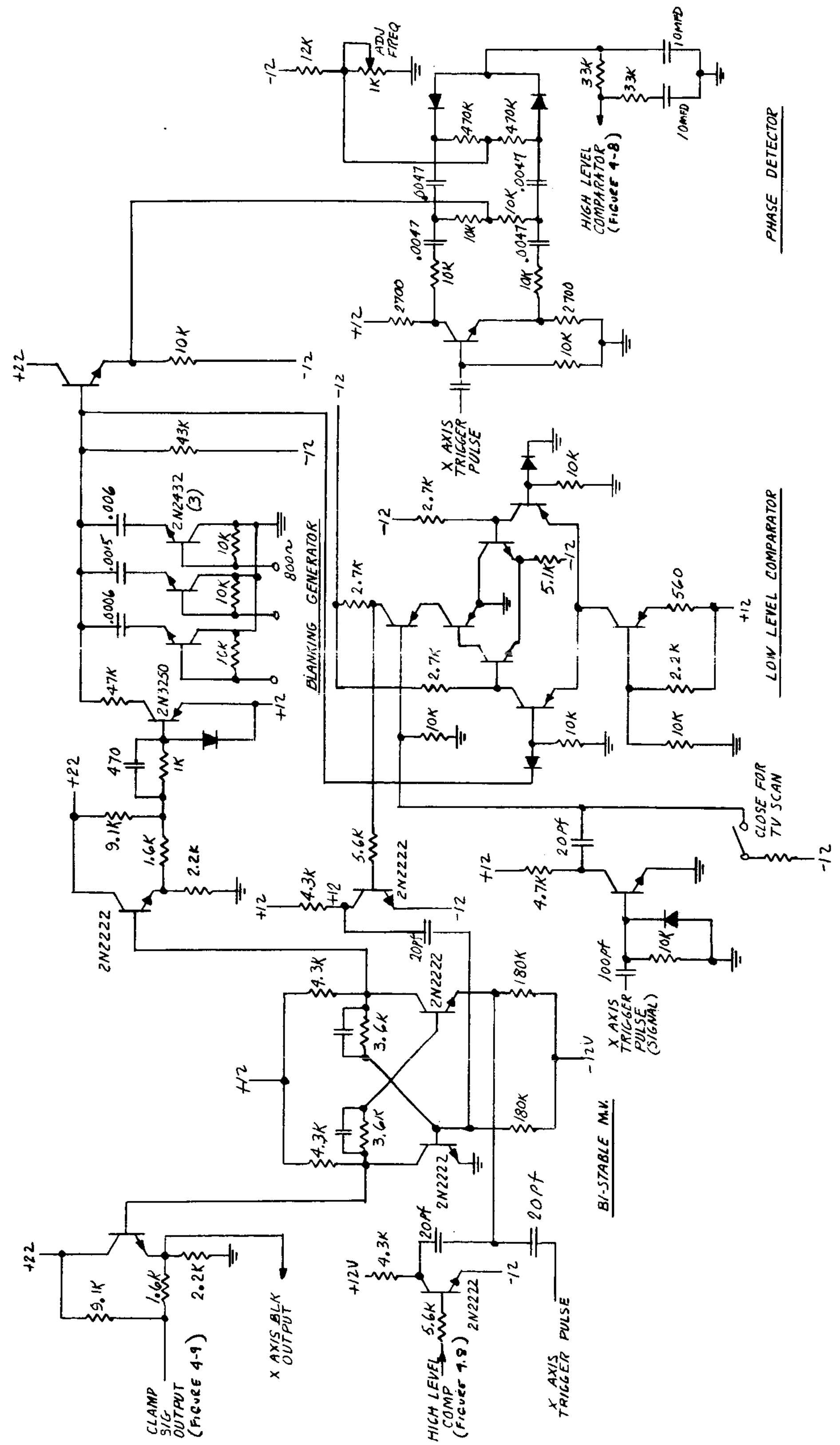


Figure 4-10. X-Axis Blanking Generator & AFC

The output signal of the bistable multivibrator during the blanking period provides a clamp signal for a sawtooth generator which is identical in design to that used in the Y-axis deflection circuit previously discussed.

The sawtooth voltages are sensed by a high input impedance differential amplifier and the output signal is DC offset to provide the proper DC level signal to a two stage NPN-PNP differential amplifier with common mode feedback. The deflection amplifier is driven single ended. The output stage consists of a pair of NPN transistors providing a DC coupled push-pull output to the yoke. This output circuit is a high efficiency flyback circuit utilizing the energy in the yoke coil to return the trace to the initial start position in 6 μsec. 65db of overall feedback is used to stabilize the amplifier. The signal from the blanking generator and the X-axis trigger pulse are compared in a phase detector and the resultant DC output, which is a function of the phase relationship, is fed to the reference input of the high level comparator to provide frequency control of the X-axis sweep.

3. Signal Display (figure 4-7, figure 4-10)

For the signal display mode the sawtooth generator and its associated differential input amplifier is switched from the Y-axis deflection to the X-axis deflection circuit. The output of the video amplifier is switched into the magnetic and electrostatic Y-axis amplifiers to provide signal modulation in the Y-axis. The operation of the X-axis sweep circuit in the signal display mode is similar to that of the image display mode except that the automatic frequency control circuit is disconnected. The low level comparator circuit provides the required timing for the retrace of the sweep but its output is biased to withhold the trigger pulse to the bistable multivibrator. The next subsequent trigger pulse, derived from the signal input to the monitor, exceeds the hold-off bias, causing the bistable multivibrator to change state and start the generation of the X-axis sweep.

4. Deflection Switching (figure 4-11, and figure 4-12)

The switching of the various capacitors, voltages and circuitry is controlled through a diode switching matrix and diode biasing activated by a simple switch on the front panel. The output of the matrix is connected to the appropriate transistor which performs the function of a switch. An inverter circuit is used in the switching matrix to reduce the number of diodes required.

5. Power Requirements

The X-axis output deflection amplifier consumes the maximum power in the deflection circuits. In the image display mode the average power consumed is 5.4 watts. For the signal display mode the minimum power consumed

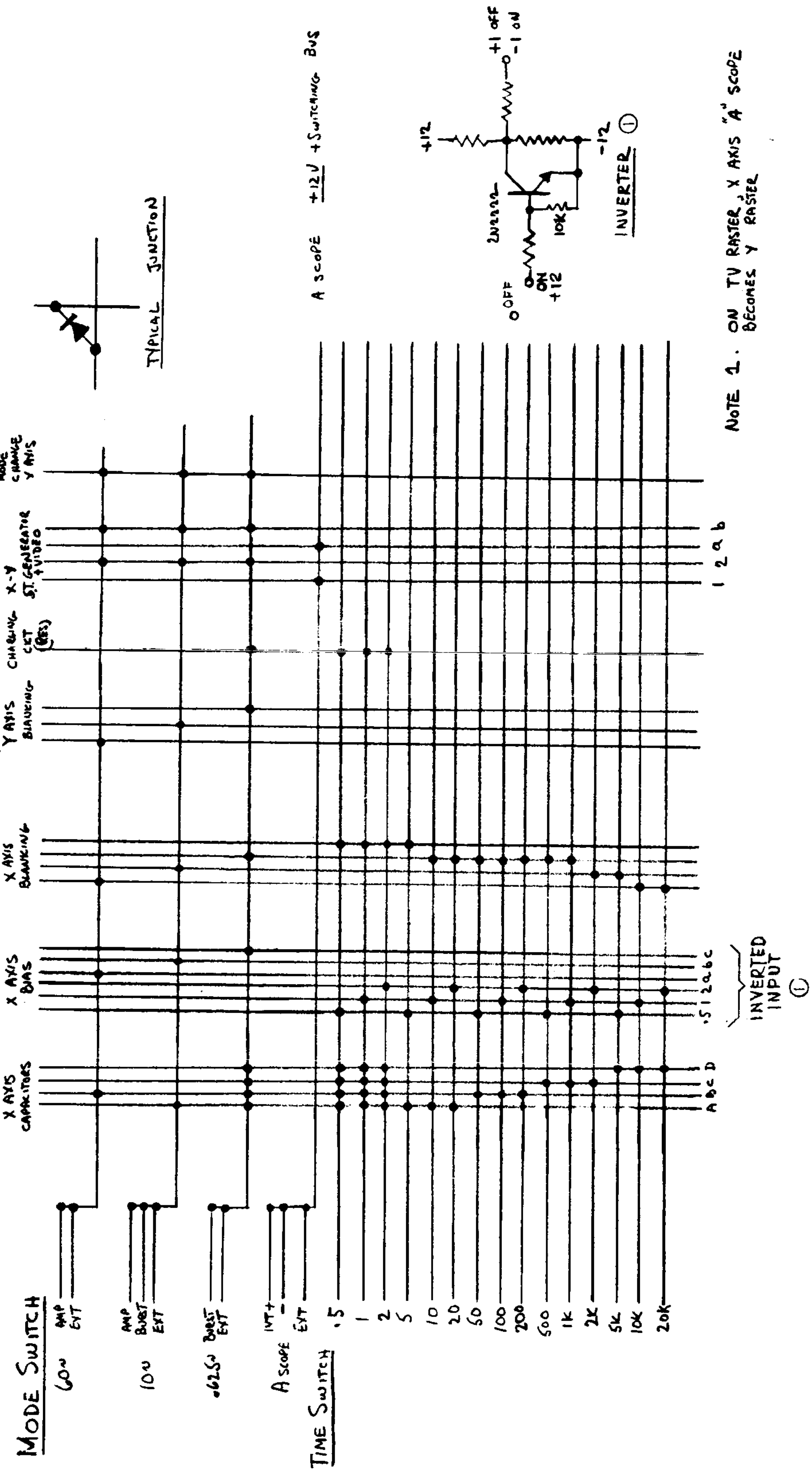


Figure 4-11. Deflection Switching Matrix

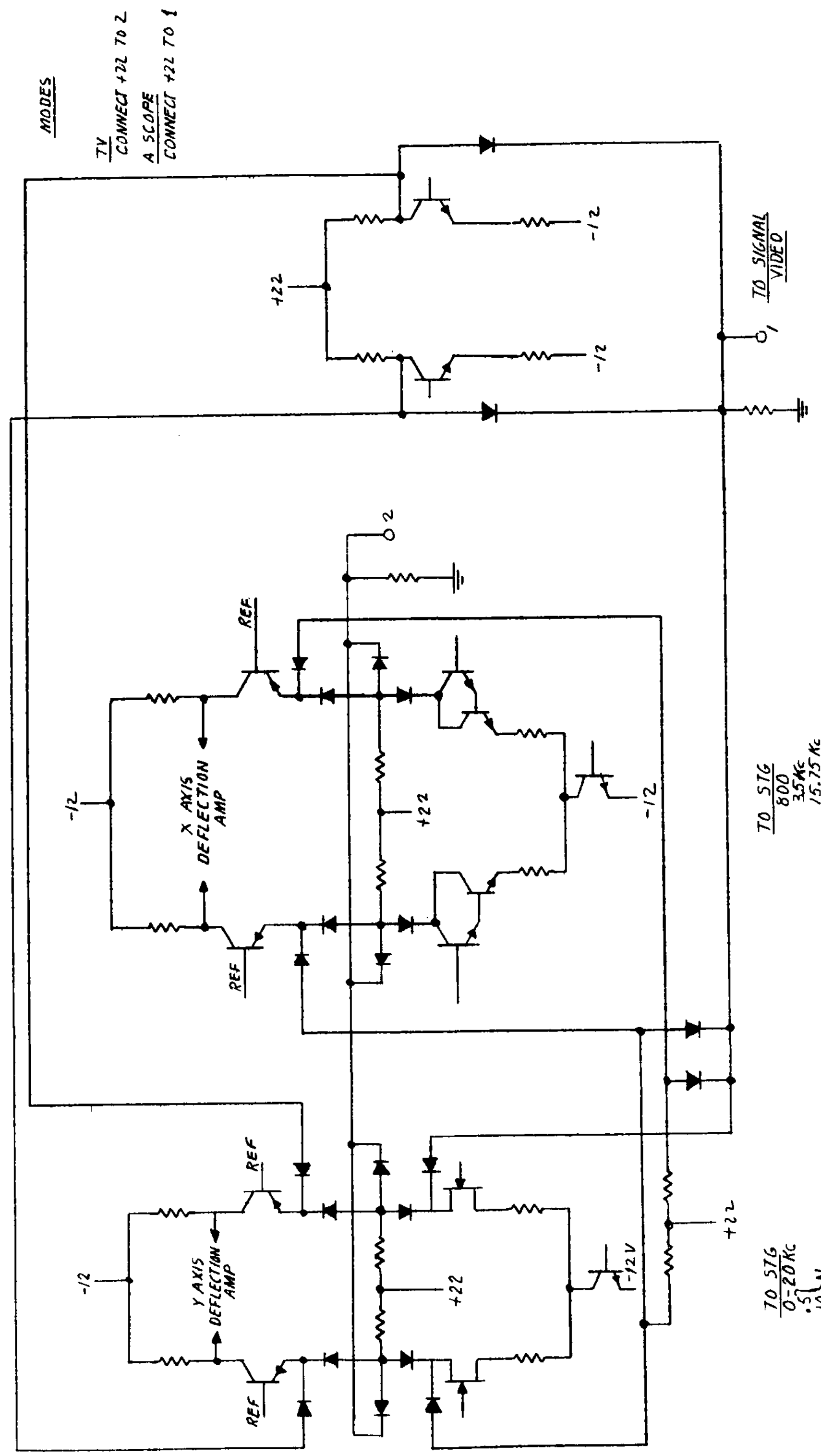


Figure 4-12. Video & Sawtooth Switching

under quiescent conditions will be 2.5 watts. When the sweep is triggered at its maximum repetition rate the power consumed will increase to 5.4 watts. The Y-deflection electrostatic amplifier consumes 3.33 watts under all signal conditions. The Y-deflection magnetic output amplifier consumes 1.2 watts in the image display mode, dropping close to zero power when the input video signal amplitude is reduced. The total power consumed by the entire deflection circuits under maximum operating conditions is 9.9 watts.

G. PREREGULATOR

The input power of the video monitor (+24 to +32 VDC) is fed into a switching type regulator circuit shown in figure 4-13. This regulator provides +22V out at 85% efficiency, (2.6 watts), while maintaining ±1% regulation with very low ripple over a temperature range of 0 to +100°C. It uses a transistor pass stage that is switched between full saturation and cutoff to obtain a minimum collector dissipation. The series transistor is controlled by positive output pulses originating from a multivibrator. The pulse width of the multivibrator output is regulated by the difference between the regulated load voltage and a dc voltage reference. By means of the varying pulse width, the duty cycle of the series transistor switch is varied to regulate the output. The output series transistor is applied to a low-pass integrating filter to transform the dc pulse into a smooth dc voltage with less than 100 millivolts of ripple.

A 10Kc current mode astable oscillator provides the basic switching frequency. A current mode astable oscillator was selected because of its inherent self-starting ability eliminating the need for a starter circuit.

A LC line filter precedes the preregulator so that the Video Monitor does not generate any transients at its power input greater than 0.25v peak to peak which shall include initial turn-on of power. For this purpose, the power source shall be considered to have an equivalent dynamic output impedance of 0.3 ohms. This filter will also reduce the input line transients and ripple so that the Video Monitors performance is not impaired.

H. POWER SUPPLIES

All power for the Video Monitor is derived from the +24 to +32V input bus. From this bus the +22V power is derived directly by the input preregulator previously described. DC to DC converters operating off the +22 volt supply, see figure 4-14 and 4-15, are used to develop all other voltages. The voltages delivered by the DC to DC converters are ±12V, +440V, +220V, -30V, -60V, +6KV, +4.5V and 6.3 VAC.

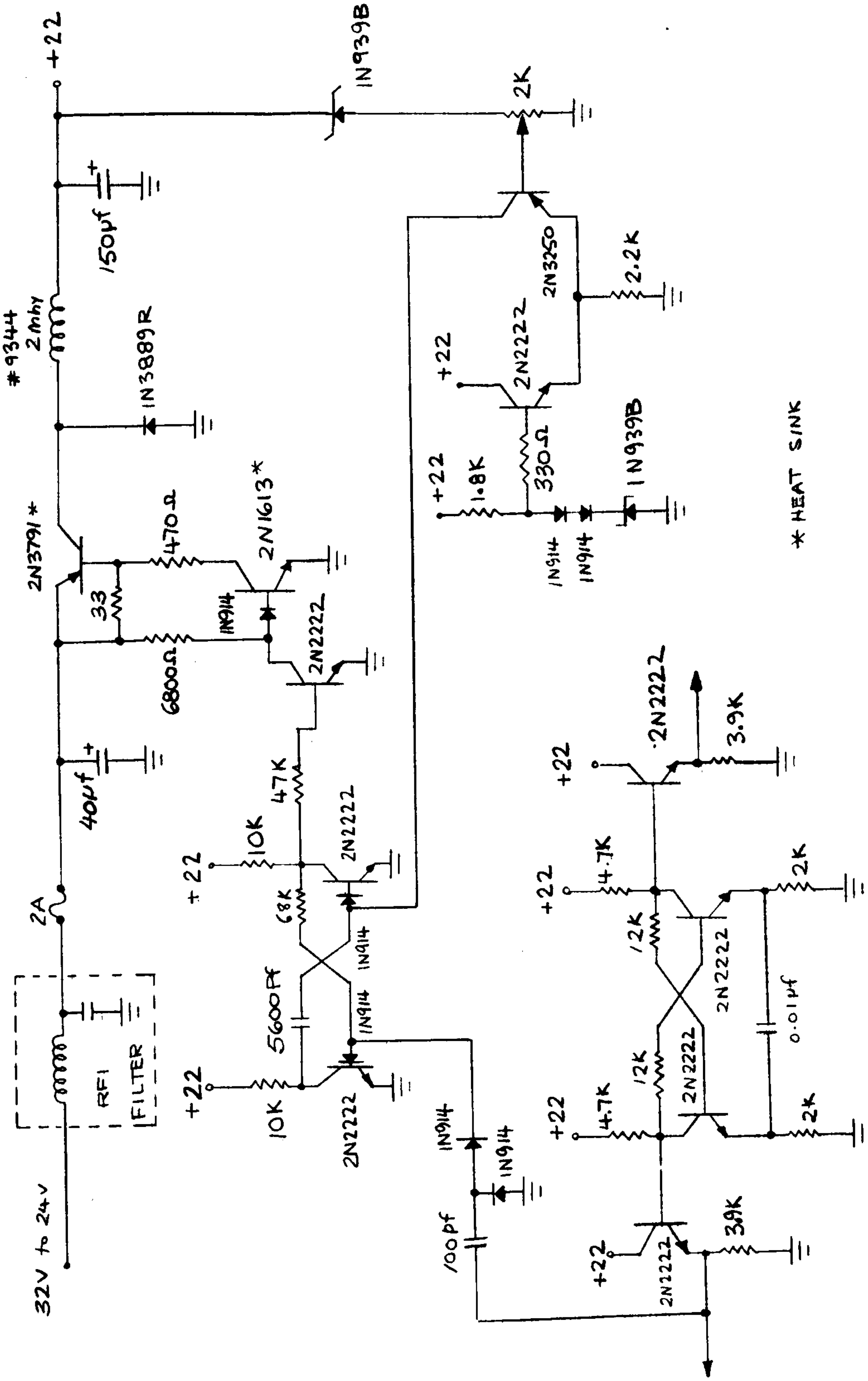


Figure 4-13. Pre-Regulator

+4.5

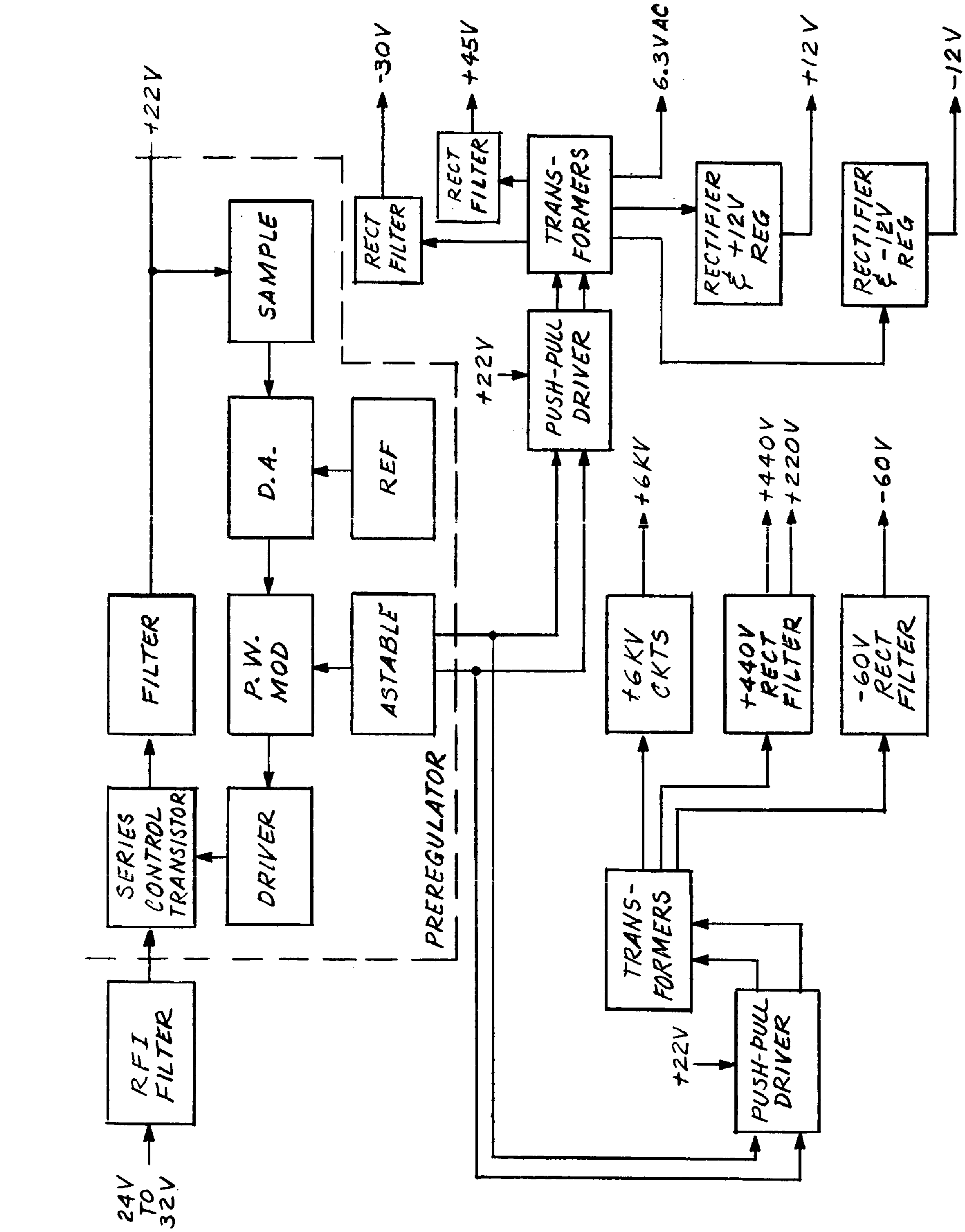


Figure 4-14. Video Monitor Power Supplies

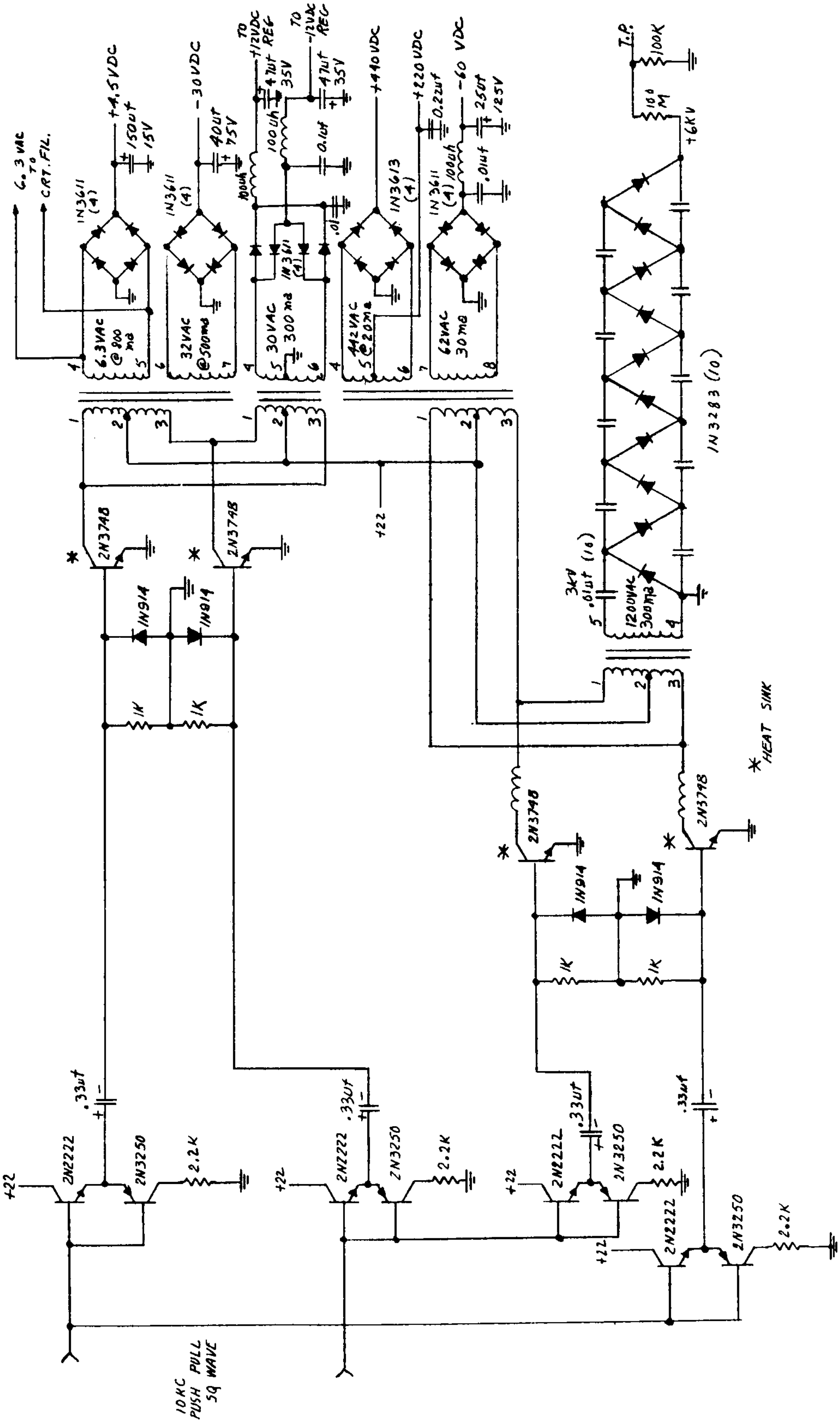


Figure 4-15. Monitor Power Supplies

The 10KC oscillator in the +22V preregulator provides the basic switching frequency for the DC to DC converters. Its push-pull outputs are buffered and used to drive two pairs of driver transistors, each pair having two transformers as collector loads. One set of drivers are used to derive output voltages which are lower than the input 22V supply. This DC to DC converter has the highest efficiency of the two, about 90%. Its outputs are, +4.5V, +12V, -30V, 6.3VAC. The other driver stage has an efficiency of 75% due to the fact that the output voltages are higher than the input (+440V, +220V, -60V, +6KV).

Two driver stages are used to increase the overall operating efficiency because the efficiency of a DC to DC converter decreases when the output voltages are higher than the input due to the fact that the capacitance on the secondary windings used for filtering reflects back on the primary by the square of the voltage ratio. This increases the rise and fall times during switching, thereby increasing the power consumed in the transformer drivers. Four transformers are used to increase the regulation of the various supplies by reducing the amount of magnetic coupling between supplies as the load varies from minimum to maximum current.

The ±15V windings are full-wave rectified and filtered. These voltages are applied to two 12V regulators (figure 4-16) capable of maintaining their output within ±1% over the required temperature range.

The +1200V winding drives a 5 stage doubler circuit providing a 6KV high voltage for the CRT's ultor and electrostatic deflection plates.

The remaining windings are just full-wave rectified and filtered for use in the monitor's electronic circuits. The 6.3V winding is also used directly for the CRT filaments. The power consumed by the converters is approximately 3 watts.

I. FRONT PANEL CONTROLS

The following are the controls located on the front panel of the Video Monitor.

a. Mode Selector Switch

To reduce the physical size of this switch due to the limited space behind the front panel, it was decided to use a single deck Rotary Selector switch manufactured by Janco. This switch, which is already approved for use in the Gemini program, drives a diode matrix, (see figure 4-17), to obtain the various logic functions required by the electronic circuits. The

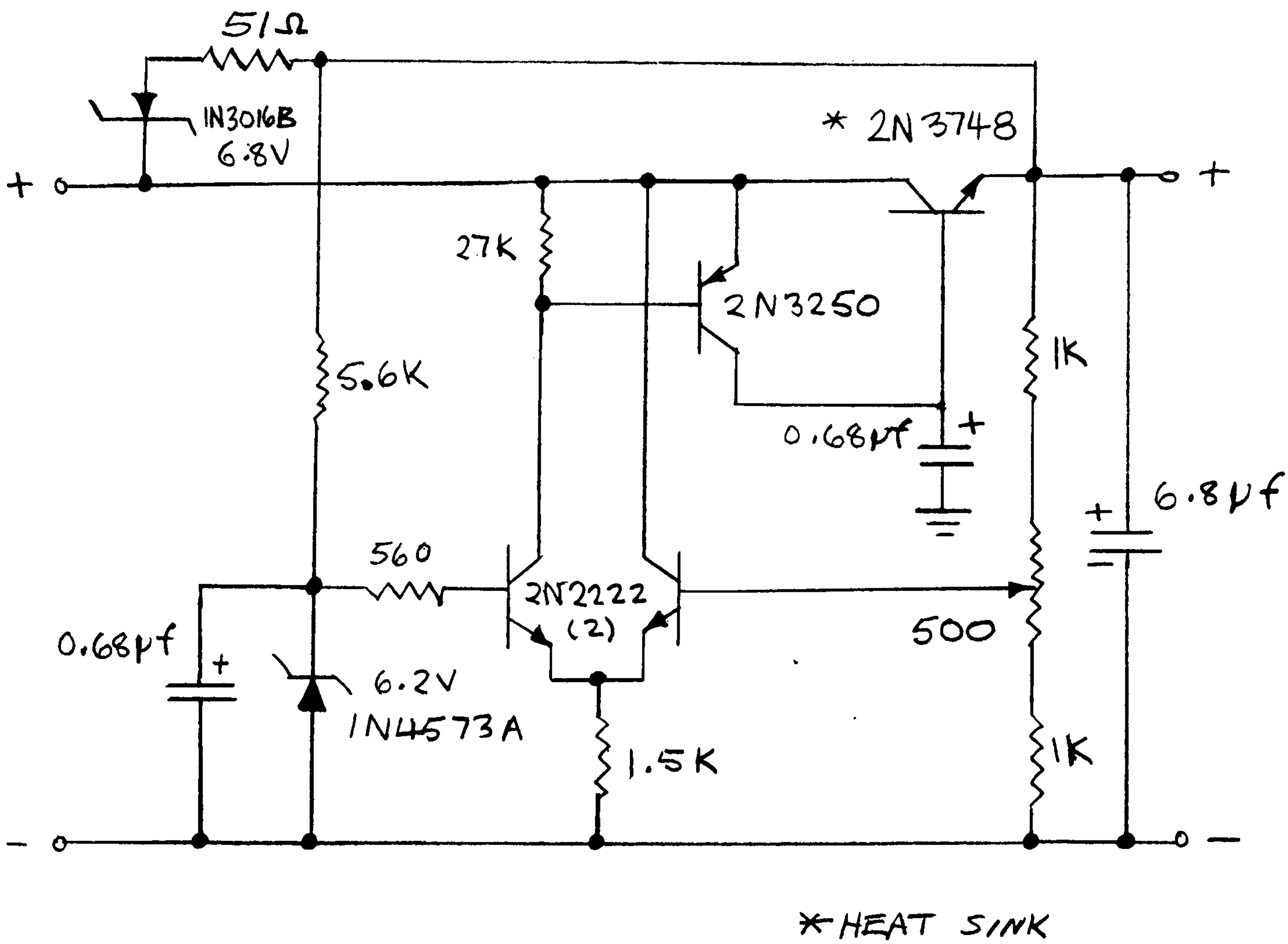


Figure 4-16. 12V Regulator

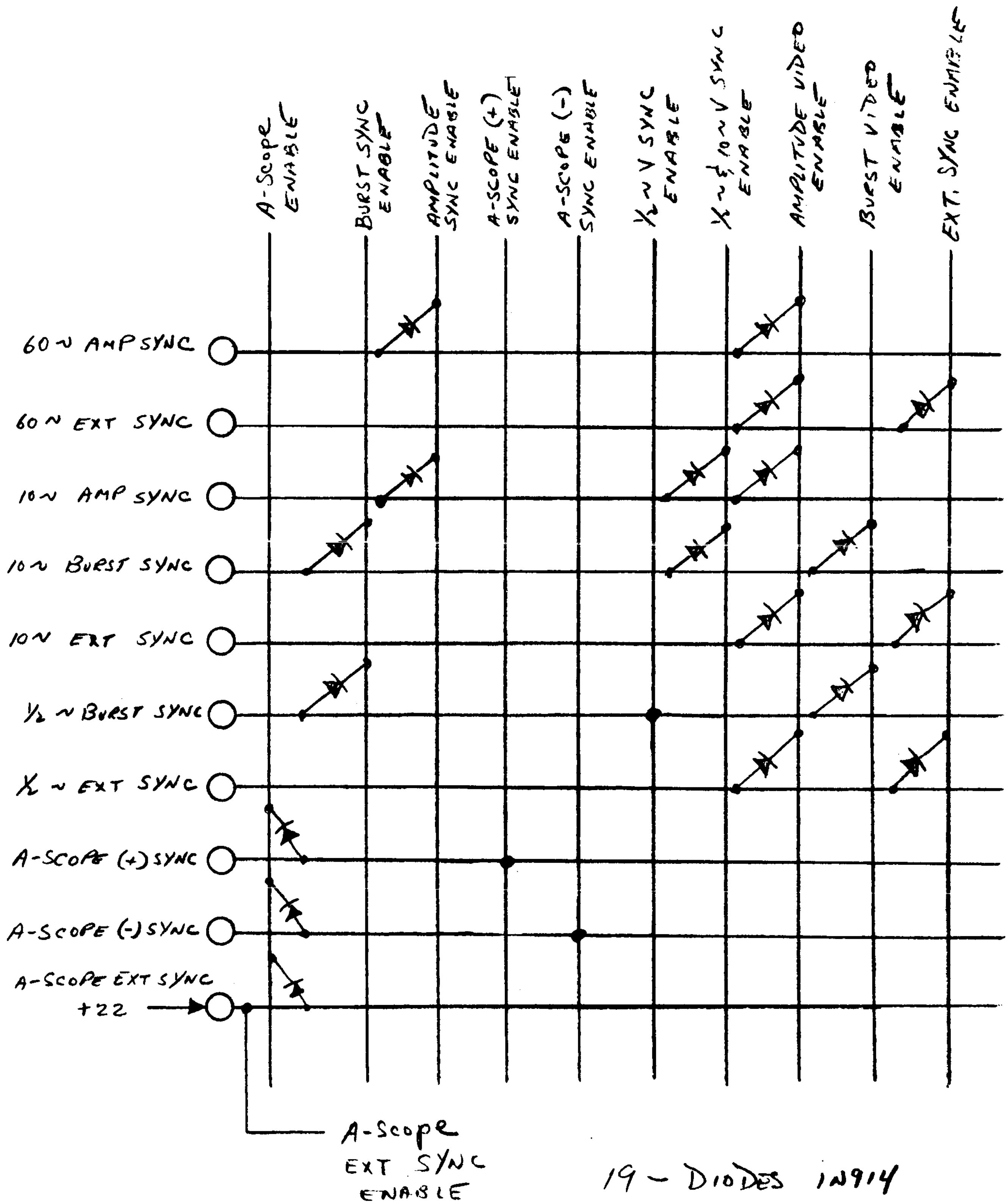


Figure 4-17. Video & Sync Separator Switching Matrix

following is a list of the switch positions.

1. 60 cycle external sync
2. 60 cycle amplitude sync
3. 10 cycle amplitude sync
4. 19 cycle burst sync
5. 10 cycle external sync
6. 0.625 cycle burst sync
7. 0.625 cycle external sync
8. A-Scope positive internal sync
9. A-Scope negative internal sync
10. A-Scope external sync

b. Contrast Control

The contrast control determines the amount of image video modulating the grid of the cathode ray tube.

c. Brightness Control

The brightness control sets the amount of grid to cathode bias on the CRT, thereby determining the tube's brightness level.

d. Power On Switch

The power on switch is in series with the input power line. It is included as front panel control so the Video Monitor may be turned off when not in use to conserve power in the spacecraft. Associated with this switch is a power on lamp.

e. Horizontal Hold

This controls the free-running frequency of the horizontal sweep generator and locks it to the video sync signal.

f. Vertical Hold

This controls the free-running frequency of the vertical sweep generator and locks it to the video sync signal.

g. Vertical Positioning Control

This pot controls the vertical location of the A-scope. It has sufficient range to position the trace completely off the top or bottom of the screen, or to any intermediate point.

h. Trigger Level Adjust

Using this control in the A-Scope mode of operation, the horizontal sweep can be continuously triggered at any point on the waveform so long as the slope of the waveform is great enough to provide stable triggering.

i. AC-DC Coupling

Input signals to the signal video amplifier can be either AC or DC coupled by placing this switch in the appropriate position. DC coupling applies both the AC and DC components of the input signal to the vertical amplifier circuit. This permits the measurement of DC voltage levels as well as the amplitude of the AC component.

j. Vertical Sensitivity Switch

This control is a nine position 4-pole Rotary Selector Switch which determines the vertical deflection sensitivity in calibrated steps of 1, 2 & 5 from 0.02 to 10.0 volts per cm.

k. Horizontal Time Base Switch

This control is a Rotary Selector Switch providing a total of 15 calibrated sweep speeds from 0.5 cycles to 20 KCPS in steps of 1, 2, & 5. This switch drives a diode matrix, see figure 4-11, to obtain the various logic functions required.

SECTION V

MECHANICAL DESIGN

The one-package design concept discussed in detail in Chapter II-F. established the minimum weight and volume criteria using hard mounted printed circuit boards mounted in modular trays. The Mechanical Design of the Video Monitor, considering design parameters such as interface with the spacecraft, thermal design, and structural design for the dynamic environment, is discussed in this section. Other considerations in this design are replacement, accessibility, and maintainability of the equipment.

A. MECHANICAL DESIGN CONFIGURATION

The main structure of the Monitor consists of a front panel rigidly connected to two outboard modular trays. The unit is attached to the Spacecraft Display Console (SDC) at the front panel and at the rear of the two outboard modular trays. See figure 5-1.

Internal design of the one-package Video Monitor system consists of four sections.

1. Cathode Ray Tube and Support Structure
2. Electronics and structure
3. Control Panel
4. Optical Filter System

1. CRT Support Technique

The CRT structural support is cantilever mounted from the main mounting plate at the front of the Monitor and is structurally independent of the remainder of the Video Monitor to eliminate undue loading on the CRT. The CRT is mounted to the structural supports using a form-fitting rubber bezel around the rectangular front face and a conical shaped rubber ring at the rear of the bottle. The system is designed to keep the resonant frequency of the CRT in the order of 150-200 cps. This design goal resonant frequency is high enough to limit the effects of shock loading on the CRT, and low enough to attenuate the input loads to the CRT neck and electron gun at their respective resonant frequencies. The CRT support is constructed of welded magnesium alloy structure. Stiffened tubular construction is used with front and rear stiffeners to provide the rigidity of a casting. The stiffeners prevent torsional rotation, bending deflection, and associated loads transmitted to the CRT.

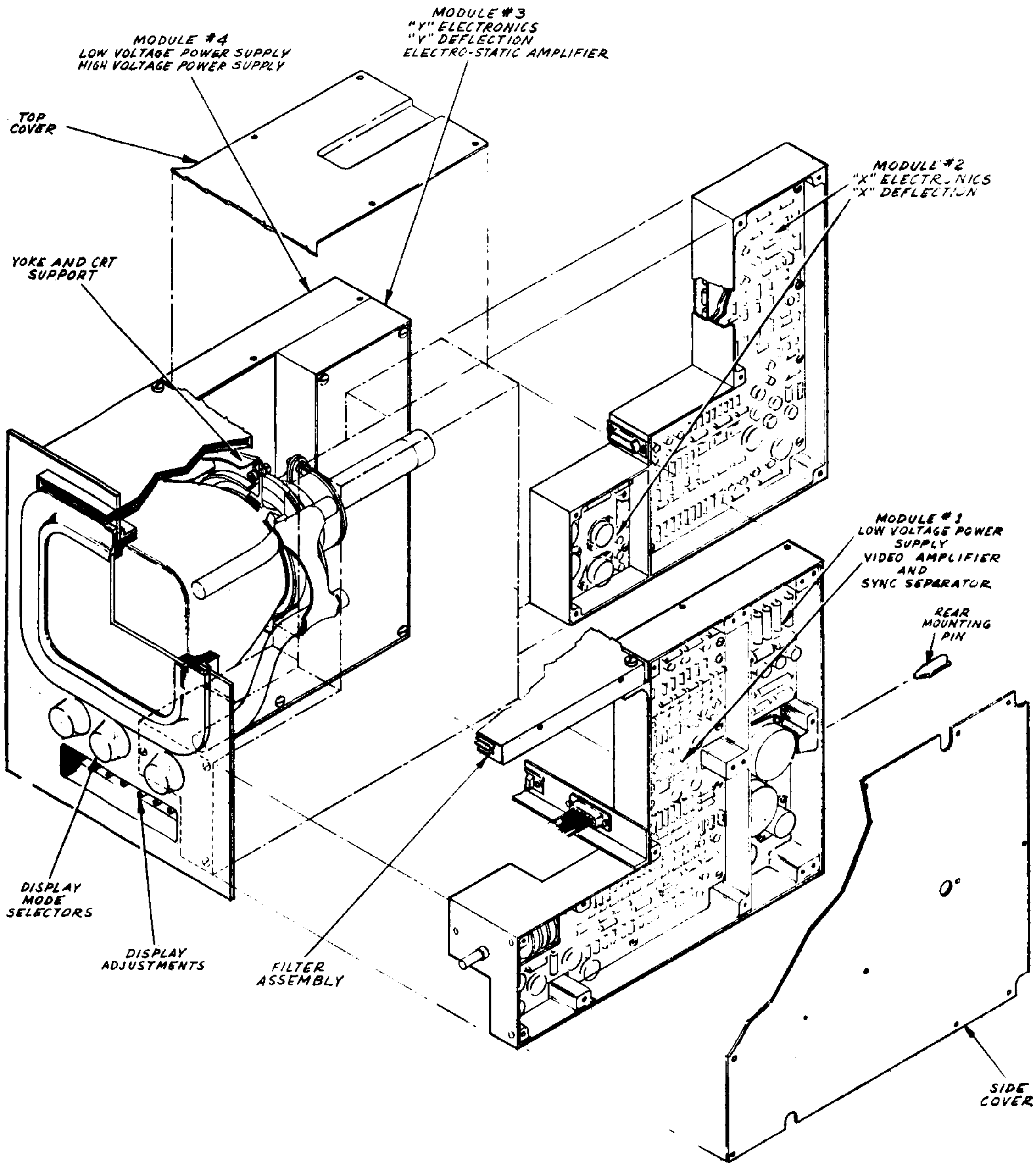


Figure 5-1. Video Monitor Ass'y Dwg.

The CRT is replaceable from the front of the Video Monitor and held in place between the front panel rubber bezel and rear tetainer. Adjustment screws at the rear retainer are used to load the CRT in compression. The CRT deflection yoke is mounted to the Structural Support; however, it remains structurally independent of the CRT. A radial gap of .010-.015 inches between the CRT neck and the inner diameter of the yoke allows for relative deflection due to dynamic loading.

2. Electronics Support Techniques

The design concept shown in figure 5-1 rigidly houses all the printed circuit boards and heat sunk components within four modular trays fabricated of magnesium alloy. Conical or wedge shaped shear pins support the outboard trays, modules #1 and #4, to the console's structure and load these modules onto the SDC heat sink surface. Printed Circuit Boards and heat sunk components within these modules become accessible by removing a cover plate on the outboard side of each module. Modules #2 and #3 are mounted to modules #1 and #4, respectively, using screws from the outboard sides. Modules #1 and #4 form a part of the structure and are not removable, while modules #2 and #3 are removable from the Monitor for servicing. Cover plates on the outside vertical surfaces, over the top, back, and bottom provide structural support, and act as the dust covers. In the current design, the Optical Filter housing structurally attaches the top of modules #1 and #4 to the front panel (see section A.3). Modular trays #1 and #4 (figure 5-2) each have a U channel cross sectional construction for rigidity. There is an additional vertical stiffening wall within the module. Modular trays #2 and #3 each have H (or I) construction with printed circuit boards on each side of the vertical wall (web). A panel perpendicular to the web provides additional stiffening to each tray. Vertical stiffeners are positioned to isolate circuits as integral units.

Modules #1 and #4 are electrically wired directly, while modules #2 and #3 are provided with plug-in connectors. A Monitor connector is mounted to the back wall between trays #2 and #3.

3. Control Panel

The location of the Video Monitor controls have been designed into an area below the CRT. Other areas (i. e. above, left and right sides of the CRT) were considered but eliminated due to difficulty of operation (human factors).

Three rotary selector switches, approximately 1-1/4 inches in diameter, perform the function of selecting the desired operating mode. The signal video selector switch is enclosed in Module #1 and is R.F.I. shielded with the video circuit.

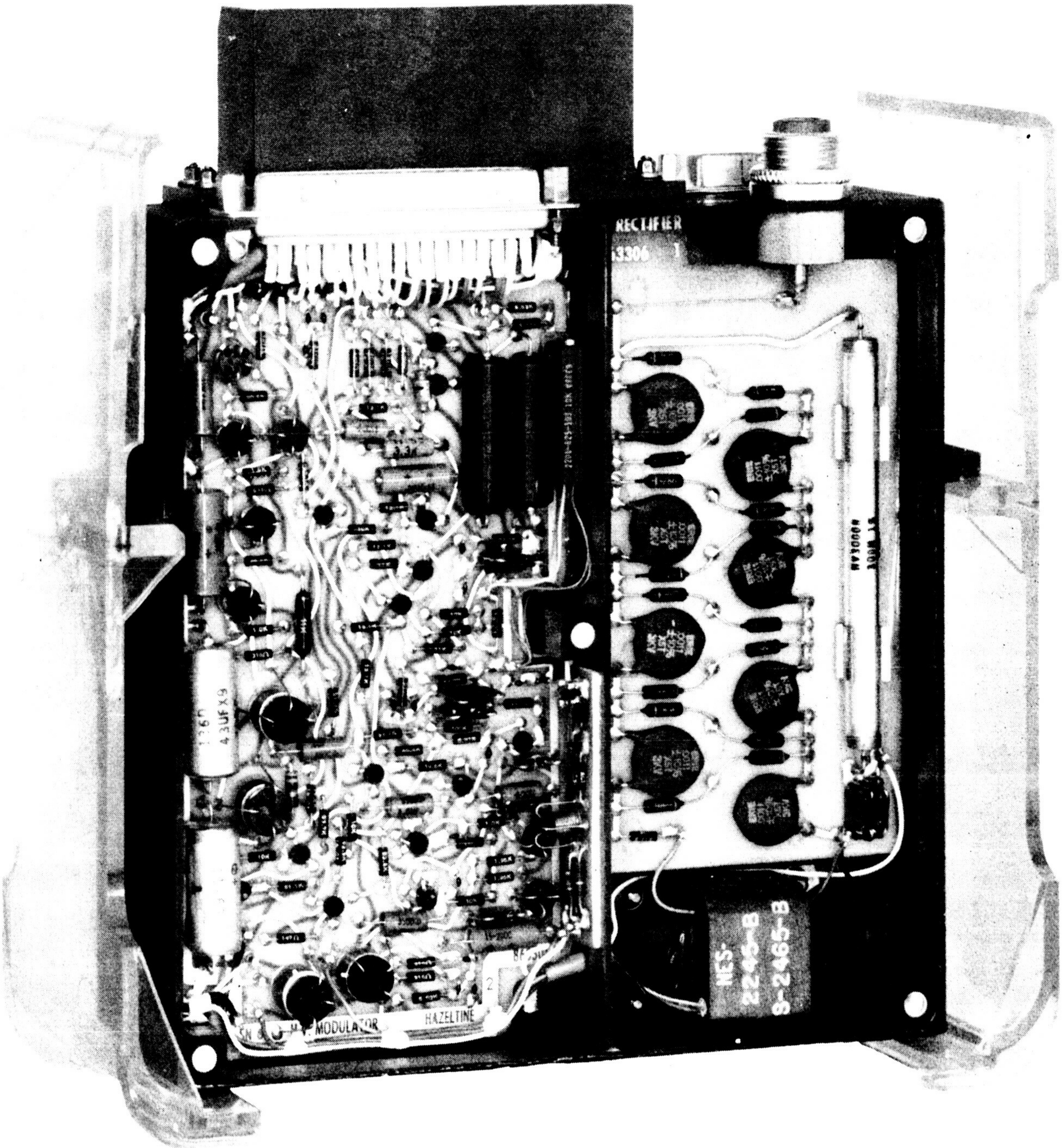


Figure 5-2. Typical Module Tray Construction

Directly below the three selector switches are the secondary controls used to make fine adjustments on the selected display. The width of the controls area is determined by the width of the CRT. The height is determined by the double row of switches and potentiometers. The volume behind the front panel is used for packaging the electronics, eliminating wasted space.

4. Optical Filter System

The two required glass optical filters have been incorporated into the design as shown in figure 5-1 with storage provisions in a compartment located above the CRT. Two alternate approaches are presently being investigated which would eliminate the need for the storage compartment. The three different techniques for providing the necessary optical filtering are as follows:

a. Two Glass Filter System

The two glass filter system consists of a blue filter and an orange filter each supported in a frame, stored above the CRT in the storage compartment, and locked in this position. Each filter is deployed separately and locked in place in front of the CRT face plate. This technique of using movable rigid filters is susceptible to damage and breakage. This filtering system is heavy and requires a deployment and locking mechanism in two positions for each filter. The weight and volume estimates presented in Chapter II-F. "Packaging Trade-Off Analysis" are based on this system.

b. Two Flexible Filter System

This filter arrangement consists of two non-rigid, flexible type filters mounted onto a band or tape. The optical filter is protected against damage or scratches, since it is free to move in a slot between the lucite grid and a protective overlay. A simple deployment and locking mechanism for each position is required.

c. One Dichroic Glass Filter System

This filter consists of a glass plate with a dichroic coating. Angular motion of the glass plate relative to the viewing plane changes spectral transmission of the filter. This system does not require storage space since the filter is continuously in front of the CRT. Volume and front panel area of the Video Monitor is reduced. Only one glass plate in a frame is used, thus minimizing weight and a simplified mechanism is used to change the viewing angle. The disadvantage of the dichroic filter design is the limited viewing angle.

B. CONCLUSIONS TO THE DESIGN ANALYSIS

1. General

In the monitor package, the CRT is the most susceptible component to the dynamic environment. The CRT is internally ruggedized but the comparatively large and fragile tube must be supported in a manner to assure over-all reliability. During the study phase, main consideration has been placed on the CRT structural support. All printed circuits and electronic components except for front panel controls will be mounted to rigid trays.

The design concept of hard mounting printed circuit boards into magnesium alloy (AZ31B-H24) modular trays has been used successfully in the past by Hazeltine in the Mariner "C" Plasma Probe. This system survived the following launch environmental conditions and operated continuously in the vacuum of space for the duration of the Mars fly-by experiment.

<u>Shock</u> 200 g .5 to 1.5 milliseconds. sawtooth three planes.

<u>Acceleration</u> ±14 g three planes.

<u>Vibration</u> - <u>Sinusoidal</u>

1 to 4.4 cps	±1.5 inches
4.4 to 15 cps	2.1 g rms (3 g peak)
2 cycles,	1.5 minutes each, 3 planes

<u>Random</u>

14 g rms	15 to 2000 cps 36 seconds

<u>Combined Sinusoidal and Random</u>

5 g rms	15 to 2000 cps (random)
+2 g rms	15 to 40 cps (sinusoidal)
5 g rms	15 to 2000 cps (random)
+9 g rms	40 to 2000 cps (sinusoidal) increasing and decreasing logarithmically for 10 minutes.

The loading described above is more severe than the presently anticipated environment. Therefore, confidence in the modular tray design concept has been established and heavier study and analysis is placed on the CRT tubular support structure.

2. Conclusions to Vibration Analysis

In order to protect the CRT against imposed shock loads, a design goal resonant frequency of 200 cps was selected. See Section B-3 "Environmental Loading Parameters". As shown by calculations which are summarized in Table 5-1, decoupled torsional and bending resonant frequencies are expected at 171 cps and 188 cps, respectively, for the CRT. Some coupling can be expected which will slightly decrease the CRT resonant frequency. A CRT rocking frequency is expected at 168 cps which coincides with torsional and bending frequencies. Structural support torsional and bending frequencies are expected at 568 cps and 1,215 cps, respectively, which is within safe limits.

Calculations show that structural resonance of the CRT neck will be greater than 1,170 cps. With CRT isolation at about 150 cps, loading on the electron gun section is approximately one-eighth of the imposed load of 9.7 g peak during random vibration, or 1.2 g peak input to the CRT at resonance. Dynamic bending stress at the base of the tube neck under this condition is 6.0 psi. During shock, the imposed shock load at the CRT may be as high as 33 g peak which yields a stress of 165 psi (or 44.5 g, and 222 psi with the design load safety factor). This stress level is well within the allowable limit for the glass material.

Since the electron gun structure within the CRT is small, lightweight, and ruggedly constructed, its resonant frequency is expected to be five times higher than the shock pulse frequency and not cause a problem during environmental loading.

Vibration tests will be conducted on a dummy CRT mounted on the tubular support structure. Compressive load across the CRT and rubber stiffness will be varied to achieve the most desirable dynamic CRT response.

TABLE 5-1
CRT TUBE MOUNT
SUMMARY OF VIBRATION ANALYSIS

Torsional Resonance Frequency	
CRT on rubber isolator	171 cps
Yoke, etc. on tubular frame	568 cps
Lateral Bending Frequency	
Two mass, coupled	
CRT on rubber isolator	188 cps
Yoke, etc. on tubular frame	1,215 cps
Decoupled Single Degree of Freedom	
CRT on rubber isolator	200 cps
Yoke, etc. on tubular frame	1,190 cps
CRT Rocking Mode Frequency	168 cps
CRT Neck Resonant Frequency	
As a cantilever, free end	1,170 cps
As a cantilever, pin end	5,100 cps
CRT Tubular Frame	
As fixed-fixed beam in lateral bending	5,900 cps

3. Environmental Loading Parameters

Consideration of Section 3.0 "Environmental Parameters" of the contract specification Exhibit "A" yields the following analysis which establishes structural design parameters.

a. Shock

Shock Loading is specified as 30 g's, 11 milliseconds (three perpendicular axes). The shock load factor is determined utilizing figure 3.2.2 of the referenced document. * In order to establish a shock amplification factor of 1.1, the frequency ratio should be approximately 4.5. This yields design goal resonant frequencies in the order of 205 cps. Calculations of the CRT Tube Support indicates resonant frequencies in the order of 168 cps to 188 cps. Considering that structural resonant frequencies may be in the order of 150 cps, the shock load amplification factor is re-estimated at 1.3 (f_1/ω_2 ** = 3.3). Therefore, the amplified shock load factor is taken as 30 x 1.3 = 39 g.

b. Acceleration

The specification for acceleration is 7 g (three perpendicular axes). This is not considered significant since the shock load factor is higher. There are no moving parts in the Video Monitor system, eliminating the effects of inertia loading.

c. Random Vibration

The random vibration level is specified as:

10	- 60 cps	6 db increasing
60	- 400 cps	.015 g^2/ cps
400	- 2000 cps	6 db decreasing

* "Dynamics of Package Cushioning," by R. D. Mindlin, Bell Telephone System Technical Publications, Monograph B-1369.

** $f_1 = 150$ cps; $\omega_2 = \dfrac{1}{2(.011)} = 45.5$ cps (equivalent shock load frequency).

2 AM 2 R-1

Structural design resonant frequencies are approximately 150 cps. Equivalent structural damping is approximate as 5%, yielding a magnification factor (Q) of 10. With an input spectral density of 0.015 g^2/cps, the rms response of a lightly damped single degree of freedom system is given as *

$$G_{rms} = \sqrt{\frac{\pi}{2} \; fn \; Q \; \sigma in}$$

where:

fn = natural frequency of the single degree of freedom system, cps

Q = magnification factor, no units

σ in = input spectral density, g^2/cps (assumed constant over the entire frequency band)

G_{rms} = output rms response of the single degree of freedom system, in G's, rms.

$G_{rms} = 6.0g$

G peak = 1.41 (6.0) = 8.4g peak (response)

d. Conclusions

The load factor on structural members imposed by the environmental parameters is as follows:

(a)	Shock	39 g at 150 cps
(b)	Acceleration	7 g
(c)	Random Vibration	8.4 g at 150 cps

The design load factor of safety shall be 1.35 applied to the specification dynamic level loads. Therefore:

(a)	Shock	30 x 1.35	=	40.5 g at 150 cps
(b)	Acceleration	7 x 1.35	=	9.5g
(c)	Random Vibration	8.4 x 1.35	=	9.7g at 150 cps

The design load factor, therefore,is 40.5 x 1.3 or 52.6 g for shock loading. This value will be used for establishing the structural design.

* "Electronic Designer's Shock and Vibration Guide for Airborne Applications," R. E. Barbiere and W. Hall, WADC Document No. 58-363, ASTIA Document No. AD-204095, December 1958, pp. 223-224.

4. Conclusion to Stress Analysis

The stress analysis performed on the CRT structural support indicates that the dynamic stresses induced in the support due to environmental loading are low. The stress induced in the Main Structural Ring of the tubular support is in the order of 8400 psi. Structural tube stress at the built-in end is 1660 psi. The magnesium alloy (AZ31B-H24) used for the Tube Support has the following properties:

a.	Tensile yield strength	29,000 psi
b.	Compressive yield strength	24,000 psi
c.	Fatigue Strength (at 10^7 cycles)	20,000 psi (approx.)

The calculated stresses are well within the allowable load carrying limitations of the material.

Each screw can carry 2200 pounds in tension, and 2100 pounds in single shear. Actual loading on each screw is 143 pounds in tension and 46 pounds in shear. These screws are adequate to support the tube mount (No. 10 screw, AN-3).

The stress and loading analysis has been limited to those areas which are considered critical. Design of these parts is considered safe.

5. Heat Transfer Design

The Video Monitor is designed to transfer head by conduction and some radiation from - (a) components on printed circuit boards to modular trays, (b) heat sunk components mounted directly to modular trays -- to the base of the trays. Heat is conducted from the base of the trays to the console heat sink surface. Wedge (conical) shaped mounting pins located at the rear of the Monitor will assure good contact to the heat sink plate and minimize thermal resistance.

Radiation heat transfer coupling between printed circuit board mounted components and the opposite wall of a modular tray will increase heat transfer and utilize both walls of a modular tray for heat transfer toward the base of the unit. When practical, internal radiation heat transfer will be increased by increasing emissivity (i.e. black paint finish, $\epsilon = 0.9$). Radiative type shields or high reflective surfaces (i.e. low absorptivity surface finishes) will be used where necessary and practical to reduce heat transfer where required.

Present estimates indicate that other devices mounted to the Spacecraft Display Console (SDC) and the heat sink plate (SDC cold plate) will operate at approximately 110°-120° F. If high power dissipation devices adjacent to the Video Monitor operate at 120° F with the heat sink at 110° F, then infiltrated heat radiated to the Video Monitor will be in the order of 9.8 Btu/hr. (2.5 W.), conpared to 68 Btu/hr. dissipated by the Monitor. This quantity of infiltrated heat is tolerable and can be easily transferred to the heat sink plate via conduction. This small additional quantity of heat has a negligible effect on increasing temperature. However, if infiltrated heat becomes appreciable, several layers of radiant heat superinsulation material (i.e. NRC-2) will be placed around the Monitor to suppress infiltrated heat to approximately 1.0% of the imposed radiant heat energy. The material can be freely applied, secured in place, with very small weight penalty.

The following assumptions are being made for the purposes of designing the thermal interface:

a. The heat sink contact area to the SDC cold plate will consist of the two outer structural trays and have an area of approximately 28 square inches.

b. Based on available data, thermal conductance between two surfaces is estimated at 136 Btu/hr. sq. ft. °F, based on a contact pressure of 25 psi.

c. The heat sink surface has a finish of 32 rms.

d. The heat sink mount is capable of structurally providing an interface pressure of 25 psi across 28 sq. in. of the base of the Video Monitor.

Since the Monitor dissipates approximately 20 watts, heat transfer in an atmosphere is not considered a significant problem. Natural convection from wall surfaces will adequately cool the monitor.

SECTION VI

DISPLAY PERFORMANCE CHARACTERISTICS

A. GENERAL

The performance of the Video Monitor breadboard was measured and evaluated under controlled conditions resembling, as closely as possible, the spacecraft environment. The breadboard was assembled on a bench in a light tight laboratory room. The various scanning format modes of operation were set up and optimized in the electronic circuits. The video input signals to the Video Monitor were simulated by a specially constructed signal generator. The signal generator was capable of supplying video signals for all three image display modes: the normal 60 fields per second scan, the 10 frame per second slow scan, and the very slow scan of 0.625 frames per second. The signal generator video signal provided a resolution test pattern, a gray scale test pattern, and a linearity test pattern.

In addition to the signal generator, live video was presented on the Video Monitor at the normal scan 60 fields per second rate and at the 10 frame per second rate slow scan. The former was supplied by commercial, off-the-air, television stations, and the latter by a slow scan camera viewing a scene containing moving objects. The very slow scan rate was not tested with live video because the intended purpose of this operating mode is to provide photographic record of still images and motion is not a critical parameter.

The Video Monitor was also tested in the A-scope mode of operation by a sine-wave generator and a pulse generator providing a video signal with a wide range of frequency, pulse width, duty cycle control.

The spacecraft environment was simulated by a diffused white light source producing a background illumination between 1 and 2 foot-candles on the screen of the Video Monitor cathode ray tube. The light measurements were made by a spot brightness meter whose spectral response is matched to the human eye.

A series of Kodak Wratten and Rosco Roscolene color filters were inserted in front of the CRT screen to test the relative selectivity of the filter with the spectral response of the phosphor. The selection of the filter was accomplished by a subjective process dependent on the judgment of several viewers which comparatively rated the appearance of the resultant display.

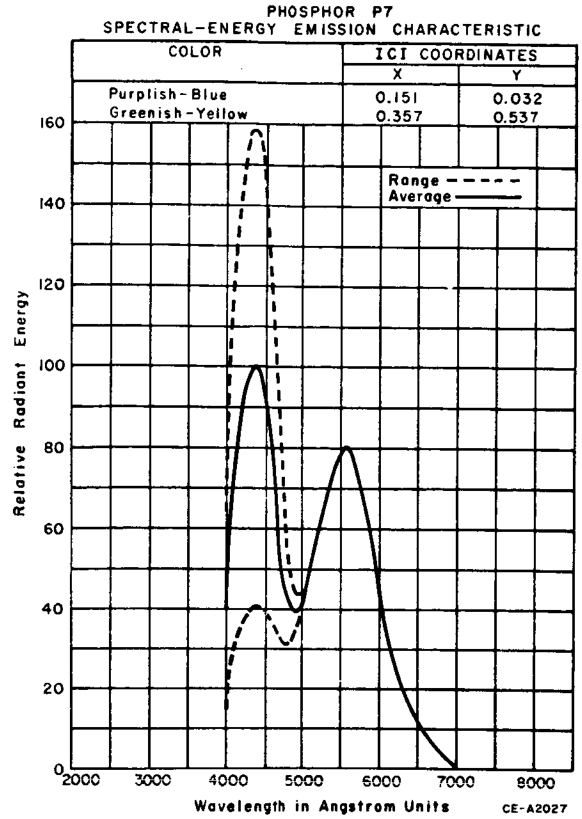
The judgment was based on such factors as brightness, flicker, image motion smear, image quality, viewing ease, contrast, and eye fatigue. The results obtained from the tests performed and measured on the Video Monitor Display are detailed in the following sections.

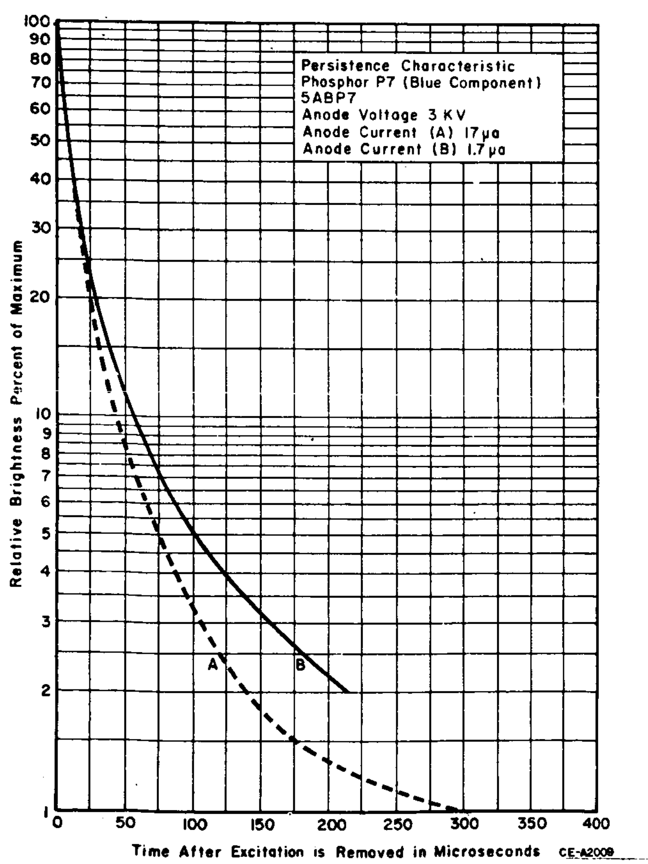
B. CRT PHOSPHOR CHARACTERISTICS

Two CRT's with different phosphor characteristics were evaluated. One CRT is a Thomas-type 6M15P7M with a 6-inch rectangular screen and a P7-type phosphor whose response characteristics are shown in figure 6-1. This cascade type phosphor exhibits a dual persistence characteristic. One component of the light output decays rapidly and the other decays slowly. The desired persistence characteristic can be selected by an appropriate color filter. The fast decay component light output peaks at 4200 ANGSTROM (blue), the slow decay component light output peaks at 5600 ANGSTROM (yellow). This phosphor was selected over other cascaded phosphors because its persistence characteristics match best the three image video frame rates that must be displayed. The fast decay component persistence luminance drops to 1% of the excitation luminance in 300 microseconds. This is suitable to the normal scan of 30 frames per second display and generates a pleasing image without image motion smear. The slow decay component persistence luminance drops to 25% of the excitation luminance in 100 milliseconds, and down to 4% in 1.0 second. This is suitable for both slow scan frame rates. The relatively small drop in brightness in 100 milliseconds minimizes the flicker at the 10 frame per second rate with tolerable smear for slow moving images. The long decay to 1.0 seconds permits viewing of the image at the 0.625 frame per second rate.

The P7 phosphor is an efficient phosphor and generates adequate brightness at low electron beam currents, thus permitting high resolution displays.

The second CRT is a Thomas-type 5M28PEM with a five inch round screen. The screen is made of a mixture of two phosphors; a type P1, and a Thomas-type E (which is similar to Ferranti Type L3), whose response characteristics are shown in figures 6-2 and 6-3 respectively. These phosphors have different persistence characteristics which can also be selected by an appropriate color filter. The fast decay P1 phosphor light output peaks at 5200 ANGSTROM (green), and the slow decay type E phosphor light output peaks at 5900 ANGSTROM (red). This mixture of phosphors was selected because of its persistence characteristic response curve. The phosphor retains the excitation luminance for a period of time after removal of excitation, and then decays rapidly to zero. The fast component decay to 6% of excitation luminance in 30 milliseconds. The slow component decays to 90% of excitation luminance (only a 10% drop in brightness) in 100 milliseconds, and then decays rapidly to 10% in 1.6 seconds.





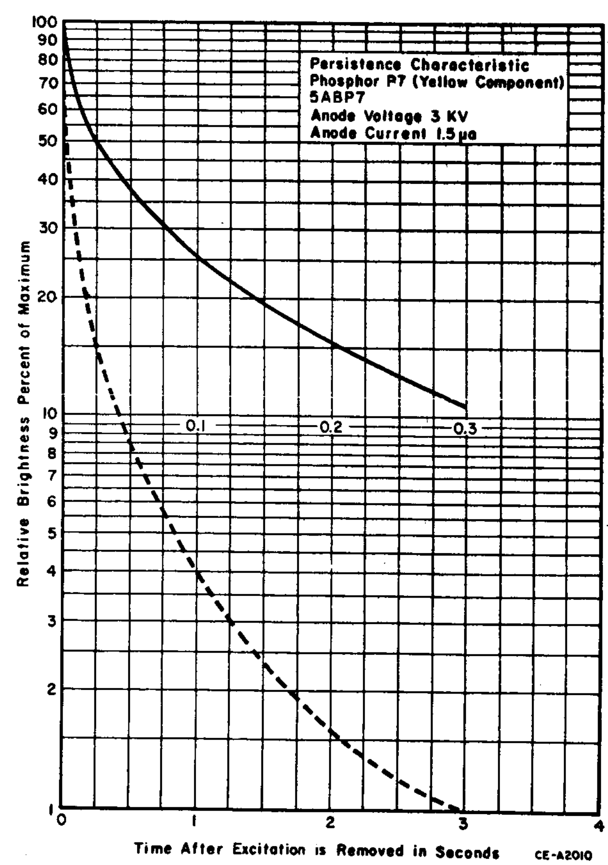
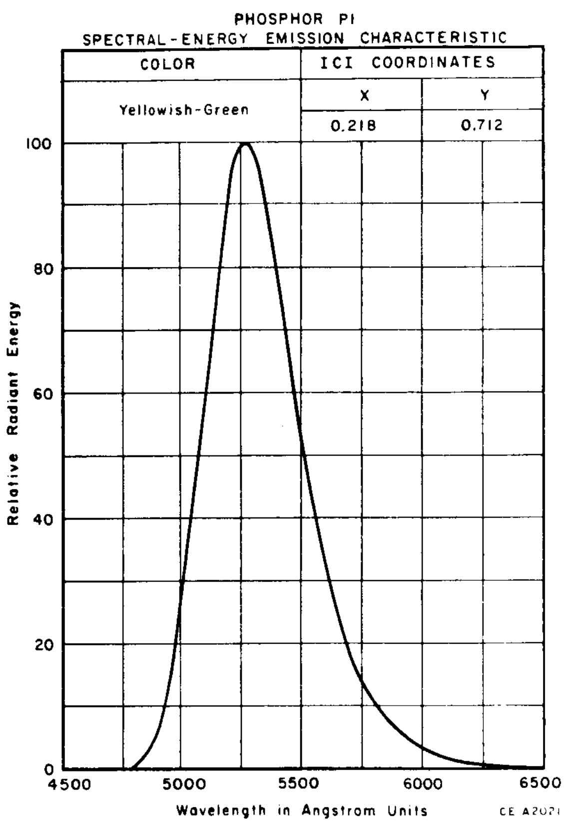


Figure 6-1. P7 Phosphor Characteristics



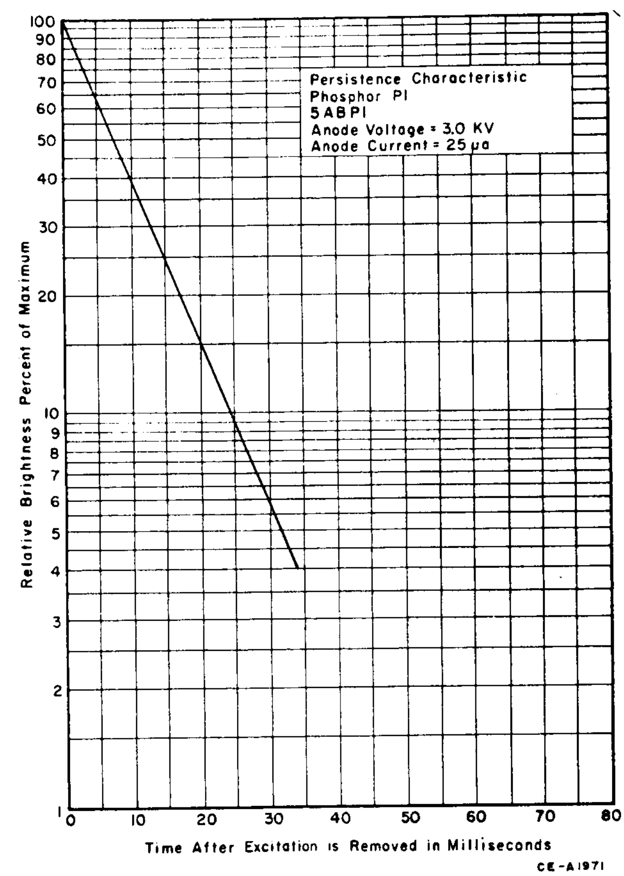


Figure 6-2. P1 Phosphor Characteristics

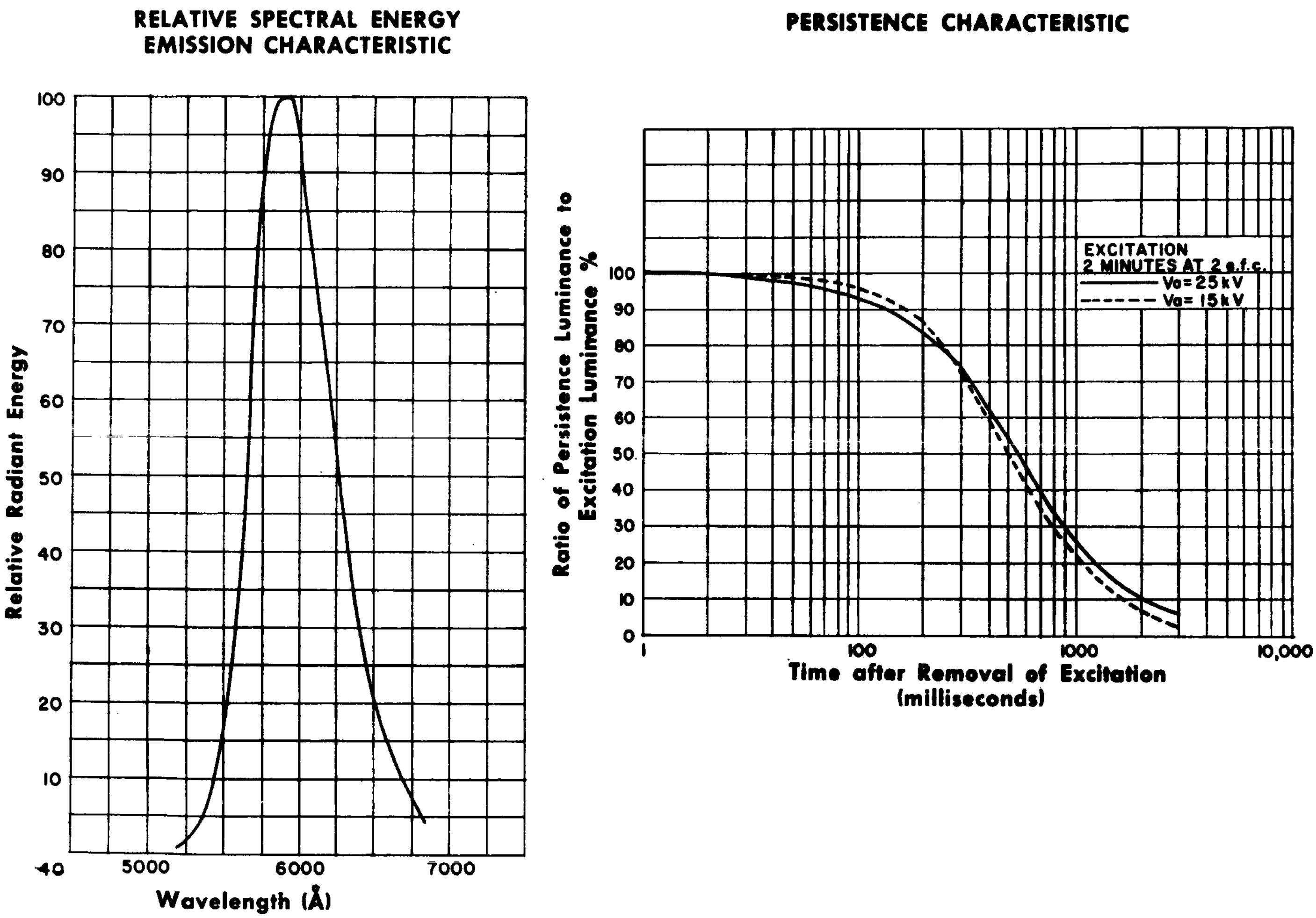


Figure 6-3. Type E Phosphor Characteristics

C. QUALITATIVE DISPLAY DESCRIPTION

Because of the complex response of the human eye to the various modes of image display, some of the visual characteristics of the Video Monitor cannot be meaningful measured but can only be evaluated in terms of a comparison between various display alternatives followed by a subjective selection of the "best looking," "most pleasing," or "less tiring" display.

The following subsections qualitatively describe the image display performance in the various modes of operation.

1. P7 Phosphor Performance

a. 60-Cycle Image Display

Viewed without color filters the display exhibited an objectionable blue-yellow image which gave the appearance of a two-color newspaper print with color misregistration. Furthermore, image motion produced a pronounced smear and after-image.

With a deep blue filter (Kodak Wratten 65A) a clean, clear, smearless, and pleasing image was obtained. No flicker was perceptible and no yellow component could be detected. However, the resulting attenuation of the brightness seemed to produce certain eye fatigue.

With a pale blue filter (Roscolene #856) the image was most pleasing with little attenuation in brightness. A small amount of the slow yellow component could be detected after careful examination, but not enough to produce significant image motion smear. No eye fatigue was experienced after prolonged viewing, and the human eye readily adjusted and assimilated to the blue image in a way similar to eye assimulation to black and white displays.

b. 10-Cycle Image Display

Viewed without filters, this display exhibited very objectionable flicker. A combination yellow-orange filter (Roscolene #813) reduced the flicker to a level where, in the opinion of several observers, it was no longer objectionable. To be sure, the flicker was not completely eliminated, but the resulting image could be viewed for extended periods without apparent eye strain, eye fatigue or mental fatigue. The yellow image was more pleasing than the blue at 60 cycles in terms of black and white and gray shade assimilation.

Rapid image motion produced smear and loss of contrast in the moving image, however, tests demonstrated that a significant portion of the smearing, in fact most of it, was generated by the live vidicon camera used in the experiment. It could be concluded, however, that for the slow motion expected in most spacecraft and extraterrestial scenes the smear can well be tolerated by the observer without undue loss in information. The general opinion expressed by most observers of the filtered 10-cycle display was that the image appeared much better than expected.

c. 0.625 Cycle Image Display

Without 0.625 Cycle Image Display filter the display produced a very bright writing line moving from top to bottom of the screen. With strain, the viewer could concentrate his attention on the decaying information behind the writing line and reconstruct the image in his mind. With a yellow-orange filter (Roscolene #856), however, the improvement in the image was dramatic. The writing line could still be detected, but the brightness of this line was drastically reduced while at the same time the brightness of the decaying image seemed to increase to the point where the two appeared almost equal. A significant portion of the image was retained from the previous frame and was clearly visible just ahead of the writing line. The human eye experienced little strain or fatigue viewing the images in this display and could readily adjust to this format as well as color.

d. A-Scope Display

The A-Scope dispaly image followed the same general characteristics described above in relationship to the scanning time base and duty cycle. In fact, the availability of a selection of persistence characteristics enhanced the image at the particular scanning rate.

2. Mixed Phosphor Performance

a. 60-Cycle Image Display

Without color filters the smear of a moving image is objectionable on the screen of this tube. With a green filter (Roscolene #871) the P1 phosphor is well separated and a pleasing image is generated. The display appears brighter than the blue component of the P7 phosphor because the eye is more sensitive in the green portion of the color spectrum. The smear resulting from image motion is almost imperceptible. The quality of the display is very similar to the P7, perhaps slightly better. No flicker was detected at this scanning rate.

b. 10-Cycle Image Display

Without filters the flicker in this display is very objectionable. With a deep red filter (Kodak Wratten #25) the improvement in the image was dramatic. The flicker is reduced to a point where it is no longer detectable by a casual observer. The eye readily assimilated to the red image. The smear of a moving image was tolerable. However, the brightness of the red display was deemed insufficient and an orange filter was tested. With the orange filter (Kodak Wratten #23A) the brightness significantly improved at the cost of a small increase in apparent flicker.

The type-E phosphor performance with either a red or orange filter, was superior in every respect to the performance of the P7 phosphor at the 10-cycle frame rate.

c. 0.625 Cycle Image Display

At this frame rate the image appeared best without any color filters. With an orange or red filter the luminance decayed very rapidly and the image faded in less than one frame. Consequently only a portion of the image could be seen at any one instant of time. The persistence drop-off of the Type-E phosphor after 100 milliseconds is much more rapid than is indicated in figure 6-3. While this improves the smear performance at the 10-cycle rate, the performance at the 0.625 cycle rate is degraded. The major contribution to the luminance of the screen one second after excitation is made by the green P1 component. This component permits viewing of the full image without filter, but at the cost of the glare eminating from the writing line flash.

At the very slow scanning rate of 0.625 cycles per second the performance of the P7 phosphor was clearly superior to the P1 and Type-E mixture.

3. Phosphor Life

The half brightness life of a phosphor is directly dependent on beam current and the area of display. The life factor of a phosphor is stated in coulombs per centimeter squared. P1 phosphor has a life factor of 100, while P7 is 10 and type is 0.1. This means P1 will last 10 times longer than P7 and 1000 times longer than type E.

Assuming a beam current of 20 μa evenly distributed over the CRT screen size of 4.8 inches by 3.6 inches a type E phosphor will have the following life time:

$$\text{Life Time} = \frac{(0.1\ \text{coulombs/cm}^2)\ (4.8\ \text{in.})\ (3.6\ \text{in.})}{20 \times 10^{-6}\ \text{amp}} \frac{(2.54\ \text{cm})^2}{(\text{in.})^2} \frac{(1\ \text{hr.})}{(3600\ \text{sec})}$$

Life Time = 157 hours

Therefore a P7 phosphor with a life factor of 100 times type E will last 15,700 hours at the 20-microamp beam current.

4. Recommended Phosphor for the Video Monitor

The performance of the P1 - Type-E mixture screen was superior at the 60-cycle and 10-cycle image display. However, the screen display quality at the 0.625 cycle image display is poor. Furthermore, the half brightness life of the Type-E phosphor, at the present state of development, is only 150 hours at 20 microamps of beam current. This characteristic would require periodic replacement of the CRT for prolonged use of the Video Monitor equipment. Therefore, unless the display quality performance requirements can be lowered for the 0.625 cycle image display the mixture of P1 and Type-E is not suitable to the spacecraft application.

The performance of the P7 phosphor is only slightly poorer at the 60-cycle and 10-cycle display rate, and is quite satisfactory at the 0.625 cycle rate. The P7 phosphor provides a useful image at all frame rates with adequate brightness, low flicker, low image motion smear, good image quality, good contrast and viewing ease. The half brightness life of the P7 phosphor is 15,000 hours at 20 microamps of beam current. The P7 phosphor meets the wide range of the display requirements of the spacecraft and is therefore recommended for use in the Video Monitor.

D. QUANTITATIVE RESULTS

The following tables are data taken on two experimental tubes with P7 and Type E-P1 phosphors. The P7 phosphor has a blue fluorescence and a yellow phosphorescence, while the E-P1 has a green phosphoresence and a orange-red phosphorescence. Various optical filters were used to separate the two components.

Data was taken at the three frame rates, 60, 10, and 0.625 cycles per second with a resolution and a gray scale pattern supplied by a Video Signal Generator. Off-the-air live TV programs were also used. The ambient lighting level in all cases was 1.5 foot-lamberts measured on a Spectra brightness spot meter.

Resolution measurements were taken at the 0.625 cycle rate on both tubes. The resolution frequency on the P7 tube was $\frac{1}{2.3}$ μsec at 20 μa of beam current. This corresponds to a resolution of 980 lines. On the type E-P1 tube the resolution frequency was $\frac{1}{4.0}$ μsec at 20 μa of beam current. This corresponds to 565 lines. This resolution is about half of what the P7 was because the raster size was reduced by a factor of two. The raster size was smaller due to the fact that this tube is a round 5-inch tube used only for the phosphor evaluation tests and has a low deflection sensitivity. The resolution measured was limited by modulation on the deflection sweeps and not indicative of the maximum resolution that can be obtained in the final system.

Gray scale measurements at different beam currents were taken on the 10 and 0.625 rate. The data shows that at least six shades of gray were displayed, in some cases seven. The number of gray shades that can be displayed was limited by the gamma characteristics of the CRT which is greater than unity. A linear staircase waveform was used to test the Video Monitor's gray scale capability. However in the final over-all system with a vidicon camera, which has a gamma less than unity, the combined system will display a greater number of gray shades.

Contrast ratios were measured at different beam currents on all frame rates. The data shows contrast ratios varying from 97 percent at 60 cycles without a filter on the P7 phosphor to 50 percent at the 0.625 cycle rate. The contrast ratios in some cases were low because of the background light reflecting off of the optical filters. In the final system, the filters wll have a special non-reflecting coating which will improve the contrast ratio.

TABLE 6-1
EXPERIMENTAL DISPLAY DATA

60 Cycles - Ambient 1.5 Ft. L

P7 Phosphor

$50\mu a$ I_b (Roscolene #856 Light Blue Filter)

Black	0.2 ft. L
White	0.9 ft. L

$100\mu a$ I_b

Black	0.3 ft. L
White	1.0 ft. L

$50\mu a$ I_b (#65A Wratten Filter)

Black	0.25 ft. L
White	1.3 ft. L

$100\mu a$ I_b

Black	0.3 ft. L
White	1.5 ft. L

$100\mu a$ I_b w/o filters

Black	1.6 ft. L
White	11.0 ft. L

Type-P1 Phosphor

$50\mu a$ I_b (Roscolene #871 Light Green Filter)

Black	6.0 ft. L
White	30.0 ft. L

$100\mu a$ I_b

Black	9.0 ft. L
White	45 ft. L

TABLE 6-1 (Cont.)
EXPERIMENTAL DISPLAY DATA

10 Cycles Ambient 1.5 Ft. L
Resolution Pattern

P7				Type E-P1			
Roscolene #813 Light Amber Light		Roscolene #806 Medium Lemon Filter		Red Wratten #25		Orange Wratten #23A	
$I_b = 100 \mu a$				$I_b = 100 \mu a$			
Black	1.0 FL	Black	1.5 FL	Black	0.25 FL	Black	0.6 FL
White	8.8 FL	White	16. FL	White	2.2 FL	White	5.3 FL
$I_b = 80 \mu a$							
Black	0.9 FL	Black	1.5 FL				
White	8.0 FL	White	15. FL				
$I_b = 50 \mu a$				$I_b = 50 \mu a$			
Black	0.9 FL	Black	1.3 FL	Black	0.2 FL		
White	6.0 FL	White	11 FL	White	1.5 FL		
$I_b = 30 \mu a$							
Black	0.8 FL	Black	1.3 FL				
White	3.6 FL	White	6.8 FL				
				$I_b = 25 \mu a$			
				Black	0.2 FL	Black	0.3 FL
				White	0.8 FL	White	1.9 FL

TABLE 6-1 (Cont.)
EXPERIMENTAL DISPLAY DATA

0.625 Cycle Ambient 1.5 FL
Resolution Pattern

P7				Type E-P1			
Roscolene #813 Light Amber Filter		Roscolene #806 Medium Lemon Filter		Red Wratten #25		Orange Wratten #23A	
	I_b =	90 μa			I_b =	100 μa	
Black	0.9 FL		1.5 FL	Black	0.3 FL		0.7 FL
White	2.3 FL		3.6 FL	White	0.8 FL		1.0 FL
	10 + FL		10 + FL		2.8 FL		10 + FL
Res. Freq.	3.5 μs	(645 Lines)	3.5 μs				
	I_b =	60 μa			I_b =	50 μa	
Black	1.0 FL		1.6 FL	Black	0.2 FL		0.4 FL
White	2.0 FL		3.5 FL	White	0.7 FL		0.9 FL
	10 + FL		10 + FL		1.6 FL		10 + FL
Res. Freq.	3.5 μs	(645 Lines)	3.5 μs	Res.Freq.	4.5 μs	(500 Lines)	4.5 μs
	I_b =	40 μa					
Black	1.0 FL		1.4 FL				
White	1.8 FL		2.8 FL				
	7.0 FL		10 + FL				
Res. Freq.	2.5 μs	(905 Lines)	2.5 μs				
	I_b =	20 μa			I_b =	20 μa	
Black	0.85 FL		1.3 FL	Black	0.15 FL		0.25 FL
White	1.5 FL		2.4 FL	White	0.4 FL		0.8 FL
	6.5 FL		10 + FL		0.6 FL		2.0 FL
Res. Freq.	2.3 μs	(980 Lines)		Res.Freq	4.0 μs	(565 Lines)	4.0 μs

TABLE 6-1 (Cont.)
EXPERIMENTAL DISPLAY DATA

0.625 Cycles Ambient 1.5 FL
Gray Scale Pattern

P7			Type E-P1	
Roscolene #813 Light Amber Filter		Roscolene #806 Medium Lemon Filter	Orange Wratten #23A	
I_b = 30 μa			I_b = 20 μa	
Black	0.5 FL	1.0 FL	Black	0.35 FL
1	0.8 FL	1.3 FL	1	0.4 FL
2	1.0 FL	1.7 FL	2	0.6 FL
3	1.3 FL	1.9 FL	3	0.8 FL
4	1.5 FL	2.1 FL	4	0.9 FL
5	1.7 FL	2.4 FL	5	0.95 FL
White	1.7 FL	2.4 FL	White	1.0 FL
I_b = 40 μa			I_b = 40 μa	
Black	0.6 FL	1.0 FL	Black	0.2 FL
1	0.8 FL	1.3 FL	1	0.45 FL
2	1.3 FL	1.9 FL	2	0.8 FL
3	1.5 FL	2.3 FL	3	0.9 FL
4	1.7 FL	2.5 FL	4	1.0 FL
5	1.9 FL	2.8 FL	5	1.1 FL
White	1.9 FL	2.8 FL	White	1.1 FL

All Values are Minimum, Not Peak Values

TABLE 6-1 (Cont.)
EXPERIMENTAL DISPLAY DATA

10 Cycles Ambient 1.5 FL
Gray Scale Pattern

	P7		TYPE E-P1		
	Roscolene #813 Light Amber Filter	Roscolene #806 Medium Lemon Filter		Red Wratten #25	Orange Wratten #23A
	I_b = 60 μa			I_b = 80 μa	
Black	0.8 FL	1.5 FL	Black		0.4 FL
1	1.4 FL	2.6 FL	1		0.9 FL
2	3.2 FL	5.8 FL	2		2.3 FL
3	4.5 FL	8.5 FL	3		3.3 FL
4	6.0 FL	10.0 FL	4		4.3 FL
5	7.0 FL	11.0 FL	5		5.1 FL
White	6.5 FL	10.5 FL	White		6.0 FL
	I_b = 40 μa			I_b = 40 μa	
Black	0.9 FL	1.5 FL	Black	0.35 FL	0.35 FL
1	1.7 FL	3.0 FL	1	0.55 FL	0.8 FL
2	2.9 FL	5.2 FL	2	0.9 FL	1.6 FL
3	3.8 FL	7.0 FL	3	1.1 FL	2.2 FL
4	5.0 FL	9.1 FL	4	1.4 FL	2.8 FL
5	5.9 FL	10.3 FL	5	1.7 FL	3.4 FL
White	5.8 FL	9.9 FL	White	1.8 FL	3.9 FL
	I_b = 20 μa			I_b = 20 μa	
Black	0.8 FL	1.5 FL	Black		0.4 FL
1	1.3 FL	2.5 FL	1		0.5 FL
2	1.8 FL	3.5 FL	2		0.9 FL
3	2.4 FL	4.3 FL	3		1.2 FL
4	3.0 FL	5.3 FL	4		1.7 FL
5	3.5 FL	6.1 FL	5		2.0 FL
White	3.4 FL	5.9 FL	White		2.5 FL

APPENDIX I

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