A COMPACT MULTICOLOR DISPLAY FOR VECTORCARDIOGRAMS

by

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I wish to extend my thanks to all my associates at ITT for their encouragement and particularly to

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CHAPTER 1

INTRODUCTION

Vectorcardiography is not a new presentation technique for displaying the electrical activity of the heart. However, it has not achieved widespread use in the past due in part to a lack of suitable display devices. Other researchers have devised various schemes for presenting the vectorcardiogram in three-dimensional format. These systems are generally quite complex and costly, and in many cases do not provide real time information display but depend on data analysis and plotting off of prerecorded heart signals.

It would appear that the best approach to providing a real time three dimensional display of the heart vector information is a display making use of a color cathode ray tube presentation. Two types of color displays are in common use today. The first is the common color matrix display of the type that is used in color television receivers. The second uses a penetration phosphor in the display tube, producing different colors as the depth of penetration of the electron beam is varied by changing the final accelerating potential applied to the display tube. Both of these approaches are complex and generally require a computer to process the incoming information and control the display. Unless a suitable computer can be dedicated to the task of processing the vectorcardiographic information this approach does not fill the need for a real time display.

The display to be presented here is a relatively simple, easy to operate, low cost analog display which presents a vectorcardiographic signal on a multicolor display in either the standard two axis formats or a quasi three dimensional format for increased ease of interpretation. This display depends on a display tube which uses special phosphors to provide a variable spectral output which is dependent on the current density of the electron beam.

CHAPTER 2

BACKGROUND

2.1 Normal Heart Action

Normal heart action begins in the sinoatrial node (SA), which is the the pace setter for normal heart action. The excitation resulting from the depolarization of the SA node spreads over the atria at about 1,000 millimeters per second and reaches the atrioventricular (AV) node. The AV node depolarizes at a much slower rate, so that the signal effectively transverses this node at 200 millimeters per second. The excitation wave then travels down the right and left bundle branches (or bundles of Hiss) to the perkunje system which spreads the excitation wave over the indocardial surface of the ventricals at a rate of 4,000 millimeters per second. The depolarization of the ventrical muscles begins from the endocardium and progresses to the epicardium with the impulse spreading at a rate of 400 millimeters per second. Repolarization of the ventricals occurs from the epicardium to the endocardium. To help visualize the heart activity, reference should be made to Figure 2.1-1 which is a pictorial representation of the human heart.

2.2 Sign Convention

The reference system normally used in vectorcardiography is shown in Figure 2.2-1.[1] The two axis vectorcardiograms are obtained by projecting the heart vector on

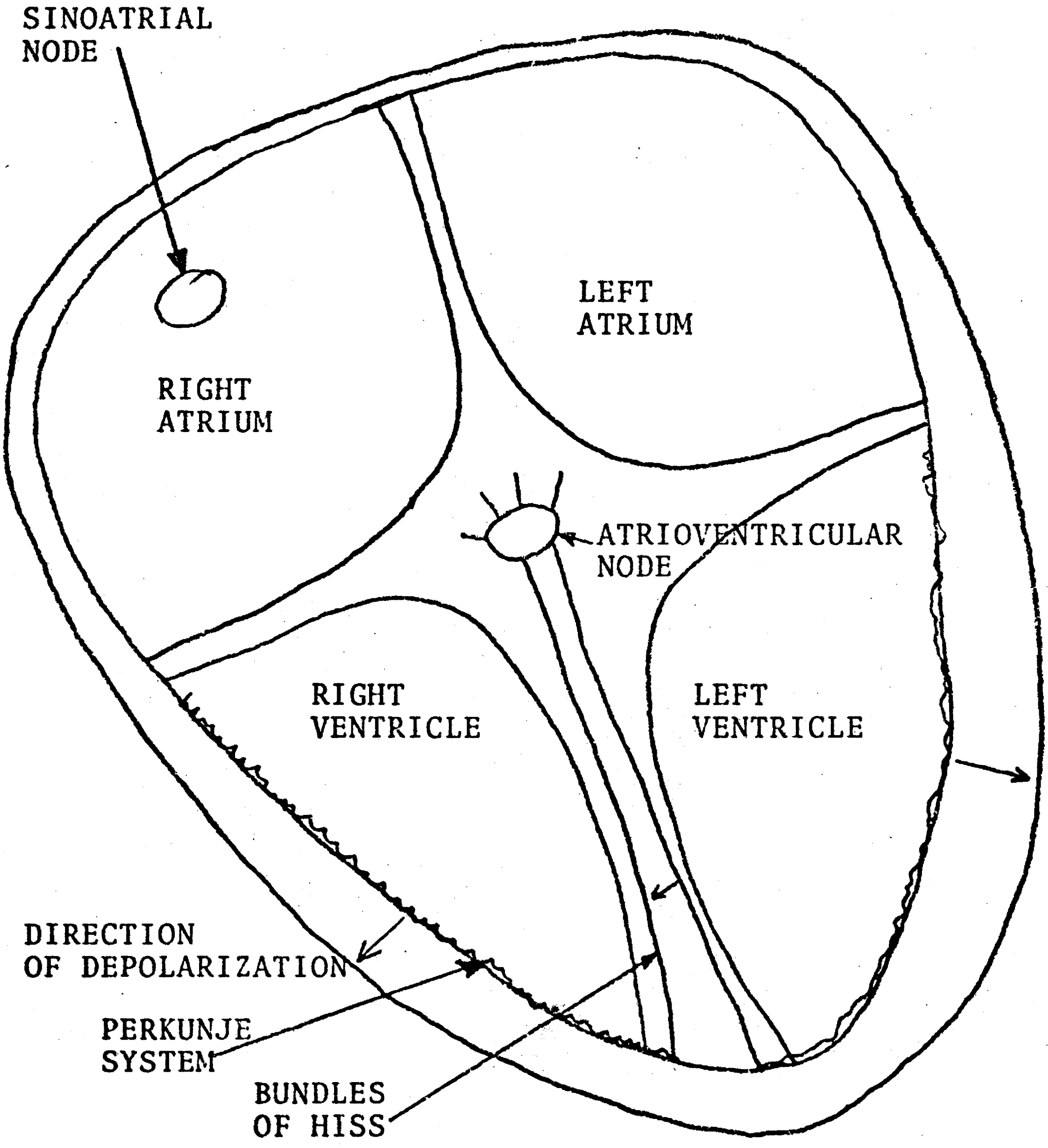


FIGURE 2.1-1 Pictorial diagram of the human heart

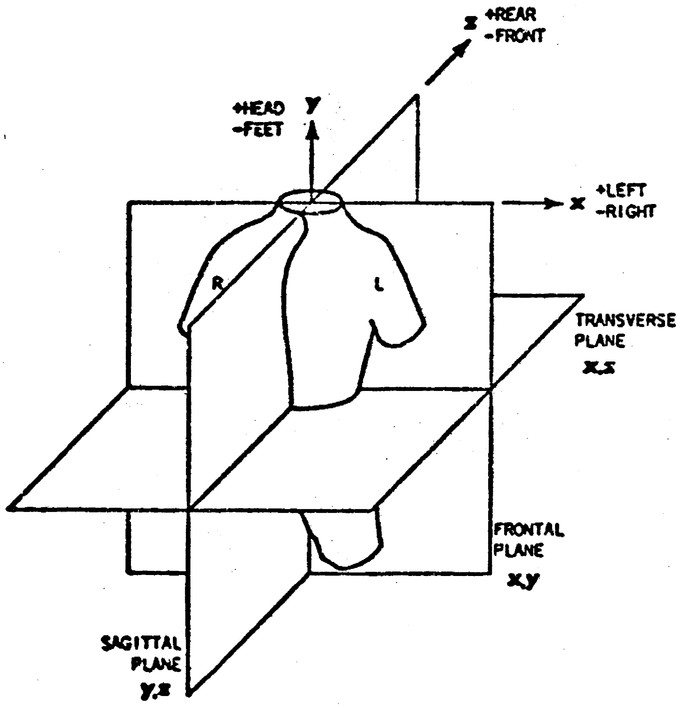


FIGURE 2.2-1 Vectorcardiograph reference system

to the three principle planes shown in this figure. Note that a left handed coordinate system is assumed.

2.3 Vectorcardiographic Displays

Although, the vectorcardiographic concept had existed since the early 1920's relatively little progress was made in this area, prior to World War II, due to the lack of suitable display devices. During and after the Second World War research activity expanded rapidly as a result of the ready availability of oscillographic display devices developed during the war. Much progress has been made over the last three decades in the development of vectorcardiographic techniques and presentation equipment. Figure 2.3-1 shows a basic ventorcardiographic display system. This system consists of:

1. An input compensation network to provide corrected X, Y, and Z axis signals from the particular pickup lead system being employed.
2. An X-Y oscilloscope with the necessary input amplifiers to provide a useable signal level to the deflection plates of the oscilloscope.
3. A method of intensity modulating the writing beam of the oscilloscope to provide directional information on the vector presentation.

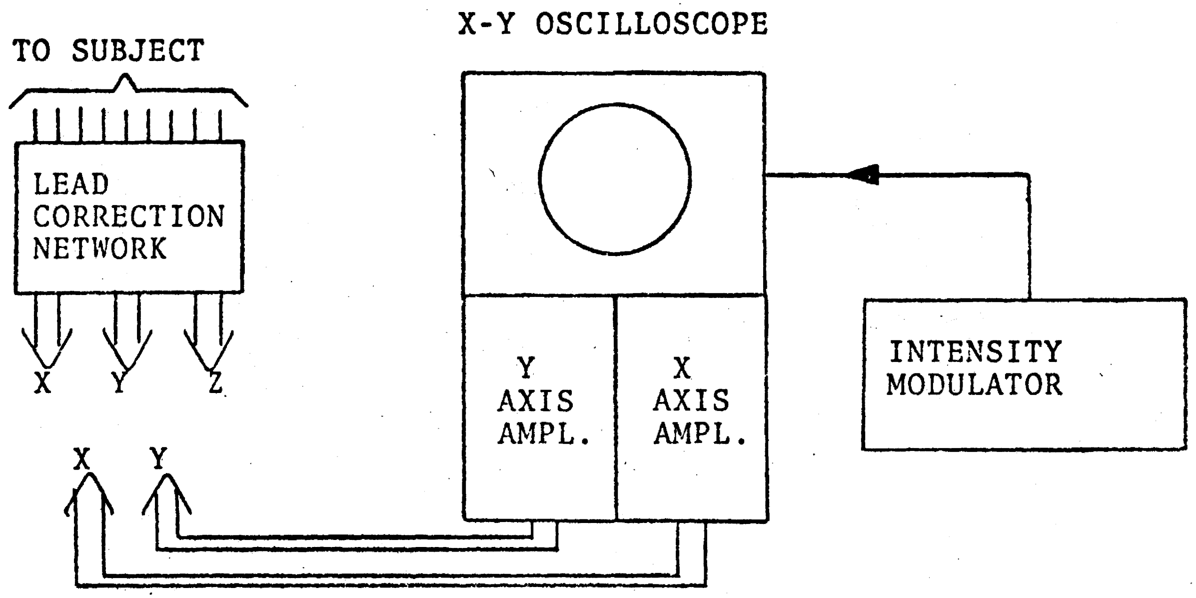


FIGURE 2.3-1 Basic vectorcardiograph display

This display system will provide a two axis presentation of the heart vectors in any one of the three normal planes. This leaves much interpretation to be done by the observer in order to visualize the vector loop in three-space. Various instrumentation schemes have been tried in an attempt to eliminate this difficulty. In one instrument[2], resolvers were used in order to make it possible to view the vector loop in its plane. Another instrument[3] was constructed in which the builders attempted to provide a sterographic display, showing the heart vector in three dimensions. More recently, general purpose computers have been used to process the vectorcardiographic signals and provide an image of the heart loop, in perspective[4]. All of the more sophisticated systems are quite complicated, costly and difficult to use. All of these factors have tended to limit the availability of vectorcardiographic equipment to the doctor.

2.4 Lead System

A number of different lead systems have been proposed for vectorcardiographic use. The most popular of these systems at this time is the Frank lead system[5] shown schematically in Figure 2.4-1. There are seven signal pickup leads plus an eighth ground lead connected to the right leg. The body locations to which these leads are connected are as follows:

I - right midaxilary line in the fourth intercostal space

A - left midaxilary line in the fourth intercostal space

E - anterior midline

M - posterior midline

C - V_3 precordial lead location

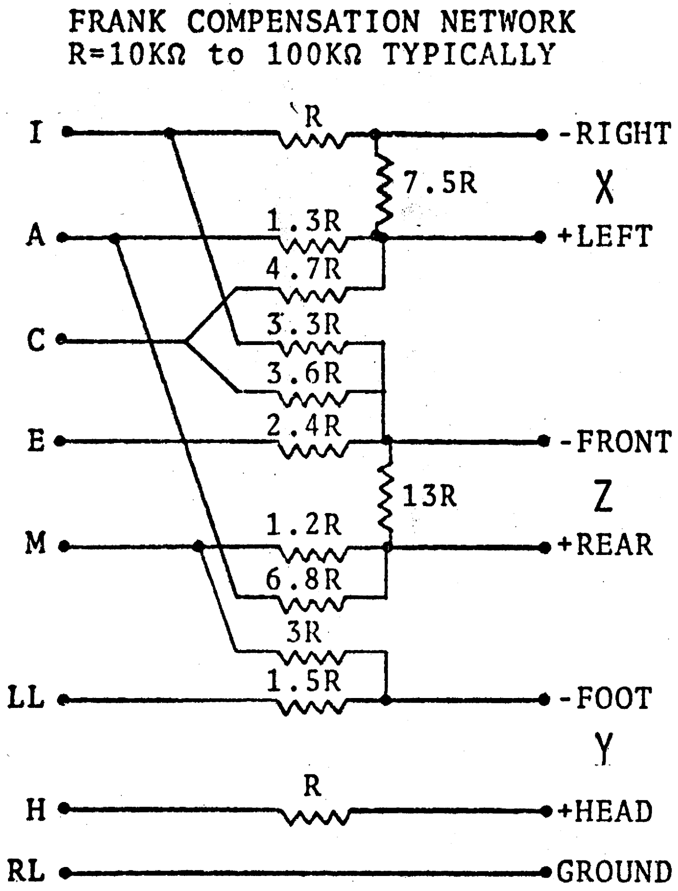
F - left leg

H - back of neck

For practical use the chest leads are often attached to a continuous elastic strap so that they can easily be placed on, or removed from the body. The location of these leads is quite critical and must be maintained within rather close tolerances, from one subject to the next, if usable comparative information is to be obtained. The resistive compensation network for the Frank lead system is also shown in Figure 2.4-1, in normalized units. The value of resistance "R" can be any convenient value but is normally in the range of 5,000 to 10,000 ohms.

2.5 Clinical Use of Vectorcardiography

The vectorcardiography display is particularly helpful in analyzing circulatory problems associated with the heart (such as ischemia, infarct, etc.). It is also very useful in analyzing certain conduction problems (bundle branch block) but is not applicable to the analysis of heart problems resulting in arrhythmia. The general



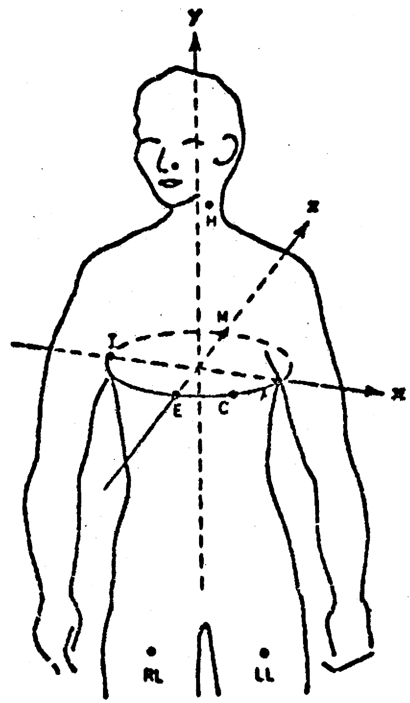


FIGURE 2.4-1 Frank lead system

inavailability of vectorcardiographic equipment and lack of acceptable standards of comparison, for diagnostic use, has resulted in the almost total absence of clinical use of vectorcardiographic techniques[6].

2.6 The Display Tube

The display system makes use of a display tube which employs a screen composed of a mixture of super linear and sublinear phosphors of two different colors (green and red). Figure 2.6-1[7] shows typical characteristics of these phosphors. As the current density of the electron beam is varied from a low level to a high level the display intensity and spectral output will also vary. Color changes from green through yellow and shades of orange to red can be realized by modulating the electron beam intensity.

In this system the electron beam is modulated by varying the voltage on the first grid of the display tube. Shown in Figure 2.6-2[8] on a chromaticity diagram, is the output characteristic of a typical display tube for electron beam current density variation from Ø.Ø1 to 1Ø.Ø microamps per square centimeter.

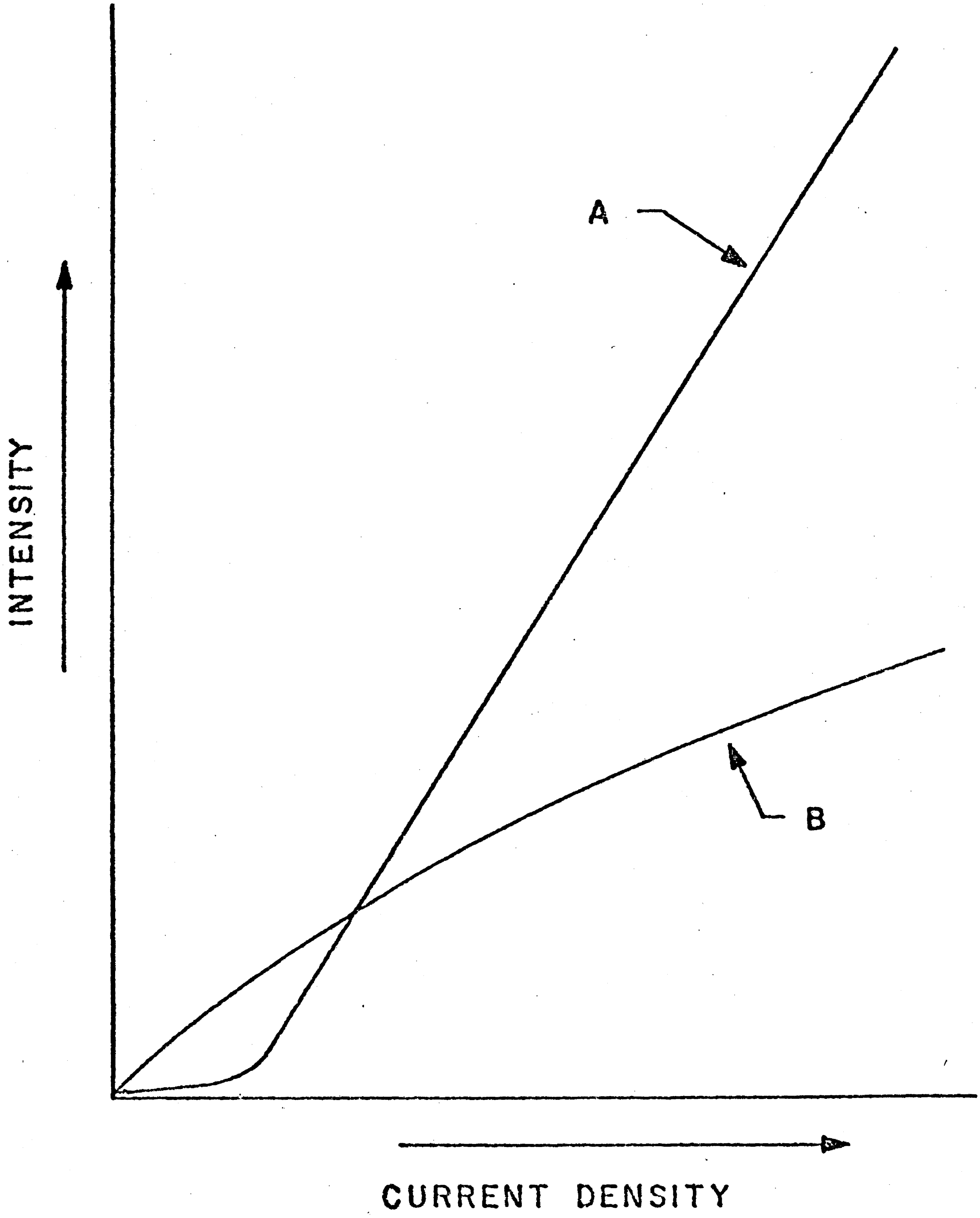


FIGURE 2.6-1 Phosphor characteristics

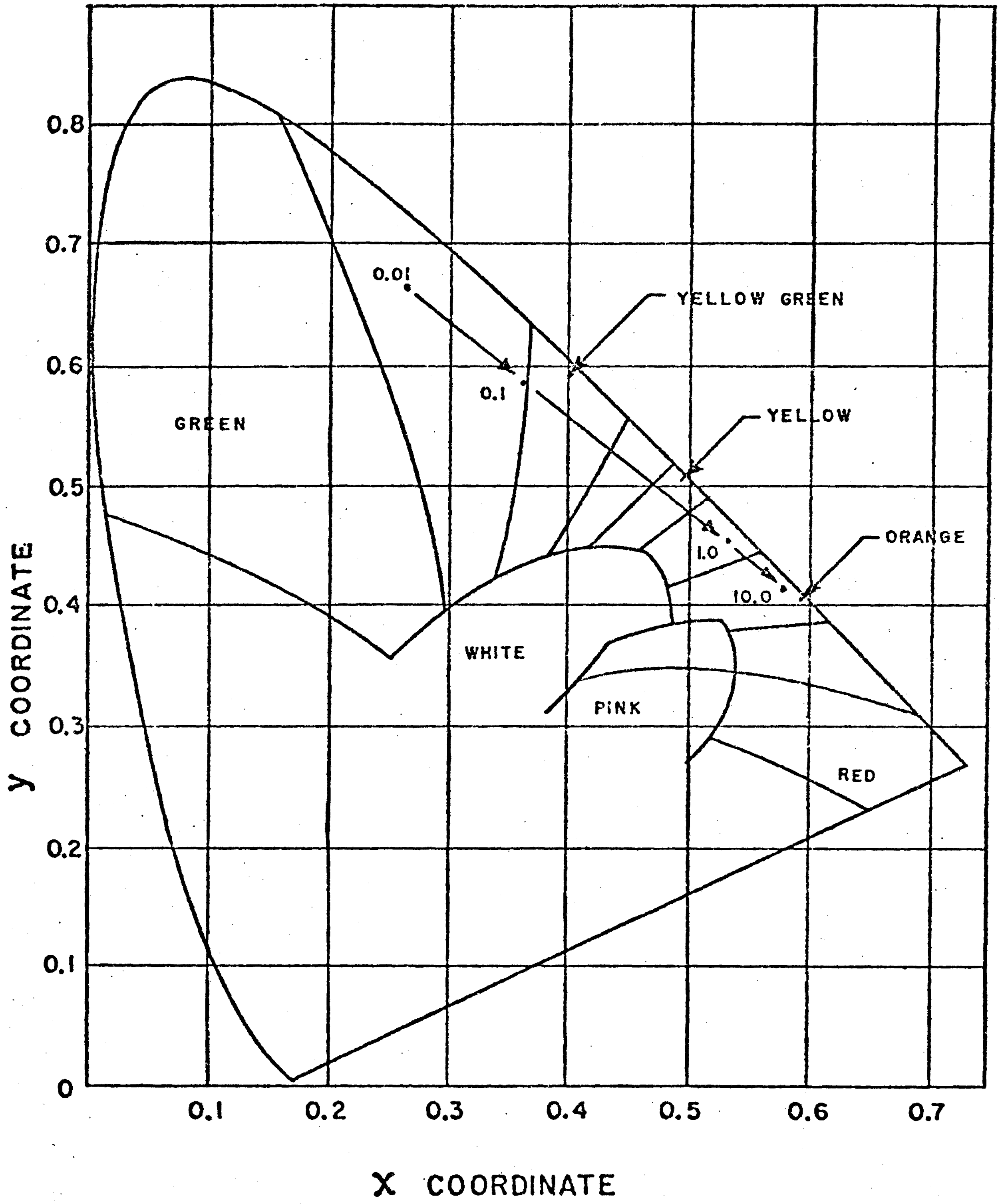


FIGURE 2.6-2 Chromaticity chart

CHAPTER 3

SYSTEM MECHANICAL DESIGN

The preamplifier section with its associated Frank network is constructed in a small (6" wide X 3.5" deep X 2" high) cabinet which can be located near the subject. Thus, the low level signal leads can be maintained at the shortest practical length, minimizing noise pickup. The amplified signals are fed to the display unit through long shielded leads. The power source for the preamplifier is an internal battery pack and was chosen for both safety and convenience.

The remainder of the vectorcardiographic display is contained in a case 8.5" high, 17" wide, and 14" deep. This does not represent the smallest practical enclosure size. A 30% to 40% reduction in volume could be easily achieved.

Most of the electronic circuitry is contained on five plug-in circuit cards. These cards were assembled using a wire with burn off-film insulation. This greatly simplified the wiring of the circuit cards.

A subassembly approach was followed in constructing the display which is made up of five major subassemblies:

1. The front panel with controls.
2. The color modulator board which contains all of the high voltage circuitry associated with color

control of the display.

3. The card rack which contains the bulk of the amplifier and signal processing circuitry.

4,5. Two power supply subassemblies which provide all the power required by the main display unit.

A photograph of the front panel is shown in Figure 3-1 and a photograph showing the major subassemblies is presented in Figure 3-2.

FIGURE 3-1 Photograph of front panel

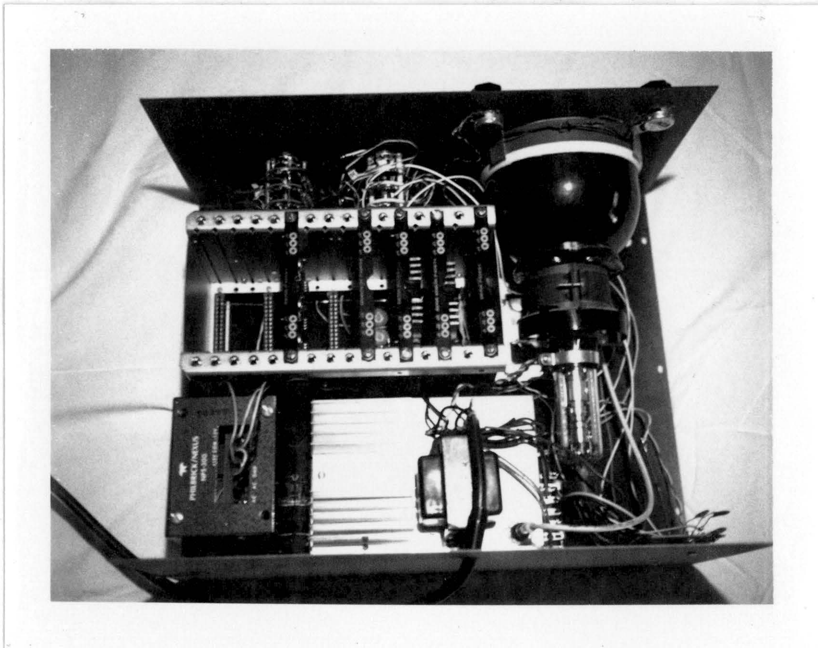


FIGURE 3-2 Photograph of major subassemblies

CHAPTER 4

SYSTEM ELECTRICAL DESCRIPTION

The vector heart signals must be amplified and conditioned for proper presentation on the multicolor display tube of the vectorcardiographic display. The block diagram of a suitable system is shown in Figure 4-1. A Frank eight lead pick-up system is used to pick-off the heart signals from the body surface and correct the potentials to provide a three component Cartesian output which is supplied to the inputs of the three channel preamplifier. The three channels of the preamplifier are identical; each channel consisting of an integrated circuit instrumentation amplifier operating at a voltage gain of 1ØØ. The three information channels then pass through variable gain amplifiers, each with a switch selected gain range of 1 to 1ØØ in a 1-2-5 sequence. From the variable gain stages the signals are passed to the combining network and the zero crossing detectors.

In the combining network (actually a number of switch selected networks) the three axis signals are combined in such a way as to provide a replica of the three axis signal, in perspective, on the two axis display. These combined signals are passed through the buffer amplifier which acts as a summing amplifier with the combining network. The buffer amplifier also acts as a preset variable gain stage to set overall system gain for the two display axes to equal values. The deflection amplifiers act as voltage to current converters to drive the deflection coils.

In order to provide the necessary color changes on the display, as the heart vector moves through the triaxial co-ordinate system, the signals at the output of the variable gain amplifiers are sampled by zero crossing detectors. These zero crossing detectors provide logic output signals which are combined in a logic network to determine the location of the heart vector with respect to the co-ordinate axes. The output of the logic network drives the color modulator which controls the first grid voltage of the cathode ray tube and thus determines the color output of the display, as the phosphor output color is determined by the current density of the impinging electron beam.

The rest of the system consists of a low voltage power supply for the solid state components and a high voltage power supply for the display tube.

A schematic diagram of the entire system is shown in Figure 4-2. The individual sections of the system will be discussed in the following sections of this paper.

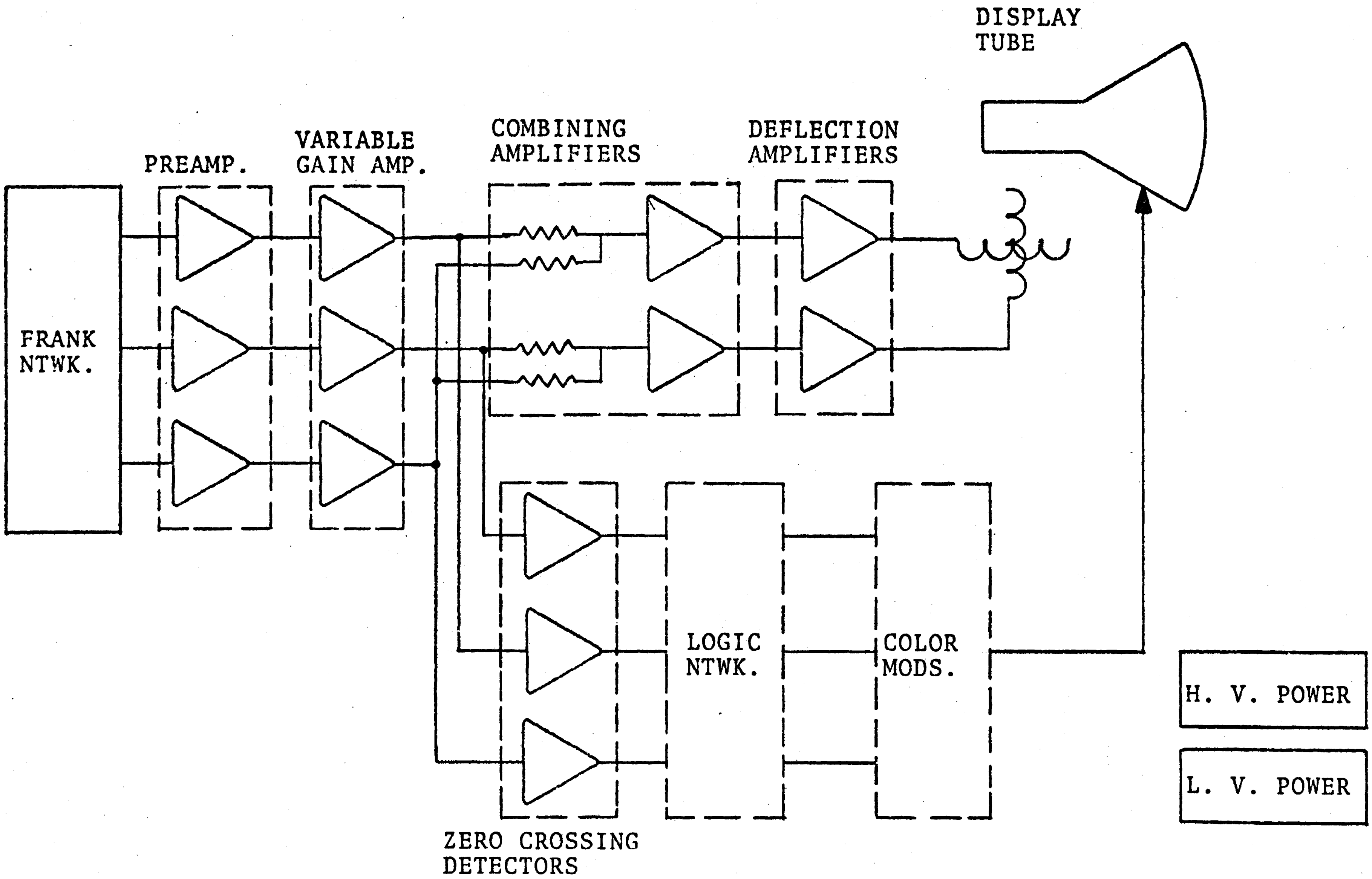


FIGURE 4-1 System block diagram

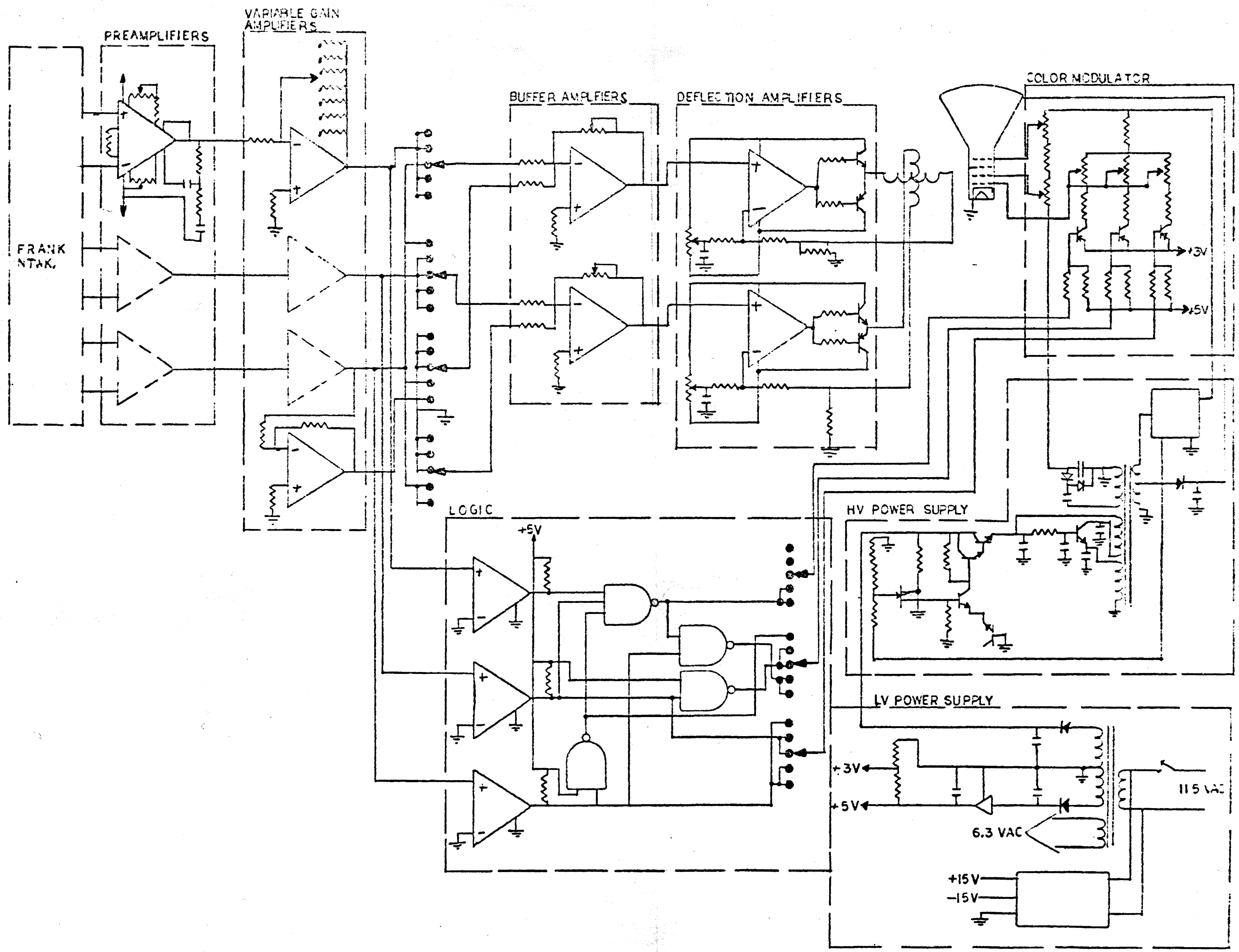


FIGURE 4-2 SYSTEM SCHEMATIC DIAGRAM

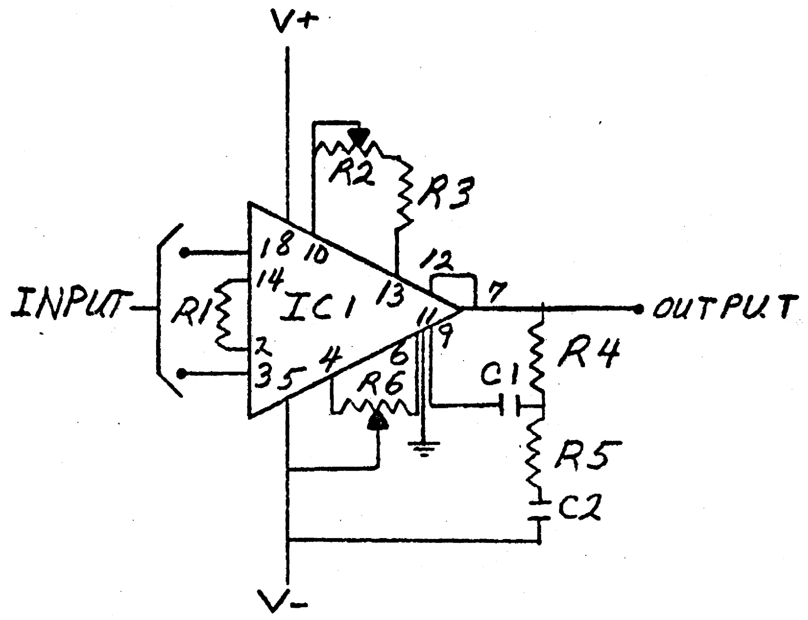
4.1 Preamplifier Section

The heart signals picked off the subject are applied to the Frank network which corrects for inhomogeneities in the body. The outputs of the Frank network are applied to the inputs of the three preamplifier channels. An integrated circuit instrumentation operational amplifier (Analog Divices AD521) is used in this section because of its excellent common mode rejection ratio of 100 dB. The gain of the amplifier state is easily adjusted by setting the value of R1 shown in Figure 4.1-1. Provision is also made for trimming the gain to the exact value desired and for trimming of the input offset voltage. The network consisting of R4, R5, C1 and C2 provide a low pass filter function which can be set up to provide a desired high frequency cutoff. This can be achieved by using the values for R4, R5 and C2 shown in Figure 4.1-1 and determining the value of C1 by using the equation[9]

$$C1 = \frac{1}{3.14X10^5\ (f)} \qquad 4.1\text{-}2$$

where f is the frequency of the desired break point. The amplifiers in this unit are set up for a 50 Hertz cutoff frequency.

Considerable difficulty was encountered in using the circuit recommended by Analog Devices as it resulted in unstable operation when used in the three channel configuration needed in this equipment. After consulting with an



C1 = .068 μf
C2 = 1.0 nf
R1 = 1 KΩ
R2 = 25 KΩ
R3 = 82 KΩ
R4 = 680 Ω
R5 = 330 Ω
R6 = 10 KΩ
IC1 = AD521

FIGURE 4.1-1 Basic preamplifier schematic diagram

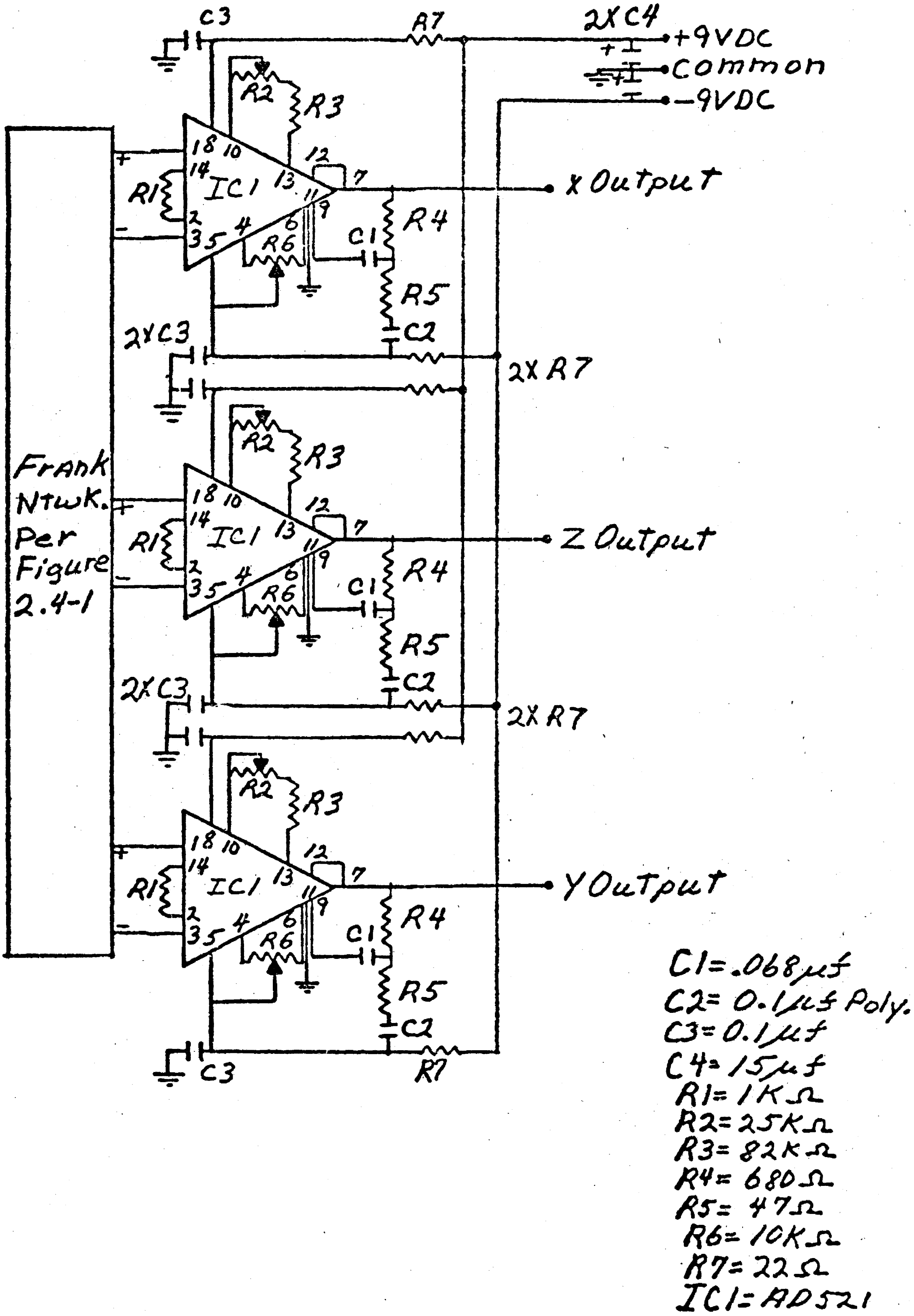


FIGURE 4.1-2 Complete preamplifier schematic diagram

Analog Devices engineer, it was determined that there was a defect in their device. A new configuration, which was recommended by them, was used in the equipment as shown in Figure 4.1-3. This change in combination with the decoupling shown provides stable operation.

4.2 Variable Gain Amplifiers

The variable gain amplifier, one channel of which is shown in Figure 4.2-1, is a standard current summing configuration using a type 741 operational amplifier. The gain of this amplifier is adjustable over a range of 1 to 1ØØ in a 1-2-5 sequence. The circuit impedances have been set at a relatively high level in order to minimize the effect of switch contact resistance. Three of these amplifiers are used in the display with the gain switches ganged on a common shaft to provide simultaneous control of all channels, in order to maintain the proper amplitude relationship between the three vector signals. The gain variation in this amplifier provides an overall sensitivity variation of Ø.1 millivolt/inch to 1Ø millivolts/inch.

The Z channel has an additional inverter which is not present in the other channels. This inverter is used to provide an inverted Z axis signal to the zero crossing detector and combining network, which is necessary for one of the presentation modes. If other presentation modes had been chosen additional inverters in the X and/or Y

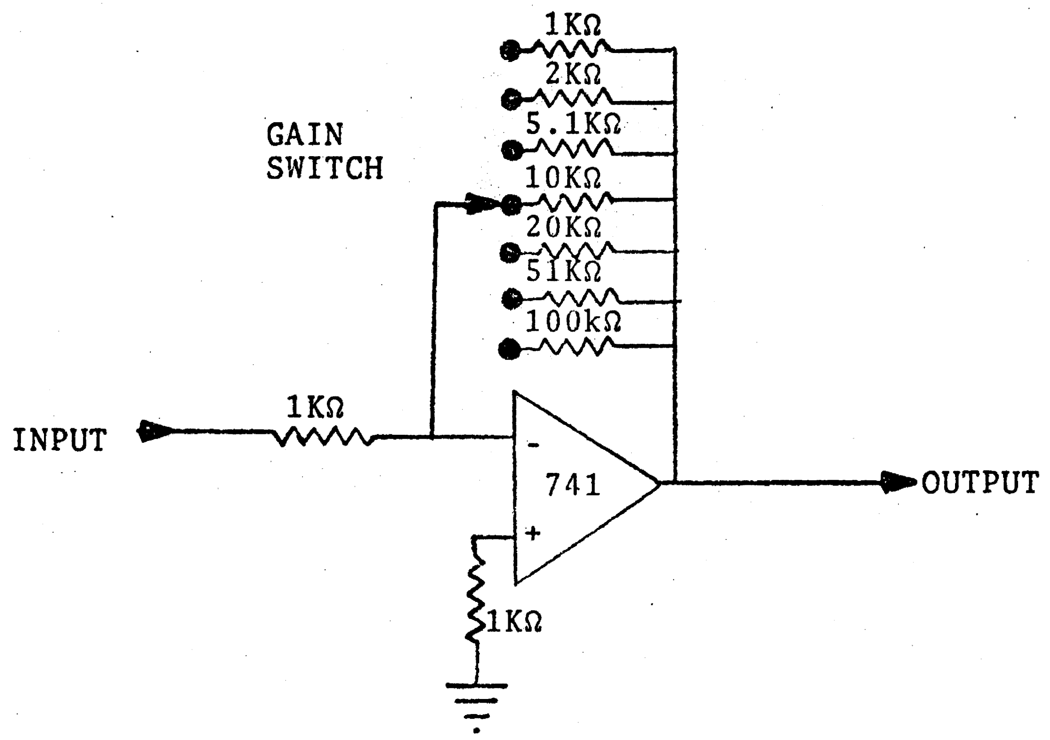


FIGURE 4.2-1 Schematic of variable gain amplifiers

channels might have been needed.

4.3 Buffer Amplifiers and Combining Network

The buffer amplifier is a summing amplifier with a maximum voltage gain of five. The combining network is a resistor network which applies the proper amplitude components of the amplified X, Y, and Z input signals to the X' and Y' display channels to provide the desired form of two or quasi-three dimensional display. An adjustment potentiometer is provided in each display channel to provide a means of adjusting the channels for equal gain. This is necessary in order to compensate for differences in the deflection amplifiers. This adjustment is not accessible in normal operation and is used to set the overall gain of the main display unit.

By proper selection of the input resistors in the summing amplifier it is possible to simulate viewing the heart vector from any vantage point. The axis system chosen to be included in the display is shown in Figure 4.3-1. It provides a simulated view, as if the heart were viewed from above and to the front of the left shoulder. No attempt has been made at providing a view in true perspective since this is extremely difficult. The axis system chosen provides a presentation that is easily interpreted and since the X and Y axes are perpendicular and the Z axis is displayed at a 45° angle with the true Z magnitude appearing in the X-Z and Y-Z planes, it is easy to determine the

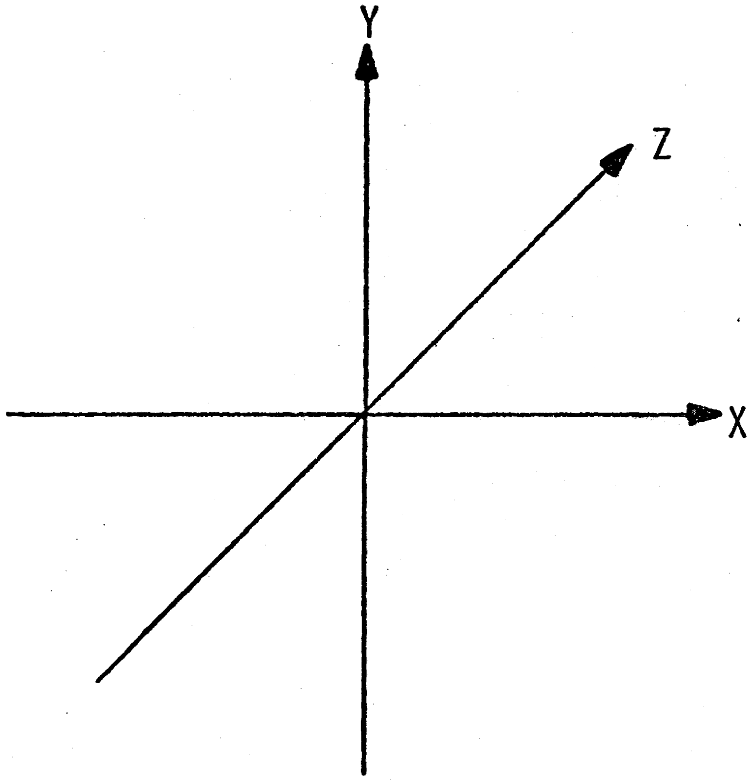


FIGURE 4.3-1 Coordinate system used in display

point at which the heart vector pierces any of the reference planes.

The complete schematic diagram of the buffer amplifier and combining network is shown in Figure 4.3-2. The switch positions of the function switch provide the following functions:

Position 1. Two dimensional view of the heart vector as if viewed from above the subject.

Position 2. Two dimensional view of the heart vector as if viewed from the front of the subject.

Position 3. Two dimensional view of the heart vector as if projected on the sagittal plane and viewed from the left side.

Position 4. Three dimensional view of the heart vector as if viewed from in front of and above the left shoulder.

Position 5. Three dimensional view of the heart vector as if viewed from the lower right rear of the subject.

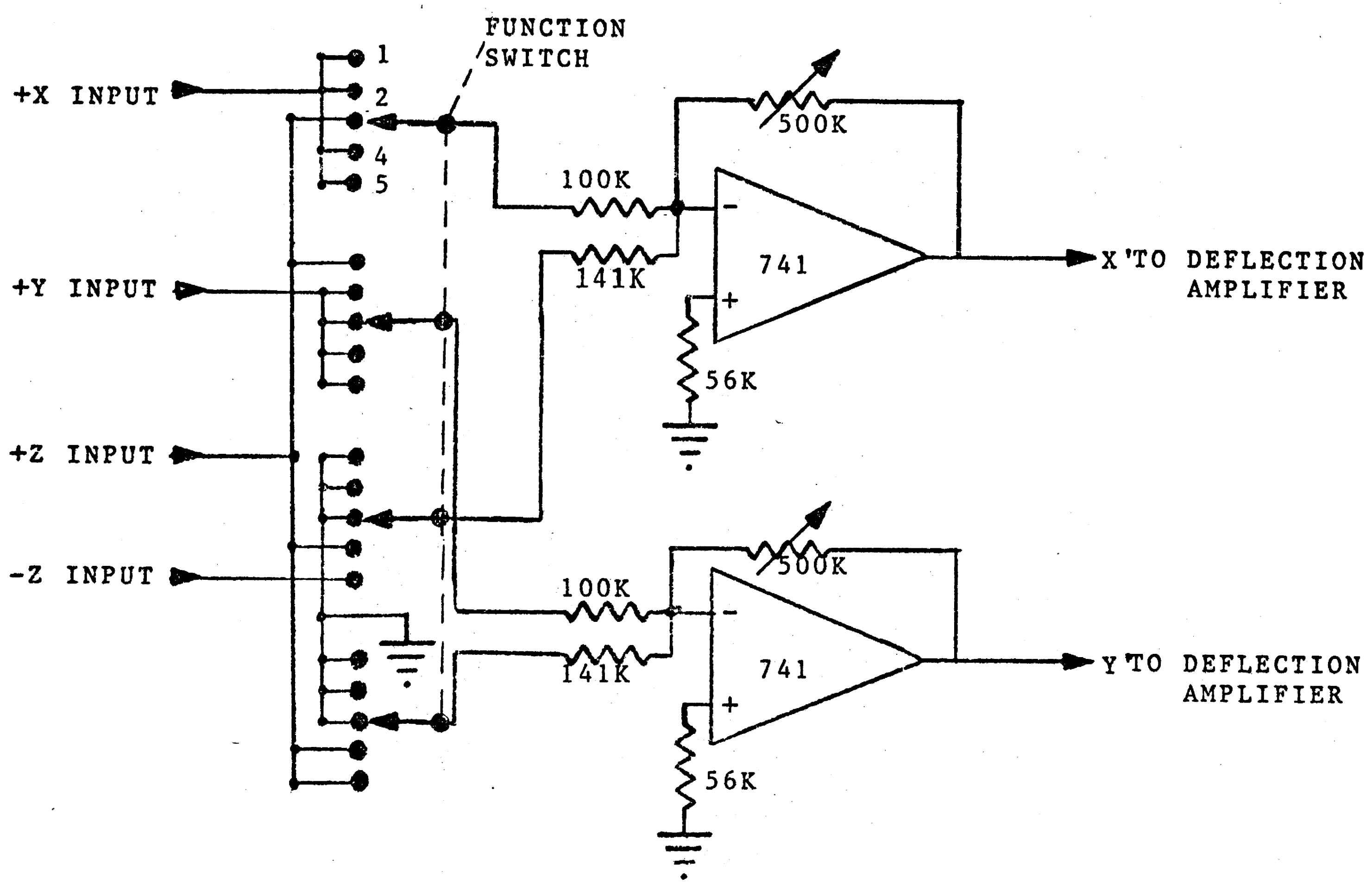


FIGURE 4.3-2 Buffer amplifier and combining network schematic diagram

4.4 Deflection Amplifiers

The deflection amplifier consists of a 741 operational amplifier followed by a complementary output stage which provides the current gain necessary to drive the deflection coil. Current sensing is used at the output and voltage sensing is used at the input so that the stage acts as a voltage to current converter see(Figure 4.4-1).

To consider the operation of the deflection amplifier refer to Figure 4.4-2 in which the operational amplifier and power driver have been lumped together. For the purpose of centering the electron beam on the display a variable potential is applied to the amplifier through R1. If the noninverting input is considered to be at zero volts ($V_{i2}=0$) it can be seen that the amplifier acts as an inverting amplifier with a gain of one, so that

$$V_s \approx -V_{i1} R2G1 \qquad 4.4\text{-}3$$

or

$$I_L \approx -V_{i1} R2G1G3 \qquad 4.4\text{-}4$$

If the inverting input is considered to be held constant the amplifier takes on the configuration of a noninverting amplifier with a voltage gain of two so that

$$V_s \approx V_{i2}(1+R2G1) \qquad 4.4\text{-}5$$

or

$$I_L \approx V_{i2}(1+R2G1))G3 \qquad 4.4\text{-}6$$

It is apparent that the overall gain of the system can be varied easily by adjusting either R2 or R3. Since the

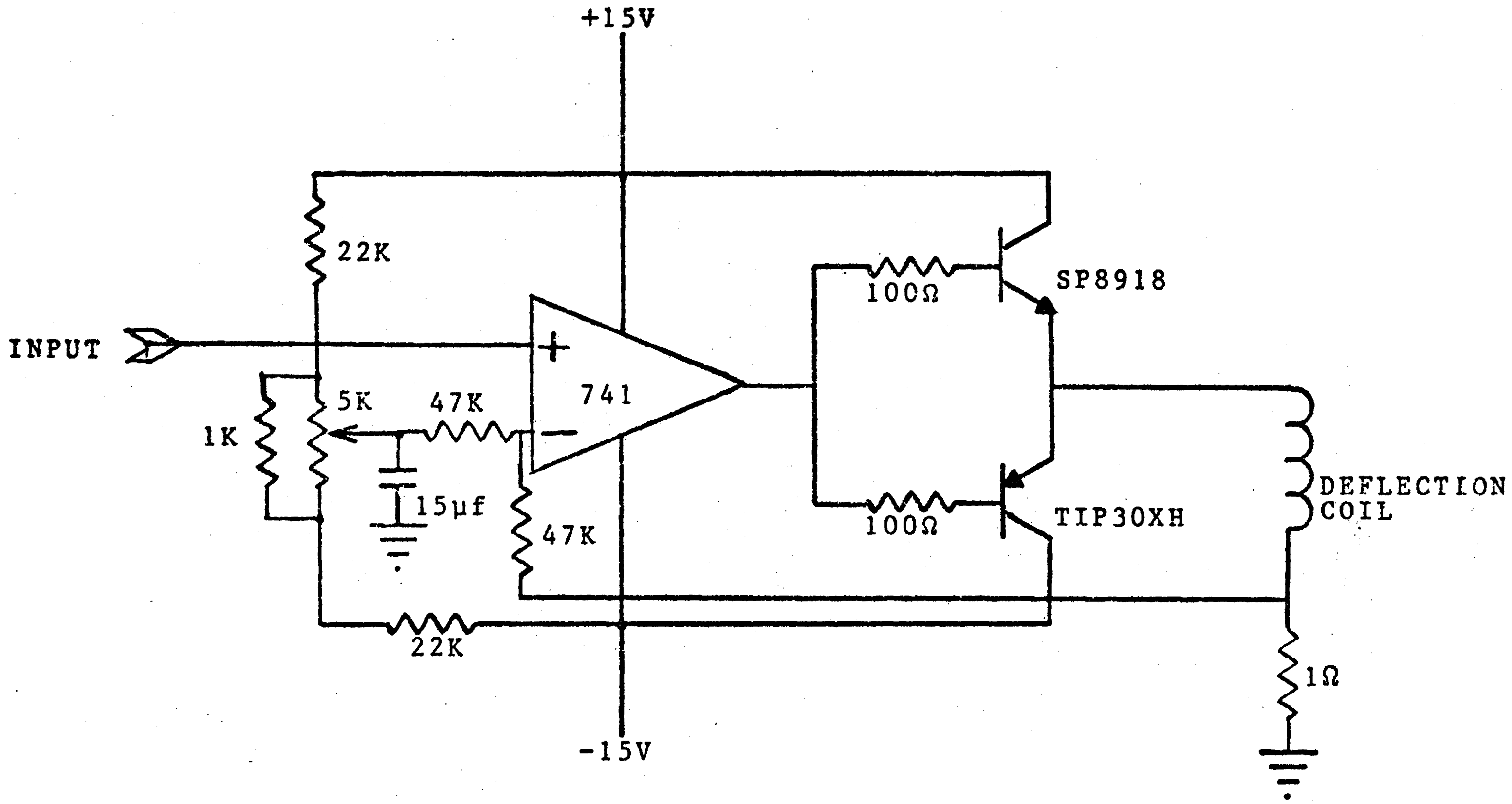


FIGURE 4.4-1 Deflection amplifier schematic diagram

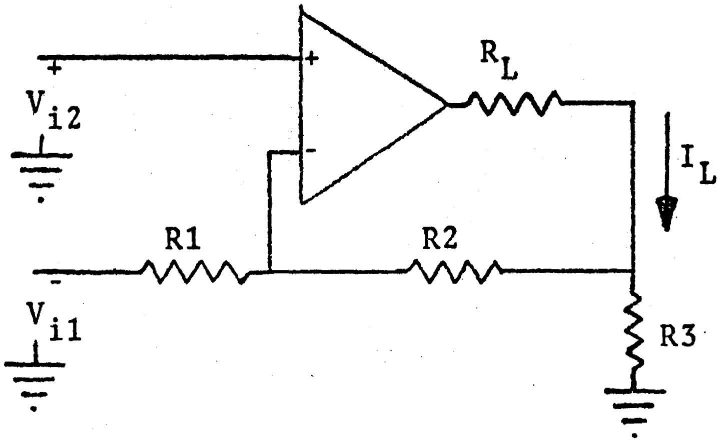


FIGURE 4.4-2 Simplified deflection amplifier diagram

circuit has no nonlinear elements in normal operation it is possible to apply the superposition principle in order to find the output due to both inputs which is the sum of the equations 4.4-4 and 4.4-6 or

$$I_L \approx -(V_{i1}R2G1+V_{i2}(1+R2G1))G3 \qquad 4.4\text{-}7$$

The deflection yoke is a standard commercial unit (Thordason Y 49) which provides a horizontal sensitivity which is about twice the vertical sensitivity. This disparity could be corrected by varying R2 or R3 but in order to maintain interchangeability the two deflection amplifiers are made identical and the buffer amplifiers are adjusted to equalize the gain in the two deflection amplifier channels.

4.5 Zero Crossing Detectors and Logic

The color output of the display is controlled by this circuit. The zero crossing detectors (311 comparitors) determine the polarity of the signals on the input axes. The logic outputs from the zero crossing detectors are processed in the logic section which drives the color modulators. The logic section determines which segments of the vectorcardiographic signal appear in a given color. Figure 4.5-1 shows the complete zero crossing detector and color logic section. The switch sections shown are ganged with the function switch discussed in Section 4.3 so that the displayed colors are changed to suit the information being displayed. The color relations are as follows:

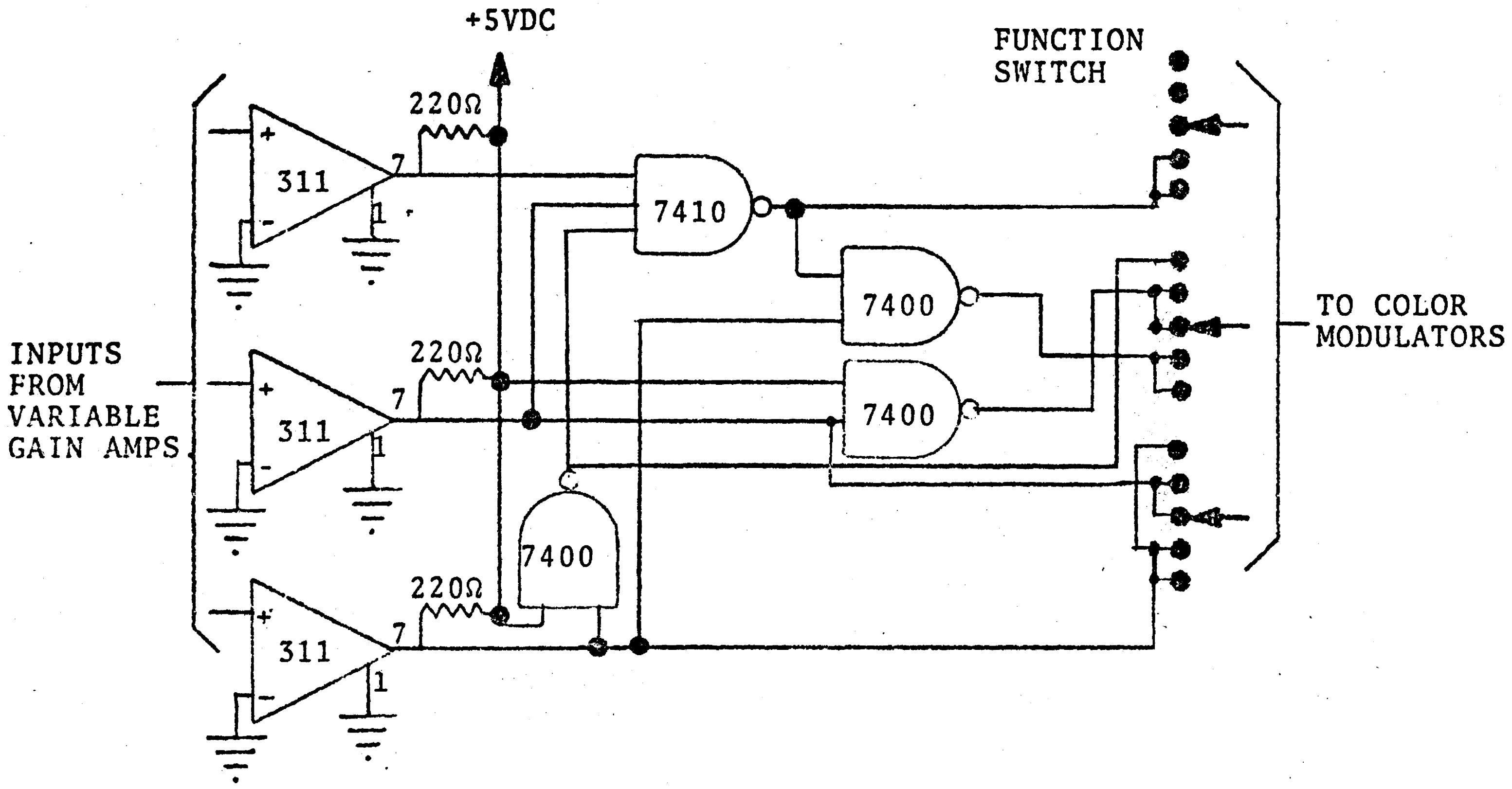


FIGURE 4.5-1 Schematic of zero crossing detectors and logic network

Position 1. The color is changed as the vertical signal (Z) varies above and below the horizontal axis (X).

Position 2. The color is changed as the vertical signal (Y) varies above the below the horizontal axis (X).

Position 3. The color is changed as the vertical signal (Y) varies above the below the horizontal axis (Z).

Position 4. The color is varied as the vector signal moves through the three axis coordinate system.

Octant 1 is one color, octants 2-3-6-7 are a second color and octants 4-5-8 are a third color.

Position 5. The same as position 4.

The color relationships of the display can be easily changed by a redesign of the logic network.

4.6 Cathode Ray Tube and Color Drive

The cathode ray tube (CRT) control and color drive circuits are shown in Figure 4.6-1. The CRT bias conditions shown on the drawing were determined by operational tests. The only unusual feature in this circuit is the color drive circuitry. The first grid of the CRT must be biased to at least -58.4 volts for cutoff and brought into a range of -58 to -38 volts to effect a green-yellow-

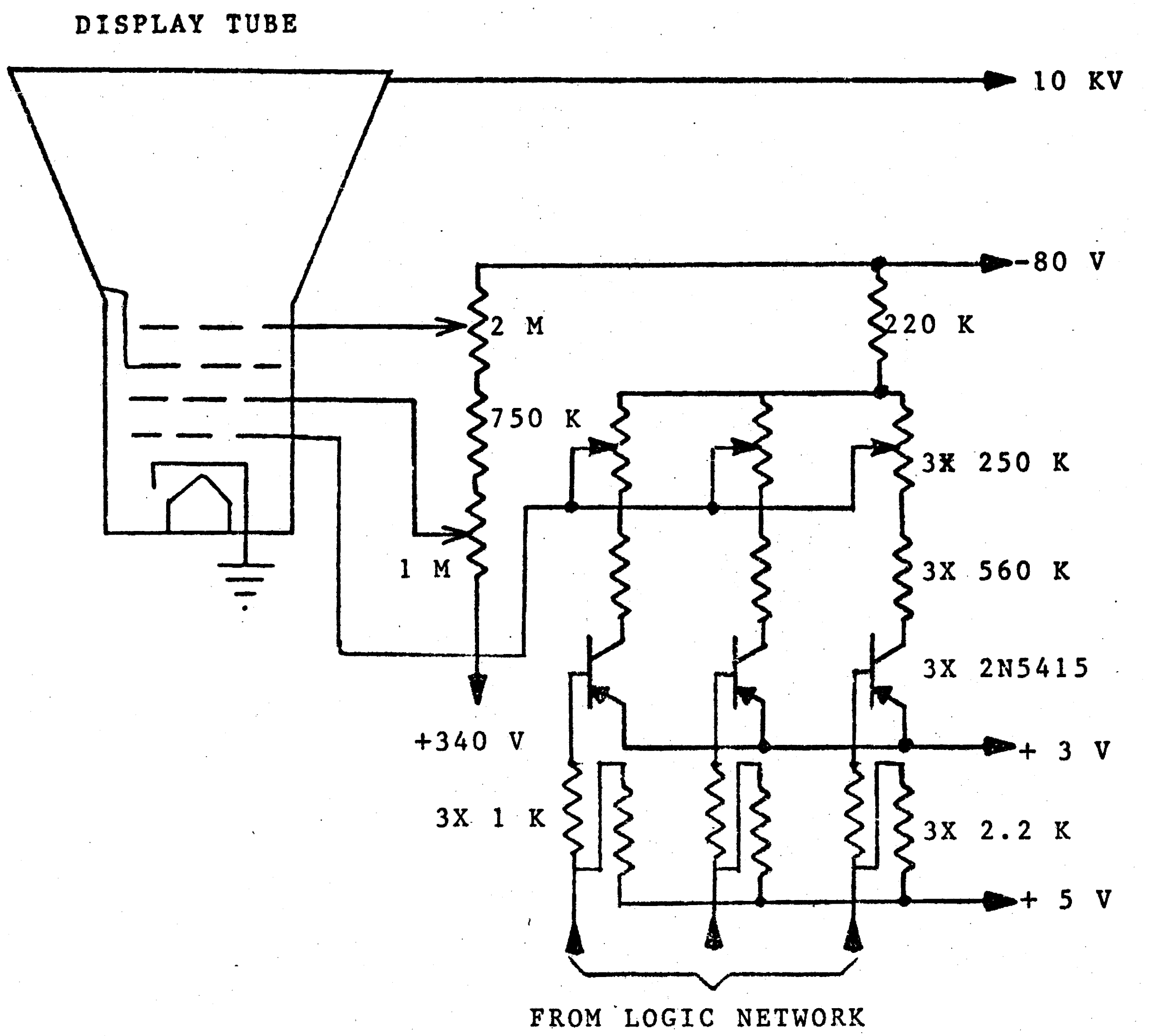


FIGURE 4.6-1 Cathode ray tube control and color drive circuitry

orange color change. Each of the color drive transistor bias networks can be adjusted over this range. A 0 to 5V logic signal is applied to each color drive transistor, as determined by the logic network. A 0 logic input turns on the drive transistor to which it is applied, generating a particular color as determined by the setting of the bias potentiometer.

4.7 Power Supplies

The high voltages necessary for proper operation of the video display portion of the vectorcardiographic display are provided by a regulated blocking oscillator power supply shown in Figure 4.7-1. The blocking oscillator is designed around a standard television flyback transformer. The flyback transformer drives three rectifier-filter networks to provide -85 VDC, +340 VDC and +10,000-VDC. A voltage tripler is used to develop the +10,000 VDC and also provides, from the first tripler stage, the feedback signal for the regulator. The feedback signal is applied to a source follower Q1 which drives the voltage comparitor Q2 which in turn drives the series pass Darlington pair Q3, Q4. The Darlington pair controls the input voltage to the blocking oscillator, completing the regulator negative control loop.

The low voltage power supplies provide power to the linear integrated circuits, digital integrated circuits and to the high voltage power supply. The power for the

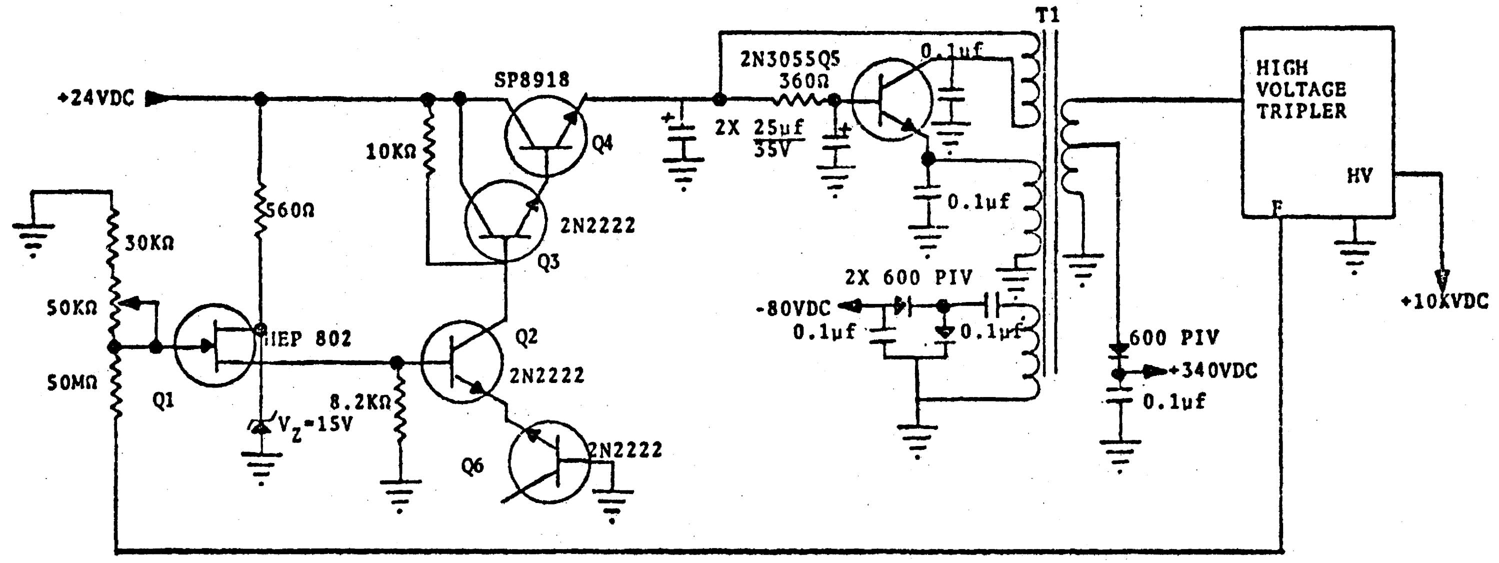


FIGURE 4.7-1 Diagram of high voltage power supply

linear integrated circuits is provided by a Philbrick-Nexus Model NP5-300 power supply at a potential of ± 15 VDC. The logic power supply was built up and employs a LM 3Ø9-K integrated regulator to provide a stable 5 volt power level. The power source for the high voltage supply is filtered but unregulated at approximately 24 VDC.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The system, as presented, does perform the function for which it was designed. It does provide an easily interpreted quasi-three dimensional display of the heart vector in real time. The overall complexity of the system is about comparable to that of an ordinary oscilloscope used in instrument service work. This relative simplicity of design is made possibly by the ability to color modulate the display tube by simply changing the electron beam current density. This approach offers a considerable savings in circuit complexity over either the color matrix type display (used in color television) or a display using penetration phosphors that requires a rapidly variable high voltage supply and a deflection system capable of correcting for deflection factor variations caused by the variation in high voltage.

The only apparent problem encountered in employing the display tube was that of phosphor damage caused by excessive electron beam current. The green phosphor (super linear) can be relatively easily damaged by excessive beam current. I am not aware of any advances in phosphor technology that would eliminate this problem, at this time.

The only serious design problem encountered was that mentioned in section 4.1 involving stability problems with the Analog Devices AD521 instrumentation operational amplifiers.

I tried to use 741 operational amplifiers for the zero crossing detectors but found them to be too slow and lacking in drive capability in this application. A switch to LM311 comparators solved these problems.

As stated in Chapter 3, a considerable reduction in volume could be achieved by mechanical redesign using current production techniques.

5.2 Recommendations

The system, as presented, does demonstrate the feasability of building a low cost, easy to operate, multicolor vectorcardiograph system using available display technology. A number of areas for possible improvement are apparent.

The vulnerability of the phosphor to damage by excessive beam current makes a current limiter a necessity in any practical system. Another approach which the author is pursuing at ITT Electro-Optical Products Division is the development of a display tube which eliminates this problem.

The preamplifier section must be redesigned and should include isolation amplifiers to eliminate shock hazard to the patient, particularly if clinical use is anticipated.

With the improving availability of low cost analog to digital converters, memory components, micro-processors and digital to analog converters, it should be possible to design a low cost digital averaging computer into the system which provides a "smoothed" flicker free display.

A "joy stick" control for changing the effective angle of observation within a given octant would be a useful addition. One approach which might be used to achieve this was presented by T. G. Bland[10].

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A COMPACT MULTICOLOR DISPLAY FOR VECTORCARDIOGRAMS

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(ABSTRACT)

Most existing vectorcardiographic displays are either simple two axis displays, or are very complex systems often employing a computer to process the vector cardiographic signals.

A display is described which presents the vectorcardiographic information in either the conventional two axis formats, or in a quasi-three dimensional format. The ease of interpretation of the displayed information is considerably enhanced through the use of a multicolor display tube.

The display tube employs a screen composed of a mix of superlinear and sublinear phosphors of two different colors (green and red). Color changes of the displayed information, from green through yellow and shades of orange, can be realized by modulating the electron beam intensity.

Details of the circuitry and construction of the display are included with particular emphasis placed on the design and operation of the color processing and display circuitry.

Possible refinements to the equipment are discussed.