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BLAST: A STEREOSCOPIC TELEVISION DISPLAY

by

LAWRENCE HENRY WALLMAN

June, 1972

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BLAST: A STEREOSCOPIC TELEVISION DISPLAY

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The Binocular Lenticular Automatic Stereo Television System as proposed by Dr. W. J. Poppelbaum is a closed-circuit stereoscopic television system. The system uses the "Xographic" method of generating a 3-D display. This method uses a series of vertically oriented cylindrical lenses which by refraction cause the left and right eye images to be separated at the screen rather than requiring the viewer to wear special glasses to separate the images at his eyes.

The BLAST system consists of a pair of closed circuit television cameras, a television monitor with a special cathode ray tube, and the electronics necessary to implement the system. The cameras are mounted such that their interocular spacing and toe-in angle can be varied. The special cathode ray tube has a lenticular screen mounted inside of it. The screen is the viewing screen and is mounted directly behind a clear faceplate. The lenticular screen consists of 256 cylindrical lenses which are on 1/32 inch spacing and have a 1/32 inch radius of curvature. They make up a six by eight inch viewing area. The electronics consist of a video chopper-mixer and alignment and synchronizing circuits.

This thesis describes the several attempts made in trying to build an automatically aligned system and the final system which is not automatically aligned.

ACKNOWLEDGMENT

The author wishes to express his graditude to Professor W. J. Poppelbaum for suggesting this thesis topic and for his continued guidance, friendship, and support. He is also grateful to Dr. W. J. Kubitz and Al Irwin for their suggestions and help in completing the BLAST system.

The author is indebted to all the personnel in the fabrication group and machine shop for their work on sections of BLAST.

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1. INTRODUCTION

Many factors are involved in the perception of depth by a human observer. Perspective, shading, overlapping of objects, relative motion, and focus are factors which are important(1). All of these do not require binocular perception. However, one of the strongest factor in perceiving depth is stereoscopic vision. Due to the fact that human eyes are separated by several inches, the images which are focused on the retinas are slightly different(2). The eyes and brain fuse these different images into a single picture which is our everyday view of the real world.

Since our natural ability to perceive three-dimensional space is highly developed, scientists have for many years tried to design a practical and acceptable three-dimensional display system.

There are basically three possibilities to be considered when a three-dimensional display is desired: pseudo 3-D, stereometric 3-D, and volumetric 3-D. These all have their own set of advantages and disadvantages.

Pseudo 3-D is the name for the system which is characterized by the fact that all information is displayed on a two-dimensional display with the third dimension represented by using extra markings or different color or shading. For example, in some air traffic control terminals, the altitude of a plane is represented by a number of dots located next to the plane's image on the display. In other pseudo 3-D displays, perspective, shading, and texture are used to great advantage in constructing a scene which contains much of the depth information needed to see 3-D. This type display has been used for pilot training, etc. This particular type of pseudo 3-D display falls short of being a truely three-dimensional display only in that it does not present any stereoscopic information.

In the stereoscopic 3-D display system the viewer is presented with two disparate images which are individually channelled to the eyes. The images are views of real scenes or artifically constructed scenes. The two images are the views necessary to present the viewer with all the 3-D information necessary to perceive 3-D. The main considerations in such systems is the method of channelling the views to the eyes. There are several methods which have been utilized. Filters at the eyes are used if the images are displayed simultaneously on a screen(3), individual optical paths using mirrors and lenses are used if the images are separated in space(4), and if the images are displayed serially on the same screen, shutters synchronized to the display rate are possible(5).

All of these channelling methods require the viewer to wear an optical apparatus. One of the eariest of these devices was Wheatstone's invention of the stereoscope in 1833(2). This is a stereoscopic device which holds a pair of pictures and allows the left and right eyes to see only the stereoscopic view corresponding to the left and right eye views of the scene. Ideally a 3-D display should not require any special headgear since these items often lead to headaches and fatigue. (Also, the stereoscopic 3-D display is degraded by depolarization and filter leakage.) There are stereoscopic 3-D techniques which do not require any special viewer-worn optics.

One such technique known as "Xography" has become popular lately in the photographic and printing areas. In this system the two images are channelled at the display screen and not at the viewer's eyes. This is accomplished by using the fact that the eyes view the display from different angles and by using selective screening at the display. The display is made up of alternating left and right view strips of picture which have their long axis vertically oriented. Placed in front of these horizontally interlaced strips is a series of opaque bars which are arranged such that they screen the left view image from the right eye while permitting the right eye to see the right view strips and vice versa for the left eye. This is shown in Fig. 1. A further refinement of this system employs vertically oriented cylindrical lenses as the screening elements. Each cylindrical lens covers a pair of picture element strips. The lenses are designed such that the picture strips lie just inside the focal plane of the lenses. With this arrangement an eye viewing a lens from the left of the centerline of the lens will see only what is under the right half of the lens and vice versa. Thus, since the eyeballs are separated and converge, they will tend to see only the image corresponding to their respectice views of the scene. In this manner the images have been separated (channelled) at the screen instead of at the eyes(1). This is shown in Fig. 2.

Volumetric 3-D displays constitute the third catagory of 3-D displays. In this type of display the information is displayed in an actual volumetric space. This is the most realistic type of display since the viewer sees an actual 3-D image. There are very few restrictions on viewing position and the viewer need wear no special appartus. Difficulty in building this type system is very great. A display medium (3-D screen) is needed which is transparent quiescently and opaque when excited. Also a source of excitation which can excite points at the interior of the medium without disturbing surrounding points is needed. The display medium can be an ionizable gas, a phosphor in a colloidal suspension, or a vibrating(6) or rotating screen(7). The excitation source can be crossed or focused beams of electromagnetic energy, a normal electron beam in the case of rotating or

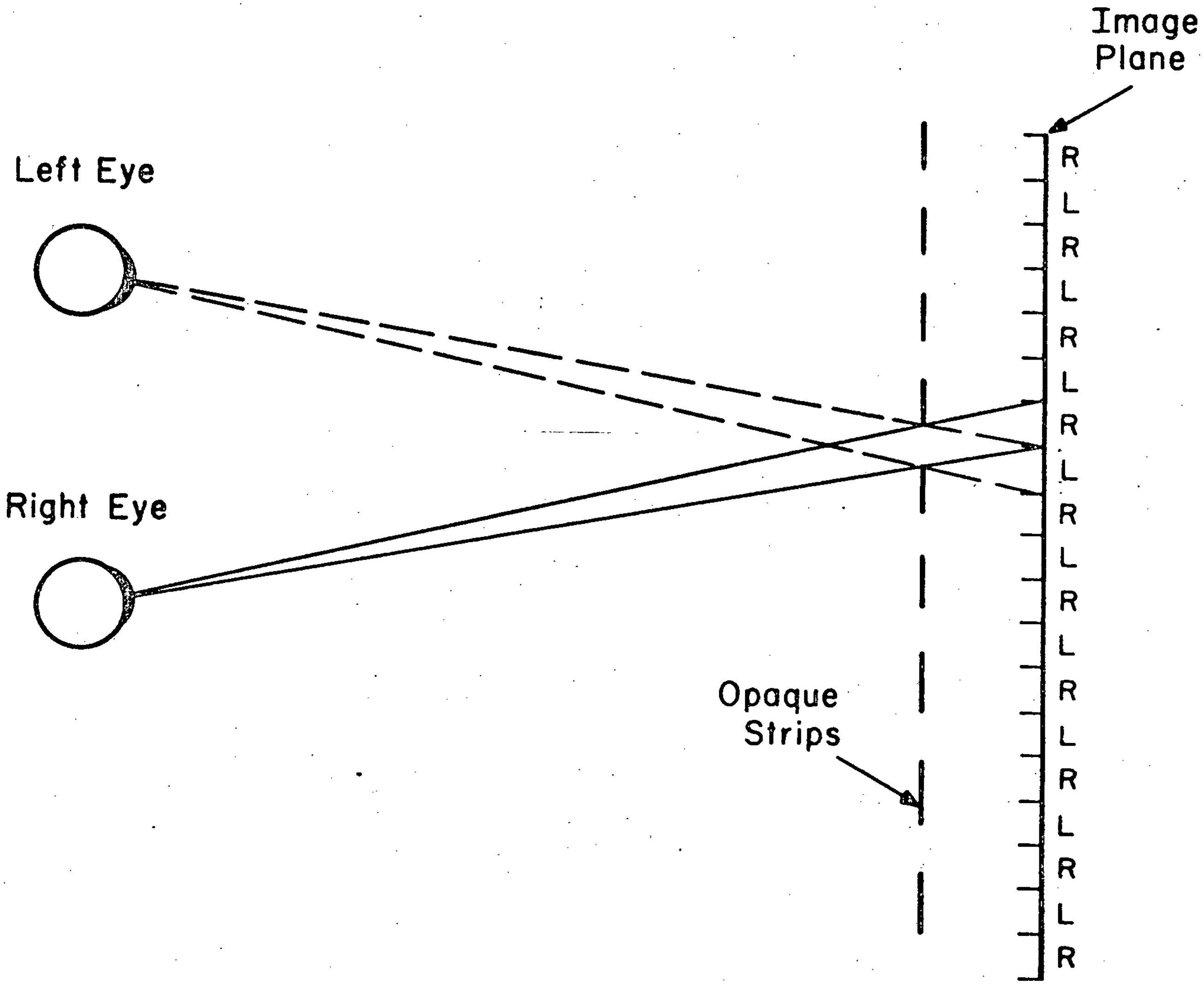

Figure 1. Selective Screening Method

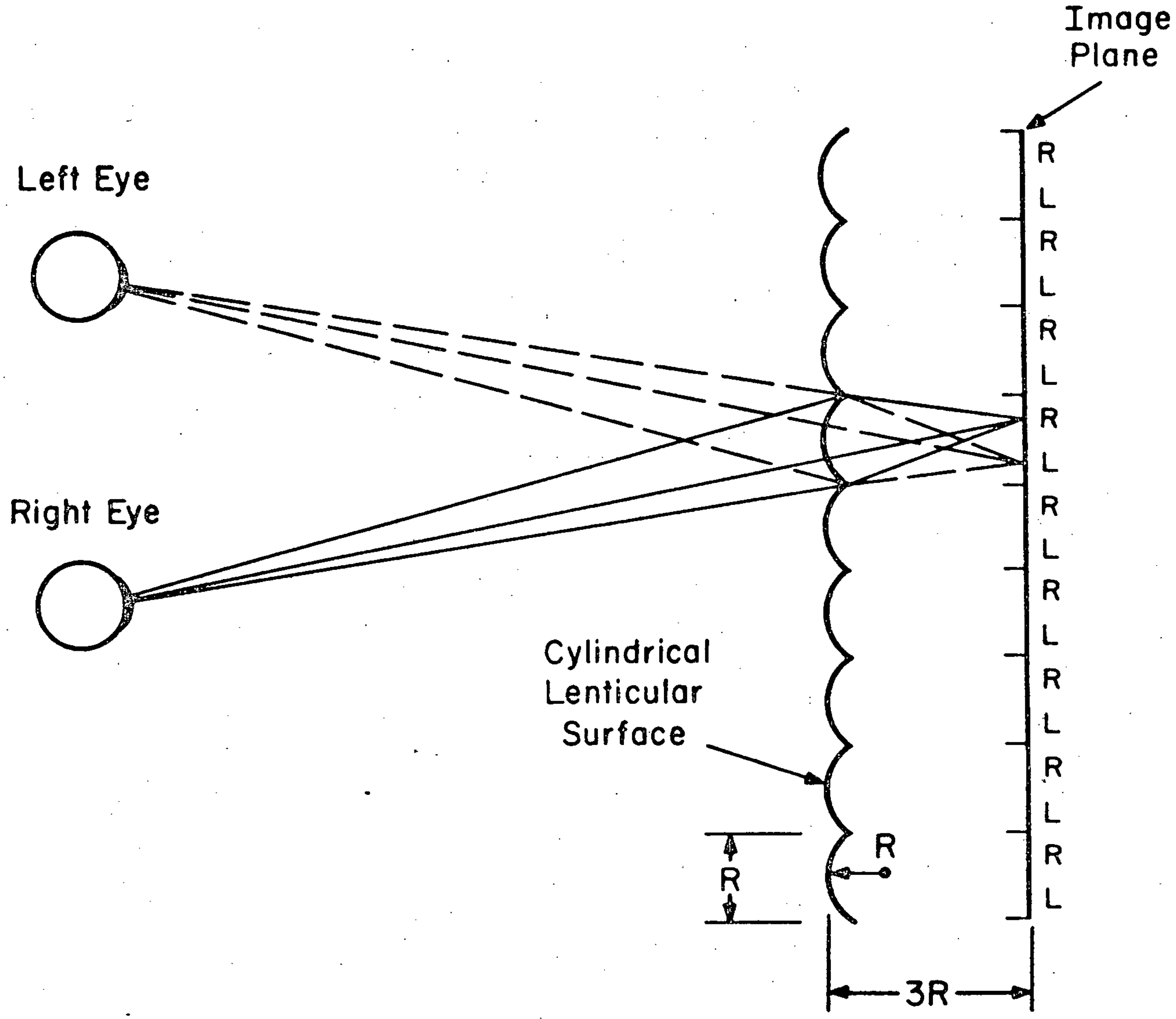

Figure 2. Xography

vibrating screens, or even a 3-D grid of crossed wires for discrete excitation. An idealized volumetric system is shown in Fig. 3.

Several attempts to build a volumetric 3-D display have been made. Special cathode ray tubes with oscillating or rotating screens have been built. In these the electron beam is synchronized to the movement of the screen and modulated so that lines and curves can be displayed in the space included by the movement of the screen. Problems here include the mechanical motion required inside a vacuum tube and the great bandwidth which is required to display a complicated scene. To eliminate the motion inside the tube, vibrating mirrors have been used to view a normal CRT with a properly synchronized display on the CRT(8). All of these systems suffer from one deficiency, namely, a very limited display volume.

In the system at hand, "Xography", the stereoscopic 3-D method, is adapted to a television type display system. If this technique proves to be satisfactory there are many applications to which it is adaptable. Air traffic control, remote operation of equipment in a hazardous environment, entertainment, and CAD are a few of the possibilities.

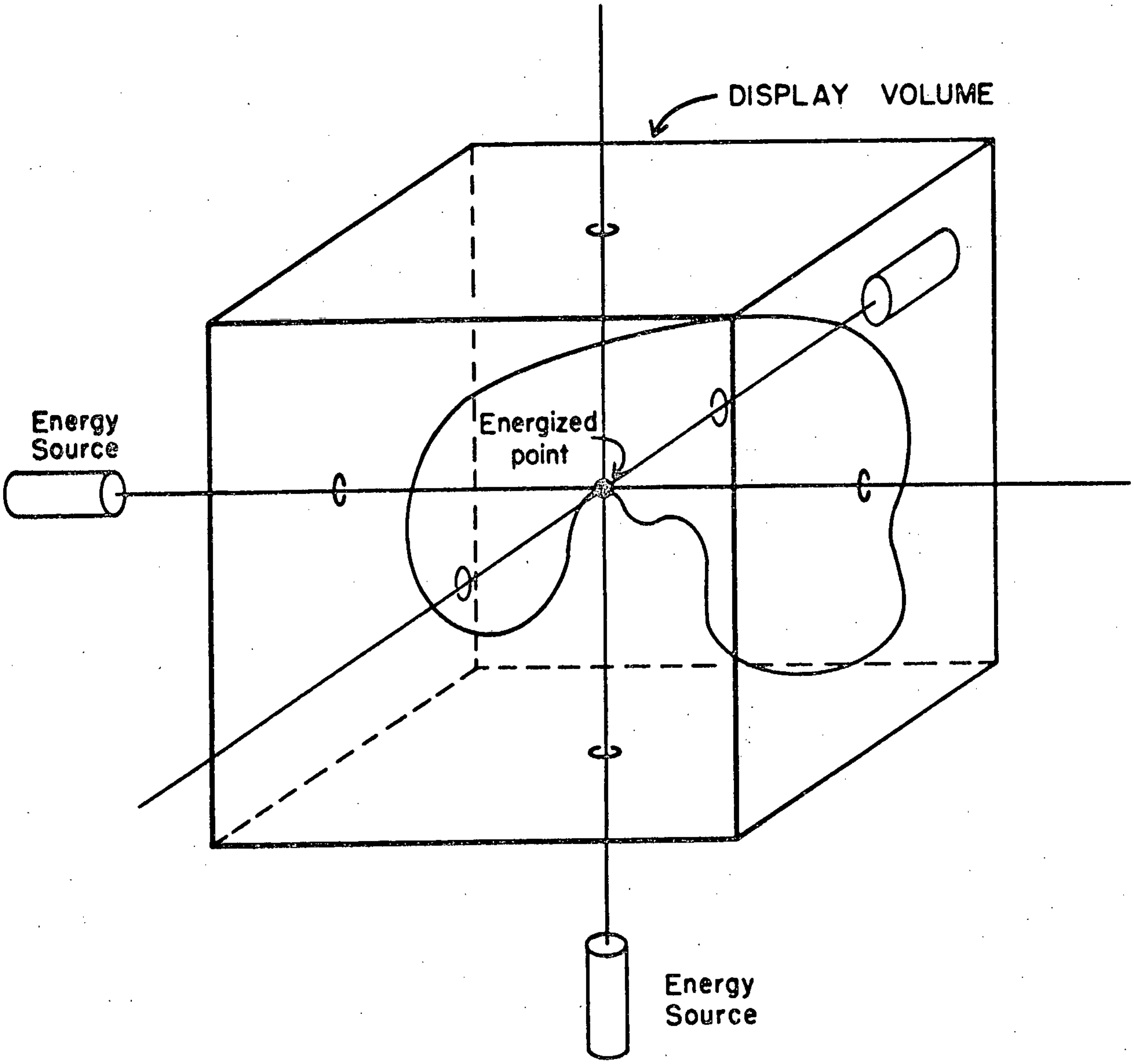

Figure 3. Volumetric 3-D Display

2. THE BLAST SYSTEM

The <u>B</u>inocular <u>L</u>enticular <u>A</u>utomatic <u>S</u>tereo <u>T</u>elevision System as originally proposed by Dr. W. J. Poppelbaum consists of a pair of closed circuit television cameras, a television monitor with a special cathode ray tube, and the electronics necessary to instrument the system. There are two possibilities available for the television system itself: (1) a system with a normal horizontally scanned raster and (2) a system using a special vertically scanned raster. The vertically scanned raster has the advantage that the raster lines will constitute the picture elements for the left and right views. If it is an interlaced system the left view could correspond to the odd field and the right to the even field, for instance. However, in the interest of maintaining as much compatibility as possible with broadcast television, the horizontally scanned raster was retained. In this case, then, a video chopper-mixer for the left and right camera video signal is required. The composite video from the chopper-mixer to the monitor consists of a sequence of samples of the left and right camera video signals because the horizontal scanning lines are orthogonal to the cylindrical lenses which consitute the lenticular screen.

2.1 Cameras

For a naturally appearing 3-D presentation the television cameras must have a spacing which is approximately equal to that of the human eyes. The average human interocular distance is approximately two and one-half inches. The cameras used in the BLAST system are manufactured by COHU and are constructed such that the camera head and the camera control are separate components connected by a multiconductor cable. The camera heads are three inches in diameter and constructed such that the minimum interocular distance possible is three inches. These heads are the smallest which are readily available commercially and the small increase over the average human interocular distance is tolerable. The camera heads are mounted on a special adapter which allows the toe-in angle and the interocular distance to be varied independently.

The natural appearance of the display is dependent on the interocular spacing. If the interocular spacing is too wide, familiar items will appear dwarfish. This is because the human observer assumes he is standard and thus, with greater interocular spacing, more eye convergence than normal is required and items will appear dwarfish. Likewise, if the interocular spacing is smaller than normal, a human observer will report that familiar items appear enlarged because less eye convergence is required. Thus, the input to the system must be comparable to the input received by a human observer stationed at the camera position(1).

2.2 Monitor

The television monitor consists of a standard high quality chassis and a specially constructed cathode ray display tube. The monitor used is a Conrac Model CQF 14/525/SP, factory modified to give a six inch by eight inch raster size.

2.3 Cathode Ray Tube

There are several ways the special CRT for BLAST can be constructed. As will be seen the main requirement is that the phosphor on which the picture is written must be near the focal plane of the lenses of the lenticular screen. Therefore, one possibility is that of mounting the lenticular screen outside of a CRT which has a fibre optic faceplate. The fibre optics will prevent the light from the phosphor from spreading and direct it to the lenslets.

Due to the size of the screen used, however, the fibre optic faceplate tube would be quite expensive. The faceplate of the tube could have the lenticular screen molded directly into the front of it, but the thickness of the glass would be much greater than the focal length of the lenses. A third method is to mount the screen completely inside of the CRT envelope so that it does not have to support the vacuum. This is the most economical method and is the way the BLAST CRT was built.

The special cathode ray tube was constructed by Electro Vision Industries, Inc., El Segundo, California. The BLAST tube consists of a twelve-inch round cathode ray tube envelope with the special flat lenticular screen mounted inside. The electron gun apparatus is standard and the same as the 14-inch rectangular tube normally supplied with the Conrac monitor. The round tube was chosen due to manufacturing considerations, the most important of which was ease in mounting of the lenticular screen and the sealing of the faceplate.

2.4 Optics of the Lenticular Screen

In designing the optics of the lenticular screen for BLAST several items of importance must be considered. First, the thickness of the glass used for the screen must be such that the screen can be supported by the edges or corners only, since any other type of support would either block the electron beam or the viewer's line of sight.. Second, the resolution of the television system has a bearing on the number of lenses used since the number of lenses can be no more than one half the horizontal resolution of the display. Third, the number of lenses also determines the speed with which the video has to be switched between cameras. Since each lens requires a full cycle of the chopper-mixer, the larger the number of lenses the higher the frequency requirement on the video chopper-mixer. Since transition times for analog gates of less than fifteen or twenty nanoseconds are reasonable, a total period for the mixer of two hundred nanoseconds allows the video information to occupy eighty percent of the area under the lenses. Since the active portion of a horizontal line in a 525-line television system is about 52.5 microseconds, dividing the two hundred nanoseconds into the active line time gives 262.5 as a realistic number of lenses across the horizontal dimension of the screen. Therefore, the restriction on analog gate transition time is not critical, since as will be seen, it produces a horizontal resolution comparable to the standard television resolution.

The thickness of the screen now must be determined to verify that it is consistent with the number of lenses. The pictorial information in a "Xographic" 3-D display system consists of horizontally interlaced strips of the picture. The descriptive term "horizontal interlace" is derived from the television term "vertical interlace" which refers to the interlacing of the horizontal lines of the odd and even fields. The interlace here is the horizontal interlace of the vertical segments of the left and right eye view picture elements. The image strips are placed under the lenses so that one pair (left and right view) are aligned under one lens. The images are placed so that when viewed from the lenticular side of the screen the strip to the left of the centerline of the lens corresponds to the right eye view and the strip to the right of the centerline of the lens corresponds to the left eye view. In order that the 3-D picture appear continuous and for the lenses to effectively screen the left and right eyes from the opposite view, the lenses must have a high magnification of the image so that the lens appears completely filled by the corresponding eye view. If the lens is viewed from left of center, it should only transmit to the left eye and vice versa for the right eye. This can be accomplished by placing the left and right eye images at or just inside the focal plane of the lenses. (See Appendix A for determination of focal length and magnification.) Then, if the radius of curvature of the cylindrical surface of the lens is taken to be 1/32 inch, the focal length will be approximately 3/32 inch. If the spacing of the vertical centerlines of the lenses is also taken as 1/32 inch, the focal length will be approximately 3/32 inch. If the spacing of the vertical centerlines of the lenses is also taken as 1/32 inch there will be 256 lenses across the eight inch dimension of the lenticular surface of the screen. This agrees nicely with the earlier calculation for a realistic number of lenses. With the radius of curvature and the spacing of the centerlines equal, the cusp where two adjoining lenses meet will not be too severe. This facilitates manufacture of the glass lenticular screen. Glass is used because the screen is placed inside a vacuum tube and plastic will contaminate the electron gun appartus through outgassing. Also, during manufacture, heat is applied to seal the faceplate of the tube and plastic would not have the required stability. With 256 lenses across the horizontal dimension the horizontal resolution is 256 lines since each lens represents one picture element horizontally. The vertical resolution of a normal television system is about 350 lines and horizontally about 300 lines. However, in the 3-D display each eye receives 256 lines of resolution, which are not necessarily the same, and therefore the apparent horizontal resolution is greater than 256 and becomes comparable to the vertical resolution. The specifications for the lenticular screen and the cathode ray tube are found in Appendix B.

2.5 Electronics

The electronics necessary to produce the display can be of two types; feedback and nonfeedback. The feedback system is a self correcting system requiring no outside control of alignment whereas the nonfeedback is a lowdrift system requiring only minor corrections to the alignment. These two possibilities will be discussed in conjunction with the actual system.

2.5.1 Video Chopper-Mixer

The electronics for both the feedback and the nonfeedback BLAST system are required to provide a "composite video" signal which can be displayed on the special cathode ray tube. This composite video is composed of the video signals from the left and right cameras. A one hundred nanosecond piece of video from the left camera is followed by a one hundred nanosecond piece of video from the right camera and so on continuing along each horizontal line. This required a 5MHz clock as the basic system clock.

The circuit which provides this 5MHz clock signal is shown in the top portion of Fig. 4. The circuit is basically an astable multivibrator with isolating diodes on the collectors to give a fast collector risetime. The risetime of the collectors is about five nanoseconds. The two five kilohm potentiometers provide the functions of frequency and symmetry control.

A circuit for mixing the left and right camera video signals is shown at the bottom of Fig. 4. The clock signal from the astable multivibrator serves to switch the constant current drawn by the 2N3642 current sink between the two differentially connected 2N709A transistors. This allows the input Video #1 or input Video #2 2N709A transistors to control the current drawn from the common base stage. Then, the mixed video signal appears at the collector of that stage. The output stage consists of an emitter follower

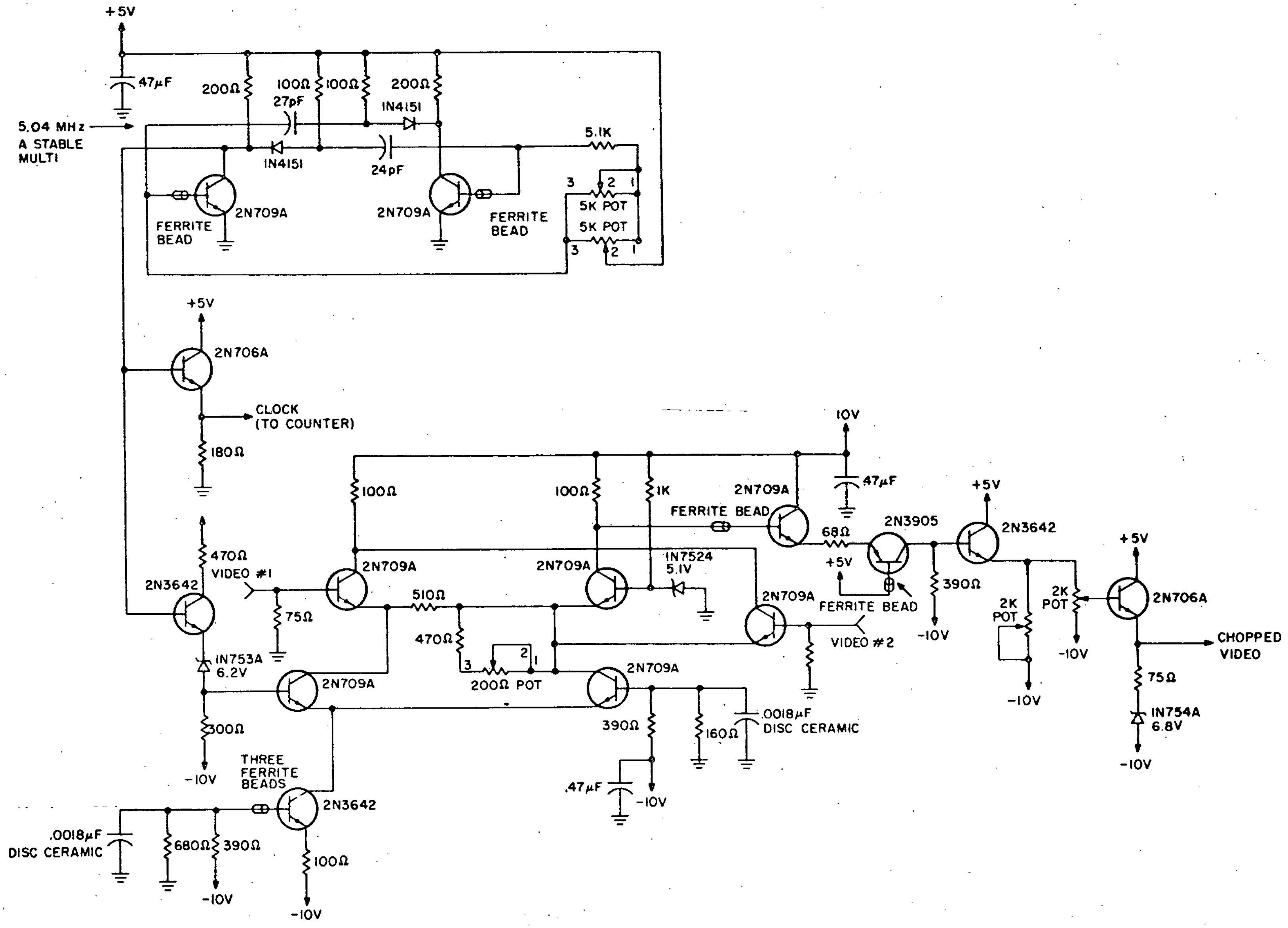

Figure 4. Video Chopper-Mixer-Discrete

followed by a common base amplifier with gain and level controls to the output driver. This circuit can switch between video inputs in approximately 25 nanoseconds. However, there is a negative transient during switching which cannot be tolerated. The ferrite beads are installed to combat parasitic high frequency oscillations to which this circuit is prone.

A better chopper-mixer was found in the MC1545, a Motorola linear integrated circuit. The MC1545, a gated, two-channel, differential video amplifier, has channel select times of twenty nanoseconds and no transients or oscillation problems. It can be used in conjunction with the astable multivibrator described earlier. This circuit is shown in Fig. 5. The one hundred ohm potentiometers on the video inputs are used to attenuate the signal input and balance the gain of the channels. This method of gain control is preferable to using a closed loop configuration to control gain as indicated in Motorola's Application Note on the MC1545, AN-491. The switching is accomplished by applying logic levels to the gate input, pin 2. To obtain a symmetrical output, the logic input from the astable multivibrator cannot be symmetrical since the gate characteristics of the MC1545 are symmetrical about 1.2 volts. Therefore, the "0" level input must be maintained longer than the "1" level input.

2.6 Synchronization and Alignment

The synchronization and alignment of the BLAST system is critical. Each bit of video information must appear on the correct side of the centerline of each lens. If the left and right video pieces are not aligned the 3-D effect of the display will be lost. Therefore, a method of aligning and synchronizing the video signal going to the monitor with the special BLAST screen is required.

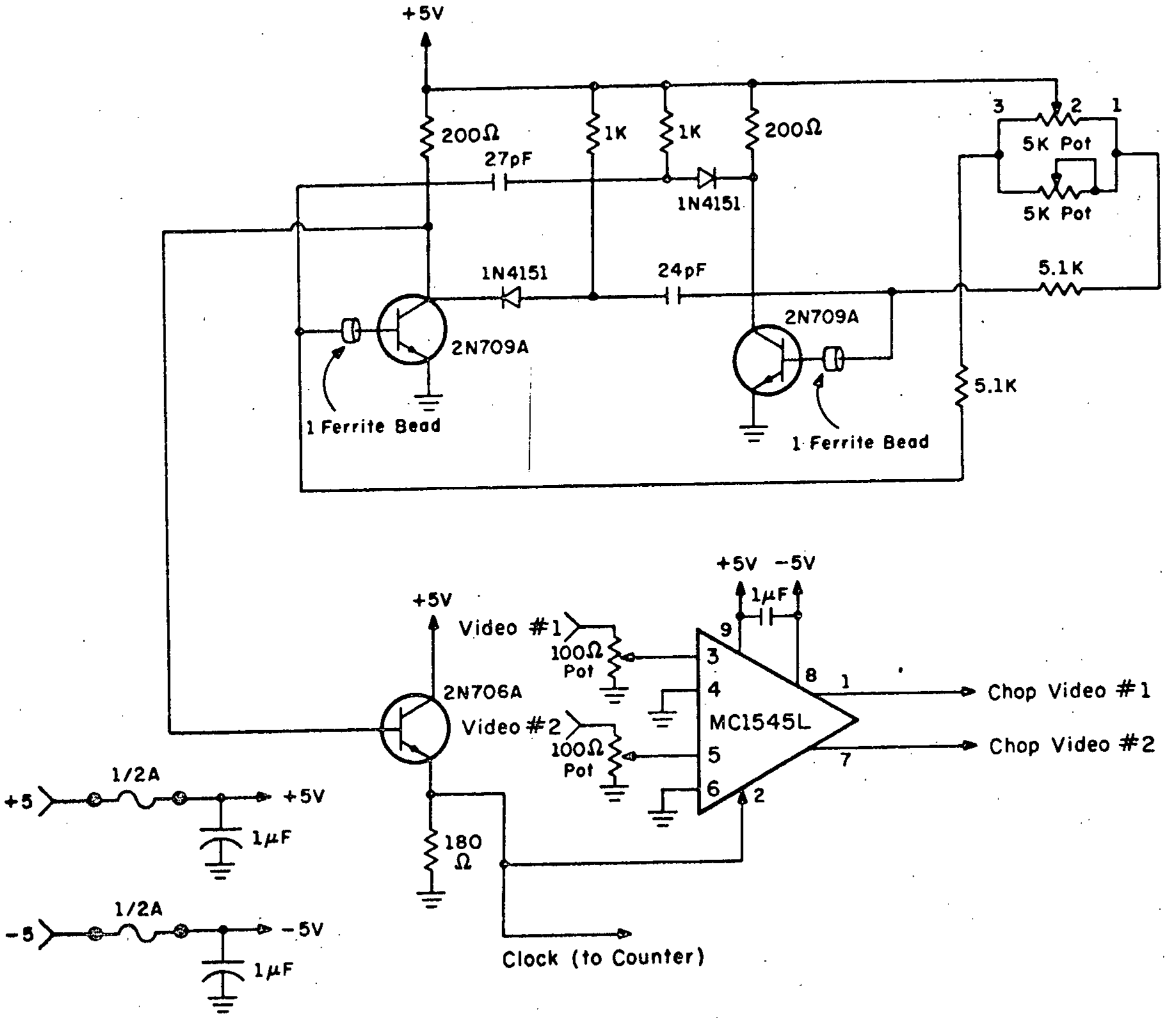

Figure 5. Video Chopper-Mixer-Hybrid

In order to produce a "Xographic" display the left and right picture elements must be aligned precisely under the cylindrical lenses. If the picture elements are not aligned properly the left and right eyes will not see their intended views. To accomplish this the exact position of the electron beam on the lenticular screen must be known. There are several methods available which can be used to determine the position of the electron beam. They all involve some sort of detection appartus installed in the tube. First, ultraviolet phosphor stripes can be laid down along with the normal phosphor. If the stripes correspond to the periodicity of the cylindrical lenses, the electron beam will strike the ultraviolet phosphor stripes at the same rate it crosses the lenses. A uv detector in the neck of the tube will then output a signal corresponding to the beam crossing the lenses. Second, a grid of thin wires stretched on a frame can be placed near the flat (back) side of the lenticular screen and if they correspond to the cylindrical lenses an electrical signal can be obtained directly from the wires as the beam strikes them(9). All wires would be connected in parallel and brought out as a single lead. Similarly, a series of conductors could be deposited directly on the flat side of the lenticular screen with the phosphor over them and the signal could be obtained from these conductors as the beam crosses them.

3. SYSTEM 1

The last method discussed in Section 2.6, namely, the conductors deposited directly on the screen, was chosen as the one to be used to implement BLAST. The reason this was chosen was because it was the least expensive and appeared to have a good chance of success. A transparent conductor, NESA, a tin oxide was chosen for the stripes so that it would not be visible to the viewer. The reader is referred to Appendix B for the specifications of the lenticular screen and conductors.

3.1 Synchronization

The signal from the conducting stripes was used to control the master oscillator either faster or slower depending upon the position of the electron beam and the linearity of the sweep. The block diagram for this is shown in Fig. 6. The signal from the conducting stripes is capacitively coupled to an amplifier which drives the chopping generator. The capacitive coupling is necessary in order to block the DC level of the signal from the conducting stripes as the stripes are of necessity held at the second anode voltage, 18 kilovolts.

3.2 Signal Detection

The circuit used to detect and amplify the synchronization signal is shown in Fig. 7. The RC network filter on the high voltage power supply is necessary to obtain a clean power supply voltage at the anode of the BLAST tube. Since the high voltage power supply is developed from a flyback type system there are large transients which occur at horizontal retrace time. These are partially eliminated by the filtering. The diodes connected across the 6.2 kilohm resistor at the input to the Fairchild μA733, video differential amplifier, are used to prevent an overvoltage from being applied to the input of the μA733 and destroying it.

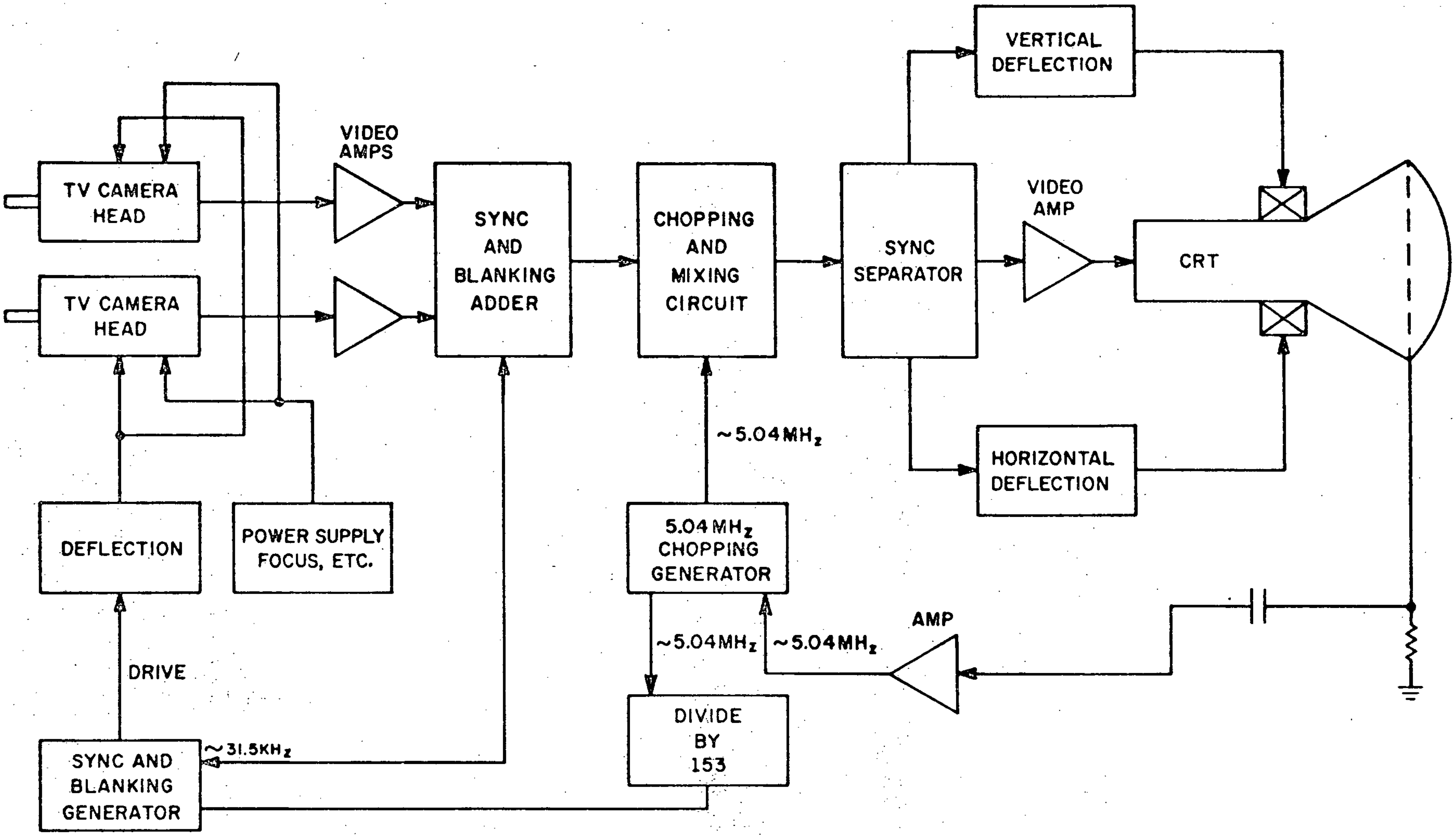

Figure 6. System One and Two

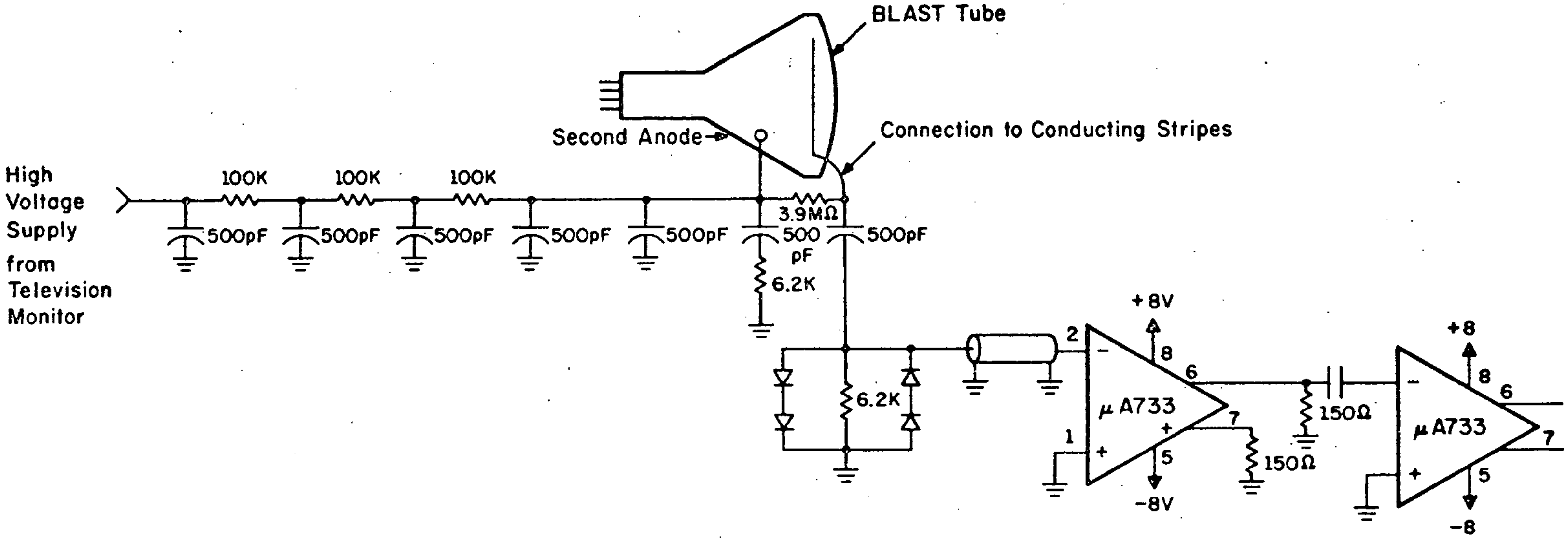

Figure 7. Capacitive Coupled Recovery of Screen Signal

Using this circuit, some moderate success was achieved in synchronizing the astable multivibrator to the screen signal. However, there was much noise on the screen due to false triggering of the astable, and it was obvious a better method of obtaining the signal was needed. In addition, large, gray vertical stripes appeared unexpectedly on the screen. They were several lenses wide and the vertical edges of them corresponded to the conducting stripes on the tube. Spikes corresponding to these gray irregularities were also present on the signal coming from the screen thus rendering it almost useless. From the screen signal it was determined that the gray areas were isolated electrically from the rest of the conducting stripes because large pulses corresponding to the gray areas appeared on the synchronization signal. Another reason for this conclusion is that the areas have less brightness than the rest of the screen due to an apparent build up of electrons on these isolated islands. Upon discussion with the tube manufacturer about this problem, they felt the NESA conductors were broken due to a localized high voltage gradient across adjacent stripes. The tube was useless the way it was, and a second tube was ordered. This second tube has a few changes, which, using what we learned from the first, make it easier to recover the signal.

4. SYSTEM 2

Due to the very weak synchronizing signal obtained in System 1, it was felt conducting stripes with a higher conductivity would increase the signal-to-noise ratio of the synchronizing signal. To this end, nickel was chosen as the material for the stripes. Nickel is not transparent, but since the stripes are only 6 mils wide, they occupy only abut 15% of the area under the lenses and so are not objectionably noticeable when viewing the display. To further increase the signal-to-noise ratio the conducting stripes were divided into two interwoven combs. This is shown in Fig. 8. There are two leads coming from the conducting stripes, one connected to stripes 1, 3, 5, ..., odd across the screen, and one connected to stripes 2, 4, 6, ..., even. With this connection the electron beam hits each set of stripes half as often as with a single set of stripes and the signal-to-noise ratio is better. Also, with this arrangement an isolation transformer is used to block the DC high voltage and transmit the screen signal to ground level. This is desirable since the noise generated by the high voltage blocking capacitors is eliminated.

An isolation transformer, hand-wound on a ferrite core and insulated with silicon rubber, was experimented with on BLAST tube number one while awaiting tube number two.

Upon receipt of the second BLAST tube the circuit shown in Fig. 9 was tried. Noise problems in this system were also considerable, and it was decided to float an amplifier at the anode potential to amplify the screen signal before it was transmitted down to ground level. This circuit is shown in Fig. 10. One problem encountered with the transformer coupling is that of large spikes at retrace. These spikes are due to coupling between the monitor electronics and the floating circuit. Using aluminum foil as a

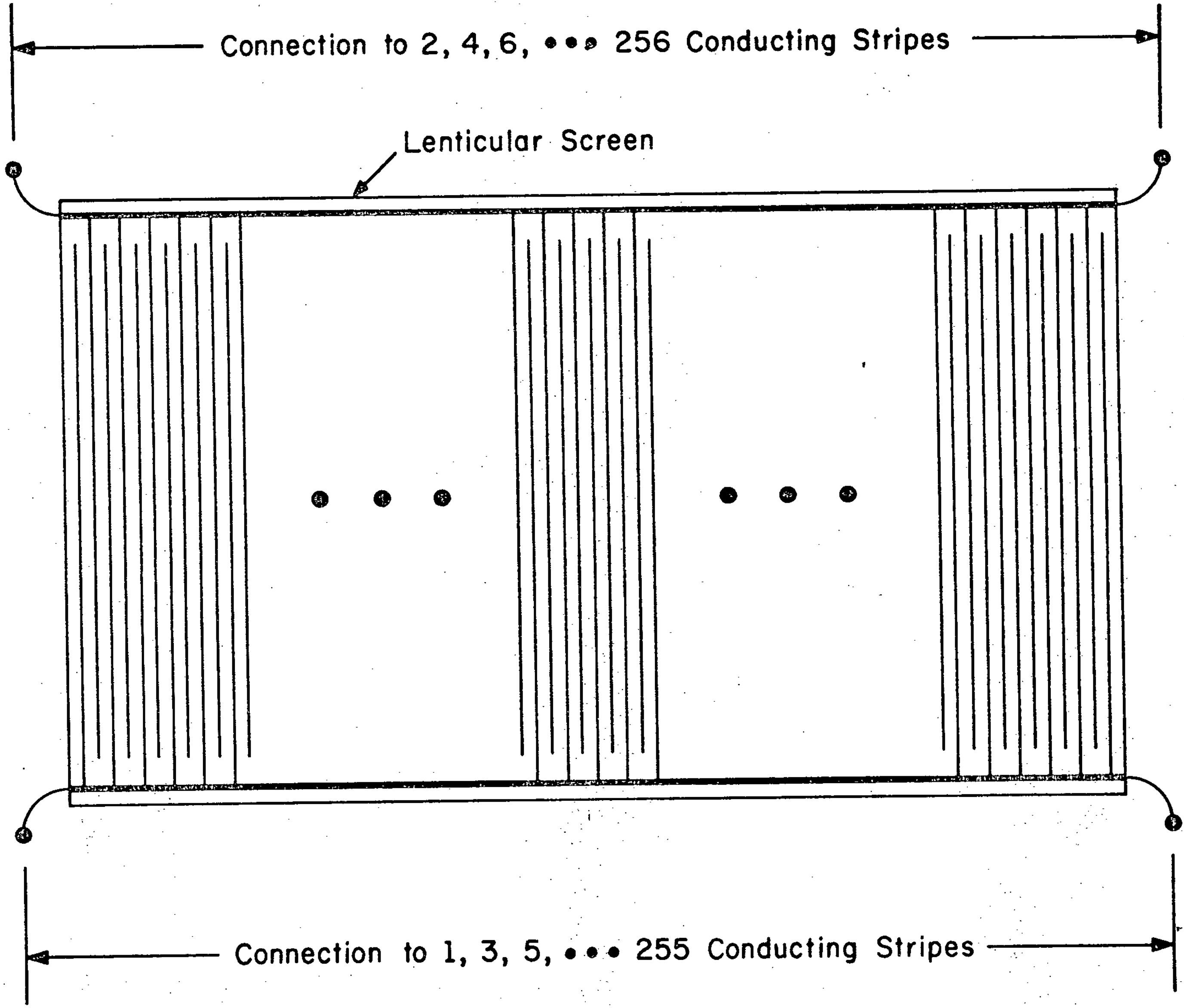

Figure 8. System Two-Conducting Stripe Pattern

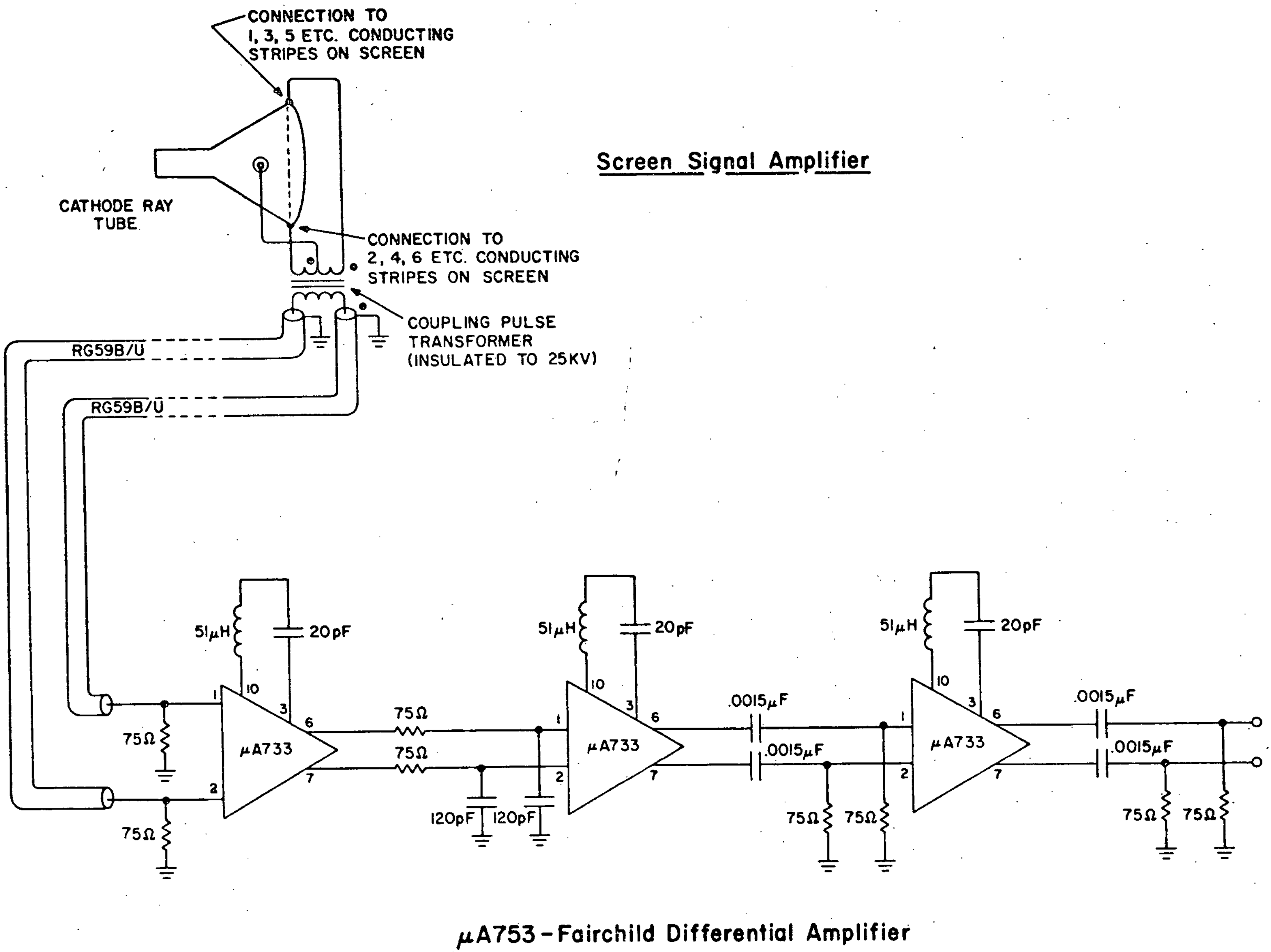

Figure 9. Inductive Coupled Recovery of Screen Signal

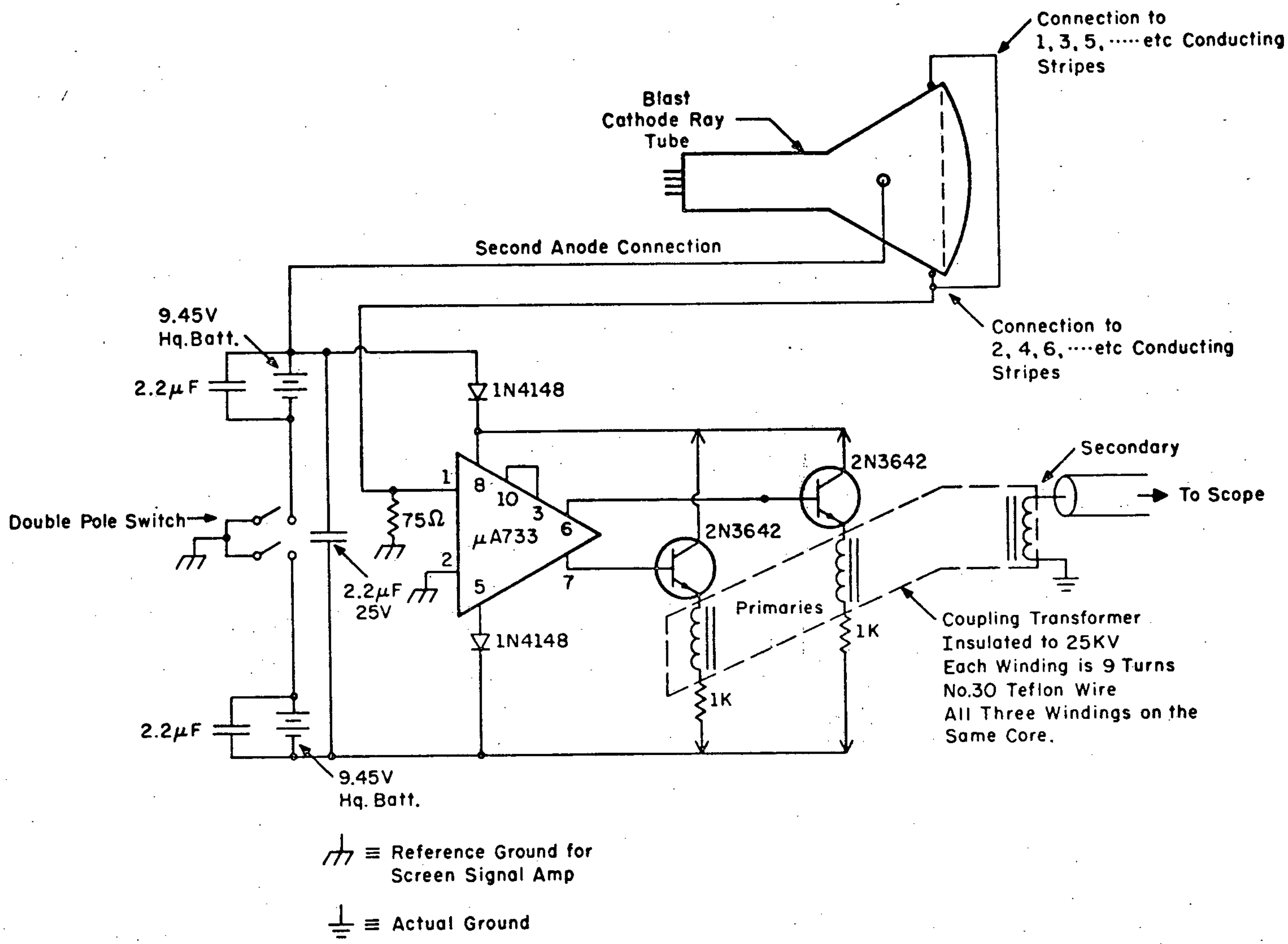

Figure 10. Amplifier Referenced to Anode

shield on the entire floating circuit, the retrace spikes caused by the coupling were made negligible. This circuit produced a signal which corresponded to the screen signal but also has considerable noise. The astable multivibrator could be synchronized in places but the noise caused false triggering.

At this point in the research the connection to one of the interwoven combs became open circuited. The reason for this breakdown is not known, but it is conjectured that, the "sandwich" type of connection used to contact the nickel conducting pad on the glass screen was constructed of incompatible metals causing a nonconducting layer to be formed between the metals. Since there is no way to repair this break, short of returning the tube, and it is of utmost importance that the project be completed, a re-evaluation of the approach to the problem of alignment was carried out.

5. SYSTEM 3

In System 1 and System 2 the electron beam deflection was left unmodified, and the chopping frequency was modified to align the video segments behind the lenses. Due to unfortunate and unforeseeable difficulties in the manufacture and operation of the special cathode ray tube it became impossible to pursue this approach to the problem of alignment.

Forsaking this approach, then, and seeking a solution using a system which does not utilize feedback from the electron beam, a "Xographic" television system has been built.

In this system, System 3, the chopping frequency has been left unmodified and the electron beam deflection has been controlled to align the video segments behind their intended halves of the cylindrical lenses. This system will require periodic adjustment; the frequency of such adjustment depending on the stability of the scanning and chopping circuitry. A block diagram of System 3 is shown in Fig. 11.

5.1 Synchronization

To insure that the chopping frequency always remains synchronized with the video signal the 5MHz clock is counted down to 31.5KHz to drive the camera sync generator, since the master oscillator frequency of the camera is 31.5KHz. The camera sync generator is modified so that either the external signal from the counter or the internal master oscillator drives the sync generator, as selected by a panel mounted switch. The normal mode of operation is with the external 31.5KHz signal enabled. Appendix C shows the modification to the camera sync generator.

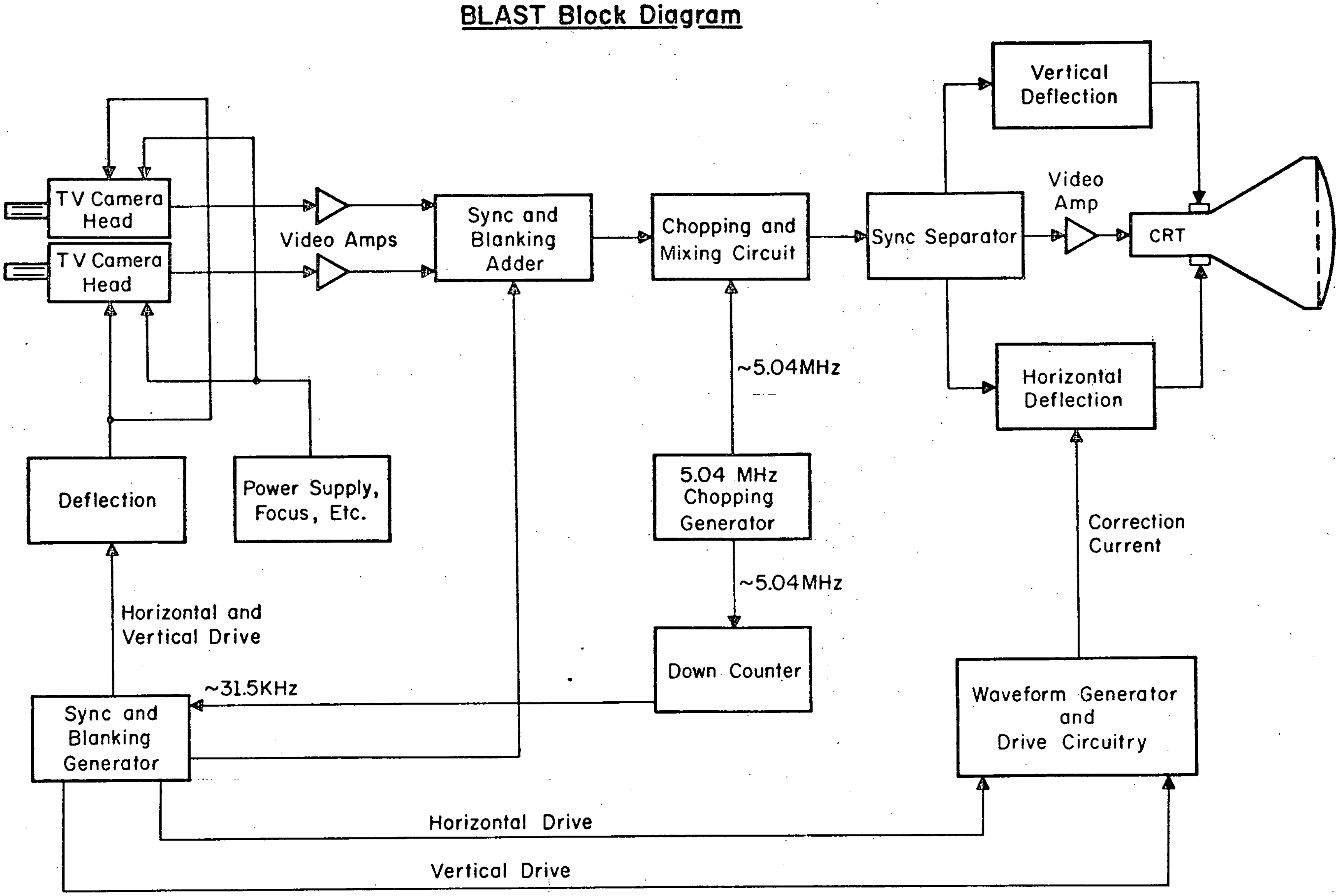

Figure 11. System Three

5.1.1 Counter

The counter circuit which generates the 31.5KHz from the 5MHz clock is shown in Fig. 12. It is an 8-bit synchronous counter constructed of SN7470N J-K flipflops with gating implemented with SN7410N, SN7430, and SN7440 NAND gates. The eight input NAND SN7430 decodes the output of the counter to 158, and its output is then inverted and "NANDED" with the input 5MHz clock to clear the counter synchronously. The output signal is taken from the most significant bit and using an emitter follower as a driver, drives a coaxial cable to the sync generator in the camera control. This type of counter was used because of its reliability and the facility with which the final count can be altered.

5.2 Scan Correction

Since a flat screen and a constant chopping frequency are used the speed with which the electron beam traverses a horizontal line must be constant and the same for all horizontal lines. The correction must increase the deflection speed as it approaches the center and decrease the speed after the beam passes the center of the screen.

In a normal CRT display, two of the problems encountered when the radius of the display screen is different from the radius of deflection are nonlinearity and pincushion distortion. Correcting pincushion distortion is not a necessary and sufficient condition for correction linearity, but correcting linearity is a sufficient condition for correcting pincushion distortion on a flatface CRT. In the BLAST system, with its flatface CRT, the pincushion distortion is corrected by using a correcting field in the drift sapce between the deflection yoke and the screen. This does tend to degrade linearity, but now the scan correction for constant velocity scan can be applied to the horizontal sweep only. (Celco Data Sheet Y2C) The

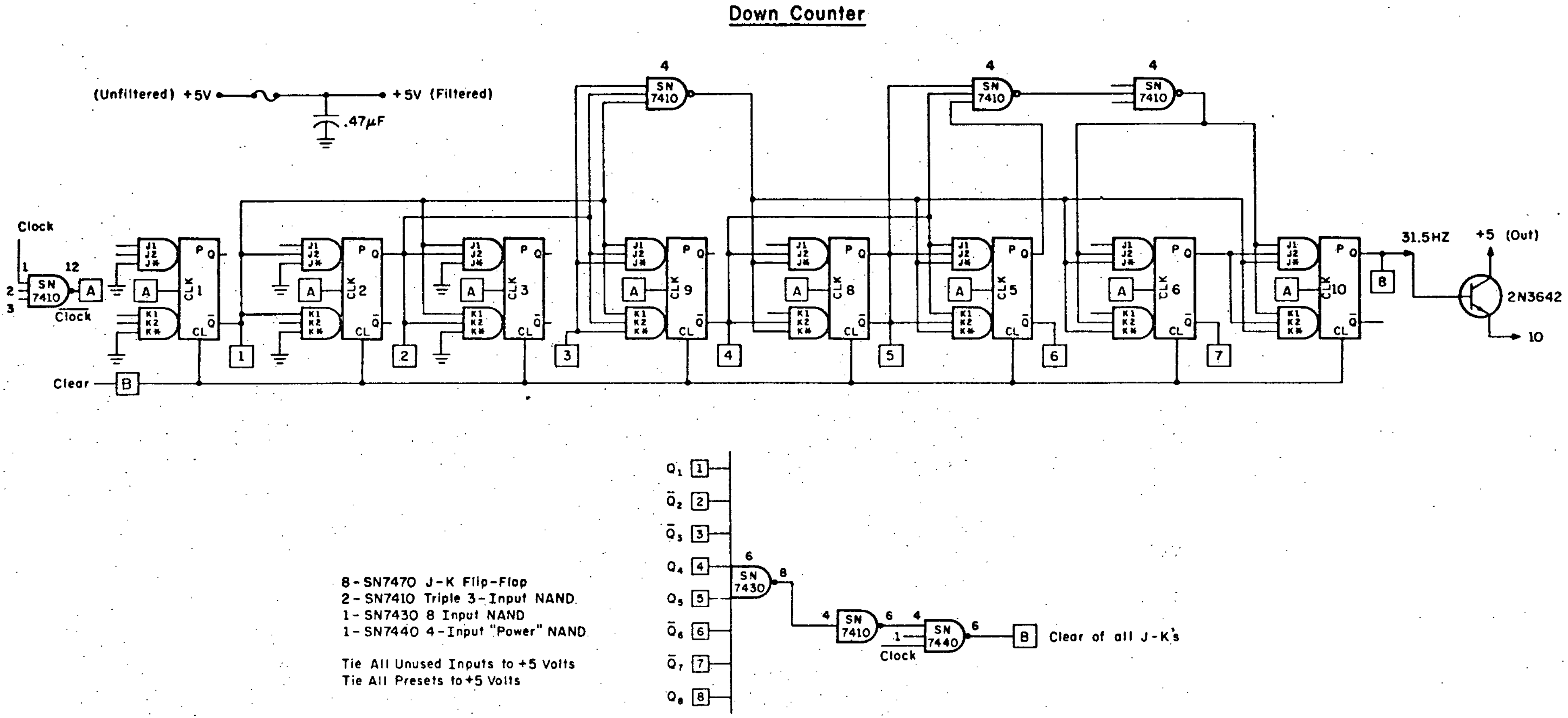

Figure 12. Counter

correcting field which is applied in the drift space is such that the same correction can be applied to every horizontal line. This correction is calculated in Appendix D.

The function determined in Appendix D for the deflection current, I(t), is one which has a slightly decreasing slope. Therefore, since the actual deflection current to the yoke is quite linear, the auxiliary deflection field must have the effect of reducing the rate of deflection as the deflection angle increases. This agrees with the previous statement made concerning the required deflection.

5.2.1 Ramp Generator

The horizontal ramp generator is shown in Fig. 13. This circuit generates the waveform which is used to drive the dynamic correction coils. The Horizontal Drive signal controls the charging cycle of the ramp generator. The 2N3905 is normally OFF and when the Horizontal Drive pulse occurs it turns ON and so turns ON the 2N3642 which is connected across the charging capacitor. The 2N3642 saturates and discharges the capacitor returning it to approximately minus 5 volts. The current source, 2N3905, connected to the capacitor, is used to provide a constant charging current.

5.2.2 Coil Driver

The previous circuit is quite straight forward. However, the coil driver is more difficult. The reasons for this can readily be seen by examinating the horizontal deflection yoke.

The inductance of the yoke is approximately 10mH and from actual measurement on the monitor the deflection current required is ±300 milliampere. The severest restriction on the yoke driver occurs during retrace. The time allowed for horizontal retrace is approximately 10 microseconds. Using the formula for the voltage across an inductor $v = L\frac{di}{dt}$ it is seen that the

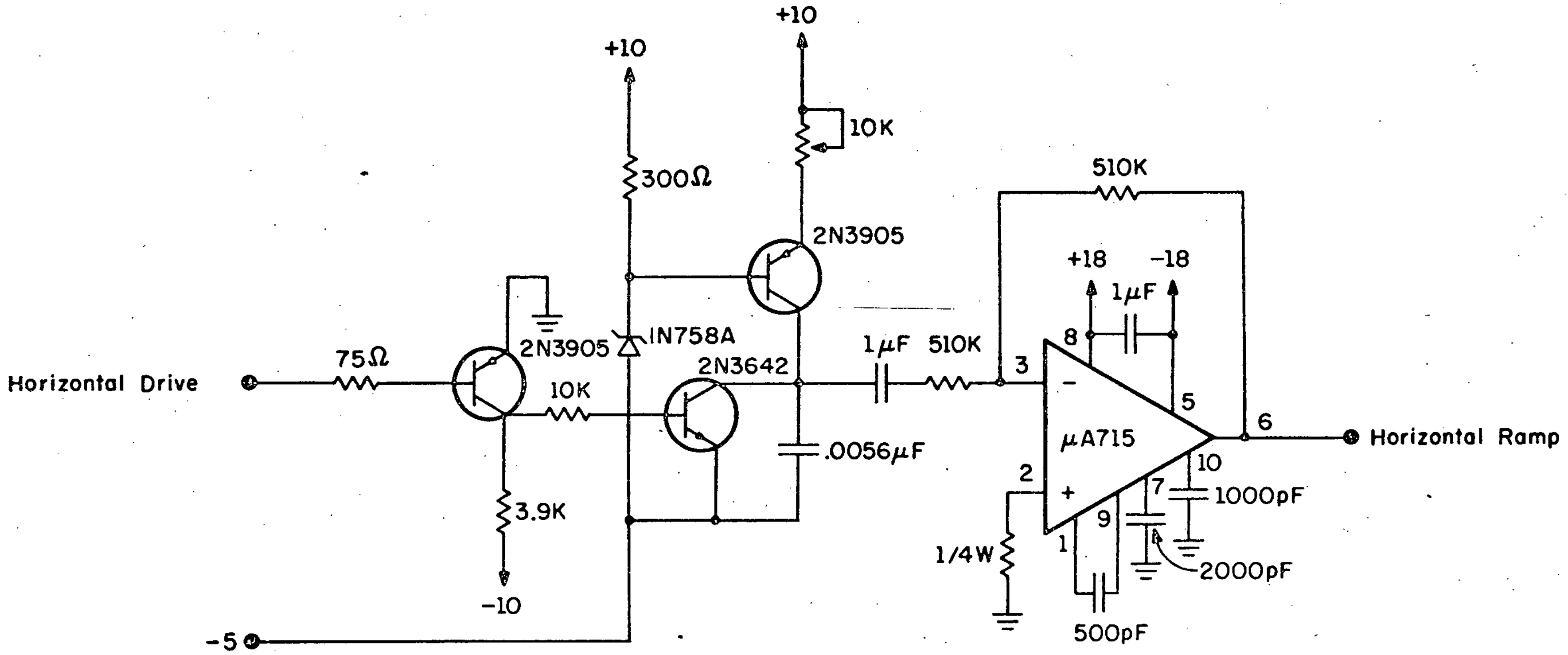

Figure 13. Horizontal Ramp Generator

voltage required to perform the retrace is approximately 600 volts. In all commercial television monitors the retrace is accomplished by using the natural period of oscillation of the yoke and letting it ring until the current is reversed. However, the system at hand requires that the control over the current in the yoke be linear and no ringing be allowed. A block diagram of the linear yoke driver is shown in Fig. 14. The calculation in Appendix E shows this circuit configuration to be a voltage-to-current converter. The current in the load, in this case, the yoke, is directly proportional to the input voltage.

Therefore, the current driver section of this circuit has requirements which are impractical to meet with available semiconductors. The technique that is actually used in BLAST required that an auxiliary coil be driven dynamically and that the high inductance yoke be allowed to do the majority of the deflection while the auxiliary coil contributes a correcting field. The circuit which accomplishes the driving of the auxiliary coils is shown in Fig. 15. The current driver consists of a 2N2219A used as an emitter follower to supply sufficient current to drive the common-base stage 2N2905. This common-base stage is used to provide voltage gain without the phase inversion required in a common-emitter configuration. The output transistors provide sufficient current and voltage ratings to drive the coils used for the deflection correction. The coils used are taken from a color television receiver's convergence assembly. They are U-shaped ferrite cores with the coils wrapped around the core near the ends. Two of these electromagnets are used in parallel. They are placed on either side of the tube neck directly behind the yoke so that their influence on the electron beam is felt before the beam enters the deflection yoke area. Two magnets are

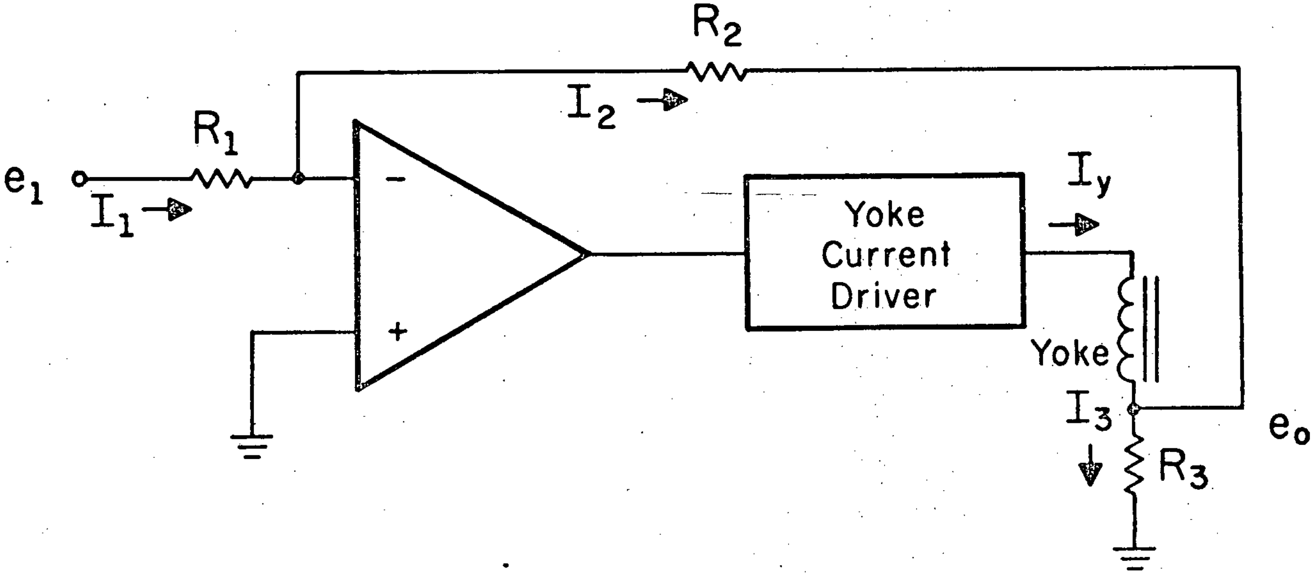

Figure 14. Feedback Coil Driver

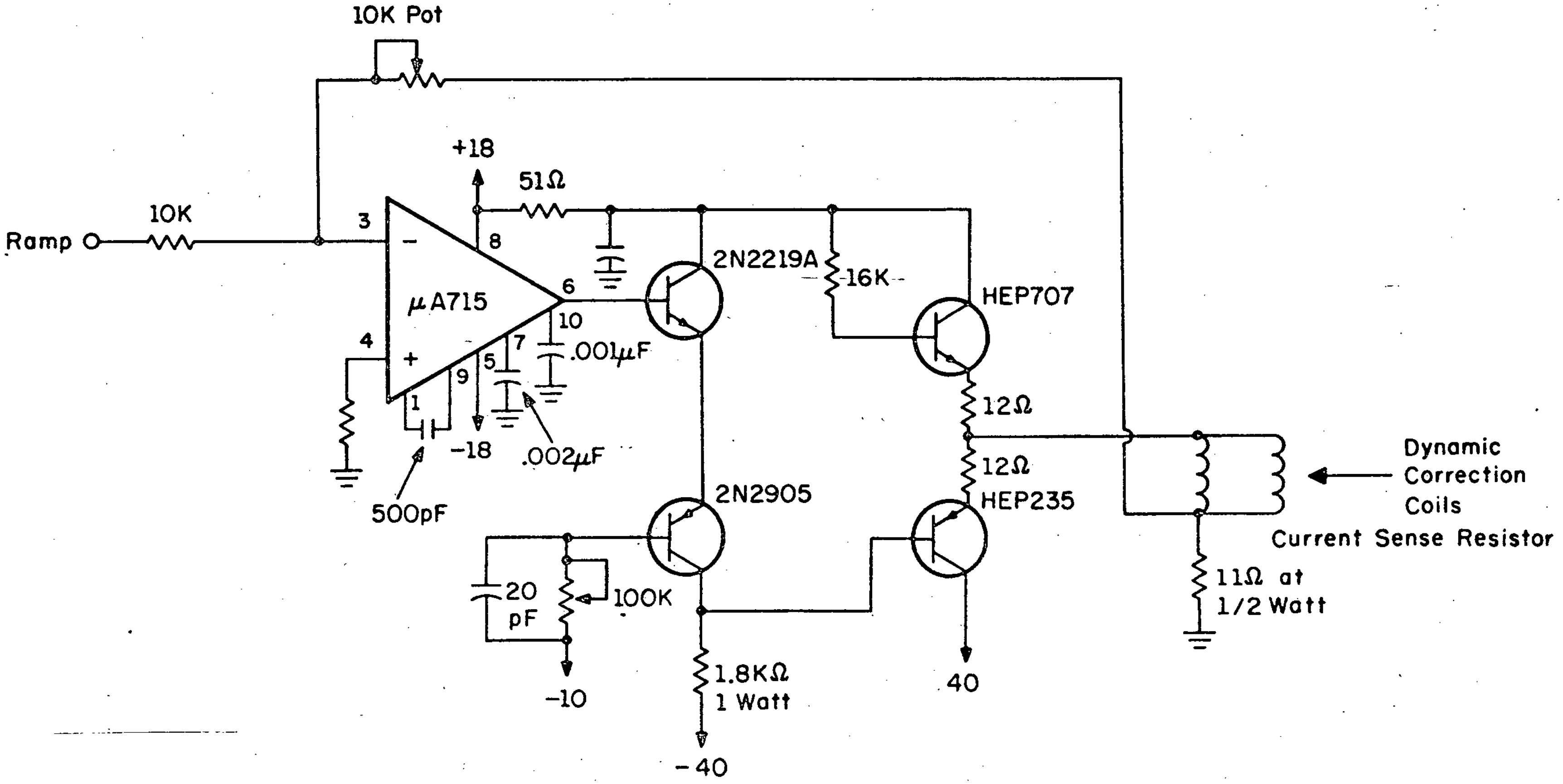

Figure 15. Coil Driver Circuit

used to decrease the inductance by driving them in parallel and also to provide a uniform field for deflection.

5.2.3 Drift Space Correction

Since a flat screen is used there is also a static correction which can be applied to eliminate the pincushion distortion. This static correction is applied using seven electromagnets spaced around the display tube immediately in front of the deflection yoke. This static correction is set experimentally for the best picture. The wiring diagram for the coils is shown in Fig. 16.

The alignment of the BLAST picture is accomplished by simply capping the lens of one of the closed circuit television cameras and observing the picture on the BLAST tube. The darkened video causes alternate dark and light video to be displayed. This results in a Moire pattern on the screen if the left and right video segments are not aligned correctly behind the lenses. By careful adjustment of the static magnets in conjunction with the dynamic correction this Moire pattern can be minimized. When the Moire pattern is minimized the alignment of the video is the best. Adjustment can be made to the magnitude of the dynamic correction by turning the potentiometer on the coil driver circuit board. The dynamic correction has only a horizontal correction because this was found to be sufficient and the vertical correction was not needed. The static correction coils can adjust the scan so that the Moire pattern consists of vertical lines and the dynamic correction can then correct the horizontal alignment without any vertical correction being required.

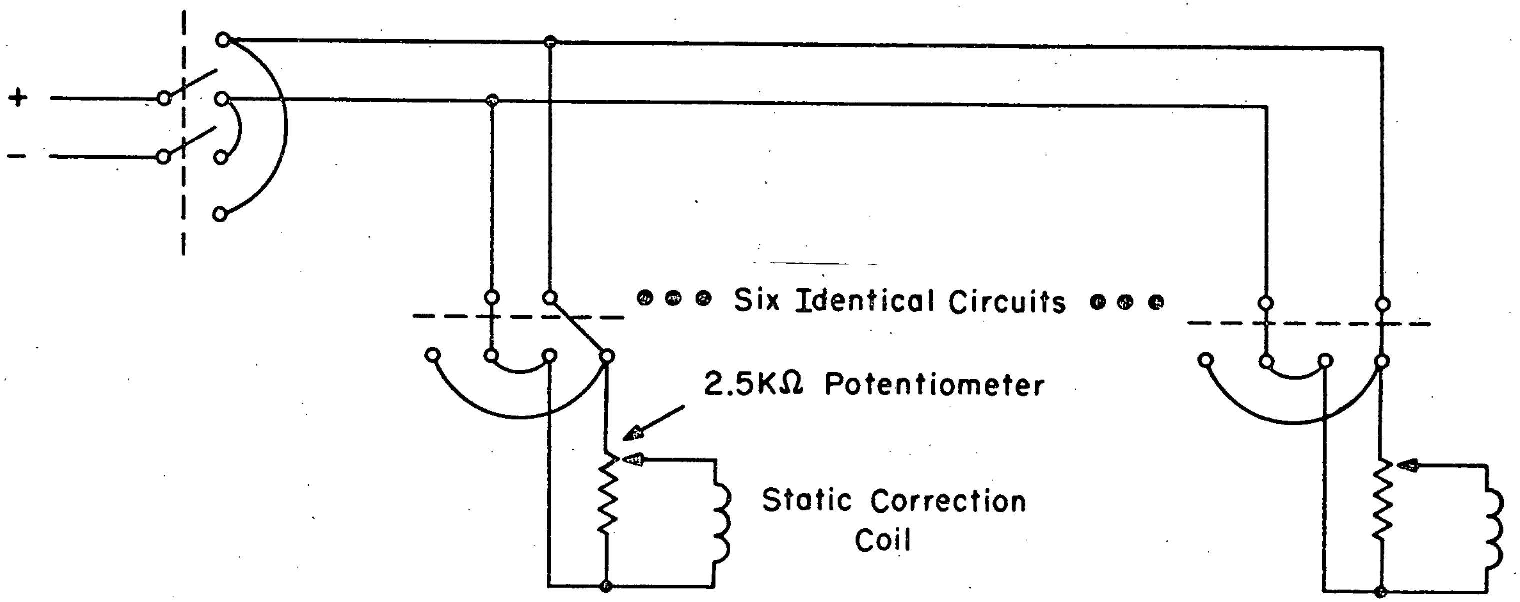

Figure 16. Static Correction Coils

6. SUMMARY OF THE BLAST SYSTEM

The BLAST system as completed is not the ideal system which was sought at the initiation of the research. As a result of major setbacks in manufacturing of the special BLAST CRT, the project's goals were modified. However, the major goal of proving that the "Xographic" stereoscopic method for producing 3-D pictures was compatible with a television-type display was accomplished. The subordinate goal of having the display fully automatic as far as alignment and synchronization are concerned was not accomplished, but the system demonstrates that the television system can be made sufficiently stable and accurate to maintain alignment over long periods of time.

Approximately, two-thirds of the stereo-image can be aligned satisfactorily with the cylindrical lenses of the lenticular screen. This results in a relatively complete separation of the images at the screen over this range. This is the center portion of the display and is the area of major interest since not much useful information is normally contained in the one-sixth of the screen on the edges.

The advantages of this system are that the user does not need to wear any special glasses to view the display and that there are several viewing zones at which viewers can situate themselves, so that more than one person can view the display at a time. Since no vertical parallax is maintained in this system, the multiple users can be at different heights with respect to the display.

One major disadvantage is that there is some noticeable feedthrough from the different images. This is primarily due to a misalignment which is minimized but is still present. Also, there is the possibility the lenses were not ground to exact specification and that there is a variation in the focal lengths and smoothness of the lens surfaces. The graininess of the display is also noticeable when the subject has very clean lines, with a textured subject the graininess is not objectionable.

7. CONCLUSION

The BLAST system demonstrates that a "Xographic" stereoscopic three-dimensional display can be built using a cathode ray tube television-type display. Even though the automatic alignment mechanism could not be implemented with the tubes which were purchased it is still felt this would be the best way of instrumenting the system. A comment should also be made with regard to the fact that synchronization pick-up might be more fruitful if a frequency signature technique(9) were used rather than having the indexing stripes occurring at the chopping frequency. In this manner the synchronizing information could be separated from the chopping noise more easily.

The system as completed would be suitable for distribution to several monitors as no feedback from monitor to chopping circuitry is required. In a feedback type system as discussed earlier only one monitor per chopper would be possible even though one set of cameras could feed several choppers. Another feedback method which could be implemented would use the synchronizing signal from the indexing stripes to correct the horizontal deflection in the monitor.

Certainly if this system were build on a mass production basis the cost of producing the special cathod ray tube would approach that of the present tri-color shadow mask tube, since the complexity is no greater. With this in mind the BLAST system would be nearly compatible with broadcast television since the required transmission bandwidth of BLAST is 5MHz.

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APPENDIX A

DETERMINATION OF FOCAL LENGTH AND MAGNIFICATION OF THE CYLINDRICAL LENSES

Using the Gaussian Formula

$$\frac{n}{s} + \frac{n'}{s'} = \frac{n' - n}{r} \qquad \text{(a)}$$

Where r is the radius of curvature of the cylindrical surface, n is the index of refraction on the convex side of interface, n' is the index of refraction on the concave side of interface, s' is the object/image distance and is positive when on concave side of interface and measured from the surface, s is the image/object distance and is positive when on convex side of interface and measured from the surface.

To determine the primary focal length, f, of the cylindrical lens

Set $s' = \infty$ Then $f = s$

From (a) $\frac{n}{f} + \frac{n'}{\infty} = \frac{n' - n}{r}$

Therefore $f = \frac{n}{n' - n} r$

$$f = \frac{1.000}{1.523 - 1.000} r = 1.91r$$

To determine the secondary focal length, f',

Set $s = \infty$ The $f' = s'$

From (a) $\frac{n}{\infty} \quad \frac{n'}{f'} = \frac{n' - n}{r}$

Therefore $f' = \frac{n'}{n' - n} r$

$$f' = \frac{1.523}{1.523 - 1.000} r$$

$$f' = 2.91r$$

Therefore, if the object is placed a 2.91r the image will appear at $s = \infty$, i.e. all light rays coming from the object will be parallel.

If object is at the focal plane, f', then light refracted through lens will emerge parallel from each point of object and magnification will be infinite since each point of the object will appear to fill the lens.

For object just inside focal plane magnification will be large and a virtual image will be formed.

APPENDIX B

SPECIFICATIONS FOR SPECIAL CATHODE RAY TUBE AND A LENTICULAR SCREEN

COO-1469-0171

Department of Computer Science

University of Illinois

Urbana, Illinois

Specifications for Special Cathode Ray Tube and a Lenticular Screen

by

Lawrence Wallman

File No. 550-134
June 15, 1970

Specifications for a Lenticular Screen

These specifications describe a flat piece of glass which has a lenticular surface on one side and a flat surface on the other. The lenticular surface consists of a series of partial cylindrical lenses placed side by side with their long axes parallel to each other and also parallel to the short dimension of the side. The lenticular surface is approximately 6 inches by 8 inches by .08 inches with 258 cylindrical lenses with a radius of curvature of approximately .031 inches placed side by side across the 8" dimension of the screen.

The lenticular screen is to be used in a cathode ray tube. It will have conducting strips and a phosphor deposited on the flat side and be mounted directly behind and parallel to the clear face plate of the cathode ray tube. The deposition of conducting strips and phosphor will be done by the tube manufacturer.

	Requirements
Type of Glass	The glass must have an index of refraction for yellow of 1.523. The common optical name of this glass is spectacle crown.
Size of the Lenticular Surface	The lenticular surface is 6" by 8".
Orientation of the Cylindrical Lenses	The long axes of the cylindrical lenses are oriented parallel to the 6" side of the lenticular surface.

Size and Period of the Cylindrical Lenses	Each cylindrical lens has a radius of curvature of .031 inches and the distance between the long axes of the cylindrical lenses is 0.031 inches. There are 258 partial cylindrical lenses across the 8 inch dimension.
Thickness of the Lenticular Screen	The thickness of the lenticular screen is .08 inches measured from the flat surface to the top of the cylindrical lenses.
Tolerance	± .005 inches on all dimensions. The centerline of each cylindrical lens is measured with respect to the first lens and the tolerance of ± .005 inches applies to this dimension. (e.g. The centerline of the 120th lens will be 119 x .031 or 3.689 ± .005 inches from the centerline of the first lens.)
Flatness	The flatside of the lenticular screen must be flat to within ± .005 inches.
Overall Size	The overall size of the lenticular screen is 7" by 9" and the lenticular surface is centered in this area. (i.e. There is a 1/2" border around the lenticular surface.)

Finish	The lenticular surface and the flat back side should be polished to a high degree of visibility.
Acceptance	Acceptance of the lenticular screen will be determined by the buyer.
Packing	The lenticular screen shall be packed so that it will not incur damage from handling, storage, or shipping.

Specifications for Special Cathode Ray Tube

These specifications describe a 12 inch round cathode ray tube which has a special lenticular screen mounted inside the tube directly behind and parallel to the clear faceplate. The electron gun and deflection coils are the same as that taken from a 14 inch tube used in Conrac Television Monitor Model CQF14.

The lenticular screen will be supplied to the tube manufacturer. The tube manufacturer will be required to deposit the nickel strips and the phosphor on the lenticular screen and build the tube with the lenticular screen mounted inside as outlined in these specifications.

General Data

Focusing Method	Electrostatic
Deflection Method	Magnetic
Phosphor	P4
Base	Small Sheel Duodecal 6 Pin
Cap	J1-21

General Electrical Data

Heater	6.3V	0.6A
Interelectrode Capacitance	Grid	5.5mmF
(to all other electrodes)	Cathode	10.5mmF
Heater to Cathode volts:	Heater positive	200V
	Heater negative	200V

	Max.	Typical Operating
Ultor voltage	22KV	18KV
G_2 voltage	500V	300V
G_4 voltage (Focus)	1100V	0 to 400V
G_1 voltage Neg. Bias	180V	
G_1 voltage for visual extinction of focused raster		-28 to -72V

Spot size: less than 6 mils at 100 ft. lamberts.

Physical Characteristics of Lenticular Screen

The overall size of the lenticular glass screen is 7" by 9". The lenticular surface is 6" by 8" and is centered in the 7" by 9" region.

The lenticular screen has cylindrical lenses on one side and is flat on the other side. The cylindrical lenses have a radius of curvature of 0.031 inches and the spacing of the long axes of the cylindrical lenses is 0.031 inches. The thickness of the lenticular glass screen is .08 inches. Tolerances are ± .005 inch.

The lenticular screen has the P4 phosphor deposited on the flat side and 6 mil nickel conducting strips deposited on the glass beneath the phosphor. These conducting strips are placed directly beneath the cusp between adjoining cylindrical lenses and parallel to and of the same period as the long axes of the cylindrical lenses. Connection to the conducting strips is made by means of two electrodes. One electrode is connected to the 1, 3, 5, . . . strips while a second electrode is connected to 2, 4, 6, . . ., etc. strips.

	General Data
Overall Size	7 inches by 9 inches by .08 inches.
Conducting Strips	Deposit on flat side on top of phosphor 6 mil wide nickel strips running parallel to and of the same period as the cylindrical lenses and located directly beneath the cusps between adjoining cylindrical lenses. The strips are connected together at the perimeter of the lenticular area and brought out of the tube as two leads. The alternate strips are electrically isolated from each other. The 1, 3, 5 . . . etc. are brought out as one lead and the 2, 4, 6, . . . etc. are brought out as a separate load.
Number of Conducting Strips	There will be 256 6 mil by 6 inch strips.
Tolerances	The tolerance on the width of the conducting strips is ± 20% of the width of the strips (i.e. ± .0012 inches). The tolerance on the registration of the centerline of the strip with respect to the cusp of the cylindrical lenses is ± 20% of the spacing of the strips (i.e. ± .062 inches).
Orientation of the Screen	The lenticular screen is mounted directly behind and parallel to the faceplate of the tube. The lenticular surface is turned to

the viewing or front end of the tube and the flat side of the screen must face the electron gun end of the tube. The long axes of the cylindrical lenses are to be oriented perpendicular to the normal horizontal scanning pattern of the tube.

Acceptance

The acceptance of the cathode ray tube will be determined by the buyer.

Warranty

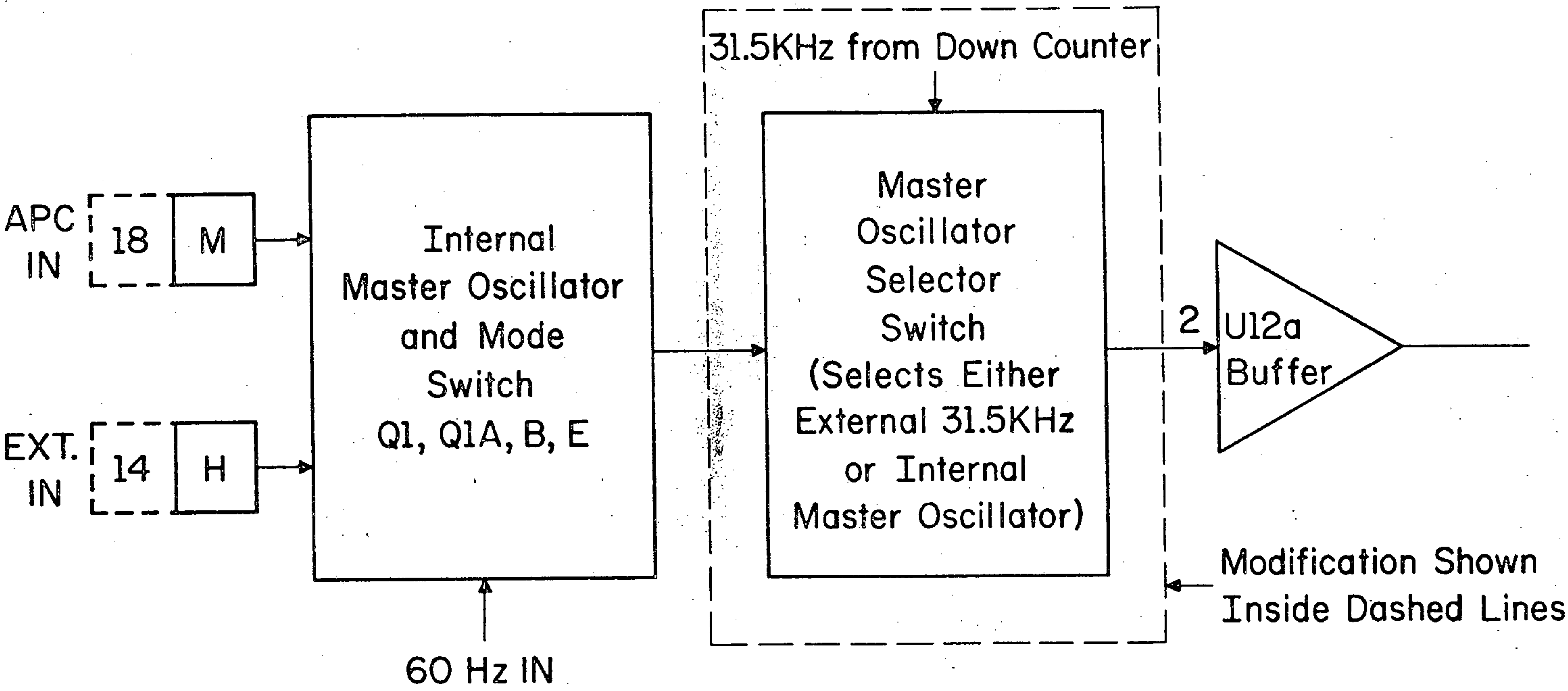
The tube will be warranteed for initial workmanship as delivered and will be further warranteed for fifteen (15) hours full warranty and fifty (50) hours pro rata.

Packing

The cathode ray tube shall be packed so that it will not incur damage from handling, storage, and shipping.

APPENDIX C

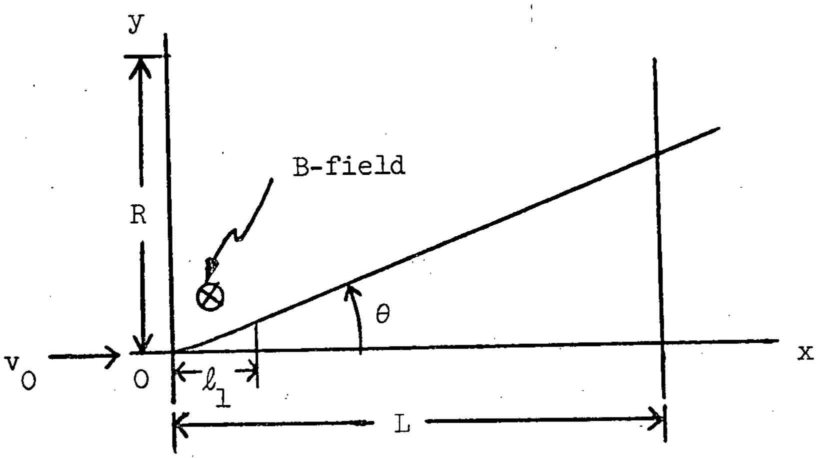
MODIFICATION TO SYNC GENERATOR ASSEMBLY



Modification to Sync Generator Assembly

APPENDIX D

To determine the dependence of θ on I.



Assume electron enters B-field with constant velocity v_0. B-field extends from $x = 0$ to $x = \ell_1$. Charged particle in B-field travels in a circular path with radius R.

Equation of path

$$x^2 + (y - R)^2 = R^2 \text{ where } R = \frac{mv}{eB}$$

so $y = -(R^2 - x^2)^{1/2} + R$ in first quadrant

Then since $\tan\theta = \frac{dy}{dx}$

$$\frac{dy}{dx} = -(1/2)(R^2 - x^2)^{-1/2}(2x) = \tan\theta$$

At $x = \ell_1$

$$\tan\theta = \frac{\ell_1}{(R^2 - \ell_1^2)^{1/2}}$$

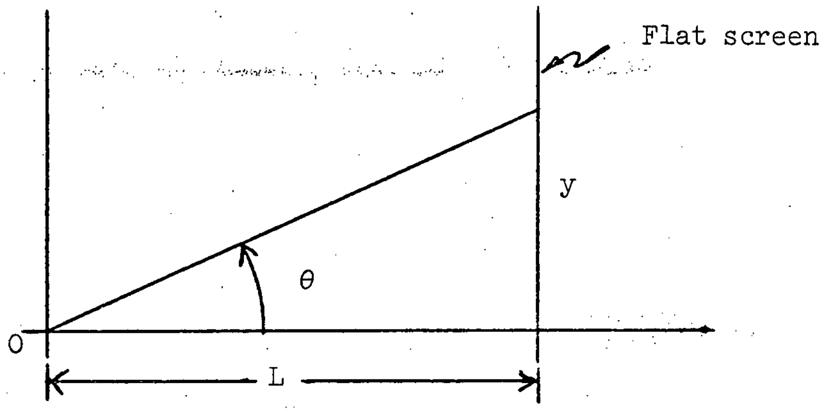
Therefore $$\sin\theta = \frac{\ell_1}{R} = \frac{eB\ell_1}{mv_0}$$

$$\sin\theta = K_1B$$

and also know $B = K_2I$

so that finally we have $\sin\theta = K_3I$

To determine I(t) to give a scan with constant velocity



The quantities in the drawing are defined as follows

θ: Deflection angle

O: Deflection center

L: Distance to the screen from the deflection center for $\theta = 0$

y: Deflection distance

From drawing

$$y = L \tan \theta$$

For constant velocity scan, it is true that

$$y = K_1 t$$

then, $\tan \theta = \frac{K_1 t}{L}$

also, $\sin \theta = \frac{K_1 t}{\sqrt{L^2 + K_1^2 t^2}}$

From the previous section

$\sin \theta = KI(t)$

Therefore, $I(t) = \frac{K_1 t}{\sqrt{L^2 K^2 + K^2 K_1^2 t^2}}$

APPENDIX E

CALCULATIONS CONCERNING THE VOLTAGE-TO-CURRENT CONVERTER

From Figure 18 it is seen that

$$I_1 = I_2 \qquad \text{(a)}$$

$$I_1 = e_1/R_1 \text{ and } I_2 = -e_0/R_2 \qquad \text{(a)}$$

and then, $$e_1/R_1 = -e_0/R_2 \qquad \text{(b)}$$

Also from Figure 18 we have

$$I_3 = e_0/R_3 \qquad \text{(c)}$$

then substituting from (b) into (c),

$$I_3 = \frac{e_1R_2}{R_1R_3} \qquad \text{(d)}$$

From Figure 18

$$I_y = I_3 - I_2 \qquad \text{(e)}$$

Then substituting from (d), (b) and (a) into (e)

$$I_y = -e_1\left(\frac{R_2}{R_1R_3} + \frac{1}{R_1}\right)$$

If, $$R_1 = R_2 \gg R_3$$

$$I_y = -\frac{e_1}{R_3}$$

Therefore, the current in the coil is directly proportional to the input voltage.

VITA

Lawrence Henry Wallman was [redacted] He graduated from Christian Fenger High School, Chicago, in 1962. He attended the University of Illinois, Navy Pier Branch from February of 1962 until September of 1964. He then transferred to the Urbana-Champaign Campus of the University of Illinois where he received his B.S. in Electrical Engineering in June of 1966. Mr. Wallman entered the Graduate College of the University of Illinois in June of 1966. At that time he joined the Hardware Systems Research Group of the Department of Computer Science under Professor W. J. Poppelbaum as a graduate research assistant. He received his M.S. in Electrical Engineering in June of 1968 as a result of work performed under Professor W. J. Poppelbaum. Since then he has continued to work under Professor W. J. Poppelbaum toward a Ph.D. degree in Electrical Engineering.

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16. Abstracts

The Binocular Lenticular Automatic Stereo Television System as proposed by Dr. W. J. Poppelbaum is a closed-circuit stereoscopic television system. The system uses the "Xographic" method of generating a 3-D display. This method uses a series of vertically oriented cylindrical lenses which by refraction cause the left and right eye images to be separated at the screen rather than requiring the viewer to wear special glasses to separate the images at his eyes.

This thesis describes the several attempts made in trying to build an automatically aligned system and the final system which is not automatically aligned.

17. Key Words and Document Analysis. 17a. Descriptors

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Television
Three dimensional
Xography

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