DEVELOPMENT OF A PULSED X-RAY TELEVISION FLUOROSCOPE FOR BIODYNAMIC RESEARCH

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FOREWORD

The development and work reported herein was carried out over the period August 1963 to May 1966 under Project 7231, "Biomechanics of Aerospace Operation," Task 723101, "Effects of Vibration and Impact."

The efforts of W. Q. Leysath and K. R. Horning were applied under Air Force Contract AF 33(615)-1878 with Admiral Corporation, Government Electronics Division, 3800 Cortland St., Chicago, Illinois 60647. Admiral Corporation was responsible for taking the initial concept of the instrument and translating this into specific hardware. Dr. E. B. Weis, Jr., of the Vibration and Impact Branch, Bionics and Biodynamics Division, Biomedical Laboratory, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, conceived the instrument as well as tested the prototype.

The device is operational at this date but development along with operational use continues inasmuch as there is considerable promise of evolving this item to a state well beyond anything commercially available both for biodynamic research and for some aspects of clinical radiology.

This technical report has been reviewed and is approved.

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ABSTRACT

This work presents a logical picture of a biodynamics instrumentation requirement, a design to answer the requirement, testing of the prototype, evaluation of the quality of the prototype, and a discussion of the advantages and limitations of the design. The operational nature of a high-speed X-ray device with certain advantages for biodynamic research is discussed. The final nature of the device is found to have certain advantages over commercially available X-ray units for general medical research purposes as well as for general clinical radiology.

SECTION I

INTRODUCTION

Biodynamic studies of man's tolerance limits for vibration and impact have been seriously hampered by a lack of an instrumentation technique to produce the measurements necessary to define the mechanodynamic characteristics of various internal organs and body segments. Conventional sensors or transducers for direct measurement of forces and displacements are not helpful because such techniques cannot ordinarily be implemented in man and because such techniques actually influence the variables to be measured. The body organs and segments, whose motions are to be measured, are actually deformable bodies and, as such, present formidable instrumentation problems.

This report concerns the result of a study of this instrumentation problem and the development of one solution. Primary consideration was given to exploration of sonic or electromagnetic wave instrumentation techniques. The sonic techniques were discarded because the antennae required are not feasible in a vibration or impact environment and because the quantitative aspects of such measurements are not sufficient for the desired accuracy and precision. There seems to be only one optical method which offers the potential to produce measurements of internal motions and this is nuclear radiation in the energy region of medical X-ray (40-120 kev).

Biodynamic research presents a unique requirement in terms of an X-ray system. In biodynamic research one studies subjects in mechanical energy environments (acoustic, vibration, impact, buffeting, etc.) and one wishes to reveal the effect of the environment on the body structure (as well as on the body physiology). However, such an environment implies dynamic motion of the subject and perhaps also the X-ray system. For example, the tolerance of man to ejection seat firing is a subject of considerable importance to the

Armed Forces and, indirectly, to land transportation equipment manufacturers. The study of such tolerance is reported elsewhere (Refs 1-4). It can be seen from this work that conventional techniques for instrumentation and analysis do not provide complete answers regarding structural limits and mechanical tolerance factors.

Therefore, the X-ray television system which is to be described in this report represents an effort to exploit basic radiology techniques by applying advances in television technology in order to provide an instrumentation system which will produce measurements of displacements in subjects exposed to biodynamically significant environments. The design and its problems will be spelled out, the results of testing will be presented. The performance, in terms of exposure dosage and picture quality will be reported and the basic limitations of the system as well as prospects for further development will be discussed.

X-ray density images are produced for the clinical radiologist by three more or less standard techniques (in terms of equipment). The usual X-ray film is produced by exposing a negative with emulsion on both sides which is placed between calcium tungstate intensifying screens to the X-ray beam which has passed through a subject. This produces an image with considerable contrast and resolution. Ancillary techniques, such as focused grids, are used to reduce the effect of scattered radiation which acts to decrease the contrast and resolution (at the expense of increased dosage). This high image quality is obtained at the expense of a relatively long exposure time to produce an image which is a time average. Exposure dosages necessary for an average chest X ray are in the range of 40-400 milliroentgens.

Fluoroscopy is a standard technique which has undergone considerable changes because of recent advances (References 5-13). Before 1948, fluoroscopy was accomplished by replacing the film, mentioned previously, with a zinc cadmium sulfide screen. The image produced was visualized directly by eye. The image produced by this technique is also a time average because of the relatively long decay constant in the screen. In addition, the relative inefficiency of screens which fluoresce in the visible spectrum requires high dosage for interpretable images (in excess of six roentgens per minute).

The image amplifier has provided a considerable advance in fluoroscopy in that electronic amplification increases the brightness of the viewed image at considerably reduced exposure dosage. In this technique the X-ray beam emergent from the subject falls on a tube which has a faceplate coating of photoelectric material (usually the same as a fluoroscope screen). The electrons emitted by this screen are accelerated and focused on a similar viewing screen on the other end of the tube. Exposure dosages in the use of an image amplifier range up to 2.5 roentgens per minute. Most operation is probably about 1 roentgen per minute. Again the use of fluorescent materials active in the green region commits the system to relatively long time constants in the decay of an image so that each image is a time average.

Television techniques have recently come into use in radiology. Usually a standard television camera is used to reproduce an image amplifier screen. The sensitivity of certain television camera tubes provides a further reduction in the required exposure dosage.

A vidicon tube which is directly sensitive to X-ray energy has been used.

This is a television tube which has a photoelectric screen on the tube face. Stimulated photoelectrons from this screen pass through a grid to strike a lead oxide coating on the interior surface of the tube face changing its conductivity at each point in proportion to the X-ray intensity. The scanning beam of the vidicon is then played over the lead oxide. The conductivity of the lead oxide determines the current flow which is collected by the interposed grid. This current flow represents the video signal. The phosphor used in these tubes is the same as in the image intensifier.

Thus, most standard X-ray units have the inherent limitation that the image produced is a time average. If there is gross motion, it is a space and time average. In terms of the subject medium this means that the frequency response of the visual system is poor. In other words, motion of the subject produces a deterioration of the image.

There are a few instances in clinical radiology when this sensitivity to motion is troublesome. In angiography (X-ray visualization of blood vessels using contrast media), including cardiac catheterization, one needs high quality X-ray images without loss of quality due to motion. X-ray units are beginning to be used in physiological research where the dynamic events are the essence of the experiment. The image amplifier has been used to study cardiac blood flow (Ref 14) by measurement of the change in X-ray density of the image during the heart cycle.

The design objectives were not entirely clear in the beginning inasmuch as a concept of instrumentation for biodynamic research was sought as well as a specific implementation of the concept. The general character of the concept called for good frequency response (0-30 cycles per second acceleration), high accuracy (2% on motion referred to the input to the system itself) negligible loading* by the instrument of the subject, ease of data handling and ruggedization. This latter requirement was indeed important because the device had to function on various motion environment simulators in acceleration environments up to 391 meters/sec^2 with total displacements up to 12 meters.

When it became clear that an X-ray television system was the most promising, further objectives were spelled out. The resolution of the system was to be such as to pick up 1 mm objects at 100% contrast ratios. The dosage required for a test of $\frac{1}{2}$ second duration at 30 cycles per second excitation had to be less than 2 roentgens. The system was to function (and produce high quality data) on a shock facility at 157 meters/sec^2 (half sine wave - 150 milliseconds - 9.45 meters/sec) as well as on a vibration table (1.27 centimeters displacement, 2-14 cycles per second - 49 meters/sec^2, 14-30 cycles per second).

There were several specific uses for which the device was intended at the design stage. It was intended that the television system function alone as a visual data handling system for tests involving the motions of the body surface. A specific example involves making measurements on prototype restraint systems as part ofan effort aimed at the development of design criteria for restraint harnesses. It was intended that the X-ray television combination be used to study the motions of the human heart and spine in response to acceleration excitation such as might be experienced in an ejection seat. It was intended that the entire system be used in conjunction

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* Loading implies that the presence of the measurement system itself affects the measurement.

with vibration table experiments with human subjects to locate and explain the causes for the pain and symptoms which limit the human tolerance to vibration.

SECTION II

SYSTEM DESIGN

There were two basic problem areas at the outset of this design effort. The acceleration environmental specifications and the subject dosage limitations. There were, of course, other problems which were related to the basic exposure dosage limitations such as resolution. The design effort was limited in scope to adaptation of commercially available components. A television system for pickup of the X-ray density image was therefore determined to be the most promising by early feasibility studies. Several possibilities were considered for converting the X-ray density image into a video signal but the most promising seemed to be the use of an ultra low light level image orthicon and a fast fluorescent screen. This decision was based on the requirements for low dosage, high resolution and fast image discharge for high speed sampling. While little data was available regarding acceleration tolerance of low light level image orthicons, the manufacturers were willing to guarantee a tube for the testing required in the development. The use of an image storage tube then nearly dictated a pulsed X-ray beam to avoid the image averaging which would occur at the target and to reduce the exposure dosage. A grid controlled X-ray tube was therefore sought. Even less data was available regarding the acceleration tolerance of such tubes. However, the manufacturer (Machlett 50 C shockproof, rotating anode, grid controlled tube) agreed to provide a reject tube to undergo the specific testing required in the development.

Therefore, the system was originally conceived as shown in the overall block diagram in Figure 1. With a basic design it was then necessary to check the X-ray exposure dosages required to make the system operate with sufficient resolution and contrast and finally to test the system performance in the acceleration environment.

The fast fluorescent screen chosen was, in fact, an X-ray intensifying screen (Radelin Type TF). The image orthicon (General Electric Z7806) was chosen for a match of its spectral sensitivity to the spectral emission of the intensifying screen and for its extreme sensitivity. There is relatively little engineering information available regarding the quantitative aspects of X-ray intensity input to the visible light output conversion by the screen. Therefore, tests were conducted to reveal the X-ray intensity required at the screen to operate the image orthicon. From this data and data regarding attenuation ratios and absorption factors for X-ray subjects, the exposure intensity and dosages to subject were calculated. These figures showed the system to be entirely feasible from the standpoint of dosages. Calculations of the resolution figure inherent in the system based on published specifications for each component were made and found to be acceptable at about 340 lines of vertical resolution and 600 lines of horizontal resolution.

Tests were conducted to show that the image orthicon and X-ray tubes would tolerate the specified acceleration environment. The television camera was shown to be unaffected by an acceleration pulse of 391 meters/sec^2 of duration 11 milliseconds (triangular shape). The X-ray tube similarly tolerated the impulse. In vibration testing, however, the target of the image orthicon was damaged by particulate matter within the envelope of the tube. The manufacturer replaced the tube and the tests were carried out on the television camera and X-ray tube at 49 meters/sec^2 acceleration or 1.27 centimeters displacement (the lower stress) up to 30 cycles per second with no deterioration of function.

The television camera was also tested for direct X-ray sensitivity by showing that a video picture was unaffected by maximum X-ray intensity exposure to the lens and image orthicon.

Therefore, it appeared that the system was entirely feasible and the actual fabrication was undertaken. A Profexray Model A9800 X-ray control unit was chosen and modified to include X-ray tube grid bias control interlocks and X-ray interlocks to permit remote activation of the system. An X-ray pulse generator was developed which was composed of a Profexray (Type A-10100) Model A-10100 X-ray generator and grid pulsing circuitry manufactured by Admiral. The X-ray generator was modified by replacing the vacuum tube diodes and filament transformers with silicon rectifiers. The X-ray tube grid bias and pulsing circuitry was installed in a high voltage tank and connections were established with the X-ray generator. A block diagram is shown in Figure 2.

The system timing is accomplished by phase lock of the television scan and the X-ray tube grid pulse independently to the 60 cycle per second supply line. A diagram showing the relationships is shown in Figure 3.

The television camera, camera control unit and video processor are Admiral Corporation units previously developed for military applications.

Block diagrams for these units are shown in Figures 4 and 5. The video processor generates ramps representing the vertical and horizontal position of the scan within a gate which size and position can be varied over the scan. These ramps are sampled by a level detecting circuit operating on the video signal within the video processor gate. These samples are output as 60 cycles per second square wave error signals whose amplitudes represent the position in the scan at the time the video signal activates the detector circuit. The television monitor is a Miratel Model ML 17 RG. An Ampex VR660 video tape recorder is used for storage of the video signal. System tests with this unit installed show that the output signal is in the range of 250-275 lines of resolution. Photographs of the system components are shown as Figures 6, 7, and 8.

The system functions as follows: The operating parameters are set up. These include the camera focus, lens aperture, beam current, video gain, monitor contrast and brightness, X-ray kilovoltage and milliamperage and X-ray timer. The operator presses a standby button which causes the X-ray control unit to check operation of all interlock circuits. When this is complete, the exposure control is activated. When the operator presses the exposure control, the X-ray control unit timer is activated and begins the exposure. This is accomplished by enabling the grid pulsing circuitry and applying power to the X-ray pulse generator transformer primary. In terms of a single grid pulse the following events occur. The image orthicon target is blanked just prior to the peak of the 60 cycles per second power supply. At the peak the X-ray tube grid is driven to the cathode for one millisecond. The resultant X-ray beam passes through the subject and produces a fluorescent image on the screen. The emitted blue light is conducted by a light proof bellows assembly to a lens (1:095 - 50 mm - Canon) and focused on the photocathode of the image orthicon. The emitted photoelectrons are focused on the target to produce a positive charge image of the X-ray density pattern of the subject. The scanning section of the image orthicon is actually scanning the first 6% of the target during the time the image is forming since the X-ray pulse cannot occur in the blanking interval. The scanning beam current which is not absorbed by the target is collected by the electron multiplier and appears as the video signal on the monitor, tape recorder and video processor after passing through the video amplifier in the camera control unit and the video patchboard. At the end of a scan the target is blanked and the sequence is repeated. When the timer expires, the X-ray control unit removes the power from the X-ray pulse generator.

The design specifications called for operation of the system up to 391 meters/sec^2 and the camera and X-ray tube were actually tested to this point. However, as a safety factor and to prolong the life of the system, an isolation mechanism using crushable paper honeycomb was designed and fabricated. This limited the loading of the system to 150 meters/sec^2 by permitting constant force displacements of the X-ray tube and television camera. The design specifications called for total system displacements up to 12 meters so the television camera included line drivers for 85 meters of cable. The X-ray high voltage cables were made 17 meters long since the X-ray pulse generator could be located more favorably.

SECTION III

TESTING

The effectiveness of the design will be discussed under four categories: (1) Measurements of Contrast and Resolution; (2) Exposure Dosages; (3) Performance under Vibration and Impact; and (4) Performance of Video Tracking Circuitry.

(1) Contrast and Resolution

A contrast phantom was constructed of pure aluminum (Figure 9). It consists of 16 discs of 2.5 millimeter aluminum. These varied from 1.27 centimeters to 20.3 centimeters in diameter in 1.27 centimeter increments of diameter. These discs are arranged in a pyramid. This produces 17 steps of gamma attenuation from 0% to 95%. This was studied with a beam intensity of 50 milliroentgens per second (Figure 10) with the back of the phantom 30.5 centimeters from the tube filter (110 kv). A picture of the video display is shown in Figure 11. Pictures of a line of video signal through the center of the phantom are shown in Figure 12. As the X-ray beam intensity is decreased, the video signal to noise ratio increases and the number of steps countable decreases. The maximum number of steps countable is 14.

A resolution phantom was constructed of .066 millimeters copper (Figure 13). This was produced by a standard printed circuit technique and the copper is mounted on a Fiberglas backing. The lines in the resolution phantom (by measurement) range from 7.9 lines per centimeter to 39.4 lines per centimeter. When this phantom is set up to fill a 16.8 by 22.8 centimeter television field, this corresponds to a range of from 59.1 lines per target centimeter to 295 lines per target centimeter (referred to the image orthicon target).

With an X-ray beam intensity of 20 milliroentgens per second (Figure 10), the resolution is found to be 118 lines per target centimeter or 19.7 lines per centimeter referred to the phantom. As the video gain is increased, the resolution is decreased, of course. A picture of the video display is shown in Figure 14. A picture of a video line at the stated resolution figure is shown in Figure 15. It is very clear that the noise from the image orthicon is limiting the resolution. One might suspect that X-ray scattering might limit the resolution; but when the resolution phantom is placed behind 2 centimeters of aluminum, the resolution phantom is still detectable and shows resolution between 79 and 118 lines per target centimeter.

(2) Exposure Dosages

A Victoreen Ion Chamber R-Meter was used to measure the exposure dosages. The back of a 250 milliroentgen chamber was situated 30.5 centimeters from the tube face. All readings were reduced to milliroentgen per second figures by normalizing to one second using the X-ray timer which has been shown to be accurate within ±5%. The results of these measurements are illustrated in Figure 10.

The minimum exposure dosage required to produce a 1 volt video signal at maximum video gain (without saturation) has been measured in the range of 2-4 milliroentgens per second.

The pulsed nature of the X-ray tube operation changes the rms value of the current through the tube. Operating with a filament heat designed to produce a current of 50 milliamperes rms, this device provides a current of (1/16.67) x (50 milliamperes rms) or 6% of 50 which is 3 milliamperes (rms).

(3) Impact and Vibration

The entire system was mounted on a shock facility known as the Vertical Deceleration Tower at the Aerospace Medical Research Laboratories. A test phantom consisting of a wooden box lined with Fiberglas (internal dimensions, 22.8 centimeter cube) was positioned in the X-ray beam. Inside the box a vertebra from the lumbar spine of a dog and a carbon cylinder rod of length 2.5 centimeters were mounted on either side of the center line. With the box filled with water the carbon cylinder was barely visible and the vertebrae was felt to be visible by some observers. With no water in the box, both objects were very clear. These structures were quite clear in 15.2 centimeters of water. The structural screws in the box were visible at all times.

This test setup was subjected to a deceleration profile of the form (very approximately) of a half-sine wave of amplitude 157 meters/sec^2, of duration 150 milliseconds, and of area about 9.45 meters/sec. Detailed study of the sequence of television fields recorded on video tape showed no relative motion of the fixed objects. The system functioned perfectly. The same test setup was employed to study the chest of a dog under the same impact conditions. Again the system functioned perfectly and thus produced the first direct observations of the motion of the heart during impact.

The entire system was mounted on a Mercury Reaction Vibration Table (Figure 7) which produces a sinusoidal displacement. Studies of the system performance were carried out at 1.27 centimeters of displacement (double amplitude) from 2-13 cycles per second and 49 meters/sec^2 (double amplitude) from 14-20 cycles per second. Again the system functioned perfectly producing good quality pictures with no distortion.

(4) Video Trackers

A test device was constructed which would produce a dynamic video pattern on which the video trackers could operate. This consists of a plexiglas wheel on which is mounted a lead disc with a hole in it. The wheel is driven by a simple AC motor by a belt and pulley arrangement. By varying the pulley ratios the revolution rate is altered. The device is shown in Figure 16. The video display which is produced is shown in Figure 17.

Since the video trackers have both vertical and horizontal outputs, the moving target was simply displayed on an oscilloscope by driving the vertical error signal and the horizontal sweep with the horizontal error signal. The oscilloscope display is shown in Figure 18.

The operation of the video trackers is such as to produce one sample of the horizontal and vertical position of the target per television frame. Thus, the display magnitudes are independent of frequency, and so only the number of samples per revolution varies with revolution rate.

The trackers are effective on contrast material which is 100 millivolts above the background. Since the contrast levels inherent in the X-ray pictures as the unit now exists are below this, it is not possible to track motions in the biological subject. However, by inserting silver clips in the subject, it has been made possible to follow the motion of the structure to which the clip is attached.

SECTION IV

PICTURE QUALITY

The quality of the X-ray picture is an extremely subjective matter. Radiologists will seldom agree on the relative quality of the image intensifier display since each individual bases the interpretation on different aspects. The quality of picture produced by the image intensifier or the unit described here is difficult to evaluate in a completely general manner. The comparison of the X-ray film and the image intensifier is difficult because of the difference in the averaging time which affects the signal to noise ratio. X-ray film sensitivity can be varied against X-ray beam intensity with exposure time as a covariant to produce an image that is a long time average (with no motion). This has the effect of averaging out the quantum noise to raise the signal to noise ratio. This is possible because with the right film sensitivity and exposure factors, the film is essentially an integrator. The image intensifier has some of this effect because of the decay time inherent in the phosphor and because of the averaging time inherent in the eye (about .2 sec). It is certainly not as great as the film. This basically affects the contrast ability of the image intensifier.

The device described here suffers from comparison in this respect because there is virtually no time averaging occurring at all. One millisecond is the exposure time available for averaging by the screen. Moreover, the decay constant in this screen is of the order of tens of microseconds. This will always be the case if one demands high frequency response.

The image intensifier has a poorer resolution at about 11.8-15.7 lines per centimeter (as measured on a clinical unit at AMRL and referred to the phantom in 8.9 centimeter diameter field). The image intensifier, however, has a better contrast ability. All 17 steps on the contrast phantom can easily be counted. Image intensifier displays of the contrast and resolution phantoms are shown in Figures 19 and 20.

Certainly, the presence of motion produces an inferior picture quality in both the X-ray film and the image intensifier compared to the unit described here.

Several radiologists and physicians familiar with image intensifiers were asked to review the picture quality and all expressed the conviction that the picture obtained with the unit described here was very comparable with the picture they were used to seeing. They were uniformly enthralled with the lack of need of a darkened room.

Considering the factors mentioned above and because it is technically extremely difficult to get a still photo of a single television field with a film negative of sufficient size, no attempt will be made to present a photo of a single television field. However, using a 1/10 second shutter speed, photos are available as shown in Figure 21. This photo represents a time average of six television fields. It can be seen that the picture quality is clearly acceptable. It may be said that the quality of a single television field as seen from 16 millimeter films of the television screen (shutter speed 1/100 second) is poorer because it is noisier. However, one seems to be able to identify the same structures in both.

SECTION V

PROBLEMS AREAS

There are two factors inherent in this device which make it less than perfect. (1) The noise inherent in the image orthicon acts to limit the contrast and resolution ability. (2) While this unit requires low dosages compared to a fluoroscope, it requires higher dosages than an image intensifier by as much as six-fold. The normal operating range for this device is the maximum operating figure for the image intensifier.

The minimum noise inherent in the video signal which is finally displayed is about 1/25 of the full video range for a signal to noise ratio of about 28 dB. Efforts are being directed toward development of video filters and derivative type crispeners to enhance this signal to noise ratio, but it is not reasonable to expect to produce a dramatic improvement by these simple methods. The basic source of the poor signal-to-noise ratio is in the amount of beam current. The image orthicon is constructed to function with a beam current high enough to just discharge the highlights of the target. However, this means that the low intensity areas of the target barely affect this large beam current, and so the signal from these low intensity areas may not be much larger than the noise inherent in the electron beam. One can see that the most desirable condition as regards signal to noise ratio is to just supply enough beam current at every point of the target to completely discharge it. A method for accomplishing this has been suggested (Ref 15). In this scheme the electron multiplier in the image orthicon is used as an amplifier in a beam control servosystem. The object is to hold the electron current through the multiplier at a constant value just above the basic noise level. Any increase in the electron current over this value is sensed as an error and used to lower the original beam current used to scan the target. Thus, the video signal now appears as the amount of beam current delivered rather than the amount of return beam current collected. There is promise of an increase of the signal to noise ratio to about 1/8000 or 78 dB according to the cited reference. While this seems rather high, it is clear that considerable improvement may be expected if the problems in implementation of the concept are soluble within the state-of-the-art.

The exposure dosage required to operate the video system is acceptable for many purposes, but in keeping with the spirit of Radiological Health concepts, the objective should be to hold it to an absolute minimum. As the unit now exists a Radlin Type TF intensifying screen is used. There are faster screens (by about 30%) which would require lower dosages (by 30%). They were not chosen originally because of the poorer resolution which is inherent with the speed. However, the testing which has been done indicates that the loss of resolution which would be associated with the use of faster screens will not affect the resolution of the overall system unless one desires to use a very small field of view.

Since the X-ray beam is pulsed, one might think that the dosage could be reduced by reducing the X-ray pulse width, but this is not the case. The image orthicon has a certain "speed." That is, it must receive a certain minimum total amount of light in order to produce an image just as in the case of film. Thus, if the width is reduced, the intensity must be increased to provide the minimum amount of light from the screen necessary to operate the image orthicon. However, one might expect to obtain a better picture by decreasing the pulse width and increasing the intensity because the quantum noise in the beam would be relatively lower.

SECTION VI

ADVANTAGES OF THE DEVICE

The size of the viewing area which can be studied with this device is virtually unlimited. There are limitations, of course. The X-ray beam geometry and intensity will not permit extremely large viewing areas because of divergence in the beam (producing a penumbra and loss of resolution as well as distortion) and square law falloff in intensity. Since the resolution of the image orthicon is fixed in terms of lines per target centimeter, there are only so many lines per field centimeter; and when the field reaches a certain size, the field resolution will become unacceptable.

The fact that the image is available as a voltage as a function of time means that it can be stored on magnetic tape or processed in any desirable manner to enhance certain aspects of the video image.

The resolution of this device is, as it exists, beyond the resolution capability of the standard image intensifier.

The television system is not inextricably linked to the X-ray unit so that it may be used for standard video purposes.

The short X-ray pulse produces a stroboscopic effect as regards stopping motion so that virtually any physiological velocity will not deteriorate the image. The sampling rate, however, limits the frequency response to 30 cycles per second. Above 30 cycles per second there will be less than two samples per cycle of sinusoidal motion, and, as one knows from the sampling theorem, there are not enough samples to reconstruct the motion.

The device operates entirely in ambient light in contrast to image intensifiers. The only light proof coupling required is between the screen and the image orthicon. This coupling system is itself quite flexible and simple in nature.

The system has been shown to be entirely rugged and completely functional in biodynamic environments at and beyond the tolerance capacity of man. The single limitation found is that the image orthicon may not be tilted photocathode down (camera lens down). The tube cannot be exposed to motion environment with components along the long axis of the tube. This type of motion will cause any particles within the envelope to strike the target, and this will destroy a certain area of the target.

SECTION VII

DISADVANTAGES OF THIS DEVICE

The contrast attainable with the device, as it exists, is limited. There is, however, considerable promise that this can be drastically improved.

The dosage required for operation of this device is, at present, somewhat higher than that required for an image intensifier but there is considerable expectation that this will not be true with the reduction of the signal to noise ratio in the image orthicon and the use of faster intensifying screens.

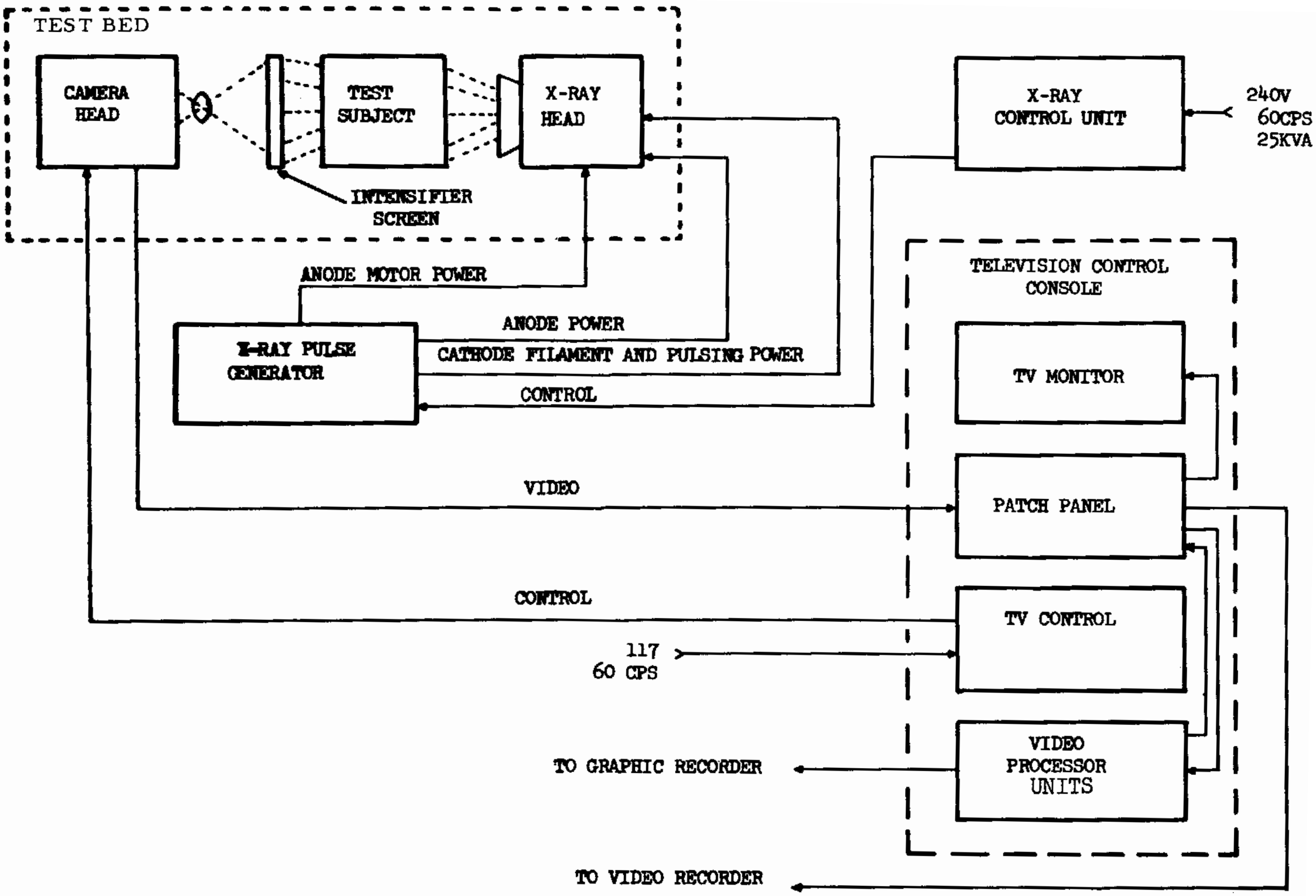

Figure 1. System Block Diagram

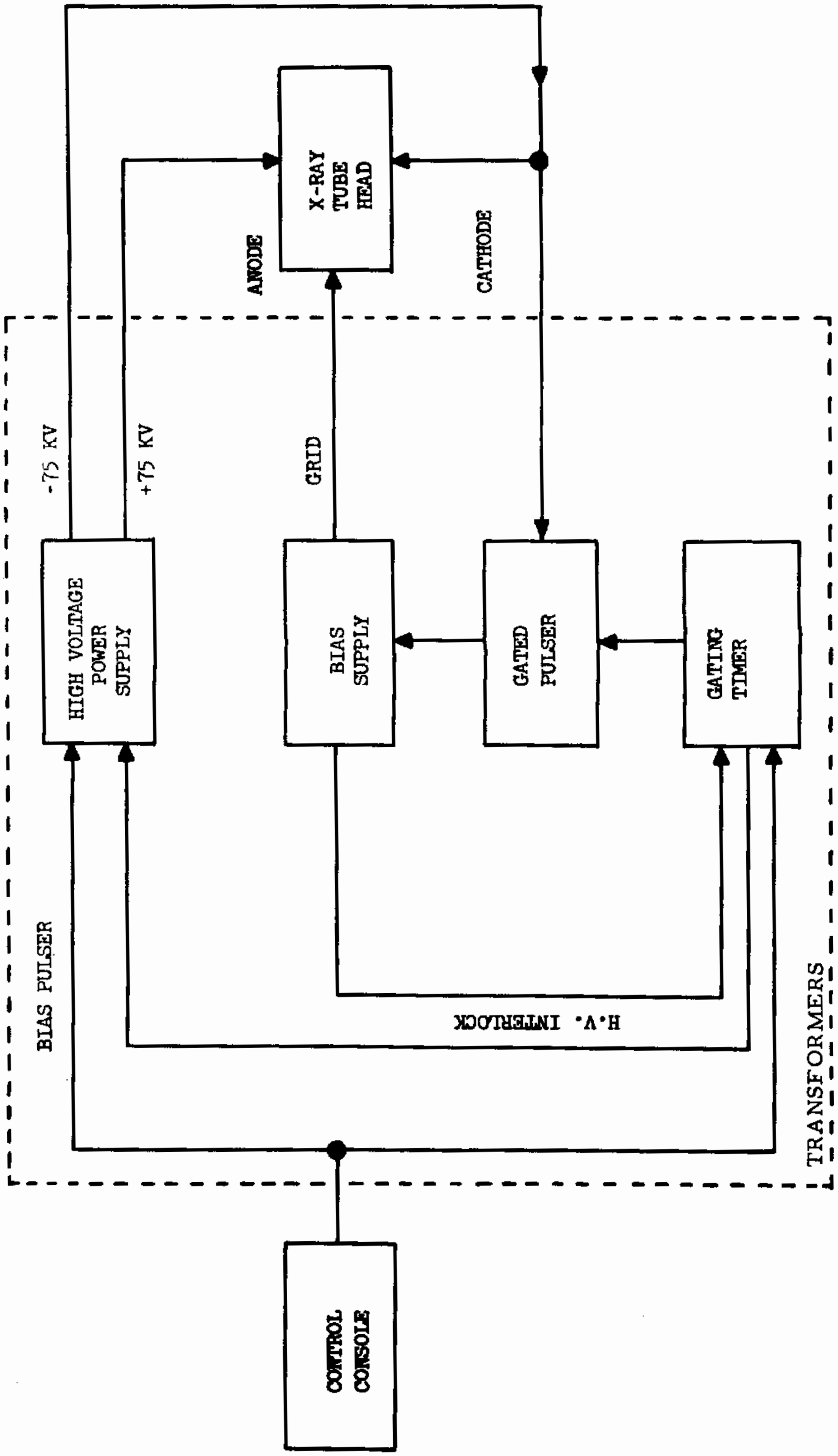

Figure 2. X-Ray Pulse Generator Block Diagram

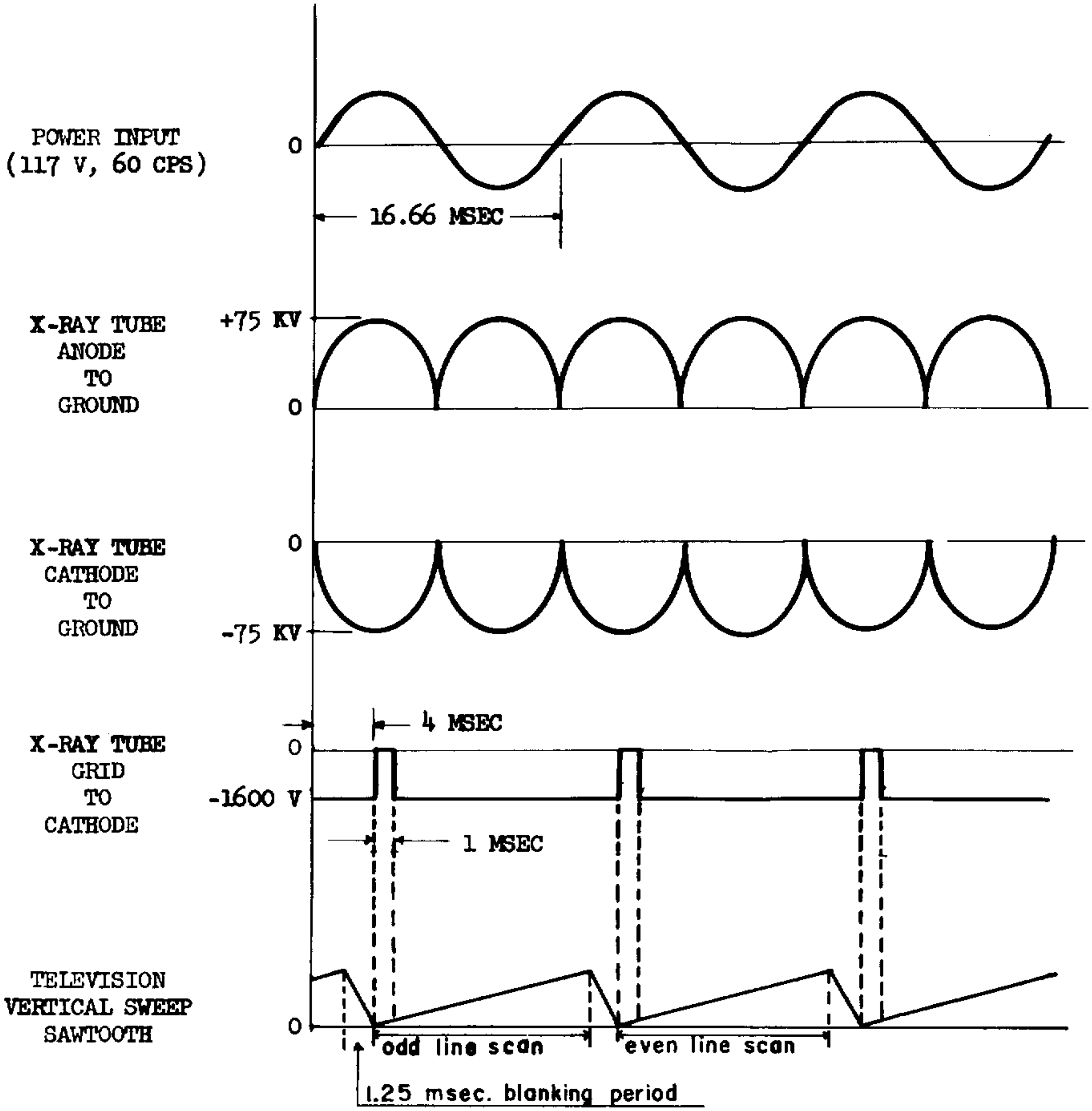

Figure 3. System Timing Relationships

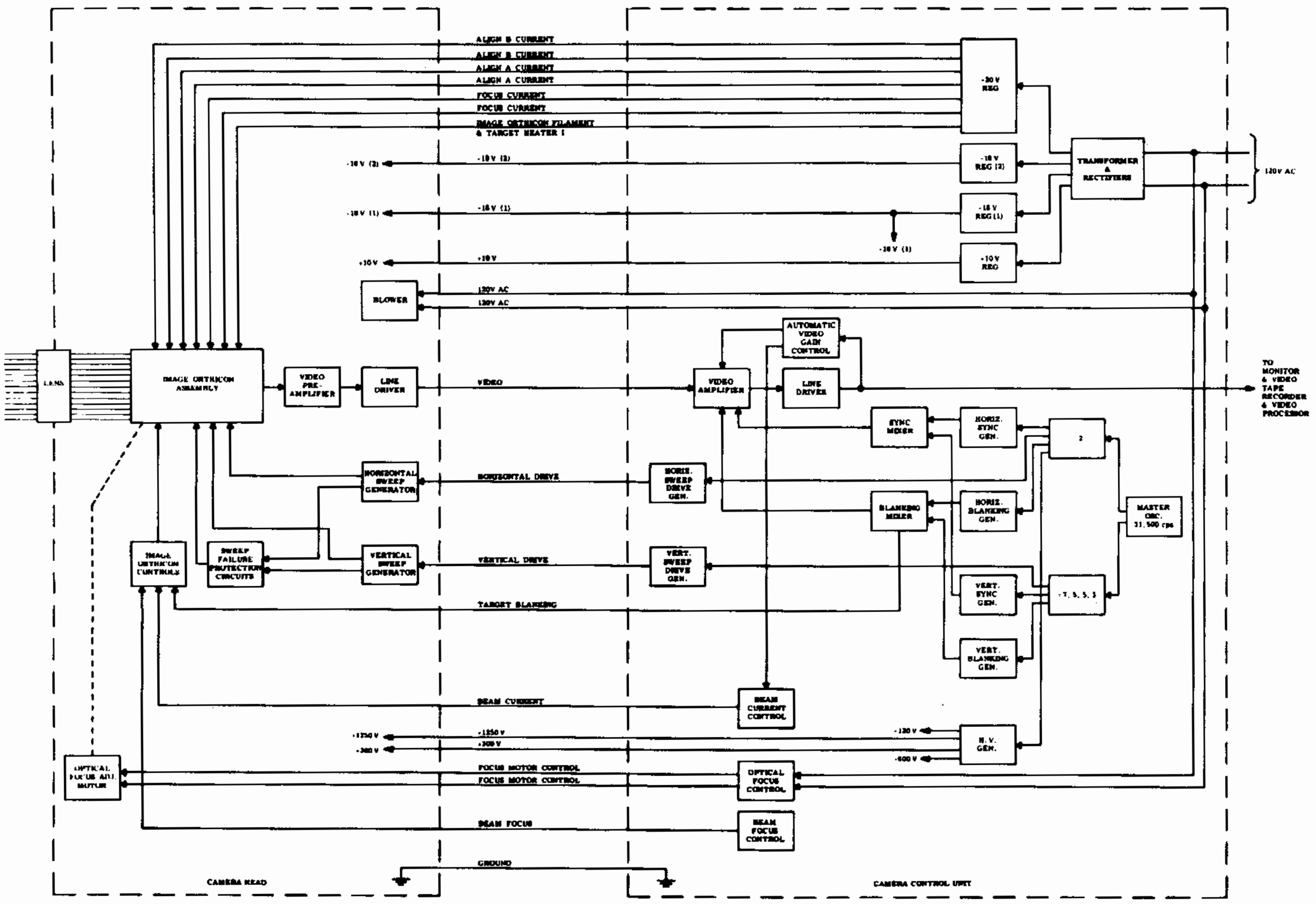

Figure 4. Television Camera Block Diagram

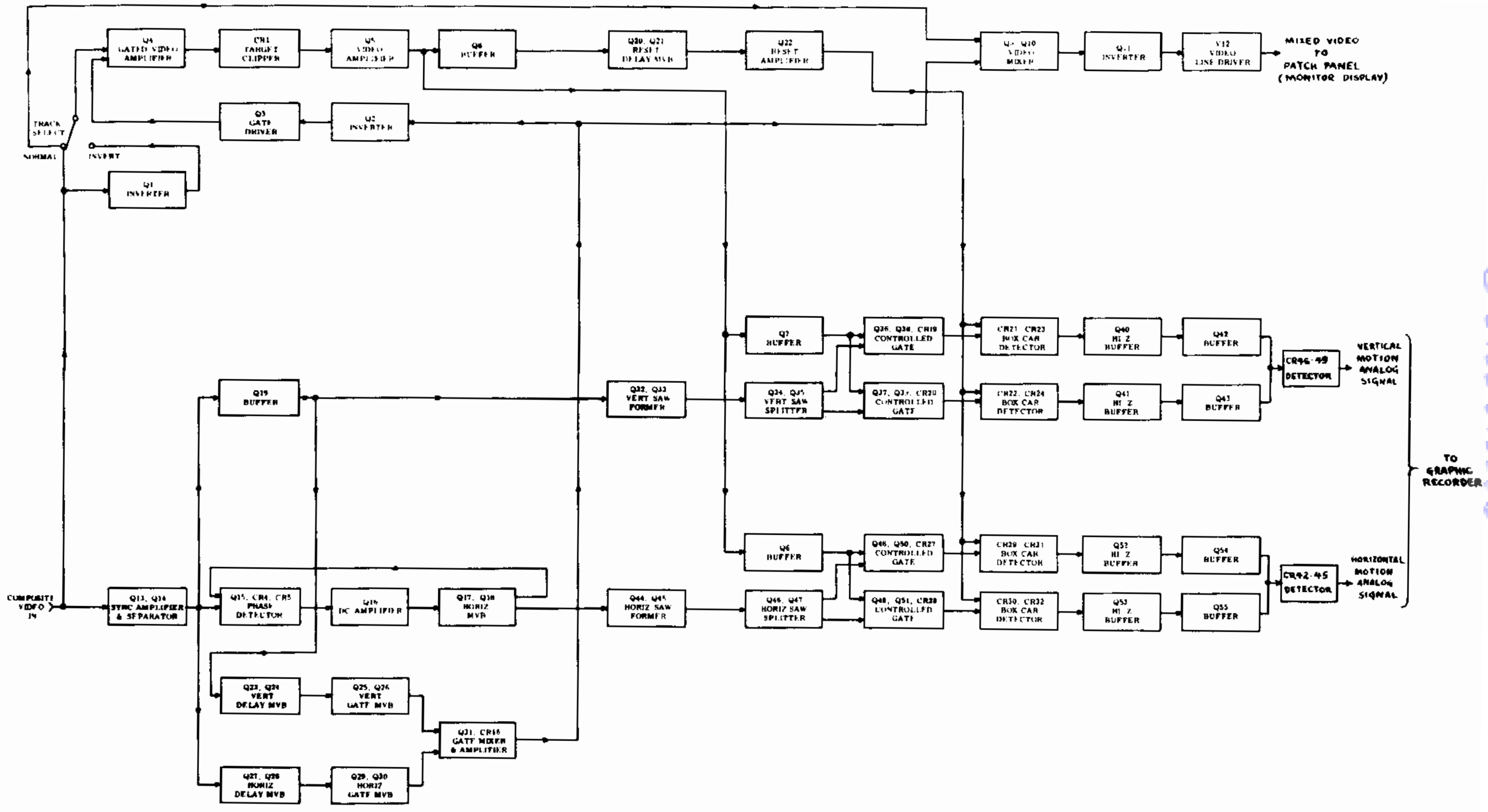

Figure 5. Video Processor Block Diagram

Figure 6. X-Ray Control Unit, Television Control Unit and Video Tape Recorder

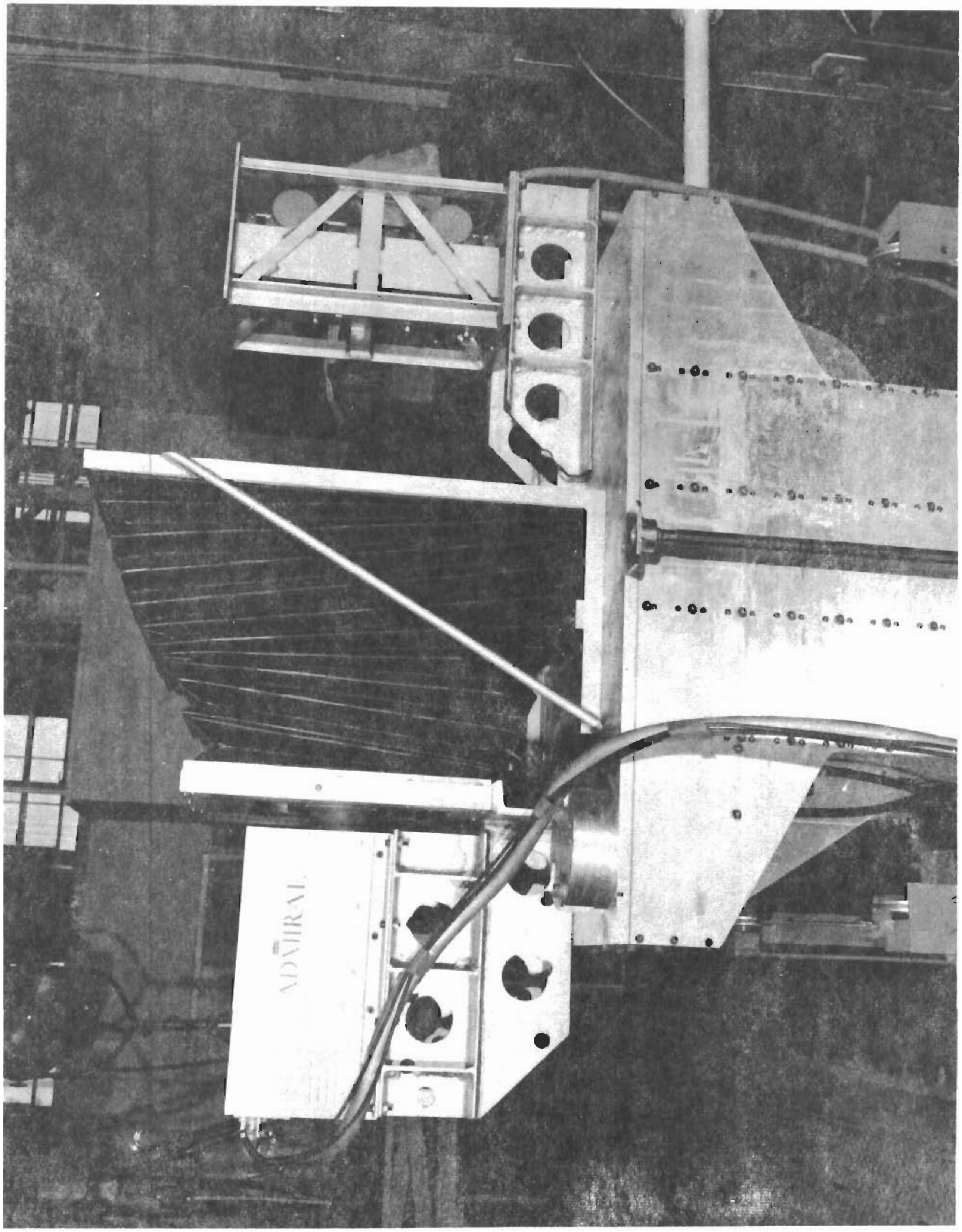

Figure 7. Television Camera, X-Ray Tube and Bellows Mounted on Vibration Table

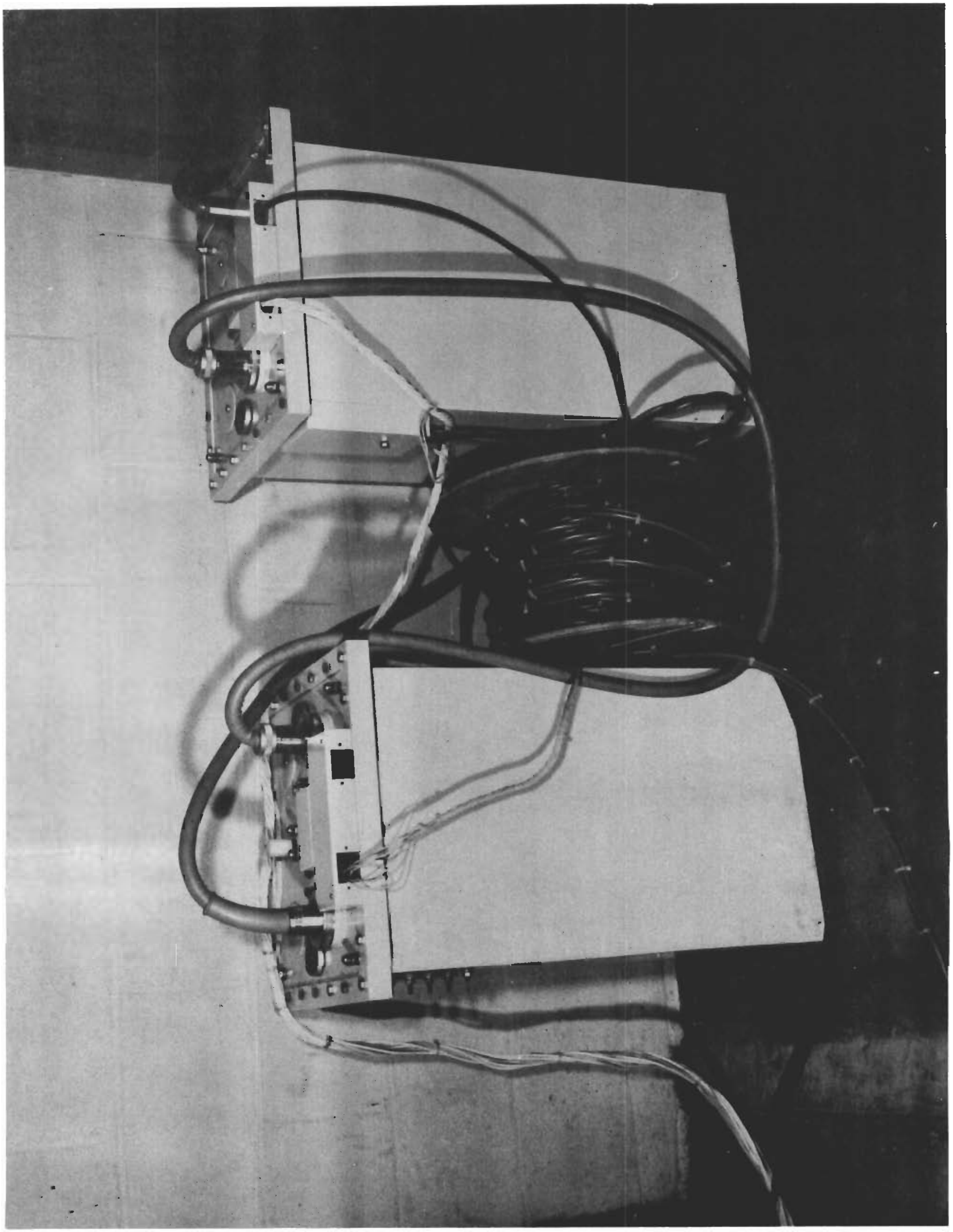

Figure 8. X-Ray Pulse Generator

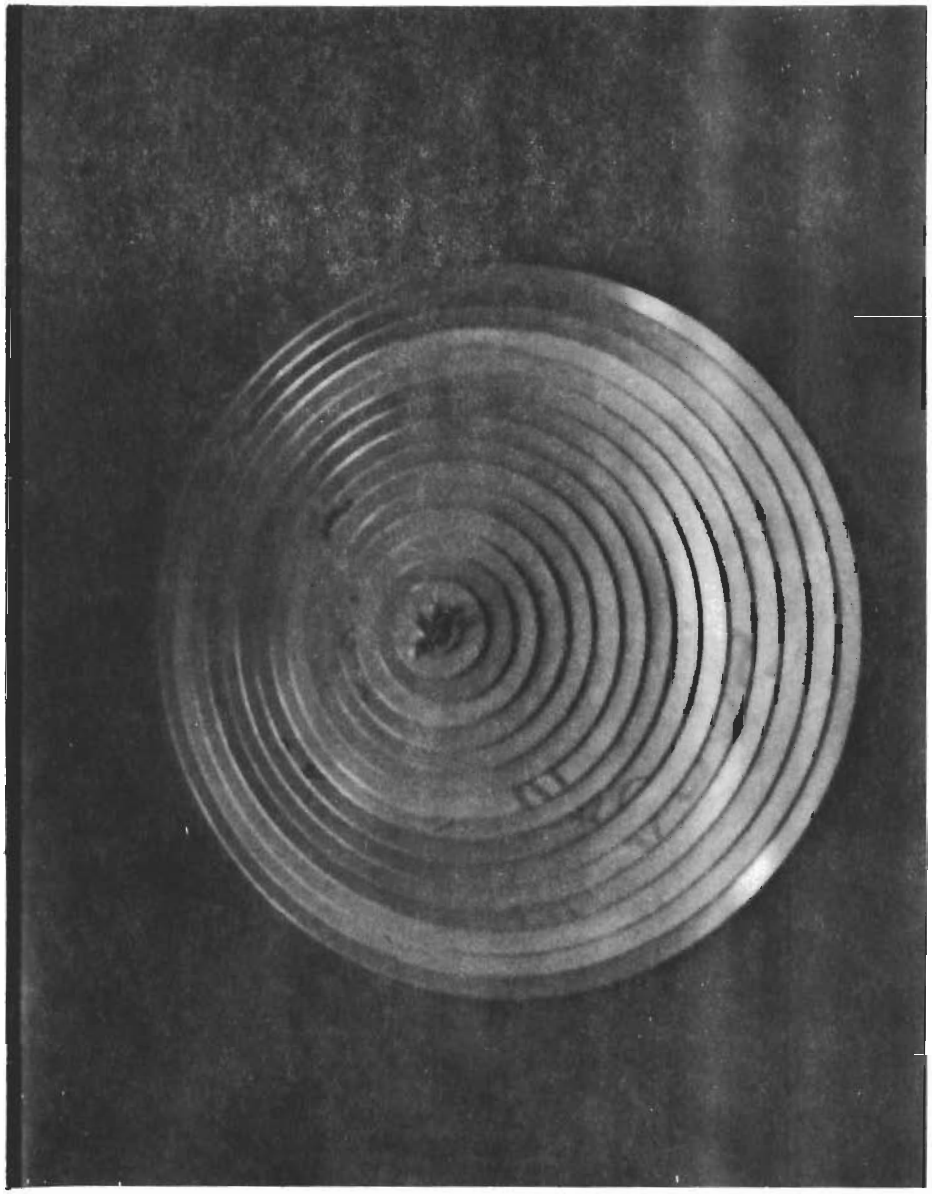

Figure 9. Contrast Phantom

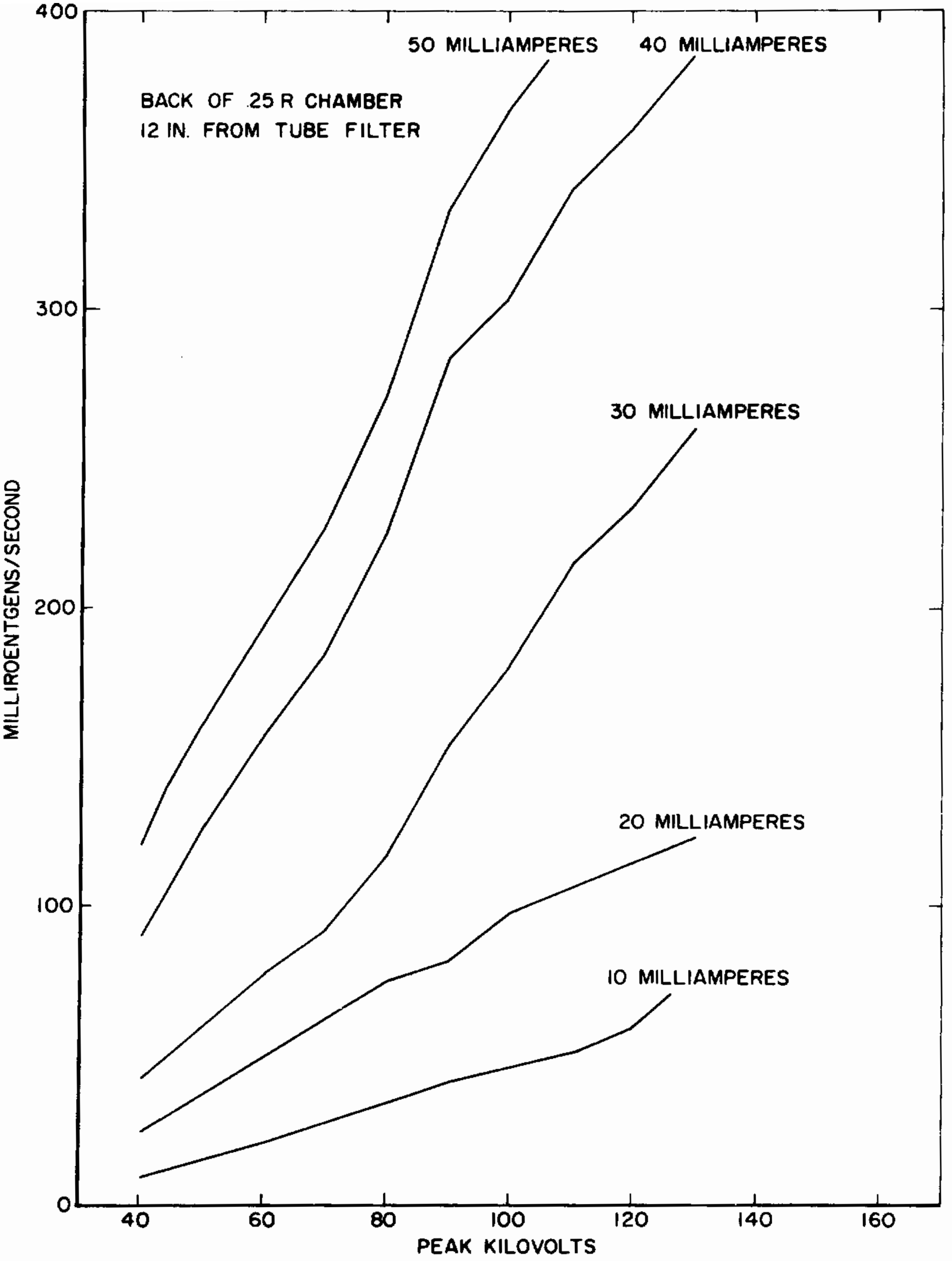

Figure 10. X-Ray Exposure Dosages

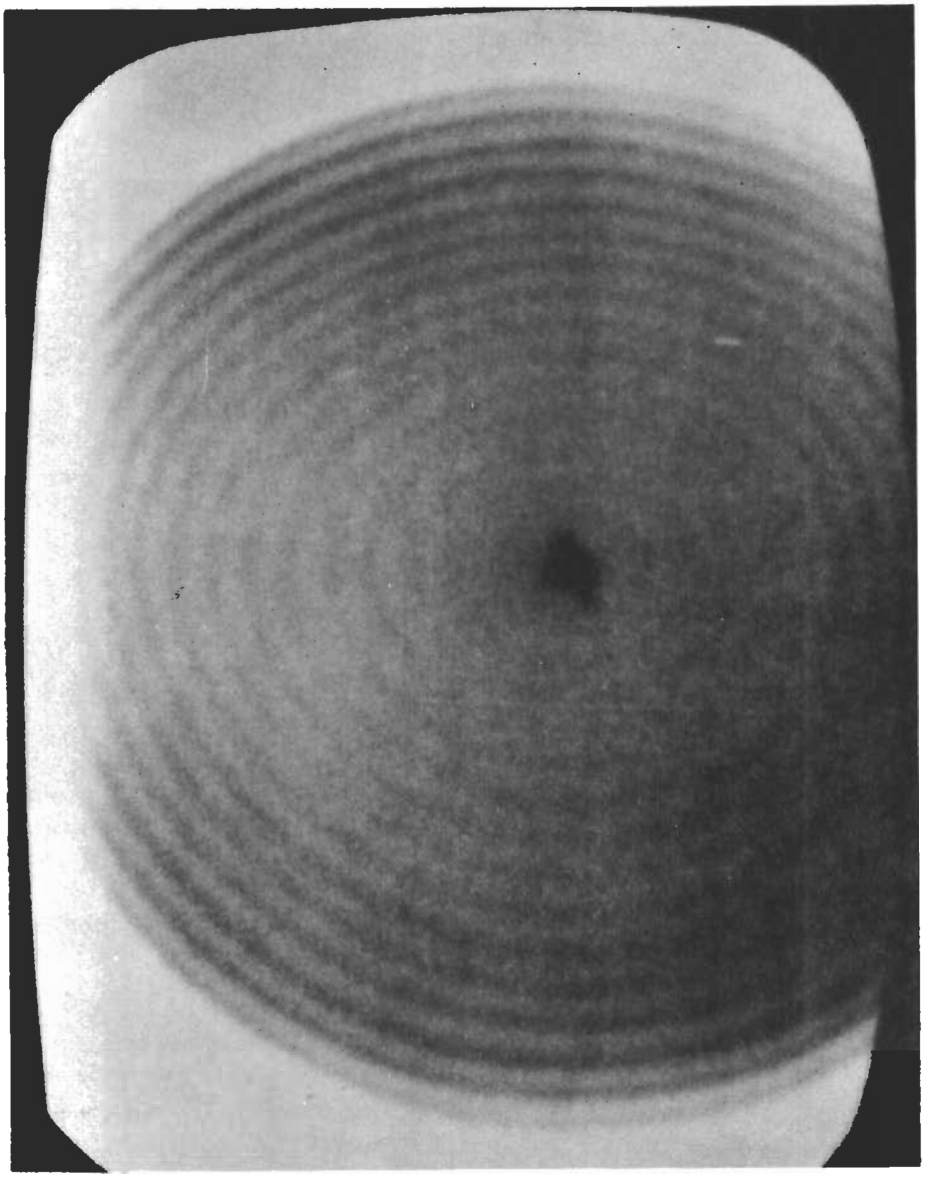

Figure 11. Video Display of Contrast Phantom

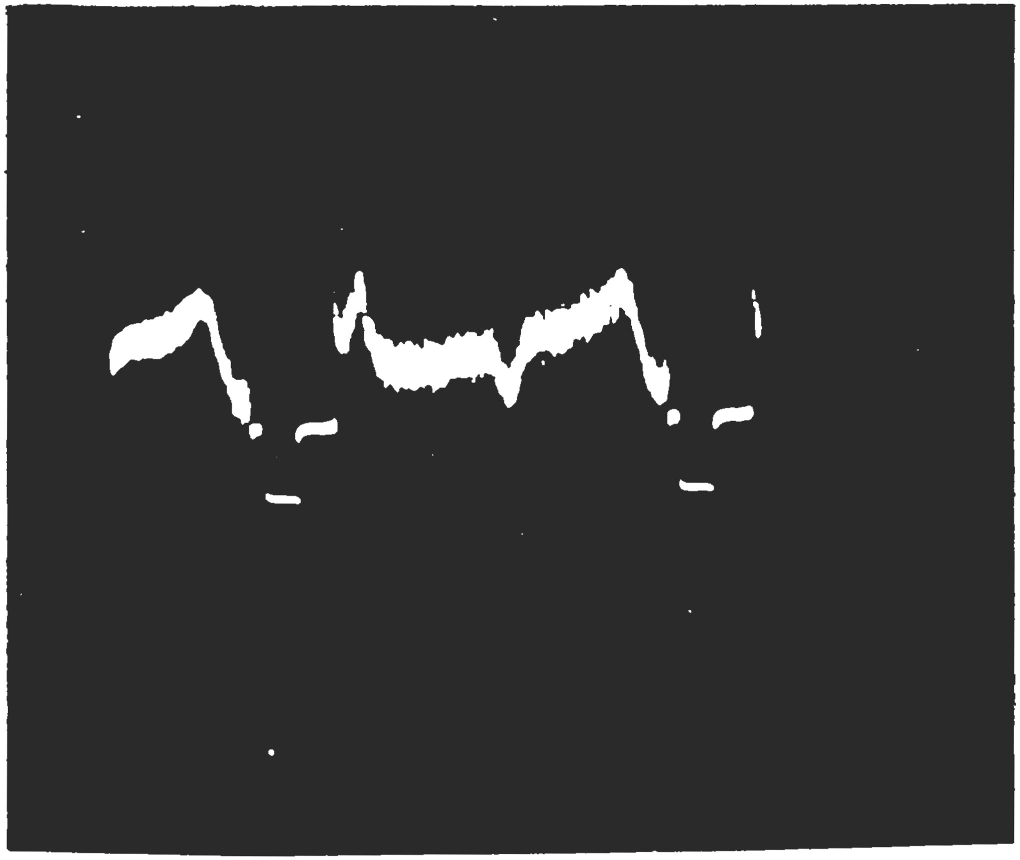

Figure 12. Video Line Through Center of Contrast Phantom

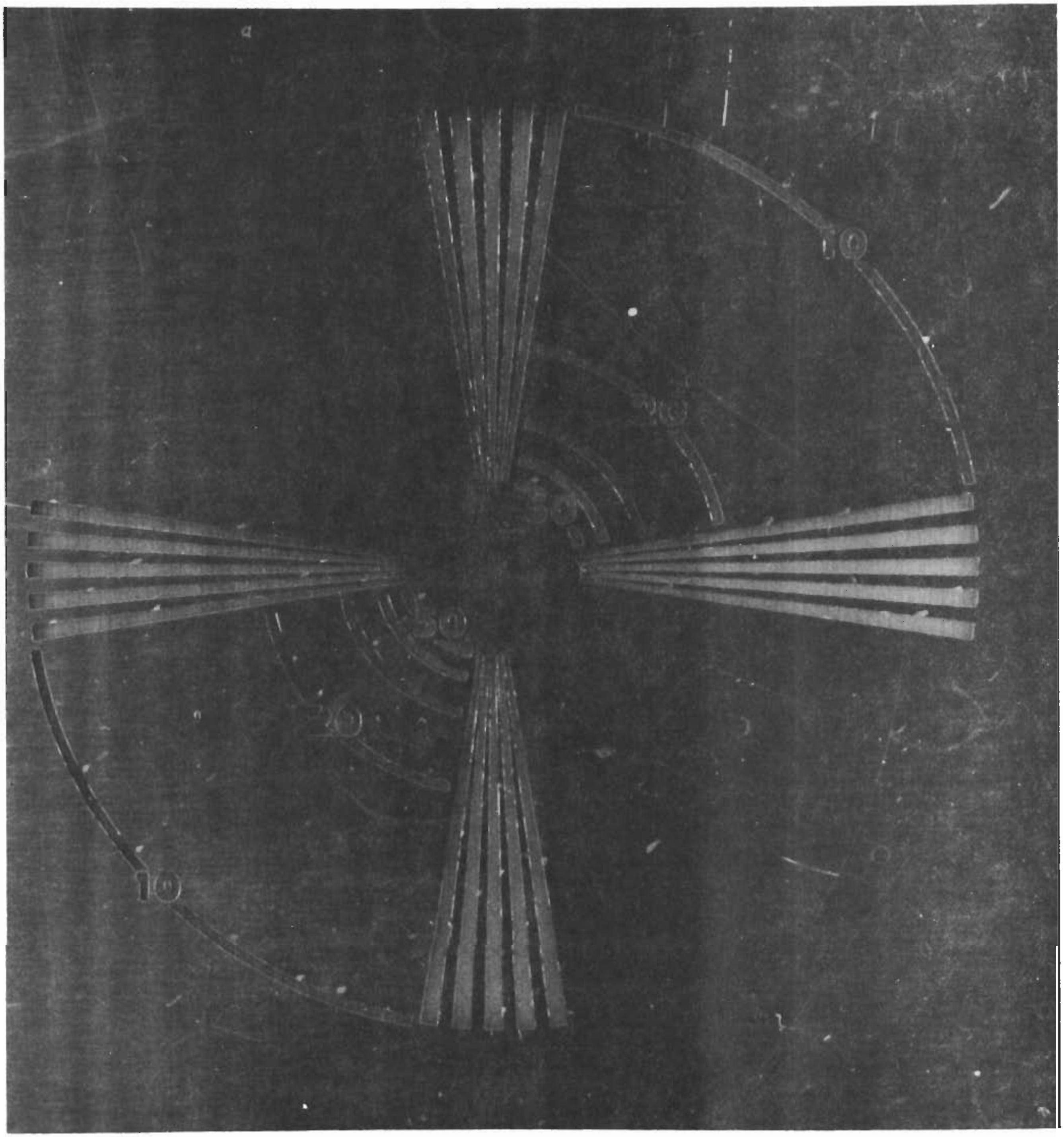

Figure 13. Resolution Phantom

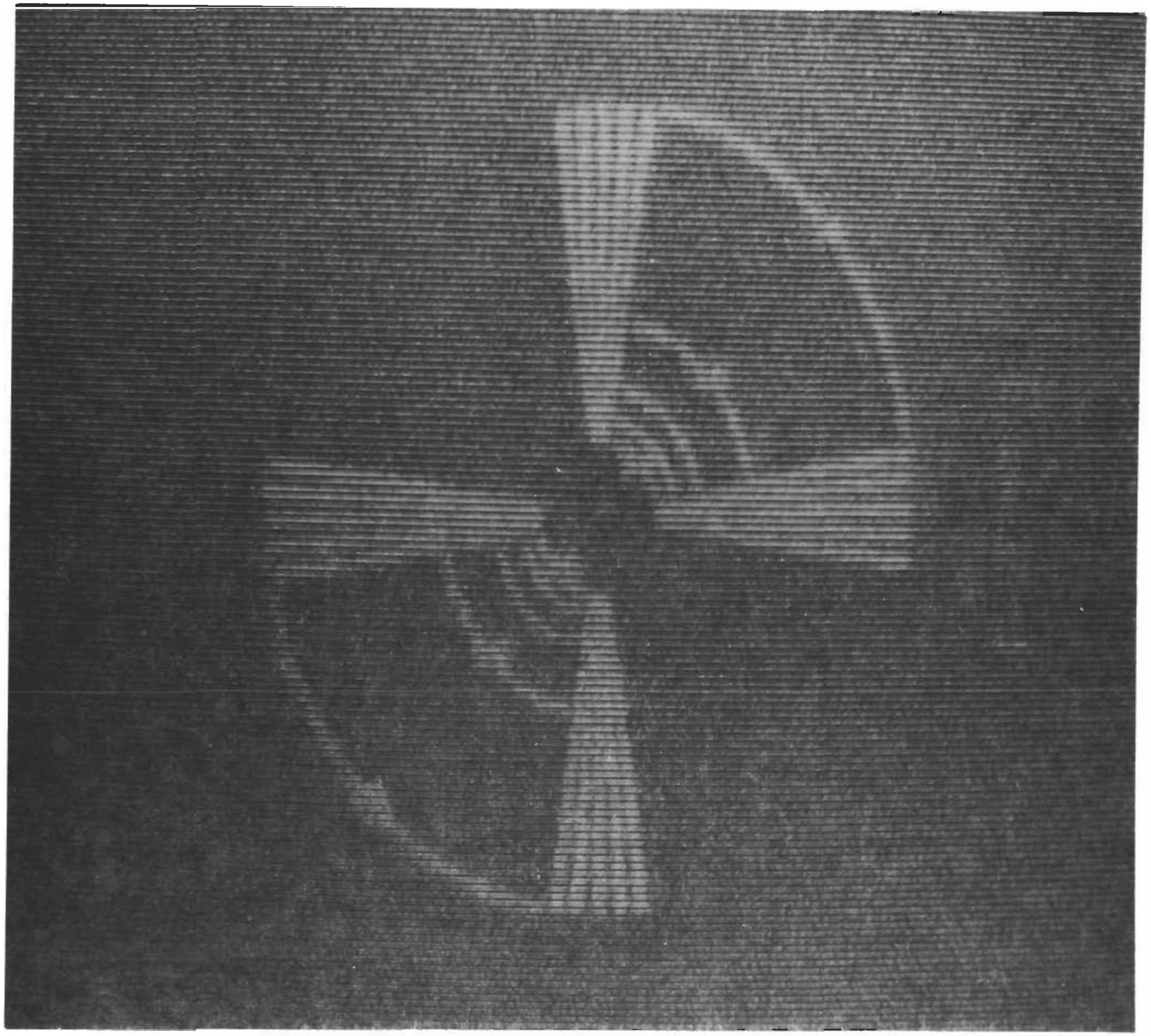

Figure 14. Video Display of Resolution Phantom

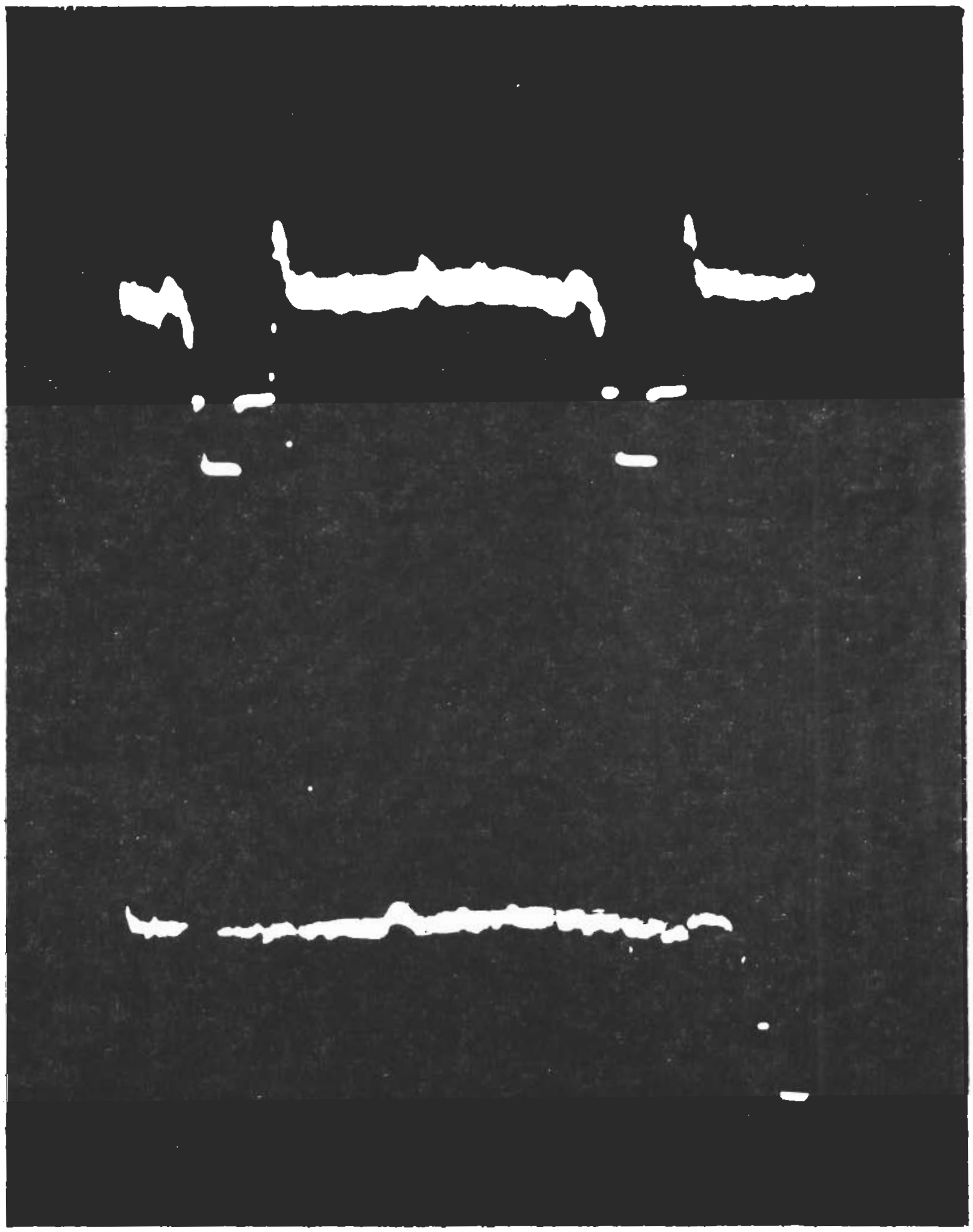

Figure 15. Video Line Through Resolution Phantom

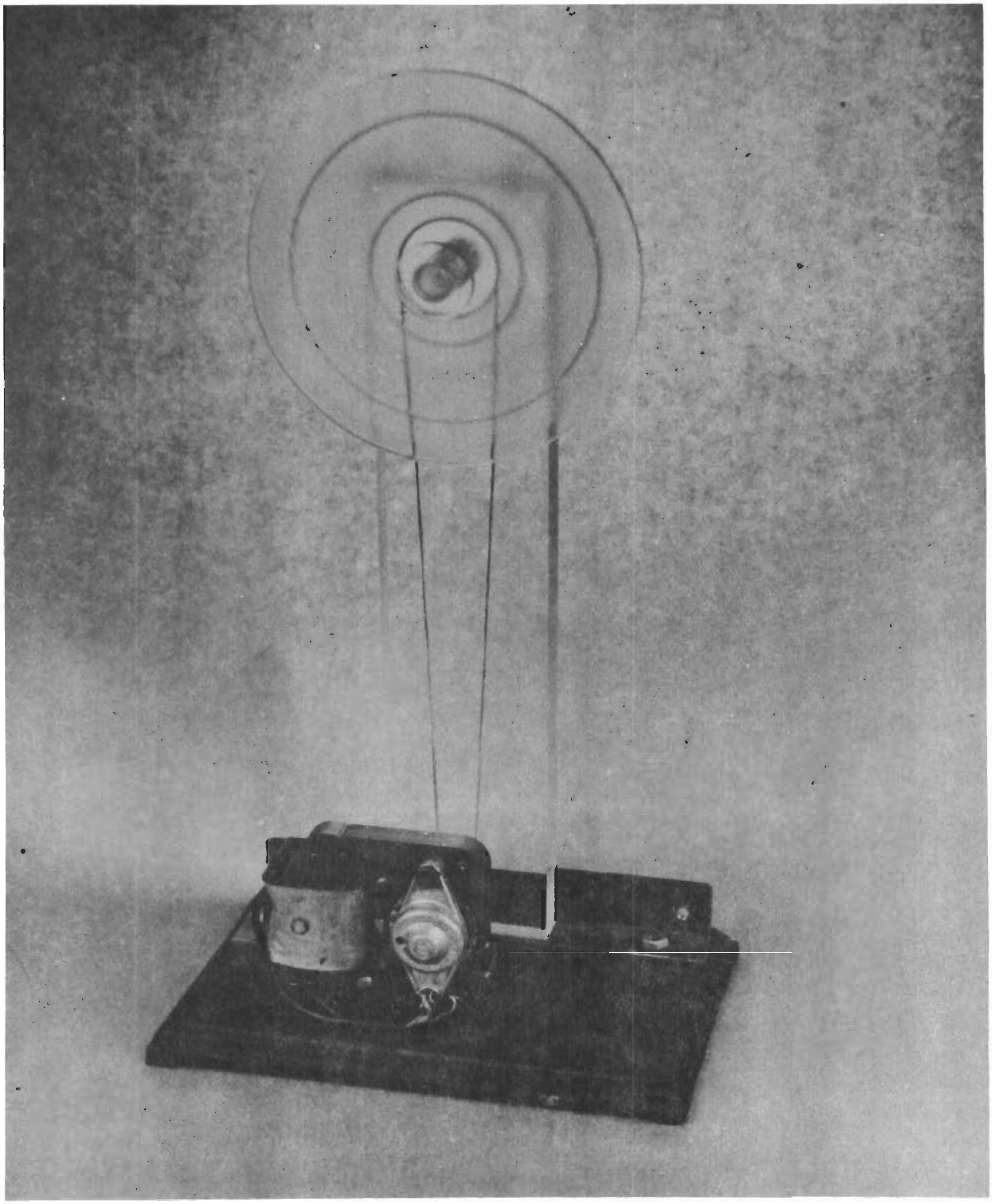

Figure 16. Frequency Response Phantom

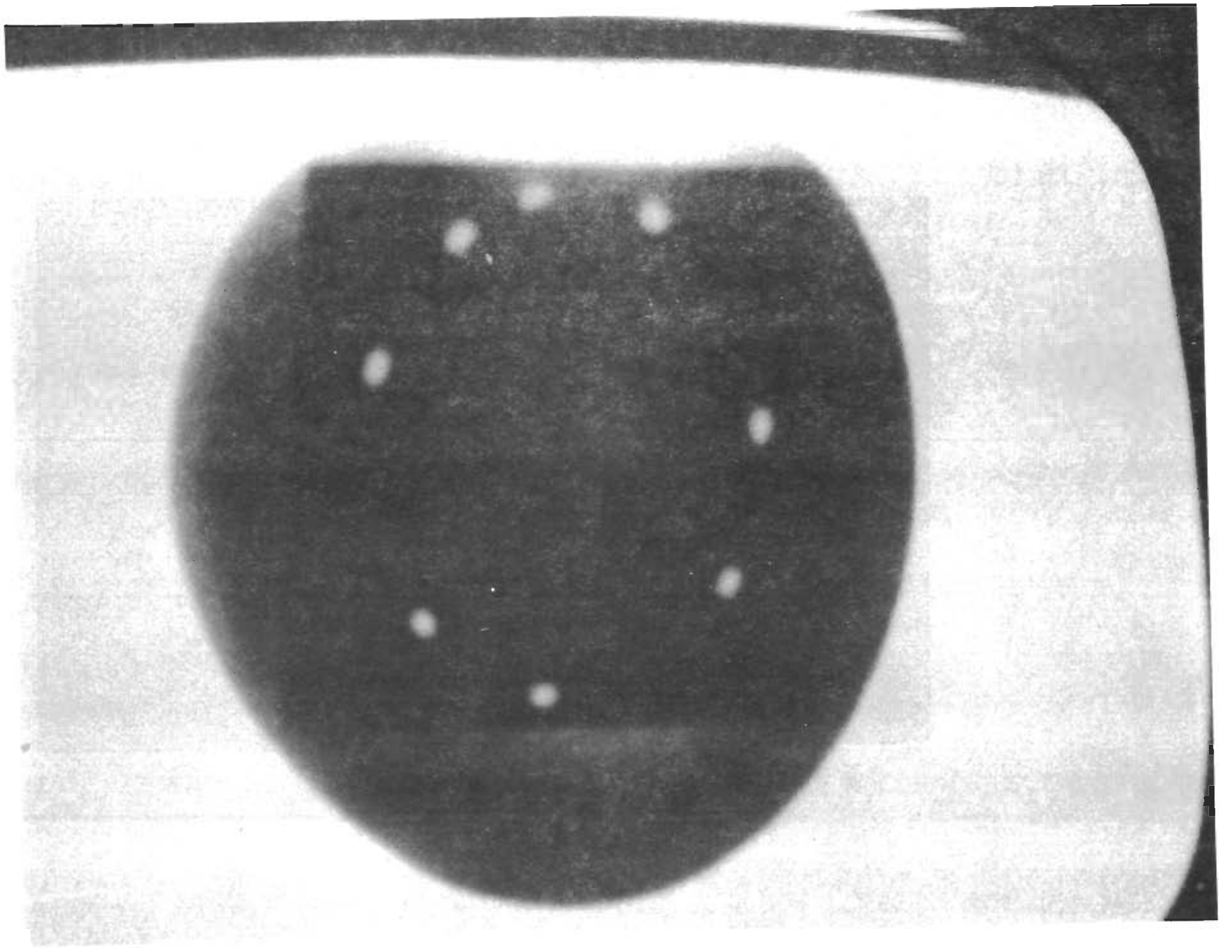

Figure 17. Video Display of Frequency Response Phantom

Figure 18. Oscilloscope Display of Video Processor Output During Tracking of Frequency Response Phantom

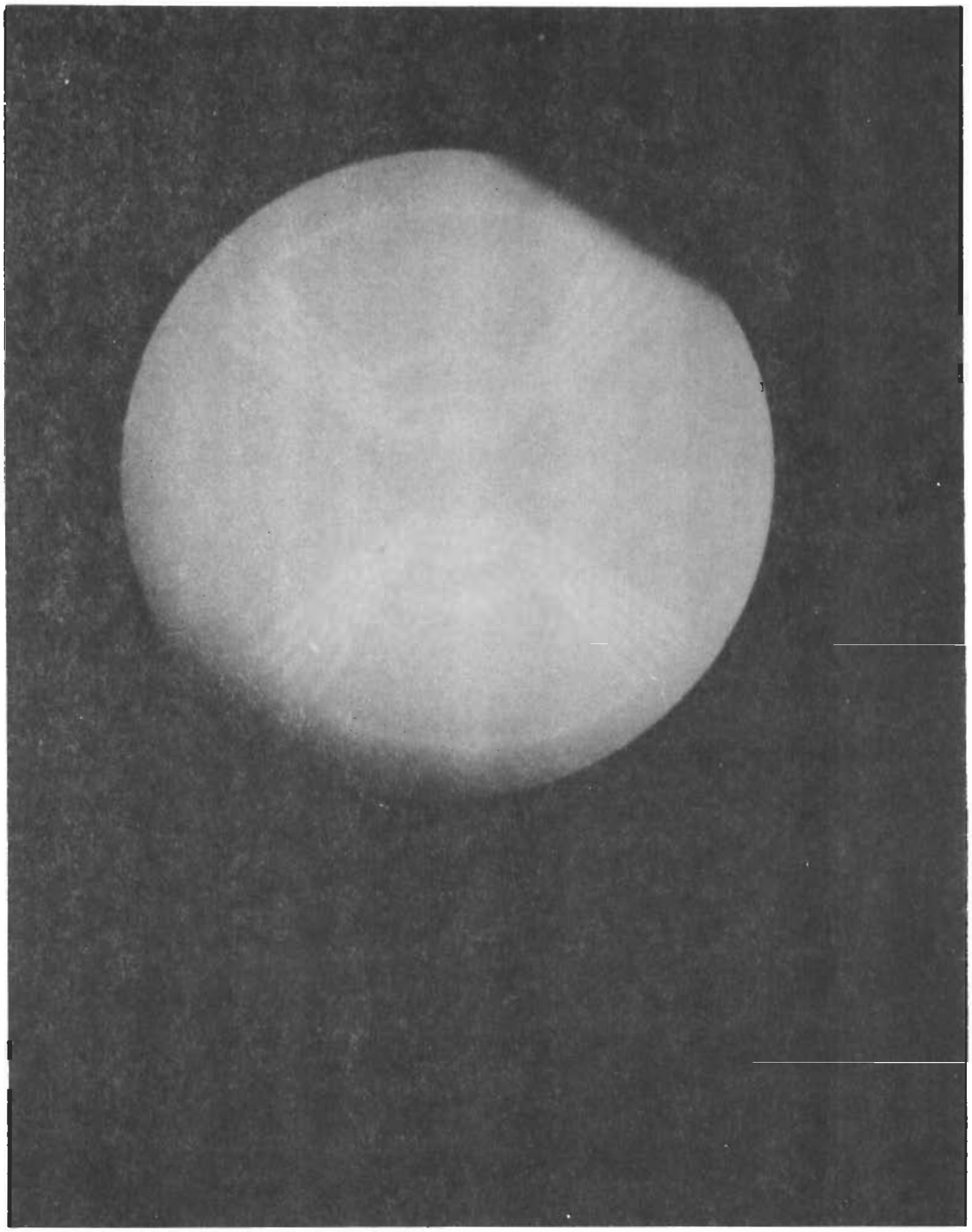

Figure 19. Resolution Phantom as Displayed on Image Intensifier

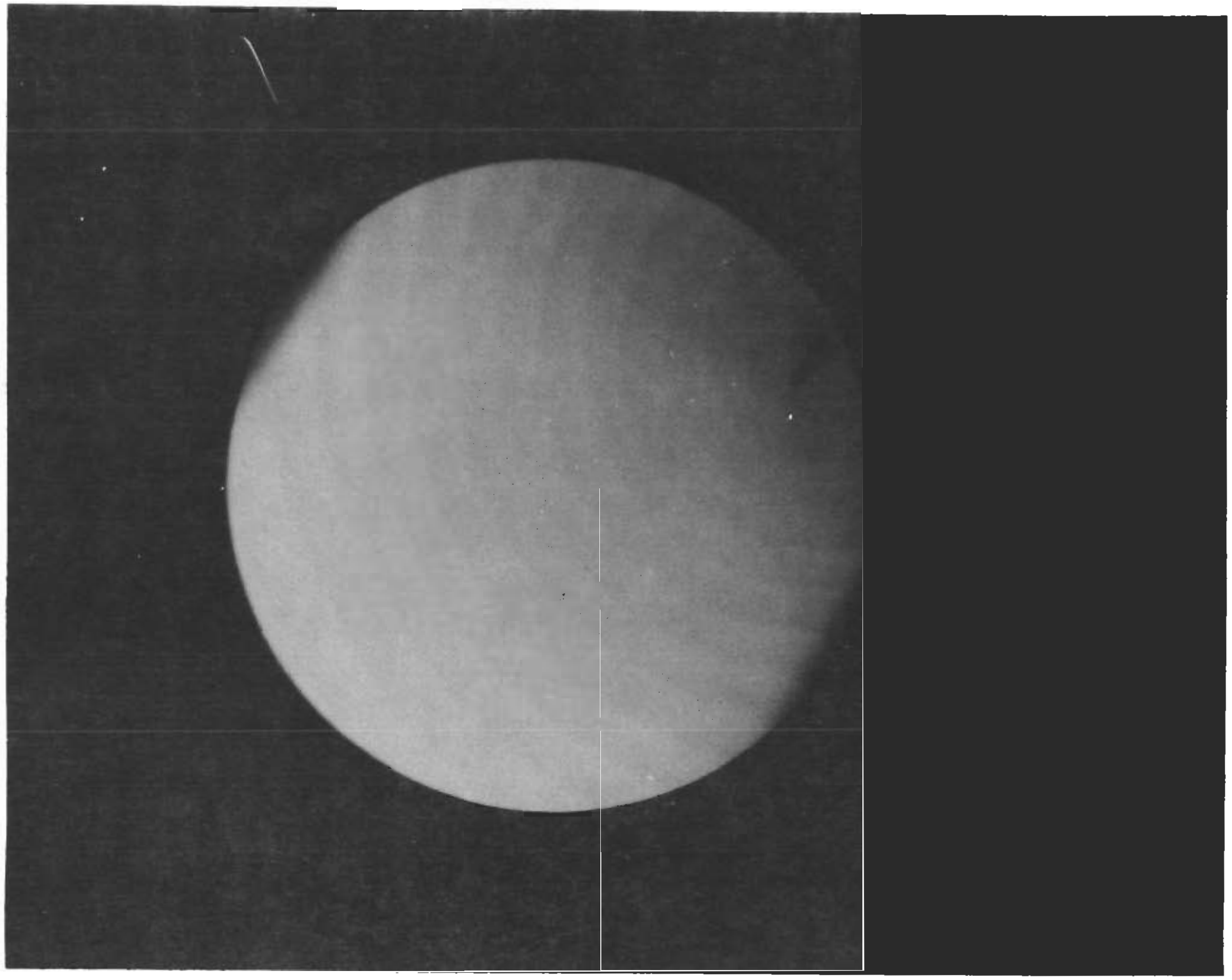

Figure 20. Contrast Phantom as Displayed on Image Intensifier

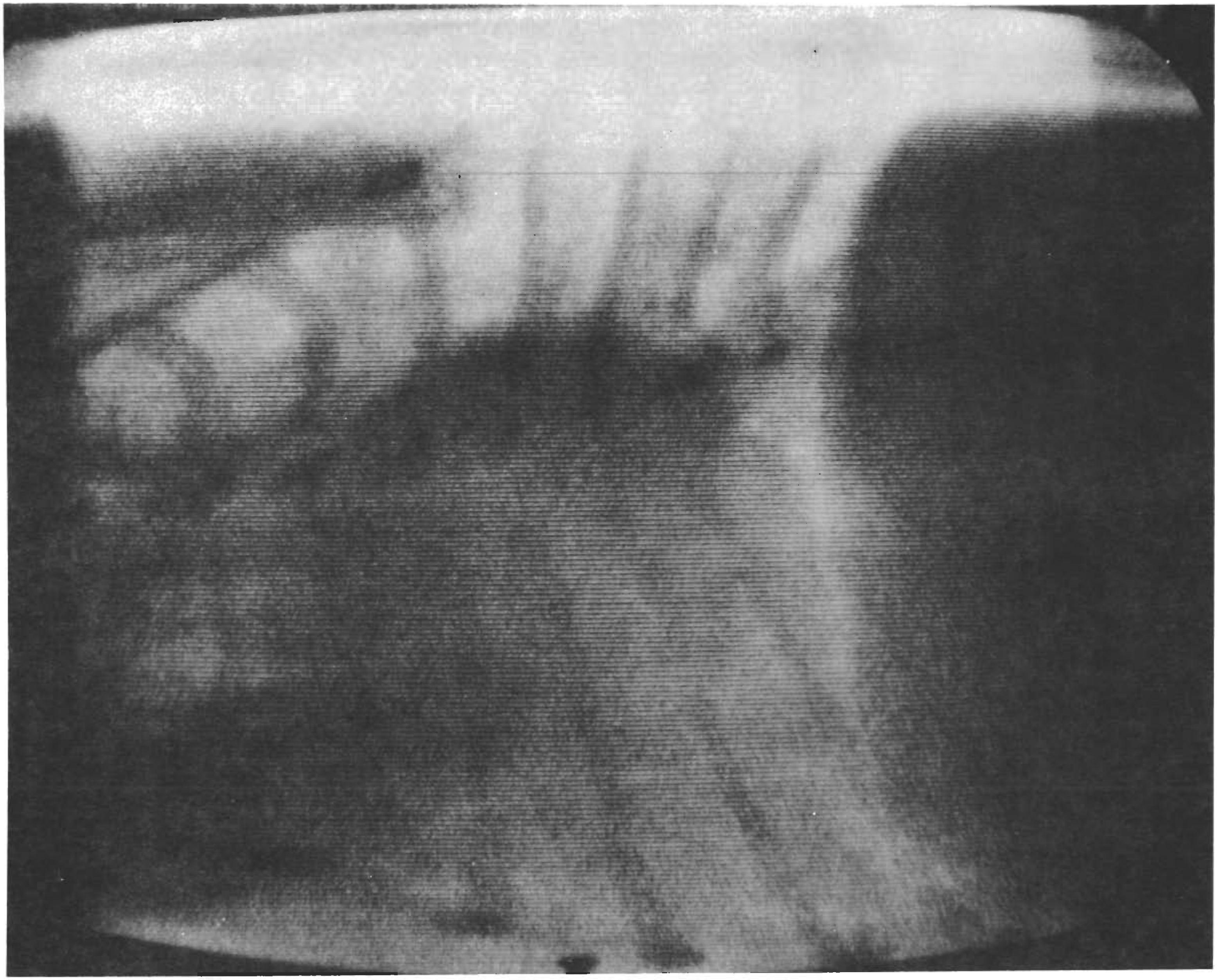

Figure 21. Video Display of X-Ray Image of Canine Chest

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13. ABSTRACT

This work presents a logical picture of a biodynamics instrumentation requirement, a design to answer the requirement, testing of the prototype, evaluation of the quality of the prototype, and a discussion of the advantages and limitations of the design. The operational nature of a high-speed X-ray device with certain advantages for biodynamic research is discussed. The final nature of the device is found to have certain advantages over commercially available X-ray units for general medical research purposes as well as for general clinical radiology.

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