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Tamper-Resistant Television Surveillance System

Owen B. Laug & Kenneth W. Yee

Product Engineering Division
Institute for Applied Technology
National Bureau of Standards
Washington, D. C. 20234

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NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

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TAMPER-RESISTANT TELEVISION SURVEILLANCE SYSTEM

1. INTRODUCTION

The problem of the design of a tamper-resistant/tamper-indicating television surveillance system has been of concern to the U.S. Arms Control and Disarmament Agency for a number of years because of the role such a system might play in the process of implementing and verifying certain international arms control or safeguards agreements. The impetus to this cause is stated in the preamble to the Treaty on the Non-Proliferation of Nuclear Weapons. It expresses on the part of the States concluding the Treaty, "their support for research, development and other efforts to further the application, within the framework of the International Atomic Energy Agency (IAEA) safeguards system, of the principle of safeguarding effectively the flow of source and special fissionable materials by use of instruments and other techniques at certain strategic points."

In the summer of 1968 it became apparent to authorities involved in safeguards in the United States of America and Canada that a cooperative safeguards development program might be of mutual benefit to the two governments and also support the principles of the Non-Proliferation Treaty (NPT) and assist the IAEA in carrying out its increased responsibilities under the NPT. After several general discussions between officials of both governments had confirmed a mutual interest, the two parties agreed to join in an effort to design, build, install, and test on a CANDU-type power generating reactor, the prototype of an unattended tamper-resistant/tamper-indicating safeguards instrumentation system. The cooperating agencies in the two Governments are the United States Atomic Energy Commission, (now Energy Research and Development Agency) the United States Arms Control and Disarmament Agency, Atomic Energy of Canada Limited, and the Atomic Energy Control Board of Canada.

Since then, a joint US/Canadian Working Group composed of members of the contributing agencies and contractors has developed the overall features desired for the instrumentation system. The program has two objectives:

1) To develop and evaluate prototype instrumentation (unattended and secure) which may be applicable to the safeguarding of nuclear material in reactors and other nuclear facilities.

2) To test tamper-resistant/tamper-indicating techniques and devices in the severe environment of an operating power reactor.

This report describes a tamper-resistant television surveillance system designed to provide over long unattended intervals high quality pictures which can be conveniently and accurately interpreted by an inspector. It is intended to complement the safeguards instrumentation system presently under test at the Nuclear Power Demonstration (NPD) reactor near Rolphton, Ontario, Canada. This system is identified by the acronym, TRUST, meaning, Tamper-Resistant Unattended Safeguards Techniques. Such a system would complement the normal activity of inspectors. Although the design considerations for this TV system have been primarily determined by the surveillance requirements at NPD, it has the flexibility to be used in many other surveillance applications where resistance to tampering is required.

2. PRELIMINARY CONSIDERATIONS

Before dealing with the particular design aspects of the TV surveillance system it is important to point out some of the decisions and guidelines that have evolved from the Working Group. It is these guidelines, some of which are political in nature, that have influenced the particular design of this TV system.

One important guideline laid down by the Working Group is that the system must be so designed that the integrity of the safeguards data is maintained, although all design and operational details of the instruments are made available to the reactor facility operator. The necessity for this arises from two considerations. It is assumed that the design details of all instrumentation would be revealed to all participating governments and that the system must be acceptable to the operator. The operator who is responsible for the safe and economic operation of the station is in the best position to determine whether a particular design involves no risk to the station. Hence, design secrecy cannot be used as a technique for maintaining measurement integrity.

It appears that no system is impenetrable. Given enough time, money, and ingenuity, any system can be defeated. However, the major purpose can still be achieved if the system is designed such that the cost and risk of fissionable materials diversion greatly exceed the value of diversion and the system indicates unequivocally that it has been tampered with. Thus, the term tamper-resistant/tamper-indicating was adopted. This does not necessarily simplify the design efforts of a safeguards instrumentation system but provides a basis whereby a crude figure of merit or cost effectiveness might be established. For example this might be the cost of diversion versus the cost of the safeguards system, or the cost of diversion versus the value of a diversion. Care must be exercised in applying such a measure of effectiveness to only portions of a system because of the interdependence of the subsystems. In addition, economics in some instances may not be the primary measurement of effectiveness.

Early in the program many designs of tamper-resistant sensors, containers, and seals were evaluated. An outstanding problem was maintaining security of the data link between the sensors and the recording station. Time domain reflectometry techniques were examined as a means of securing the data link but a number of practical problems limited its general application. The Working Group reluctantly adopted the technique of encoding data as the most practical means of securing data. Although this may seem to violate the policy of not disclosing the system design, the important distinction is that encoded data is used only for the purpose of checking the integrity of data and not for the purpose of withholding design or measurement information. In fact, many portions of the system make available both clear data as well as encoded data.

An additional problem which must be considered for any unattended system is that it is vulnerable to harassment by an operator. He can damage the equipment "accidentally," cause component failures which tend to discredit the system in the eyes of the inspector, or remove installed safeguards equipment because of an "operational emergency." Harassment of this nature is one obvious unavoidable way to defeat an instrumentation system. A good defense against subtle types of sabotaging is to employ the simplest design possible with a high proven reliability. This permits one to distinguish between true failures and harassment. The Working Group concluded that harassment was a manageable problem as long as the inspection agency retained the capability of replacing the unattended system with inspectors should it become clear that the desired effectiveness and reliability were not being achieved by the instrumentation.

3. DESIGN OBJECTIVES

Television was chosen instead of direct film photography because of its adaptability to a radiation environment. Long term, low level radiation will not obscure the records nor will a plausible accident wipe out all the data. In addition, TV conforms to the generally adopted concept of remote sensing devices reporting to one central recording station in a facility.

The following two principal design objectives for a TV Surveillance system were established by the Working Group:

1. Unattended operation and data storage capacity for a period up to 90 days.

2. Resistance to deception by video substitution on the transmission line or direct scene substitution in the TV camera field of view.

There are essentially two different approaches one can take in the surveillance of an area. One approach is to record data

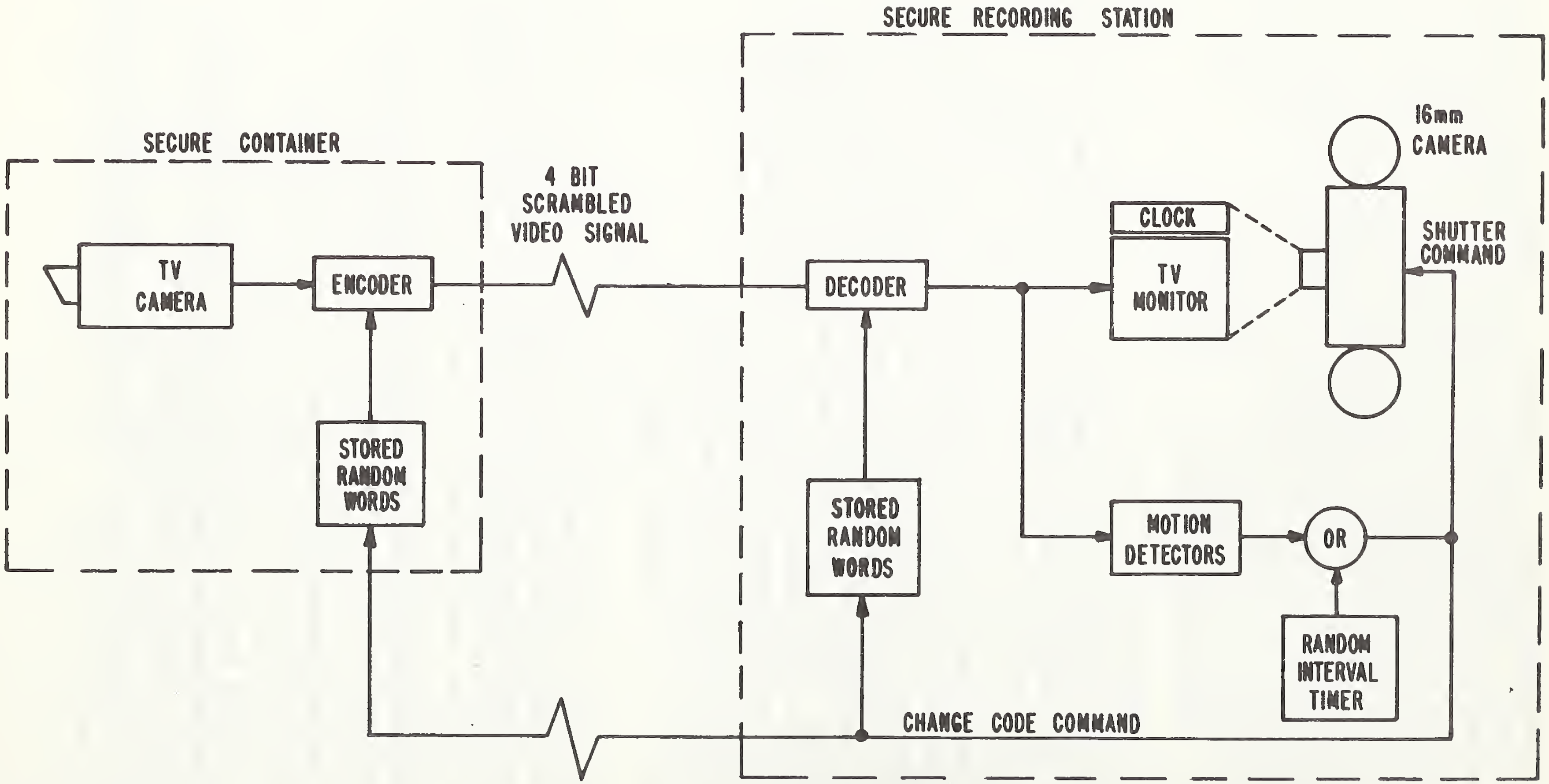

Fig. 1. Block diagram of tamper-resistant television surveillance system.

very frequently regardless of what is taking place in the area. In the case of recording pictures the total number can easily overwhelm any reasonable storage capability and more important, can make analysis difficult and costly. A bank camera uses this approach by taking pictures continuously which are only analyzed after the fact. Seldom do all the pictures have to be analyzed since the time a robbery occurred is usually known. On the other hand, if pictures are to be used to detect whether certain unauthorized activity has occurred, a second approach is often preferable. The technique is to selectively record pictures of the scene when a change occurs and limit the number when there is no change. This can be accomplished by employing motion detectors which monitor selected areas in the field of view and record a picture if there is motion at any one of these locations. This technique can also partially protect against field-of-view substitution. Protection against tampering on the video transmission line is provided by encoding the luminance levels of the output video signal. It is these two design features that have been the major area of development for this system. A qualitative description of the system follows. Explicit operational details and schematics are not included.

4. SYSTEM DESCRIPTION

Fig. 1 shows a block diagram of the tamper-resistant television surveillance system. The system employs a commercial 525 line, high resolution, closed circuit TV system coupled with a 16mm movie camera adapted for single frame use. Pictures are photographed directly from the monitor with time indicated on each frame by means of a digital clock located in the camera's field of view. The video signal from the TV camera is encoded for protection against substitution of false video information on the transmission line to the recording station. Encoded video signals are instantaneously decoded in the recording station so that a continuous clear picture is present at all times on the monitor. Coding security is insured by using matching sets of random words stored on punched tape in the camera's secure container and the secure recording station. Each word is used only once for one recorded picture. After a picture is photographed the tapes are advanced in synchronism to a new word which is used to change the encoding pattern at the instant the next picture is recorded.

Motion detectors, utilizing the video signal, monitor selected spots in the TV camera field of view and command the photographic camera to record a picture when there is motion at any of these locations. The camera can also be commanded by a random-interval timer.

A secure container houses the TV camera, encoder, and random word tapes. The container is plastic, silvered on the inside for security. A removable end cover is secured to the container by a fiber optic seal [2,3] threaded through holes in the cover and the container. The recording station stores all the data for the entire safeguards system. This area consists of a small shielded room secured by an RF intrusion monitor [4].

The reasons for choosing photographic means for recording the pictures are the high quality, low cost, and high reliability inherent with photographic techniques. Photography can be confidently employed in this location because it is well removed from any possible source of radiation. Furthermore, photographic film has the highest information packing density of any known storage medium and pictures stored on film are convenient for direct viewing or electronic analysis. Typically, a 100-foot roll of 16 mm film can store about 4000 frames which can be analyzed by use of a special projector. The projector can operate at any desired frame rate without flicker and stop on any frame indefinitely for detailed inspection.

Magnetic tape recorders could also be employed for the storage of pictures, especially for short unattended intervals and situations requiring immediate playback. Some surveillance situations have been visualized where a resident inspector may want to review pictures of perhaps an overnight sequence. If this technique were used to record single frames, provision would have to be made to reliably operate the tape recorder in a start-stop mode.

The elements of the system which determine the quality of pictures on film are the TV camera, encoder, decoder, monitor, photographic camera, and film. The primary factors which affect the overall quality of a picture are sharpness, resolution and gray scale rendition. The appearance evaluation of a picture image in terms of the edge characteristics of objects is called sharpness. Sharpness and resolution are to some extent interrelated but do not always perfectly correlate. Resolution in a television system is expressed in terms of the maximum number of lines (black and white) which can be seen in a distance across the face of the monitor tube equal to the raster height. Vertical resolution in a well adjusted system roughly equals the number of scanning lines. In practice, however, a standard 525 line system produces typical vertical resolution values of about 450 lines because some of the lines are blanked for frame synchronization purposes.

Resolution in photography is usually expressed as the maximum number of lines (counting only black or white ones) per millimeter which can be distinguished from one another. In order to relate TV vertical resolution in terms of photographic resolution the height of the frame and this factor of 2 must be considered. The height of a 16 mm frame is about 8 mm. Thus, a 450 TV line vertical resolution can be considered equivalent to a photographic resolution of about 28 (i.e. 450/(2x8)) lines per millimetre. However, to resolve the maximum TV vertical resolution on film a photographic resolution (lens & film) of greater than 28 lines per mm is required. This is because the combination of both systems operating at the same limiting resolution produces a resultant resolution less than either. Considering practical 16 mm film speeds and moderate lens qualities, measurements using standard high contrast photographic resolution charts indicated that a resolving power of about 65 lines per millimetre (center) and 50 lines per millimetre (edges) could be achieved. Evaluation of TV resolution chart images on film obtained through the entire system (i.e. TV camera, monitor photographic camera) indicated that the above resolution is sufficient to resolve the maximum vertical TV resolution. In fact, under these conditions it is possible to distinguish the raster scanning lines in an ordinary picture.

In order to obtain the full vertical resolution of a TV picture on film the 2:1 interlace system must be used. Random interlace will produce only about one half of the typical vertical resolution of a 525 line system on film.[1]

Horizontal resolution of a TV system is determined entirely by the bandwith of the system. The TV camera chosen for this application has a specified resolution of 900 lines (center) and 600 lines (edges) which somewhat exceeds the practical resolution limits of the photographic portion of the system. Hence, vertical resolution is TV-limited and horizontal resolution is photographically limited.

The gray scale rendition of the system is primarily limited by the encoding system which quantizes the gray scales of the output video signal. The gray scale of a properly exposed film usually far exceeds the gray scale resolution of typical closed circuit TV systems.

An important feature of a TV camera in most surveillance systems is the ability to compensate for variations in scene illumination. This helps to maintain a reasonably constant exposure, but more important, provides a constant amplitude video signal which limits the dynamic range of the encoder.

Listed below is a summary of pertinent performance specifications of the TV camera and monitor employed for this application.

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[1] There are two scanning systems commonly employed in closed circuit TV systems, random interlace and 2:1 interlace. In the random interlace there are roughly 262 lines per field and the line frequency is not locked to the frame rate. This produces a slight random movement of the lines for each field which the eye integrates giving the appearance of more vertical resolution. In a 2:1 interlace the scanning of a frame is divided into two parts, each part being referred to as a field. In the odd field lines are scanned in the order 1,3,5,7, etc., until half the lines have been scanned. Then scanning begins again at line 2 and proceeds in the order 2,4,6, etc., until the entire frame has been scanned. The effect of such interleaving is to reduce the flicker to the point where it is no longer perceptible to the eye.

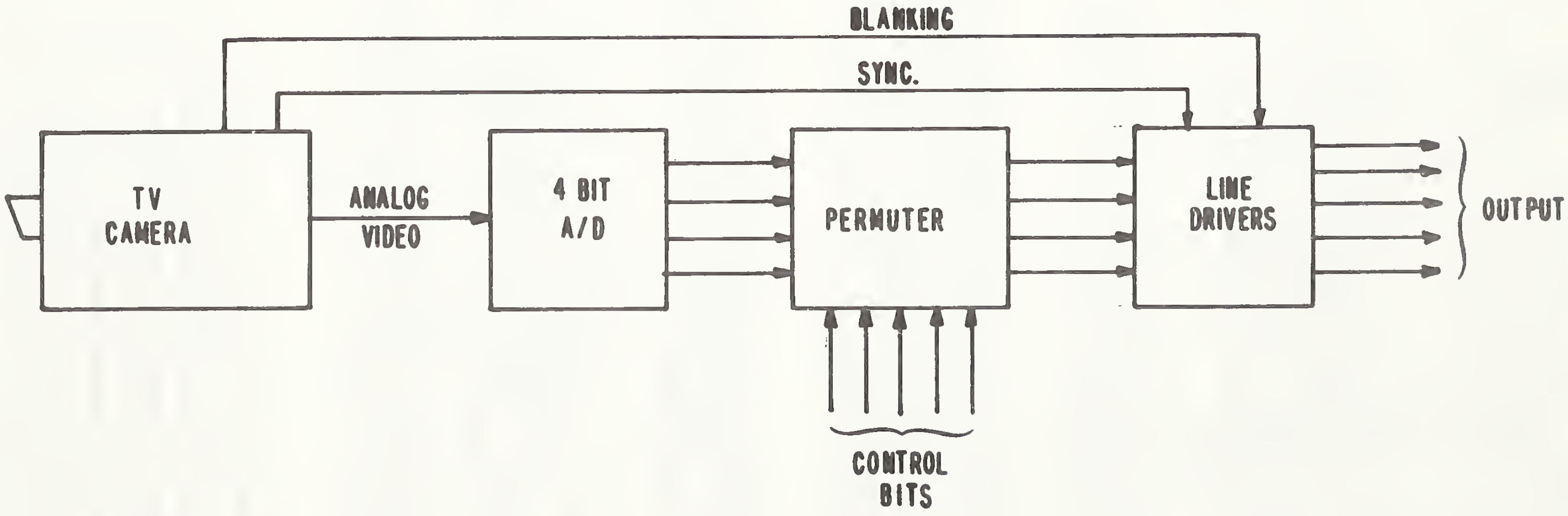

Fig. 2 Block Diagram of Encoder

TV Camera

1. Resolution-900 lines center, 600 lines in corners, at 30 frames per second, 4:3 aspect ratio

2. Automatic Light Range 5000:1, video remains constant to within 6 dB for a change in vidicon faceplate illumination from 2.2 to 1080 lux (0.2 to 100 foot-candles).

3. Gray-Scale Rendition - resolves all ten shades of gray on EIA TV Resolution Charts.

TV Monitor

1. Video Response - 10 MHz

2. Resolution - 800 lines center, 600 lines in corners

3. Linearity, Horizontal and Vertical - 2% of picture height

4.1 Encoder

Fig. 2 shows a simplified block diagram of the encoder outlined in Fig. 1. The elements consist of a 4 bit analog to digital converter, permuter, and line drivers. The video output signal from the TV camera is quantized into 16 levels coded in a 4 bit binary Gray code. Preliminary investigation and a search of the literature has shown that video luminance levels quantized with 4 bit resolution produce acceptable pictures after decoding with some noticeable contouring. Contouring caused by too coarse quantization produces pictures similar to those painted by the familiar "paint by numbers" technique. The effect is more noticeable in some pictures because the eye requires rather accurate values of luminance in large regions of gradually changing gray scale such as a close-up view of a person's face where shadowing is important to the overall composition. Pictures which contain many small details are more tolerant of gray scale quantization.

A horizontal resolution of 900 TV lines requires a bandwidth of about 10 MHz. The analog to digital (a/d) converter must be able to make conversions at this rate. A multi-threshold 4 bit converter, by far the fastest and most straightforward of all a/d converters, was designed for this application. It requires only 15 comparators, operates almost instantaneously, and is limited only by the delays of one comparator and a few logic gates. Transient errors and circuits required to suppress them are eliminated by converting to a Gray code rather than the natural binary code. A Gray code converter

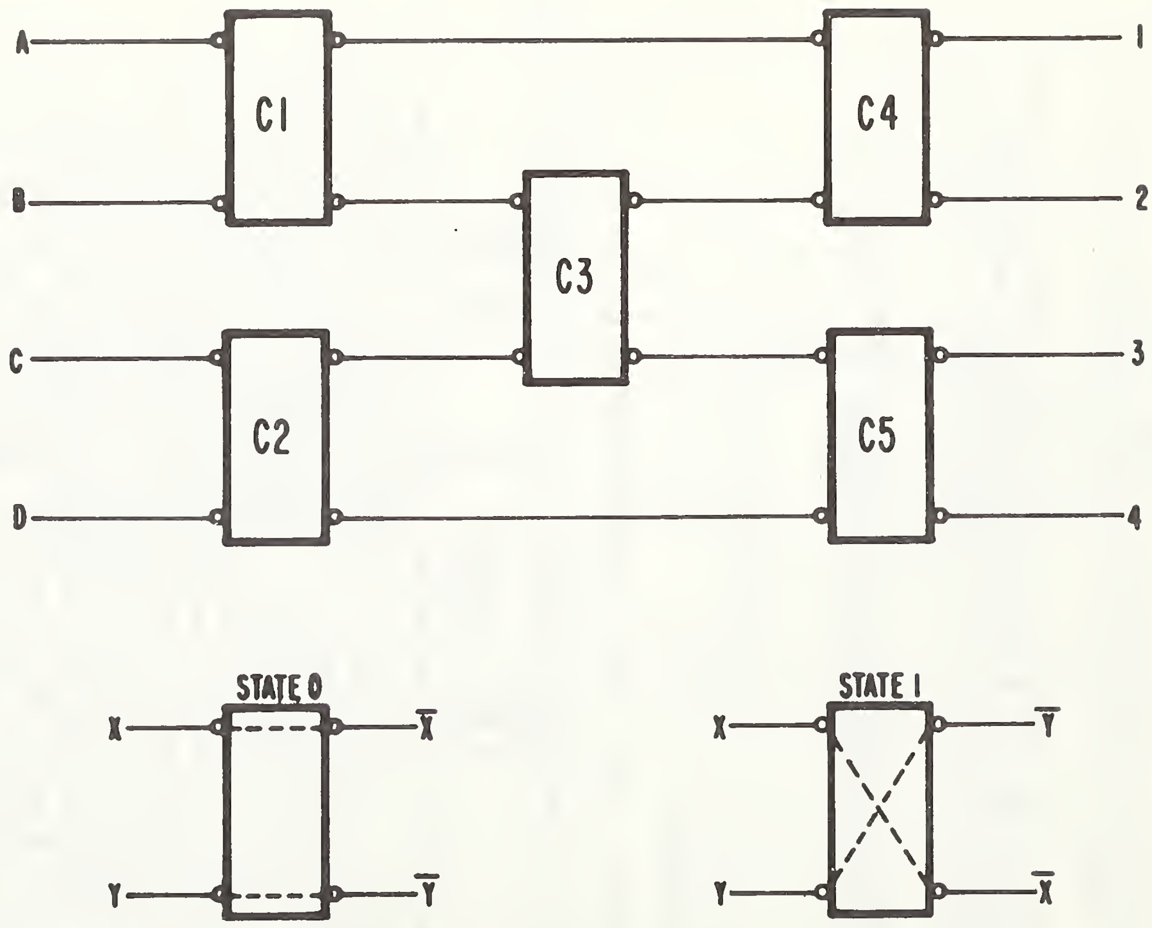

Fig. 3 Block Diagram of Permuter

offers higher accuracy and higher speed because each code differs from the adjacent numbers in only one bit position. Hence, the transitional errors of the video signal are reduced to one bit which results in minimal picture noise.

The contouring effect from the 4 bit quantization is further reduced by a simple technique which tends to smooth out intensity transitions to levels approaching 5 bit quantization. This is done by not providing hysteresis in the comparators of the a/d. This causes an individual comparator to oscillate when the signals approach the threshold levels. For instance, if the level of a video signal is at the threshold value of comparator number 8 the comparator will oscillate, resulting in encoded levels oscillating between values of 7 and 8. The frequency is high enough to produce a fine grained intensity structure which to the eye or film appears as the average between the two levels. The result is a much more pleasing picture than that produced by pure 4 bit quantization.

The permuter of Fig. 2 permutes and inverts some of the bits before they are transmitted to the recording station via the line drivers. The purpose of scrambling the digital information is to make it difficult to decode the information in a sufficiently short time to substitute a false video signal with the correct coding on the line. The maximum number of permutations for the 4 bits is 4 factorial. Thus, to effect the 24 possible combinations, a minimum of 5 binary control bits are required. Fig. 3 shows in block form the scheme used that provides 19 out of the 24 possible permutations. Each box represents a double-pole double-throw (dpdt) switch connected as a reversing switch. When the control for a switch is in state 0 the input-output data lines are uncrossed and when in state 1 they are crossed. Each dpdt switch is implemented with standard logic gates. The advantage of this configuration is that the maximum difference in signal propagation delay between any line is that of one dpdt switch which typically may be 10 nanoseconds. This amount of delay is far less than one picture element of the highest resolution picture being considered. Although this line permuter does not quite provide the maximum number of permutations it is simple; it also provides a random inversion of some bits because each dpdt switch inverts the data. Bits which go through an even number are not inverted, regardless of which state the switches are in. For the 32 possible control codes there are some repeat permutations but no code repeats because different bits can be inverted for the same permutation. For example in Fig. 3 assume the following states for each switch:

C1 = 1, C2 = 0, C3 = 1, C4 = 0, C5 = 1, then:

input A is switched to line 4 and inverted

input B is switched to line 1 and not inverted

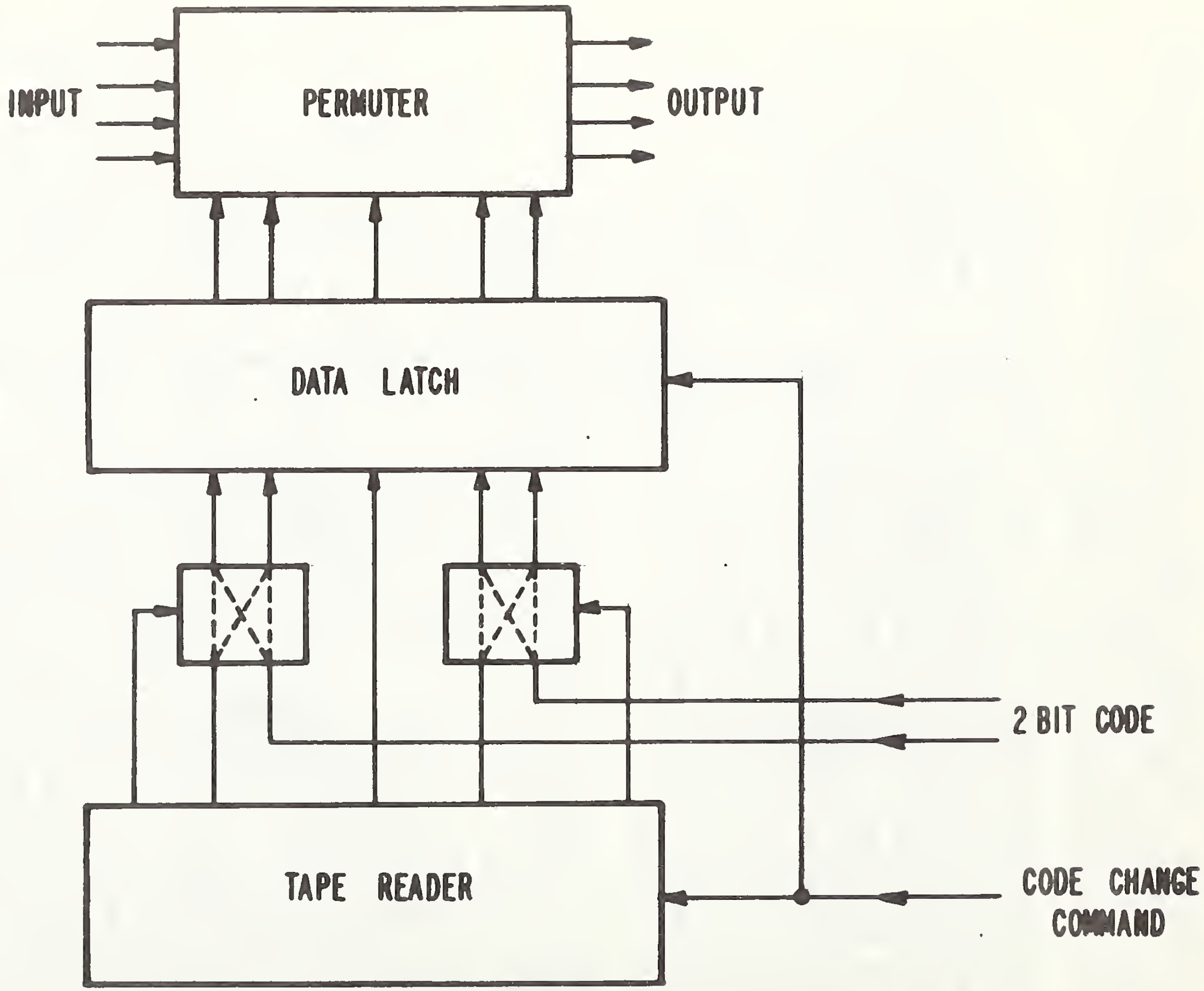

Fig. 4 Block diagram showing permutation scheme for 2-bit code.

input C is switched to line 2 and inverted

input D is switched to line 3 and not inverted.

The line drivers receive the permuted digital video signal from the permuter and convert it to a differential output signal. This signal drives a balanced twisted-pair transmission line terminated at each extreme in the characteristic impedance. The advantage is that the data is not affected by common-mode signals induced on the line thereby insuring error-free transmission and recovery of data over long lines.

During the blanking intervals of the video signals, when the synchronization pulses occur, the output of the drivers are inhibited to prevent an evader from determining which bits are inverted, because at that time the value of the video luminance signal is zero. Inhibiting the drivers during this interval also allows the use of one of the video data lines for transmission of the synchronization signal. Thus the transmission line between the camera and recording station consists of four video data lines, one of which carries the synchronization pulse, and a fifth line for the blanking signal.

The command to advance to a new stored random word in the camera package must simultaneously accompany a 2 bit random code. To avoid complication in the figure this is not shown in Fig. 1. The purpose of the 2 bit random code is to prevent an evader from falsely advancing the tape reader prior to a genuine command. If this were not done it would allow an evader to extract and record the entire supply of encoded video patterns which in turn could be transmitted to the recording station in sequence with the actual commands. Sending a 2 bit code only at the time of update forces any evasion attempts to operate in real time. In practice the 2 bit random code is permuted with 2 bits from the paper tape reader and put into a data latch before they are used as control bits for the permuter. Fig. 4 shows the scheme used to permute the 2 bit random code. Two dpdt switches similar to those used in the permuter permute the 2 bit code with 2 bits from the tape reader. An additional 2 bits from the tape reader control the state of each switch. Thus, the 2 bit code becomes part of the control code for the permuter but its identity is lost through this subpermutation process. This leaves only a one in four chance of guessing what the 2 bit code will be before it arrives, or a one chance in four of guessing how it is permuted. Injecting a known 2 bit code only helps if the bits from the tape reader happen to be the complement of the known 2 bit code. The probability of multiple successful guesses diminshes rapidly with these odds.

The entire control code for the permuter is held in a data latch which temporarily stores the code which is used until an update command is received. The update command permits a new word from the tape reader permuted with a new 2 bit code to be transferred through the latch to the permuter. Approximately

0.5 μs after the update command has been received, the control code is latched into storage and used to determine the coding pattern for the frame being photographed and subsequent frames. While the control word is held in the latch the tape reader advances to a new word so that it can be instantly used at the next update command. The instantaneous change of the code at the encoder and decoder occurs essentially simultaneously so that the position in the picture where the code was changed is imperceptible. In addition, the time of code change is unrelated to the sweep frequency of the camera, hence, the starting position of a code change in the picture is entirely random. The picture is photographed at the time the code is changed so that there exists practically no time for an evader to break the code and re-insert false video information. This is important to the security of the system because attempts to break the code require full bit-by-bit storage of the picture and accurate recognition of the time of a code change.

Early in the design phases of this system it was recognized that permuting a natural binary or Gray code is not entirely secure under dynamic conditions (i.e. a changing input signal for the same encoding pattern). This is because the least significant bit (LSB) is the busiest, i.e. it has the highest frequency content relative to the other digits. In the natural binary code from numbers 0 to 15 the LSB makes 15 transitions and the MSB makes only one. The Gray code has 8 transitions in the LSB and one in the MSB. Thus, it is possible to identify the significance of the bits from their relative frequencies by observing a scanning line of a normal video signal. An attempt was made to develop a code which roughly equalizes the number of transitions made by the LSB and MSB. This, however, complicated the design considerably and introduced more noise in the system. Although a type of Gray code with equalized number of transitions could be developed it was decided that the degree of extra security offered by choosing a special code did not warrant the added complexity and degradation in performance. Furthermore, identification of the significance of the bits does not break the code because the bits that are inverted must also be determined. This, coupled with the fact that the system runs asynchronously (no clock), makes decoding difficult. To effect an evasion by substituting false video information requires rapid identification of the code pattern and reinsertion of a properly encoded false signal all in an interval which can not be detected. The resources required to do this seem formidable particularly in relation to the low cost and simplicity of the encoder/decoder system and more than likely would force evasion attempts to other areas.

Fig. 5 is a photograph of the entire video encoder which is constructed on a 14 x 25 cm printed circuit card. The card contains the circuits for the 4 bit a/d converter, permuter, 2 bit code permuter, data latch, and line drivers.

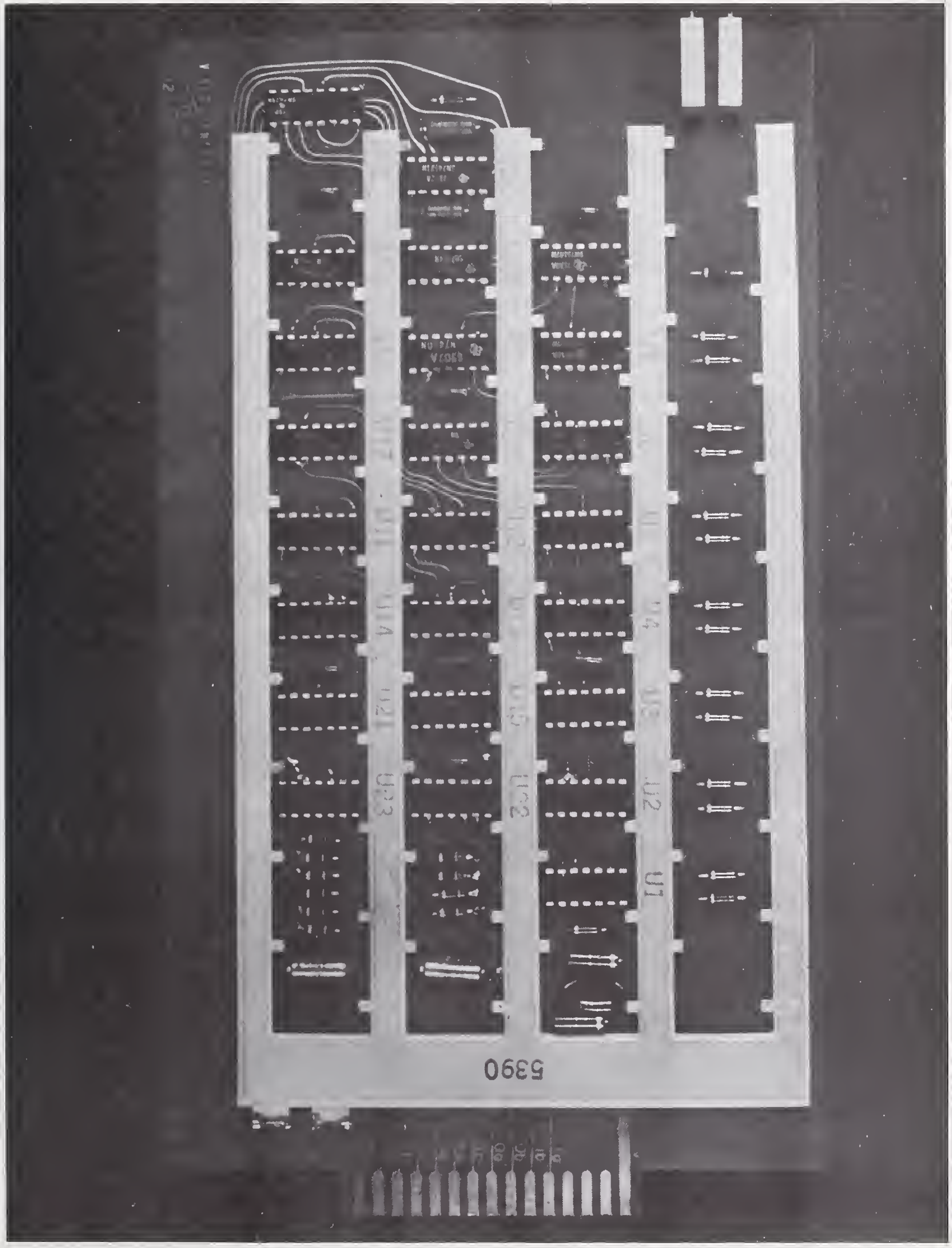

Fig. 5 Video encoder assembly.

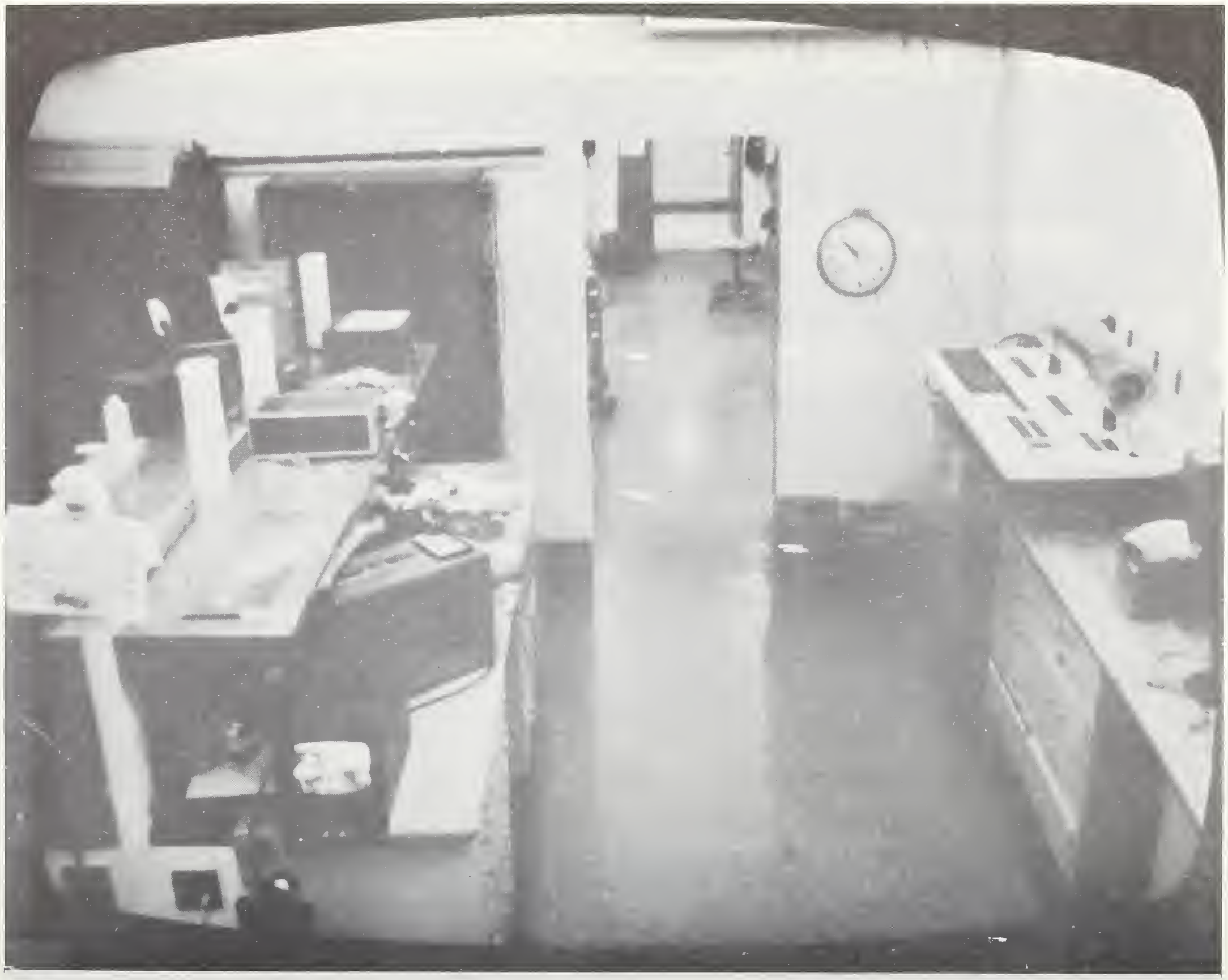

Fig. 6 Picture processed through the encoder-decoder system.

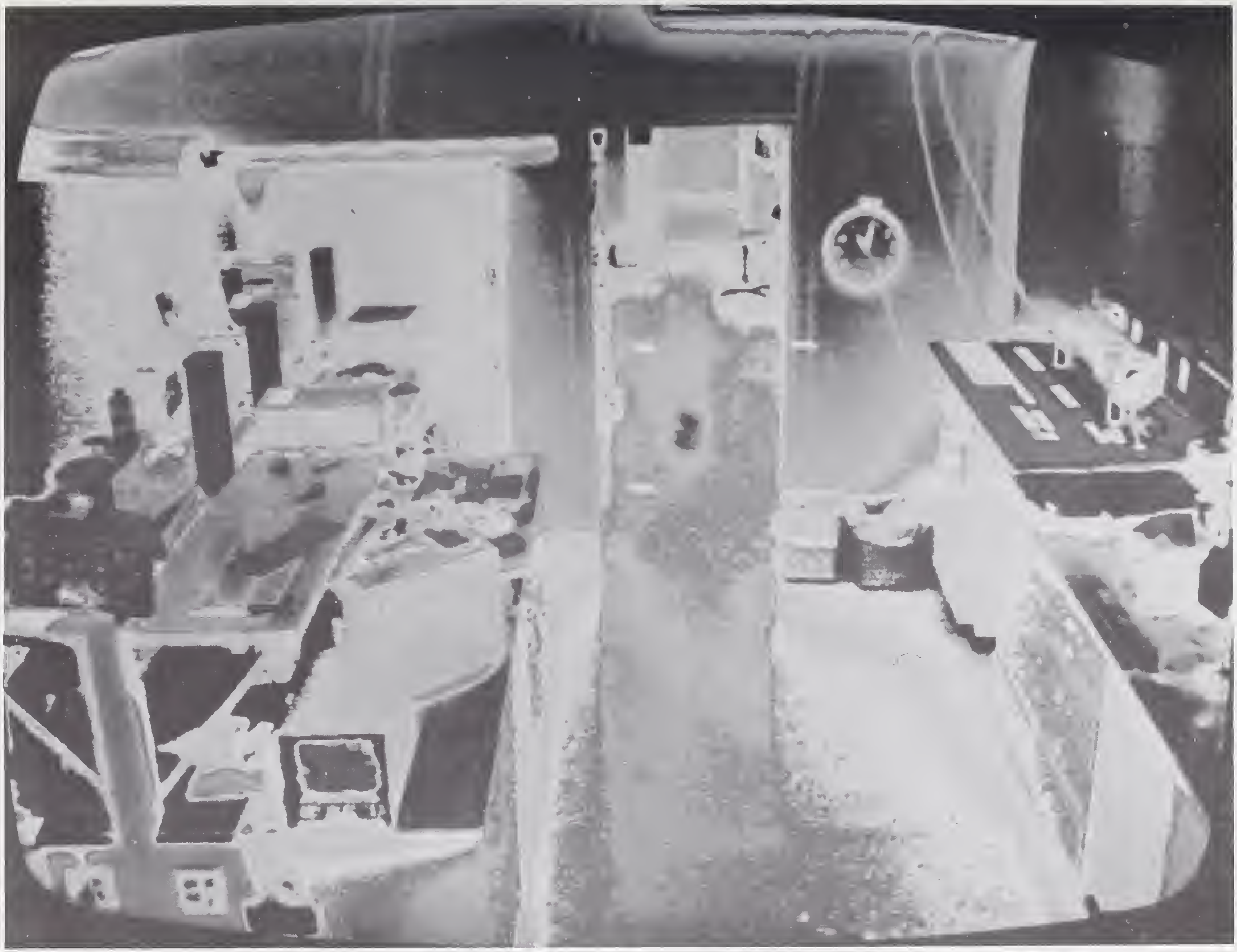

Fig. 7 Scrambled effect on the luminance of the picture as a result of a mismatch of encoder-decoder control codes.

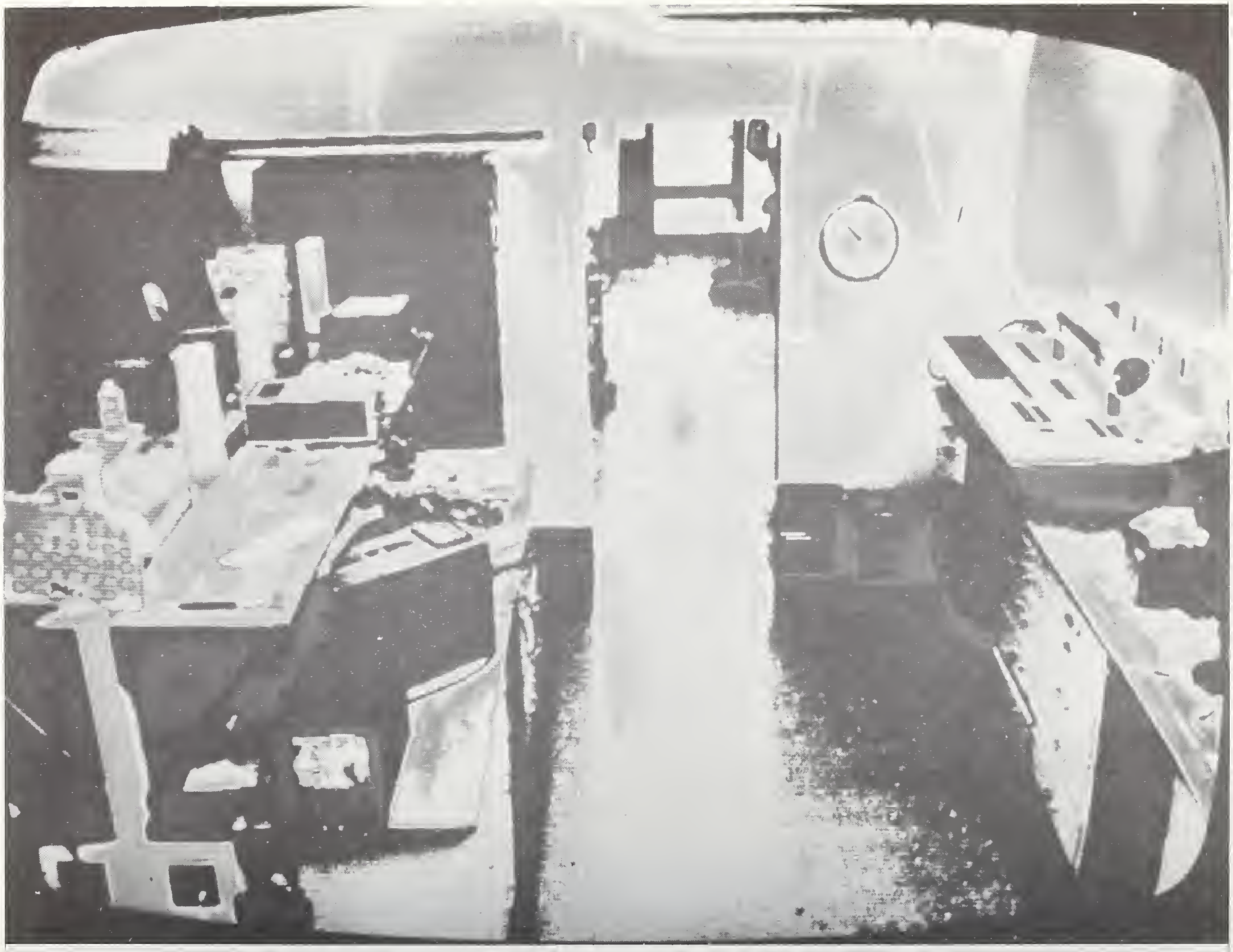

Fig. 8 Scrambled effect on the luminance of the picture as a result of a mismatch of encoder-decoder control codes.

Fig. 9 Scrambled effect on the luminance of the picture as a result of a mismatch of encoder-decoder control codes.

4.2 Decoder

The decoder consists of line receivers, de-permuter, Gray to binary code converter, and digital to analog converter. The line receivers convert the balanced differential signal on the transmission line to normal logic levels. The encoded 4-bit video signal passes through a de-permuter which is actually a second permuter of identical design to the one illustrated in Fig. 3. An identical set of words on punched tape plus the 2 bits for the random code control the permuter the same way as in Fig. 4, so that the video signal is restored to its originally generated Gray code. The Gray code must be converted to a natural binary code before conversion to an analog signal. This is simply done by a series of logic gates. The digital to analog converter produces an analog signal by summing weighted currents of each binary digit. Synchronization and blanking signals are summed at this point to provide a complete composite video signal suitable for the monitor.

The results of this tortuous path taken by the video signal are shown in Fig. 6 which is an encoded-decoded picture of a scene in the laboratory. The picture was originally taken directly from the monitor on a 35 mm transparency and reprocessed for reproduction, hence, the quality obtained is not representative of that on the 16 mm film. Fig. 7 is a picture of the same scene showing the effect of a permuted video luminance signal as a result of a mismatch in the two sets of code words or the results of an unsuccessful tamper. Note that the outlines for large objects are still clearly visible and only the identities of small objects have become obscured. Fig. 8 & 9 show additional permutation patterns. In some cases the picture appears as a partial negative with the contouring effect of quantization greatly accentuated. Some patterns do not produce a very noticeable distortion but in all cases they can be recognized as an improperly encoded or decoded picture.

4.3 Paper Tape Reader

Punched paper tape is used to store the code words which control each permuter. Commercial units were not suitable for this application because their size and shape factor generally were not compatible with the space available in the secure TV camera container. Many of the commercial units intended as input mediums for digital computers have high speed requirements which are by no means required in this application. The speed requirements are based on the minimum interval between recorded pictures which is rarely less than a few seconds.

A special tape reader in the form of a cassette was designed for this application. Fig. 10 is a photograph of the assembly with the front cover removed to show the internal details. The approximate dimensions of the cylinder are 21 cm in diameter and 10 cm in length. The unit employs one inch (2.54cm) standard

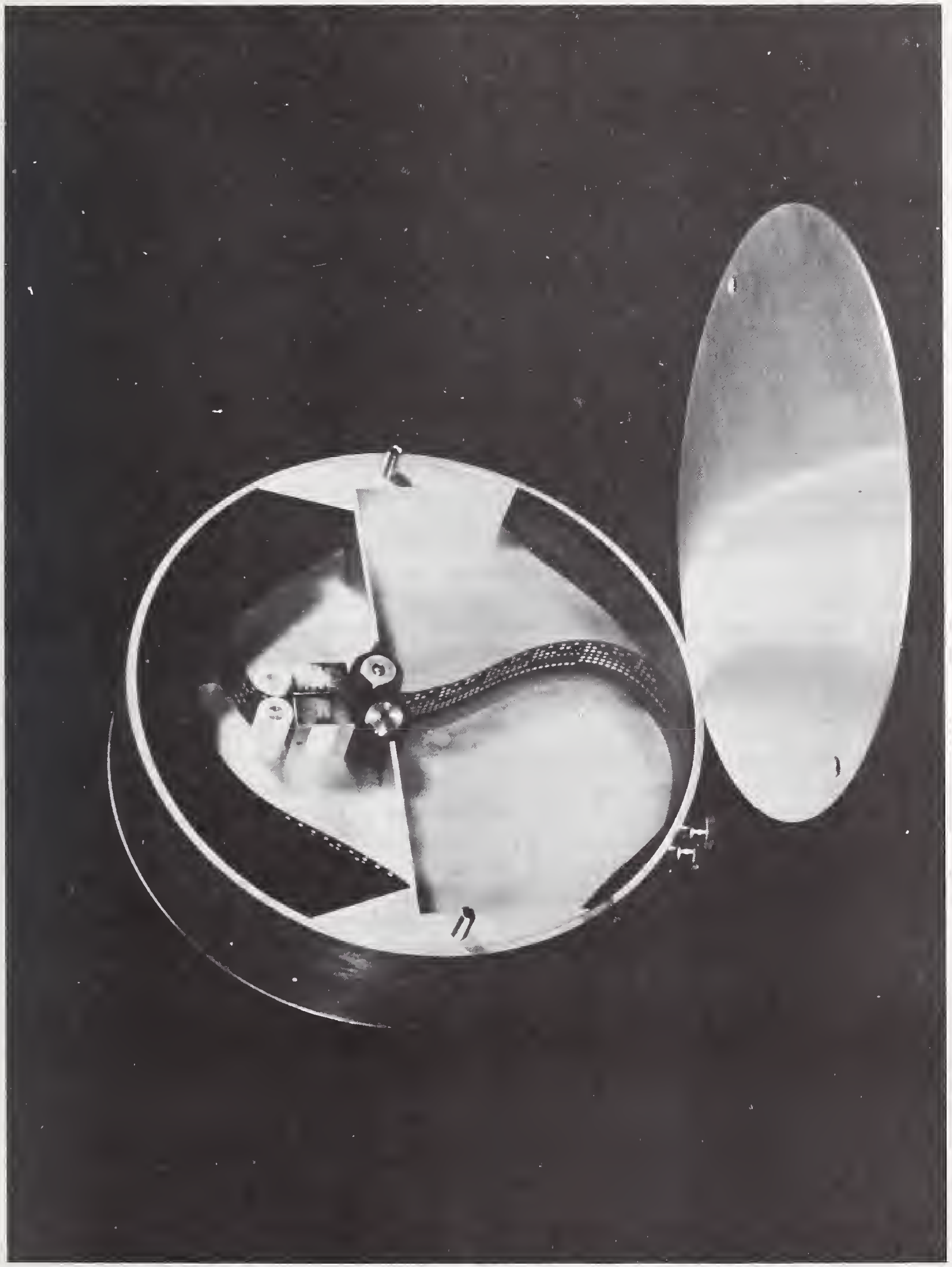

Fig. 10 Tape reader assembly.

fanfold paper tape which eliminates the need for take up reels and the associated mechanisms. A pair of rubber pinch rollers driven by a small 1 rpm clock motor advance the tape from the supply compartment to the spent compartment. As the tape is pulled through the reading head station it unfolds one leaf at a time and folds up in the lower compartment. The compartments have a tape capacity for up to 13 000 8-bit words.

Sensing of the holes at the reading station is accomplished by means of an array of nine phototransistors and nine light emitting diodes as the sources (i.e. one set for each hole). A sprocket hole, smaller in diameter than a data hole, exists for each character. This serves as an indexing hole which is also sensed by photoelectric means. The command to advance the tape to the next character starts the clock motor which then stops on the next sprocket hole.

The cassette can be removed from the system and new tapes loaded in a convenient working area. The operation of the system is not affected by removal of both tape readers since each permuter interprets this as a code of all ones. An additional benefit to the cassette approach is that the possibility of theft or surreptitious copying of tapes can be eliminated by sealing new tapes in each cassette. Thus, an inspector simply removes a spent unit and replaces it with a new sealed unit. The spent unit would be returned to some central depot for reloading.

4.4 Motion Detector

The motion detector was designed to provide for selectively recording only the most meaningful pictures of an area under surveillance in order to reduce the necessary film storage capacity and the burden of analysis. The premise to this is that activity, especially in preselected areas, may be of interest and therefore should be recorded. The basic principle of motion detection is sensing a rate of change in luminance. Objects which move generally cause a change in the luminance of the area to or from which they have moved. Of course this assumes that the reflectance of a moving object differs measureably from the background reflectance of the monitored area. The range of measurement must have practical bounds to reject rapid changes such as those caused by modulation of the illumination source and very slow changes which have no significance.

The motion detector designed for this system operates from the analog video signal to the TV monitor. Preselected spots are monitored in the TV camera field of view and the photographic camera is commanded to record a picture when there is motion at any one of these locations. Motion in these areas is detected by sensing changes in the video luminance levels which exceed a predetermined rate of change. The system is designed to provide up to ten spots which can be employed in the following two ways:

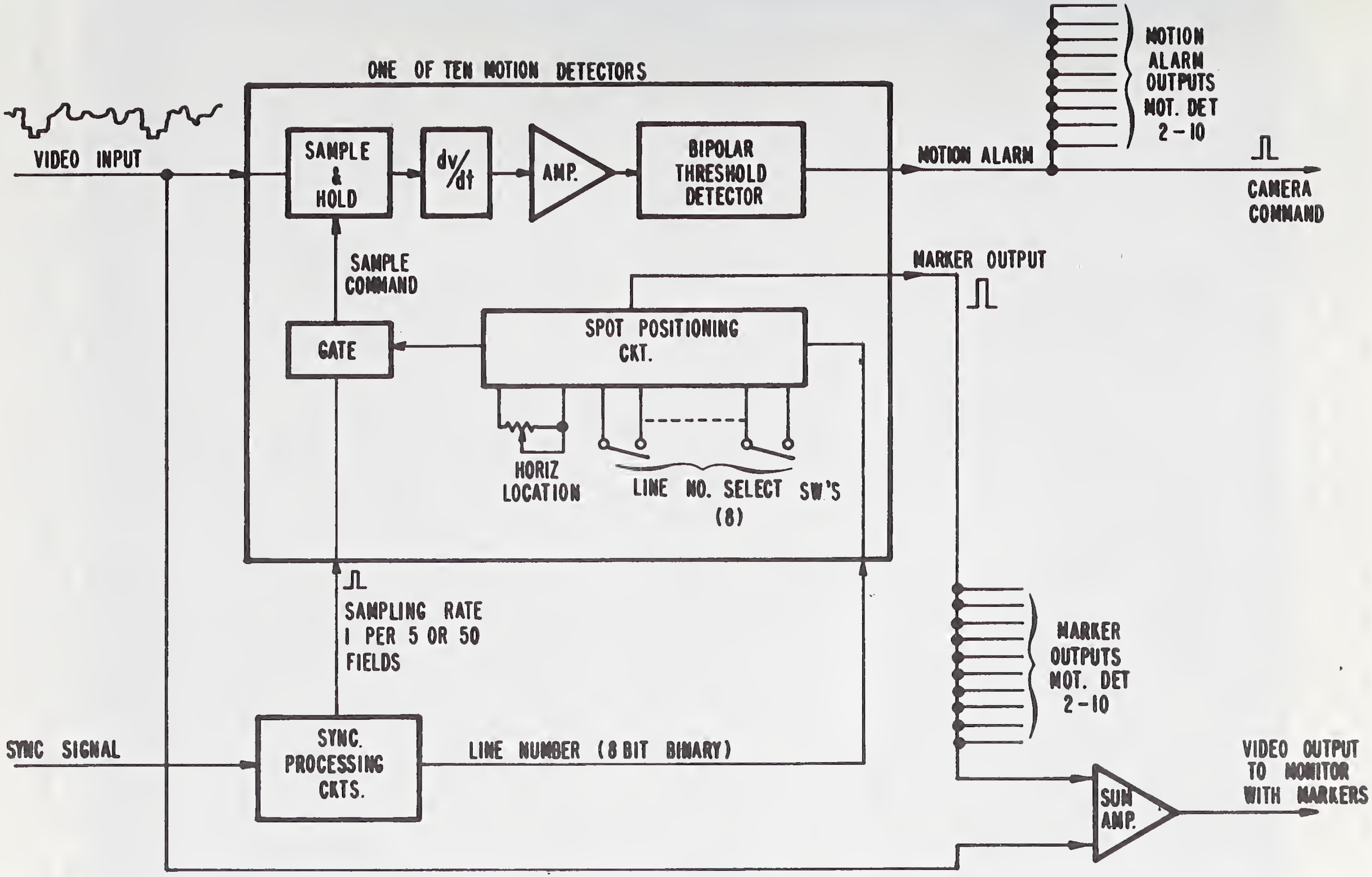

Fig. 11 Block Diagram of Motion Detector.

1. A single spot can be positioned over a critical area or object to be monitored without incurring alarms from areas which are unimportant or subject to normal activity. This application can be extended to numerous spots which individually monitor many areas of interest in the scene.

2. A series of spots may be located in a horizontal or vertical line where the passage of an object across the line is significant. For example this technique may be applied to detect objects lifted by an overhead crane. Proper spacing between spots in relation to minimum dimensions of the object of interest will allow detection of those objects which cross the monitored line. In both applications it is desirable to locate the spots where normal activity does not occur. However, extraneous pictures may be unavoidable if spots are positioned to monitor a location in the background which is below head height in the foreground where normal activity occurs.

Fig. 11 shows a block diagram of the motion detector system for one of ten detectors. The heart of the detector is a sample and hold system in which a gated video luminance signal is compared with a previously stored level over some time interval. If the new value of the gated signal differs from the stored value by a fixed threshold, an alarm is produced which commands the camera to take a picture. The motion alarm output signals of all motion detectors are connected together so that an alarm from any one will command the camera.

The synchronization (sync) signal is taken directly from the decoder before it is combined with the video luminance signal. This obviates the need to separate it again from the composite signal. The sync processing circuit does several things. First the horizontal sync pulses are separated from the vertical sync signal. The sampling rate (i.e. the rate at which a video sample is taken) is generated by a circuit which locks on to either the odd or even field and produces pulses which occur at the rate of one per five or one per fifty odd or even fields. This results in a sampling rate of 6 Hz and 0.6 Hz for a 30 frames per second system. The purpose of having available two sampling rates will be explained later. Second, the horizontal sync pulses of the sampled field are counted in an 8 stage binary counter. The 8 bit binary number representing the scanning line number of one field goes to the spot positioning circuit.

The spot positioning circuit selects the point on the raster, vertical and horizontal, where a video sample is taken. The vertical position is determined by the state of 8 switches arranged in a binary sequence. When the state of the counter matches the line number set by the switches, a pulse is formed. This pulse is delayed by a variable delay circuit which determines the horizontal

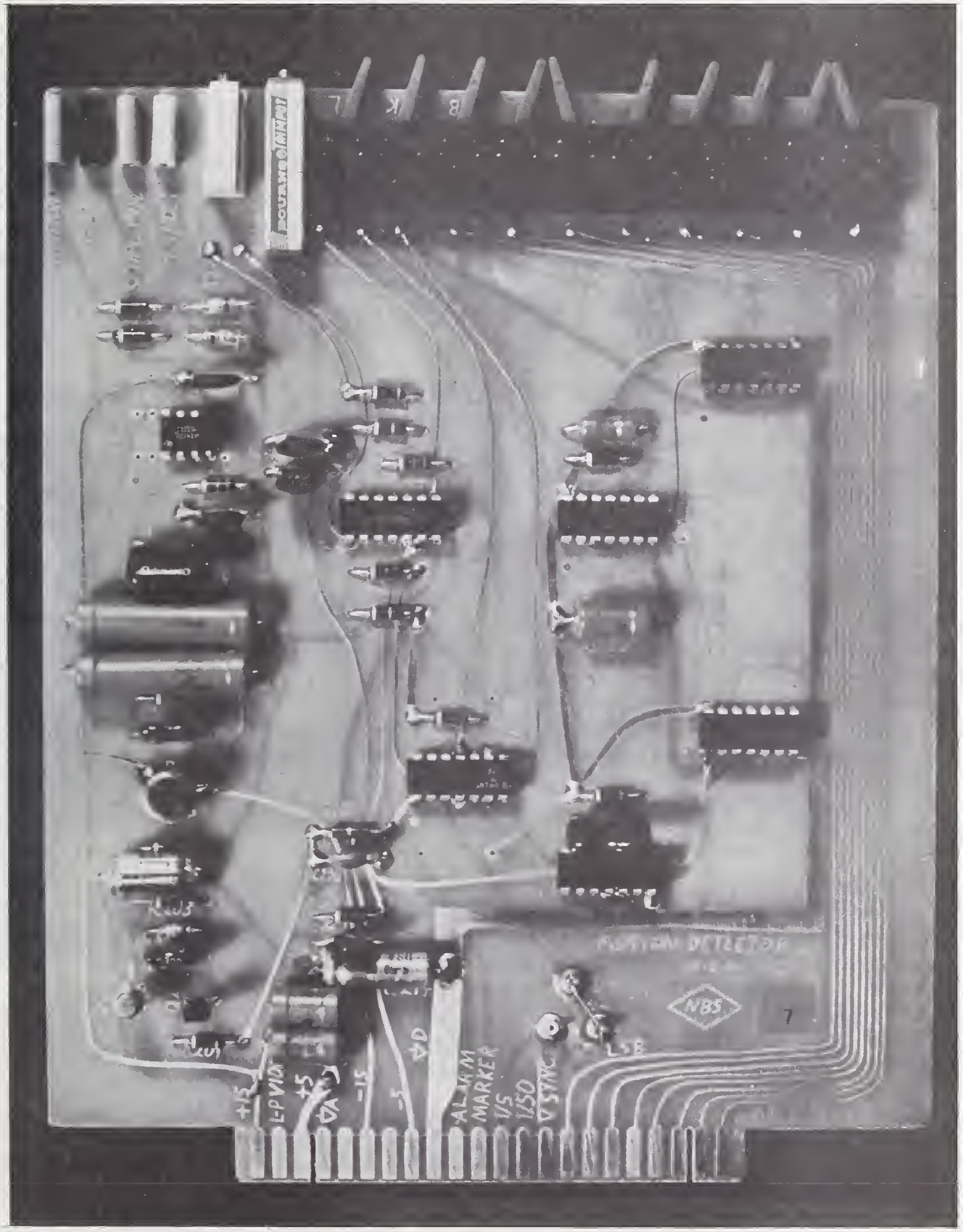

Fig. 12 One motion detector assembly.

position of the sample. The pulse, about 1/50th the length of a single scanning line, is gated at the sampling rate to produce the sample command for the sample-and-hold circuit. In general the smaller the sample the greater the sensitivity to motion. This is because the sample represents an area which should be small in relation to the area covered by a moving object to realize the greatest change in illumination. A marker pulse identical to the sample pulse is also produced and combined with the video signal before it goes to the monitor. This produces an intensified area on the monitor representing the size and location of the monitored spot. By observing the monitor the position of the spot can be set over the desired area. The pictures in Fig. 6, 7, 8, and 9 show eight spots. Two sets are located in the doorway and two sets are located to the right of the door. In this arrangement a picture would be recorded when someone walked through the doorway or moved the trash container.

The sample and hold circuit is essentially an electronic switch and storage capacitor. The sample command closes the switch and the capacitor quickly attains the voltage value of the sampled video. When the switch is open the capacitor retains this value over the sampling interval. The output of the sample and hold circuit goes to a differentiator which is composed of a single RC network. This circuit responds only to a change in voltage at the sample time. In other words if a change occurs between the time the last sample was taken and a new sample, then the differentiator will respond with an output. Conversely if there is no change in level from sample to sample, then the output of the differentiator will remain at zero. The output of the differentiator is followed by an amplifier to boost the derivative signal. The output of the amplifier goes to a bipolar threshold detector which produces a motion alarm signal if the peak voltage exceeds positive or negative threshold levels. The purpose of bipolar threshold levels is for detection of luminance changes in either direction (i.e. light to dark and dark to light).

Fig. 12 is a photograph which shows a card containing the components for one motion detector. The eight switches at the edge are for positioning the spot vertically. The two upper switches are for turning off the marker and the motion alarm signal. In most cases it is desirable to leave the markers on to help identify which spot triggered the camera. Turning off the motion alarm allows a detector to be disabled without pulling out the card. The system also permits any number of cards from 1 to 10 to be used.

The sensitivity is determined by the gain of the amplifier following the sample and hold circuit and the threshold levels. In this system the sensitivity is, to a large extent, limited by the 4 bit resolution of the luminance signal. Increasing the motion detector sensitivity much beyond this just increases the false alarm rate due to noise in the signal. A low-pass filter preceding the sample-and-hold circuit filters out the high frequency components of the signal not essential for detection of motion and reduces the noise. In practice a one part in 16 change in illumination seems to be quite adequate for motion detection.

Increasing the sampling interval enhances the sensitivity to slowly moving objects such as large cranes which lift a load very slowly. A faster sampling rate is more desirable for monitoring the ordinary movements of people or faster moving machinery. One sampling rate does not extend the sensitivity over the wide range of possible rates of movement. For instance a detector using a slow sampling rate would not necessarily detect a person walking rapidly through the monitored area. For this reason two sampling rates were made available so that a motion detector can be programmed for a fast (6 Hz) or a slow (0.6 Hz) sampling rate. If an application requires detection of both slow and fast movements in the same location, two motion detectors, one programmed for slow and one for fast can be used as in Figure 6.

A second important function of the motion detectors is protection of the system against deception from insertion of false scenes in the TV camera's field of view, movement of the camera from its mounting, and substitution of video data on the transmission line. The detection of these possibilities manifests itself in a recorded picture which shows evidence of tampering. Insertion of video signals from another source without the correct code will produce scrambled gray levels which will be sensed by the motion detectors causing a picture to be recorded. In the case of attempted camera movement the result may be a recorded picture that is misregistered in comparison to the other previous frames. Experience has shown that very slight frame misalignment of a single picture can be detected while playing back the film. The speed of response of the motion detector is such that attempts at scene substitution appear difficult. A sampling rate of 6 Hz forces an evader to mechanically position a false scene and associated optics in perfect registration in a period of less than 167 milliseconds. In addition, the approximately correct illumination must be provided. While such attempts are probably difficult to implement an evader can take advantage of a lock-out interval when no picture can be recorded. For practical reasons some lock-out interval is required to limit the number of frames when there is a great deal of motion.

The design provides for a lock-out period of approximately 2 minutes. This interval is generated by a separate clock which provides a reset once every 2 minutes regardless of the state of the motion detector output. In other words, the reset time is not related to a motion alarm. Thus, after one alarm the motion detector output might be enabled any time after that up to two minutes. The uncertainty of the time when this reset may occur coupled with the uncertainty of a command from the random interval timer makes evasion attempts risky. Although there are ways of determining the reset time, there are ways of increasing the sophistication of the lock-out logic. For instance if there is a simultaneous alarm from all the motion detectors this might

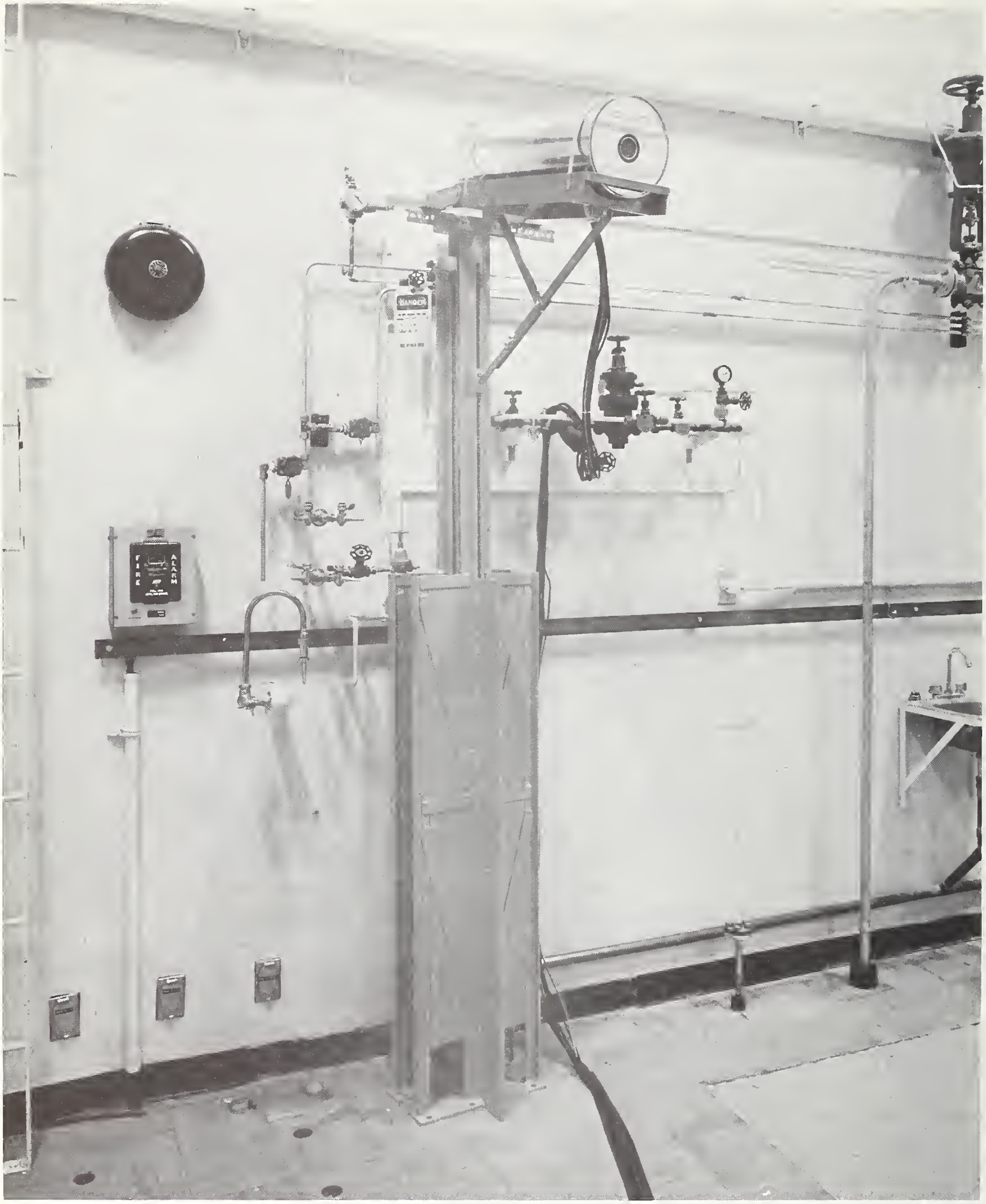

Fig. 13 TV camera assembly in the NBS Reactor fuel storage room.

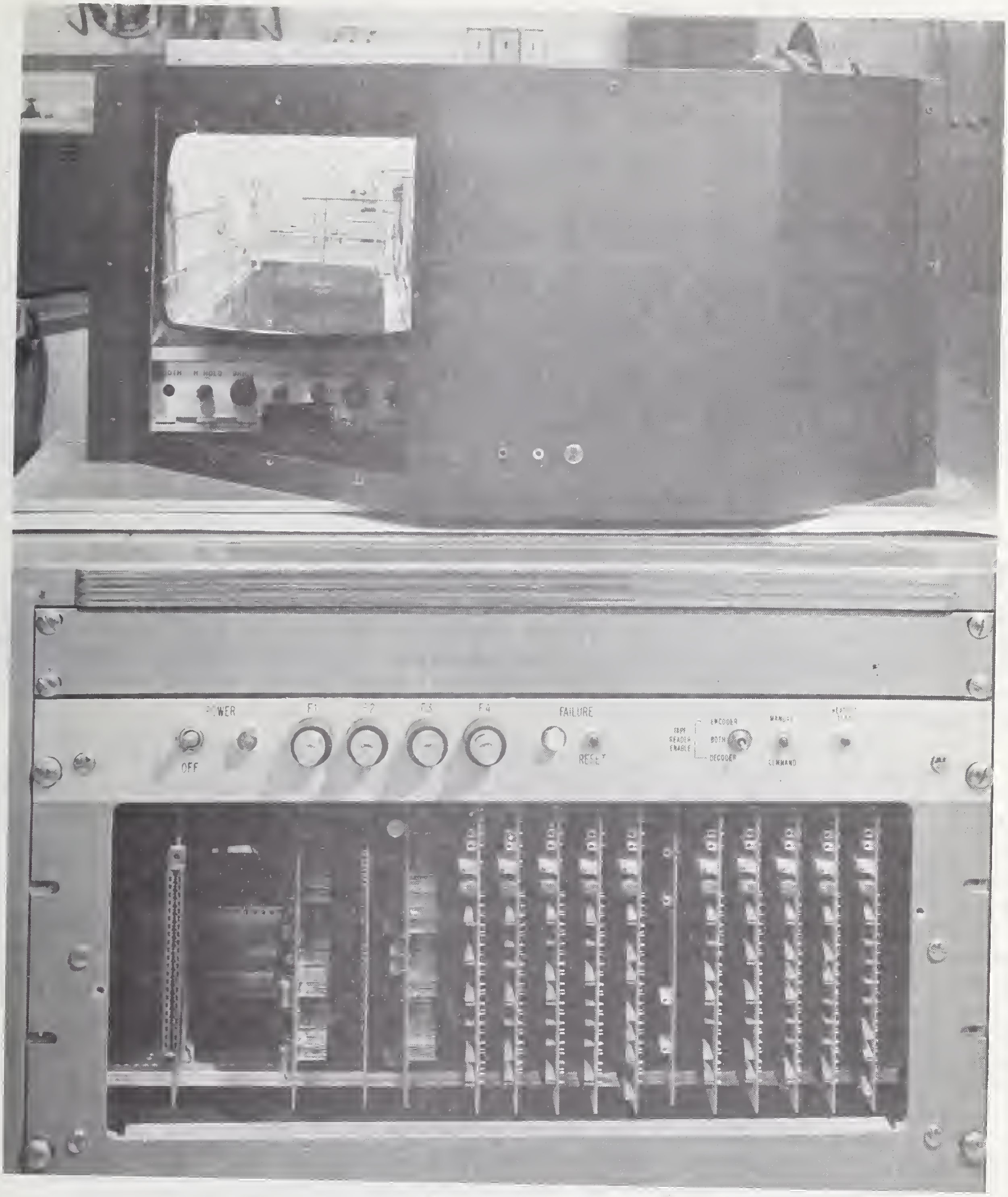

Fig. 14 TV monitor assembly (above) and chassis for ten motion detectors and video decoder.

override the lock-out because this is an unusual situation. Randomizing the lock-out interval is another approach. None of these techniques were implemented in this design mainly because the purpose was to evaluate the effectiveness of the motion detectors in a field environment.

5. FIELD TESTS

Before testing the system at the NPD reactor in Canada it was installed in the NBS reactor fuel storage room. This area provided an opportunity to make tests in an environment similar to the NPD fuel storage room. Fig. 13 is a photograph in this setting of the TV camera assembly which is mounted on a steel pedestal. The silvered plastic cylinder houses the TV camera, encoder, tape reader and power supplies. The cylinder (23 cm diameter, 50 cm length) is supported in an aluminum cradle which has an adjustable strut underneath to permit adjustments of the viewing angle.

Fig. 14 is a photograph of the equipment that would be located in the recording station. The monitor is shown with a mirror removed to provide access to the screen and controls. When the mirror is in place the image path from the screen to the camera lens is folded to provide a compact arrangement. The 16 mm camera and single frame advance mechanism are mounted behind the mirror box. The bottom portion of the figure shows the chassis and controls for ten motion detectors, video decoder, tape reader, and power supplies.

During the week of June 11, 1972, the system was installed in the fuel storage room of the NPD reactor near Rolphton, Ontario, Canada. The main area in the room consists of a deep pool of water where all the spent fuel bundles are stored and allowed to cool off. The basic purpose in applying surveillance to this area is to ascertain that no unaccounted-for spent fuel bundles or parts thereof are removed from the bay. The normal removal method utilizes a large shielded cask which is lifted by an overhead crane. There are, however, various other unconventional means of removing fuel from the bay. The various illicit means for removing fuel bundles from the bay have not been clearly defined although it appears that bundles can be lifted directly without shielding.

All ten motion detectors were used for this test. A group of spots were arranged in a line overhead to detect objects lifted by the overhead crane. The remaining spots were positioned in various areas where normal activity may occur for the purpose of exercising the system. The random interval time and clock time were obtained from the previously installed TRUST instrumentation system. The random interval timer had a mean time of 20 minutes.

Operation over approximately a six month interval revealed the following problems:

Operation over approximately a six month interval revealed the following problems:

1. The tape readers tended to get out of synchronization, causing scrambled pictures.

2. The video output from the TV camera occasionally dropped out, requiring readjustment.

3. Several of the power supplies in the system failed.

The control circuitry for advancing the tape reader was redesigned to make it less susceptible to interference and momentary power outages. The difficulty with the TV camera has yet to be resolved. It was discovered that the video often would not recover after momentary power outages which occurred rather frequently. To overcome the frequent power interruptions the system was put on the TRUST instrumentation power supply system which consists of a 28 volt battery that is charge-maintained by the 120V, 60Hz power. Since the TV system was designed for 120V, 60Hz, a 28 volt dc to 120 volt ac inverter had to be employed.

The failure of several power supplies was attributed to heat. All power supplies in the system of the potted design eventually failed. Apparently these commercial supplies cannot operate in ambient temperatures of 45 to 50°C which is well within their advertised specifications. Different power supplies of the unpotted variety are being considered for replacements.

An additional problem which developed during the period was noise on the video signal. It manifested itself in the form of occasional white bars of about 1 μs in duration. When a noise pulse occurred in the same location as a motion spot a false alarm was produced. The noise did not appear to be of periodic nature and the severity varied from time to time. Even though the system was operated on the battery power supply the noise persisted and was observable directly at the TV camera video output. The source was attributed to two possibilities; the camera itself, or a noisy machine in the facility.

The first roll of film was developed and analyzed on the special stop-motion projector. The motion detectors performed well by capturing a number of interesting sequences involving unusual fuel handling operations. During periods of no activity in the area the number of pictures recorded was essentially limited by the random interval timer indicating that the false alarm rate of the motion detectors was very low. One thing that has become apparent from reviewing the pictures is that it is desirable to shorten the motion lock-out period. Often there are sequences where motion in an area triggered only one picture. This is often insufficient information to determine the type of activity taking place. Shortening the interval produces more pictures but also consumes more frames. A more sophisticated type of lock-out logic which provides for more pictures of a sequence and economical use of frames could be designed.

Experience has also confirmed that the need for more than ten spots is the exception rather than the rule. Situations requiring more than 10 spots might occur when applications require many spots to be used as containment perimeters around certain objects.

6. CONCLUSIONS

A tamper-resistant television surveillance system has been developed. The system utilizes commercial closed circuit TV and photography coupled with a video encoding technique for security, and motion detectors for selective recording of pictures. The incorporation of these additional features adds little comparative complexity to ordinary closed circuit TV while greatly increasing its effectiveness as a surveillance tool for safeguards applications. Specific technical conclusions based on the work are listed below:

1. Video signals quantized in four bit Gray code and decoded produce negligible distortion of pictures.

2. Permuting and inverting some of the bits of video luminance signal before transmitting is an effective technique of preventing substitution of false data.

3. A 2 bit code must be transmitted to the camera package at the time of code update to maintain security.

4. The motion detectors enable a considerable saving of recording capacity by selectively recording pictures when motion occurs in preselected areas.

5. A slow and a fast sampling rate is required to adequately detect the possible speeds of motion.

6. The motion detectors help to protect the system against deception from insertion of false scenes in the camera's field of view.

7. Observing the film through a special stop-motion projector appears to be a relatively fast and accurate method of analyzing the data.

The problems revealed during the field tests do not appear fundamental in nature and can be corrected by improved design. The field test has made it clear that the motion lock out period needs to be shortened and optimized for the application. A more sophisticated lock-out logic which considers more factors in the determination of the lock-out period could be designed. This would tend to optimize the amount of useful information stored for a given storage capacity.

One thing, which was not fully appreciated before, is now apparent. The accumulation of field experience and information regarding the effectiveness of the system will require a great deal of time. Any system of this nature, although it may prevent diversions, is potentially vulnerable to harassment. This point was made more evident from some of the failures encountered, particularly the synchronization problems with the tape readers which can cause all the pictures to be scrambled. Although this problem was corrected it still may be a weakness from the standpoint of harassment and therefore require a more thorough redesign. The reason for the guarded optimism is that still too little is known of how this system might perform under a real life situation. If the system can be made to fail without indicating that it has been intentionally defeated then it will be of little value. The many possible unthought-of diversions and harassment techniques can only be uncovered by more tests and experience especially by groups not involved in the original design. Furthermore, because this system involves technology at one point in the state of the art, future advancements in technology may seriously endanger the effectiveness of the system. Hence, the system must be continuously evaluated with respect to the state of technology and the overall objective which is to provide early detection of the diversion of nuclear material to other than peaceful purposes.

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This report describes a tamper-resistant television system. This system will be part of a larger system used for verifying compliance with certain international arms control or safeguard agreements. This work is part of a joint U.S.-Canada safeguards research program to develop and evaluate tamper-resistant, tamper-indicating techniques and instrumentation that might be applicable in safeguarding reactors or other nuclear facilities. The principal design objectives are to provide a system capable of unattended operation, data storage capacity for a period up to 90 days, and resistance to deception by insertion of false video information on the transmission line or substitution of false scenes in the camera's field of view. These objectives are accomplished by utilizing commercial high-resolution closed-circuit TV and photography coupled with a video encoding technique which permutes the luminance signal in a different pattern for each recorded picture. Motion detectors, utilizing the video signal, provide the ability to selectively record pictures when motion occurs in preselected areas, and protect the system against insertion of false scenes. The incorporation of these additional features adds comparatively little complexity to ordinary closed circuit TV while greatly increasing its effectiveness as a surveillance tool for safeguards applications.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Safeguards; surveillance; tamper-resistant; television

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