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The goal of the research effort funded under this grant is to finalize the construction of two prototype DXM-1 slot-scanning digital mammography systems, conduct a technical evaluation of these prototypes and perform a clinical study to assess the efficacy of the system in the clinical environment. The technical evaluation conducted at the Radiology Department at the University of Arizona (UA). The objective of the technical evaluation is to determine system performance parameters such as dynamic range, modulation transfer function, sensitivity, etc. The clinical study is scheduled to be conducted at the Radiology Department at the University of California at San Diego (UCSD) and will establish the clinical efficacy of the system compared with conventional film/screen mammography. Construction of the prototypes is complete and the technical evaluation has been completed. Clinical images have been obtained with 2 patients. Preliminary data gathered indicates that image quality parameters of the DXM-1 system are superior to film/screen mammography and can be obtained with lower patient dose.

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John D Cox for 10/11/99
PI - Signature Date
Ronald B. Schilling

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INTRODUCTION

The goal of the research effort funded under this grant is to finalize the construction of two prototype DXM-1 slot-scanning digital mammography systems[1], conduct a technical evaluation of these prototypes and perform two clinical studies to assess the efficacy of the systems in the clinical environment. This program was scheduled to be completed during a 36-month effort.

The technical evaluation and one of the clinical studies is being conducted at the Radiology Department at the University of Arizona (UA) under the direction of Dr. Hans Roehrig. The objective of the technical evaluation is to determine system performance parameters such as dynamic range, modulation transfer function, sensitivity, etc. These parameters are to be measured and compared with film/screen performance characteristics. The objective of the clinical study conducted at UA is to acquaint and train radiologist to read digital mammograms from a monitor and to determine system efficacy in screening and diagnosis by imaging patients with known abnormal mammograms. One hundred women are scheduled to participate in this study.

The second clinical study was scheduled to be conducted at Sharp Healthcare/Sidney Kimmel Cancer Center in San Diego, California under the direction of Dr. Christine White. The objective of this study is to establish the clinical efficacy of the system compared with conventional film/screen mammography. One thousand women are scheduled to participate in this study. In the first reporting period, the principal investigator for the clinical trial program subcontracted to Sharp Healthcare, Dr. Christine White, left her position there. One of her colleagues, Dr. Linda Olson is a professor at the University of California at San Diego (UCSD). She agreed to become the principal investigator for the clinical trial program and run it through the university hospital.

A request for a change of venue was made for the clinical trial program in connection with this effort from Sharp Healthcare to UCSD on June 13, 1997. A reply was received requesting a protocol, IRB approval safety program and patient informed consent form from UCSD, a CV from Dr. Olson and a redirection of funds budget. These items were forwarded to the MCMR grants office on June 30, 1997. Final approval to transfer the clinical trial program to UCSD has since been obtained from the Army.

The revised clinical trial program was scheduled to begin on October 15, 1998. The scope of work proposed is essentially identical to the original trial and the proposed budget will not change the current level of funding for this grant. In order to expedite the initiation of the clinical trial program, a small pilot study involving 2 women was performed on October 15, 1998. This study was conducted at PGI laboratory facilities in San Marcos, CA. Data obtained from this study will be used to determine if any modifications are required to the DXM-1 hardware or software configurations before the system is moved to UCSD and the University of Arizona for the planned clinical evaluations.

The DXM-1 digital mammography system was designed and partially developed through funding obtained from the National Institutes of Health with two Small Business Innovative Research (SBIR) grants (phase I and phase II grant no. 2R44CA59104-02AI). Under these grants, the sensor chip technology was developed and an engineering prototype was produced which was used to acquire images of the Contrast Detail Mammography (CDMAM) phantom. These images established that the sensors are capable of acquiring superior quality images than conventional screen/film.

One result of the previous work was that it was determined that the original prototype sensors were not optimum for use in full-field mammography applications. A new sensor was designed incorporating several features including larger pixel size, larger active area on the sensor (i.e., more pixels) and an on-chip Time Delay and Integration (TDI) function. A camera and digital signal processor (DSP) was also designed during this effort.

Fisher Imaging Corporation, a subcontractor to this effort had previously developed a mammography gantry specifically designed for use with a digital slot-scanning imaging system using a different sensor technology. In connection with this effort Fisher has delivered two prototype gantries for use in the technical and clinical evaluation studies. However, the second gantry, which was to be used in the clinical studies was delivered over 1 year late. This was the primary reason for program delays resulting in the request for a 1-year no-cost extension.

The effort described above is broken down into three tasks: Integrate and Optimize the DXM-I Mammography System, Engineering and Technical Evaluation; and Clinical Studies. The progress made during this reporting period for each of these tasks is discussed below.

On March 15, 1999 Dr. John Cox of PGI and Dr. Tom Vogelsong of InfiMed, Inc. made a presentation to Dr. Mishra and staff. During this presentation, an overview of the progress of this grant was made. A proposal was also presented for a change-of-scope request for an IDEA grant awarded to Xicon Technologies, Inc., a subsidiary of InfiMed, Inc.

A discussion was held at this meeting regarding a number of problems encountered with the subcontractors working on this project which has led to significant delays in progress. A recommendation was made to request a no-cost extension. On April 5, 1999 a request was made to obtain a 1-year no-cost extension for this grant. On May 7, 1999 our request was granted (Modification No. P90001), extending the performance period to June 16, 2000. Consequently, this report will be an annual report covering the previous reporting period. A final report will be submitted on June 20, 2000.

Our request to change the scope of Xicon's IDEA grant was based on difficulties Xicon was having with one of their subcontractors. We proposed to change the scope of the remaining effort to apply the Thallium Bromide photoconductor material to the surface of the sensor arrays developed in connection with this grant. A change of scope request was submitted by Xicon and was approved by the Army. Subsequently, work has begun and PGI is actively participating in this effort. A copy of the proposal submitted to the Army in connection with the change-of-scope request is attached in Appendix A. A complete description of the scope of this effort and the extent of PGI's involvement is provided. PGI will continue to work on this effort during the 1-year no-cost extension period.

During the no-cost extension period, PGI will attempt to obtain additional funding from private sources to finalize the development of the DXM-1. However, no assurances can be made that such funding will be obtained. PGI is also negotiating with its subcontractors on this project to resolve some of the problems encountered relating to schedule delays and poor performance of some of the components of the DXM-1.

TASK 1: DXM-1 Mammography System Integration

This task has been completed during this reporting period and a fully integrated DXM-1 prototype has been assembled and tested. A fully-populated sensor array has been assembled containing 8 hybrid detector chips. The sensor array and its analog signal processor and digital interface has been installed in the modified Fischer Imaging Corp SenoScan digital mammography gantry. The analog signal processor is connected to a digital signal processor (DSP) which processes the image data obtained from the sensor array and formats the image for display. The DSP is connected to a Sun Ultra-10 workstation. Images of the components and fully integrated DXM-1 are shown in Appendix B.

TASK 2: Engineering and Technical Evaluation of the DXM-1 System

The evaluation of the DXM-1 prototype completed during this reporting period has established that the prototype meets several of the required parameters and several others were found to be deficient. The DXM-1 meets all of the mechanical specifications set forth in the design parameters of the DXM-1. The major deficiencies lie in the performance specifications. There are two major deficiencies in the system: 1) Sensor chip performance and 2) DSP performance.

The sensor chip design and fabrication has been the most expensive and time consuming effort of this project. The subcontractor responsible for sensor design has reported several problems with the foundry (Orbit Semiconductor, Inc., Sunnyvale, CA) that has been fabricating the sensor readout integrated circuits (IC). At the start of this effort 3 years ago Orbit had a 4-inch fab. Two years ago they purchased a 6-inch fab and started transferring their fabrication runs over to the larger facility. During this transition, a design change was made to the readout ICs. Lots of ICs were obtained that had essentially no yield. It could not be determined if the poor yield was due to the design change or Orbit's fabrication problems. A series of meetings were held between our subcontractor, Orbit and PGI to try and resolve the problem. Orbit agreed to allow us to re-run the ICs on their new 6-inch line at no additional cost. In order to eliminate one variable, the older chip design was fabricated. Lots of wafers were produced and a good yield was obtained. However, the design changes were never introduced due to the high cost of producing a new mask set and fabrication run.

In order to stay on schedule, the sensor array was populated with the sensor chips produced and the system integration effort was allowed to continue. Without a fully populated array of working sensors, many of the operational features of the system could not be tested and debugged. Upon completion of the DXM-1 prototype, additional images were obtained and the results are reported below.

An exhaustive evaluation of the sensor chip design was undertaken by our sensor design subcontractor using the newly fabricated ICs and the DXM-1 prototype. Several design errors were detected and a report was furnished by our subcontractor. This report is attached in Appendix C. The design errors manifest themselves in a loss of resolution in the in-scan axis of the image. The readout ICs perform an on-chip 4-pixel Time Delay and Integration (TDI) during image acquisition. Pixels in the cross-scan axis are read out without any such processing. During the technical evaluation of the images produced, it was discovered that the sensor array produces full resolution in the cross-scan axis but has less than half the resolution in the in-scan axis.

As reported in the previous annual report, the DSP unit designed and fabricated by our DSP subcontractor does not work at the designed operating speed (20 MHz). It has been operating at 8 MHz. The subcontractor has been unable to increase the operating speed. The primary consequence of this is that it takes10 seconds to acquire and image instead of 4 seconds as per the initial design.

TASK 3: Clinical Studies to Assess Efficacy of the DXM-1 Digital Mammography System

During this reporting period, clinical images were obtained from live patients under the supervision of Dr. Linda Olson and Dr. Michael Andre of the University of California San Diego in accordance with the IRB approved by the University and the Army. A full-field digital mammogram obtained in this study is shown in the figure below.

Full-Field Digital Mammogram Obtained with the DXM-1 Prototype

This image represents an important milestone for this project. A clinical image has been obtained and the DXM-1 prototype has been completed. Unfortunately, no clinical data can be obtained due to the poor performance of the sensor arrays. The design errors discovered during this reporting period will have to be corrected before any clinical studies can resume.

Conclusions

The goal of this 3-year effort was to complete the development of the DXM-1 prototype and complete a clinical evaluation involving 1,100 women at two clinical sites. Although the DXM-1 prototype development has been completed and a few clinical images have been obtained. There is no point in obtaining any additional images until the technical deficiencies discovered in the system have been overcome. Therefore, all clinical activities involving the acquisition of images from patients have been suspended.

During the ensuing 1-year no-cost extension, PGI intends to raise the capital required to re-design the sensor readout IC and complete the design modifications required to improve the performance of the DSP. There can be no assurance that PGI will be successful in obtaining such capital sources and it is estimated that approximately $1 million will be required to accomplish this task.

PGI will also participate in the Xicon IDEA grant effort described in Appendix A. A successful effort with the Xicon project will provide a significant improvement in x-ray imaging performance for our sensor design and will open other x-ray imaging applications where the x-ray energy is much higher than that used for mammography.

References

1. Cox, J.D., Sharma, S.R., and Schilling, R.B., "Advanced Digital Mammography", Proceedings of the Annual Meeting of the Society for Computer Applications in Radiology (SCAR), June 21-24, 1997, Rochester Minnesota.

Appendix A

Grant Number DAMD17-1-7016

TITLE: Novel High Resolution, Lowdose Flat Panel Mammography Detector Technology

PRINCIPAL INVESTIGATOR: Robert M. Iodice

CONTRACTING ORGANIZATION: Xicon Technologies, LLC.
121 Metropolitan Drive
Liverpool, NY 13088

REPORT DATE: March 1999

TYPE OF REPORT: Alternative Approach Proposal

PREPARED FOR: U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

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Introduction

Over the preceding period of this grant, we have explored the feasibility of making a mammographic imaging sensor by combining a Thallium Bromide (TlBr) photoconductor with an addressable array of cold cathode field emitters in a novel Field Emission X-ray Imaging System (FEXIS). As described in our annual report of September 1998, we were able to make significant progress on the photoconductor, but we experienced difficulties in acquiring suitable field emitter arrays to enable the proof of concept.

The development of TlBr has proceeded on plan throughout this period. We have been able to produce X-ray sensitive TlBr films of good quality up to 9" in diameter. The high DQE, superior spatial resolution, wide dynamic range, and unprecedented contrast resolution that were predicted have been verified in tube configurations with a single scanned electron beam readout. Unfortunately, the field emitter array readout technology has not progressed adequately during this period.

It was hoped that the mammography FEXIS could leverage off existing FED designs, and a suitable emitter array could be produced with only simple process modifications. However there are two special requirements for the field emitter array which make this task more difficult. One is the requirement of small pixel size required for mammography of approximately 50 microns. Field emitter displays have faced problems with keeping a small electron spot size, and many suppliers are investigating the addition of gates or structures to provide additional focussing. The second issue is the requirement for higher beam current in order to discharge the target pixel within a pixel time, compared with the line time typically used for display devices. In the display industry, demands for brighter displays are pushing vendors to increase beam current.

At the time of the annual report, it had become evident that the field emitter array technology for the display industry was not progressing as quickly as had been advertised. Field emitter displays are still limited in performance by focussing issue, as well as manufacture issues including the challenges of maintaining a high vacuum in a flat panel configuration. This has led to arcing issues that limit the applied voltage, and cause short product lifetimes. Due to these issues, our field emitter sub-contractor, FED Corporation, which had demonstrated difficulties meeting scheduled delivery dates, and supporting this program, has chosen to exit the field emitter technology arena, and focus on other display technologies.

Alternative Plan

As a result of the difficulties with the field emitter arrays, we have investigated several alternative readout mechanisms that take advantage of the superior properties of the Thallium Bromide photoconductor. Initially we investigated alternative field emitter suppliers to see if there were other suppliers, or other field emitter array technologies that would be more suited to the needs of a flat panel detector. The results, as reported in the annual report, showed that maturity of the technology is not sufficient for this product at this time, although it is likely to progress significantly over the next 2-3 years. In addition, many of the companies remaining in the field emitter display business are even more focussed on developing high volume displays and overcoming the development problems there, and are unwilling to invest effort in alternative applications.

We have investigated a second alternative readout mechanism that appears to offer much more promise, and appears to be more feasible in the near term. This alternative is to deposit TlBr directly on the surface of a readout device such as a CMOS single crystal silicon integrated circuit or amorphous silicon TFT array. In this configuration, the readout device would consists of an array of pixels each of which contains a bond pad electrode, an integrating capacitor and row/column addressing circuitry. X-rays absorbed in the photoconductor will generate a photocurrent that is collected by the array of electrodes and integrated at each pixel during the frame integration time. In order to prove the feasibility of this approach, it would be advantageous to initiate this study on a small scale sensor. This reduces the investment required in expensive deposition equipment, while allowing the fundamental materials issues to be addressed in a timely fashion.

We have discovered that such a small area CMOS readout device exists, and would be an ideal vehicle to demonstrate this concept. Such devices are currently employed in slot scan imaging. Slot scan techniques have been under investigation by several companies including PrimeX General Imaging (PGI), and the performance advantages of such an approach have been demonstrated. This approach is summarized in the “Background” section below. The approach taken by PGI, which has been partially supported by US Army Medical Research and Materiel Command funding uses silicon as the detector material. The replacement of the silicon detector by Thallium Bromide would provide higher performance and simultaneously lower the cost.

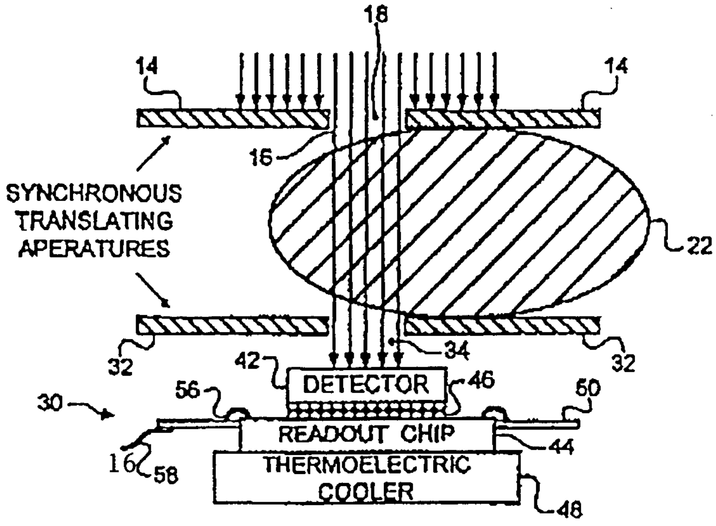
At this point in the grant, due to the lack of performance by FED Corporation and subsequent reduction of payment to the sub-contractor, much of the allocated funding remains in the grant. We hereby propose reallocating the remaining funding of approximately $220k towards the investigation of our alternative approach to a High Resolution, Low Dose Flat Panel Mammography Detector. This proposal describes the slot scan approach using silicon detectors, the advantages of combining the slot scan approach with the TlBr photoconductor, the challenges to be overcome, and the program plan to address these challenges.

Background

PrimeX General Imaging Corp (PGI) has developed a hybrid silicon-PIN photo diode detector for use in a slot-scanning digital imaging system for mammography funded in part by a 3-year, $1.6 million grant from the U.S. Army Medical Research and Material Command (Grant No. DAMD17-96-1-6239).

The advantages of a slot-scanning radiography system are lower cost and inherent scatter rejection. These advantages can only be realized if no motion artifacts are introduced into the acquired image. In order to eliminate motion artifacts the object to be imaged must not move during image scan and there can be no jitter introduced from the mechanical scanning mechanism. In mammography, the breast is immobilized during the exam even though a film image is acquired in a fraction of a second. The resolution required for mammography (10 – 20 lp/mm) implies that motion artifacts be less than 25 microns. This translates to a scanning precision of 1,000 dots per inch. This feat is easily achievable with many existing scanning systems including photocopiers and desktop scanners. Moreover, many types of motion induced artifacts can be corrected with software programs.

The ideal scanning aperture is a slit that is one pixel wide. Such a slit would provide the maximum scatter rejection. This approach is not practical for mammography since doing this would reauire an enormous amount of x- ray power to scan an 8 in x 10 in v seconds). By increasing the slit width to a "slot" opens up the slit aperture, reducing the required tube power and provides a good compromise between scanning time, image quality and the required detector surface area. Increasing the slot width increases the required detector surface area and its



cost. A slot width of 6 mm has been determined to be optimum as it provides an ideal balance between imaging performance and detector cost.

PGI's slot-scan sensor consists of a CMOS readout array that is bump bonded to a silicon-PIN photo diode. The detector contains a bifurcated array of diodes. Each array contains 61 columns and 480 rows of diodes, each diode is 50 microns square. The two arrays are offset from each other by half a pixel dimension (i.e., 25 microns in both the x and y directions).

Each sensor has an active area of 6 mm x 24 mm. The silicon diode substrate is 1 mm thick (1.5 mm thick substrates have been used as well). The diode array is connected to the CMOS readout array with an array of indium bump bonds such that each pixel is connected in parallel to the readout array. This technique is used in infrared focal plane array technology.

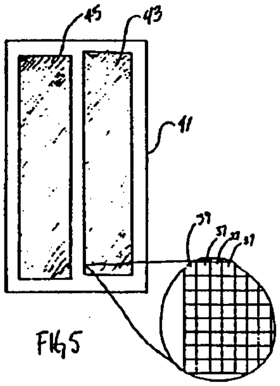
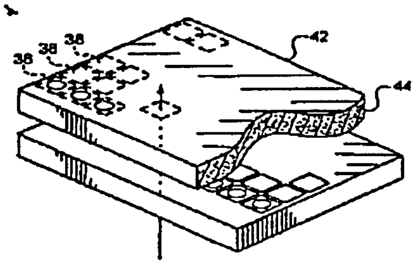
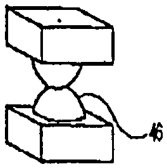


FIG 5

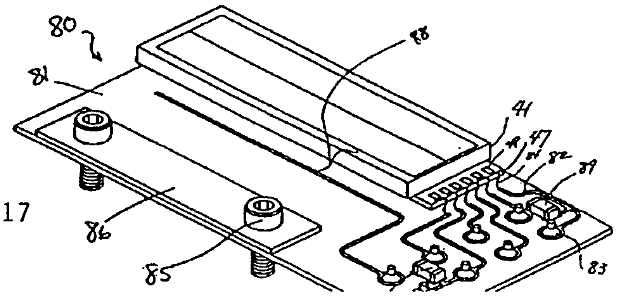


The CMOS readout array contains an integrating capacitor for each photo diode, a 4-pixel TDI register and the read out circuitry to address and clock out data. The advantage of the 4-pixel on-chip TDI register is that the overall data rate required to read out the array is reduced by a factor of four.



The advantage of using a silicon-based photo diode is that the incident radiation absorbed in the sensor medium is directly converted into electric charge that can be collected and integrated by the CMOS readout array. In contrast, a sensor using a scintillator to absorb incident radiation has an intrinsically lower performance since there are several energy conversion steps required before an electrical charge is produced. One of these steps involves the production of visible light that is emitted isotropically, scatters and is absorbed before it can be detected.

The slot-scanning detector consists of 8 discrete sensor arrays that are positioned in two parallel rows of 4 sensors. This design allows for contiguous pixel coverage in both the in-scan and cross-scan direction yet permits easy access to the bond pads



for each sensor. However, this slot configuration requires a collimator that resembles a staggered brick pattern. Such a collimator is more difficult to manufacture than a traditional rectangle but is not a significant issue.

The slot-scanning detector with its 8 sensor arrays is connected to an analog signal processor located directly underneath the detector plane. Each sensor is connected to its own digitizer and all eight sensors are read out in parallel. The digitized output signals are sent to a remote Digital Signal Processor (DSP) where the pixel data is processed. The processing functions include additional TDI, off-set and gain correction and flat fielding. An image in bitmap form is produced and stored in memory and is made available to a workstation for review, archiving and further processing.

This entire assembly including the detector, analog signal processor and DSP is designed to be sold to OEMs as a digital camera to be integrated with a mammography gantry system. Since the gantry will have to scan the image there are no retrofit options at this time. PGI has designed the digital mammography camera to interface with a scanning mammography gantry manufactured by Fischer Imaging Corporation. Fischer is currently developing a slot-scanning mammography system called Senoscan that utilizes an array of fiberoptically coupled CCD arrays. The Senoscan gantry utilizes a radial scan technique where the x-ray generator is pivoted about its focal spot. The detector array is translated along the circumference of a circle with a radius of approximately 50 cm.

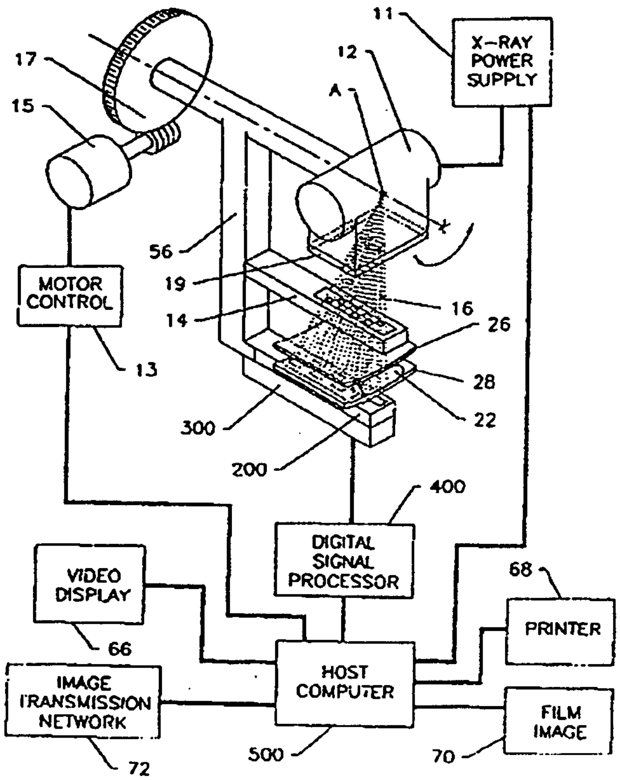
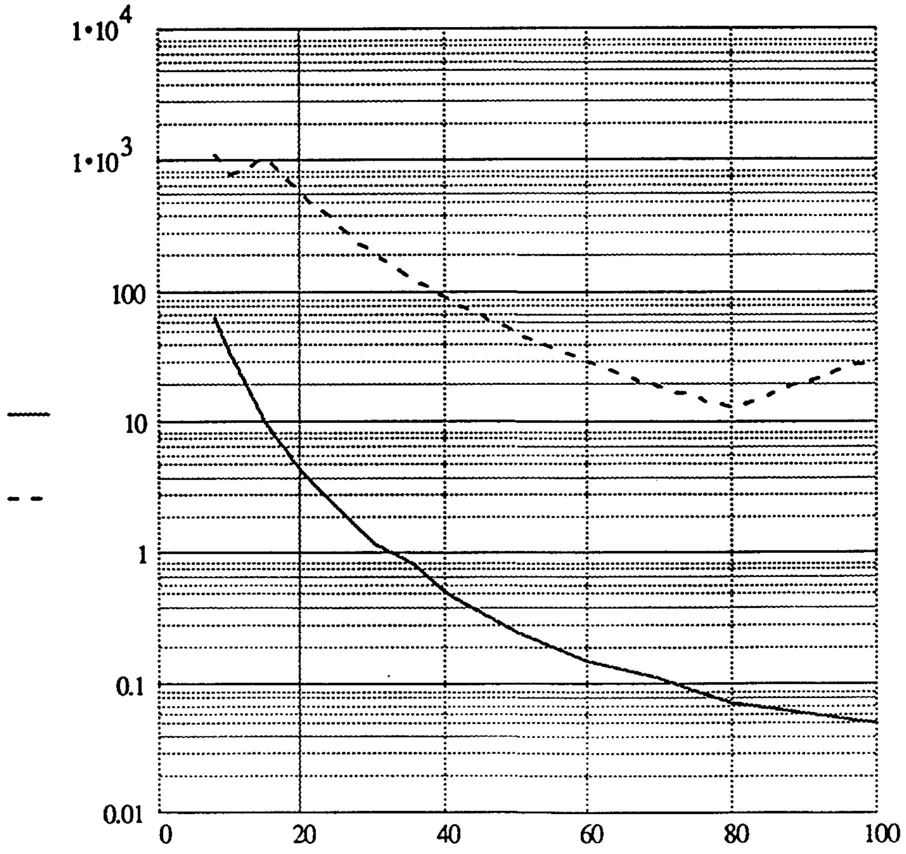


Fig. 10

Program Concept – Combine the Best of Both TlBr and Slot Scan

The silicon-based hybrid PIN diode sensor has a quantum efficiency of approximately 67% for the x-ray energies used for mammography. While this compares favorably to the quantum efficiency for screened-film (approximately 10-20%) the increased quantum efficiency achievable with alternate detectors directly improves DQE giving higher sensitivity and/or reduced dose. Moreover, the cost of hybrid sensors is determined by the need to fabricate both a diode array and a readout array, have indium bumps applied and then bond the arrays together. The performance of the sensor and the cost to produce the sensor could be dramatically improved by applying a suitable photoconductor directly on the surface of the readout IC.

Thallium Bromide is an ideal photoconductor for use in x-ray imaging applications from the standpoint of absorption properties (>90% at mammographic energies) and photoconductive gain. A plot of the linear attenuation coefficients for Silicon and Thallium Bromide is shown below.



Linear Attenuation Coefficients (cm^{-1}) for Thallium Bromide (dotted line) and Silicon (solid line) as a function of X-ray Energy from 10 to 100 keV

For silicon an electron-hole pair can be liberated with 3.65 eV and for Thallium Bromide it requires about 6.5 eV. Accordingly, a 50-micron thick layer of Thallium Bromide can produce an equivalent signal as a 1-millimeter thick layer of silicon from the absorption of a 20-keV x ray.

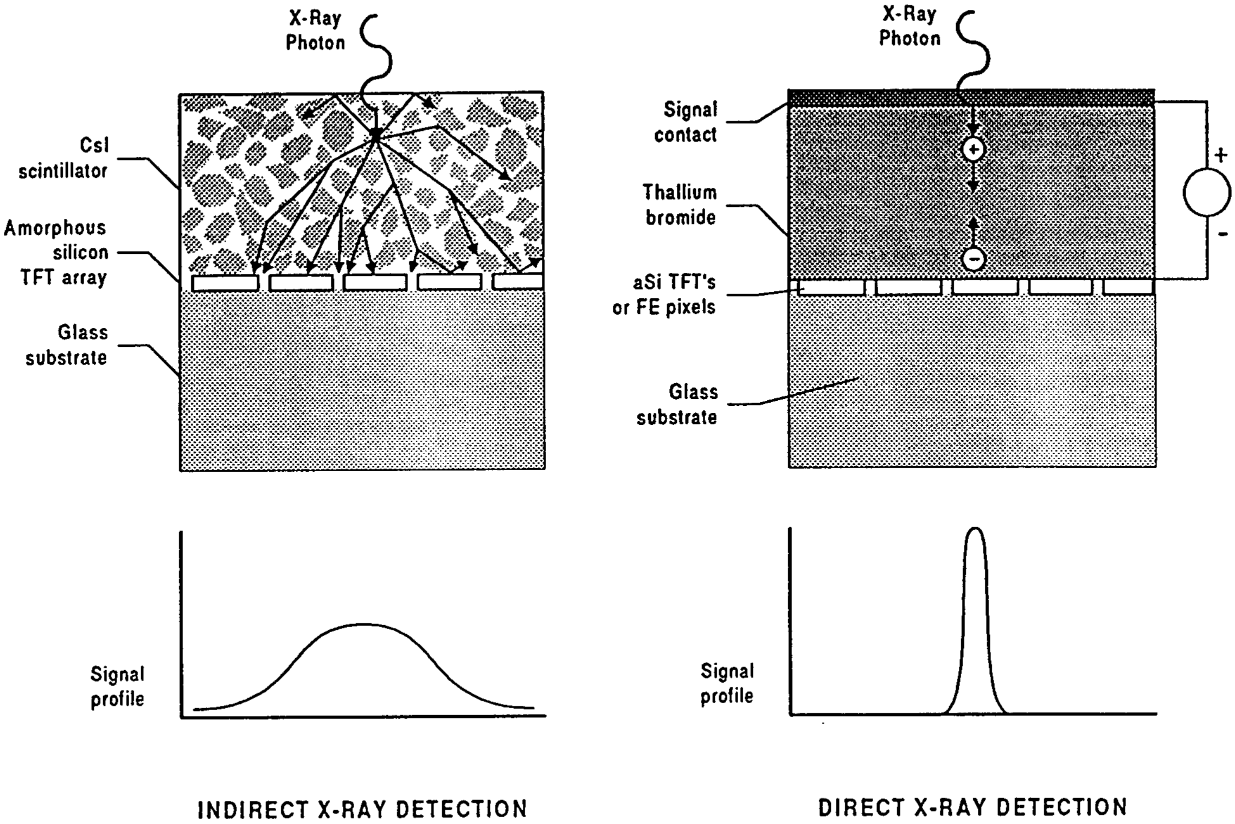
Challenges to be Addressed

However, Thallium Bromide does have some shortcomings that must be overcome if it is to become a suitable photoconductor for x-ray imaging applications. The primary shortcomings are high dark current and aggressive chemical properties. The high levels of dark current are being addressed through a materials technology program funded by Xicon. The use of a slot scan system reduces the dark current challenges since the dwell time (approximately 1 msec) is only a small portion of the frame time (several seconds).

During the past few months a review of the challenges and possible approaches to developing a process to apply a coating of Thallium Bromide to the surface of an Integrated Circuit (IC) has been undertaken. As a result of this review a number of application methods have been identified and an approach to determine the feasibility of this concept has been developed.

For the sensor design employed by the slot-scan mammography system, applying a thin coating of Thallium Bromide to the surface of the readout IC would provide a near-50% increase in quantum efficiency compared to silicon. It would also reduce the cost of the sensor by eliminating the need to fabricate a PIN diode array and the hybridization process required to attach the diode array to the readout array. The main goal of this program is therefore to determine appropriate materials and develop a deposition process for coating TlBr on silicon integrated circuits.

If such a process can be developed it would have applications to amorphous silicon flat-panel x-ray detectors as well. Several x-ray imaging equipment manufacturers are currently developing amorphous silicon-flat panel x-ray detectors. For mammography applications it is likely that a 50-micron pixel will be required. Amorphous silicon flat panel detectors have a very small fill factor (about 15%) when utilizing 50-micron pixels. This makes the use of scintillators impractical due to the fact that the light emitted by the scintillator spreads out and only 15% of the light would be collected. The use of a photoconductor eliminates this problem. X rays are absorbed in the photoconductor liberating electrons and holes which are collected at the electrodes. Shown below is a figure depicting the two processes. As shown, the signal (i.e., electrons) produced by the photoconductor is actually concentrated at the electrode whereas the signal (i.e., photons) produced by the scintillator spreads out and is diluted requiring a large fill factor to collect it efficiently.



Comparison of resolution in scintillator-based detectors versus photoconductor-based detectors.

Based on the foregoing discussion, there is a great potential to improve the performance of both scanning and area detectors for mammography applications through the use of a photoconductor. Thallium Bromide has the potential to provide superior imaging capabilities than existing photoconductors such as amorphous selenium. This potential can only be realized if the chemical compatibility issues have been resolved. It is the goal of the proposed effort to establish the feasibility of applying Thallium Bromide to integrated circuits and thus capitalize on its superior x-ray imaging performance characteristics.

Research Plan

The goal of the proposed research effort is to establish the feasibility of applying a coating of Thallium Bromide to the surface of an integrated circuit for the purpose of producing an x-ray imaging detector. Several key issues have been identified that will have to be addressed in order to determine the feasibility of this concept. A 12-month effort is proposed to address these issues and a protocol has been developed to establish methods and materials that could be used to make the concept work.

The most important issue to be addressed is determining a suitable deposition process to apply a coating of Thallium Bromide to the integrated circuit. Five deposition methods have been identified that could accomplish this task and are shown in the table below.

Tl-Br Deposition Schemes

Scheme Name	Description
Laser Ablation	Directly deposit TlBr onto IC at room or slightly elevated temperature in vacuum using laser ablation
Growth on substrate & bond to IC	Deposit TlBr on aluminum or glass substrate (properly prepared) then add patterned metalization to other side of TlBr. Bump bond TlBr to IC
Straight line evaporation	Directly deposit TlBr onto IC at room or slightly elevated temperature in vacuum by heating TlBr and controlling temperature of IC. (Similar to hot wall evaporation but without the hot walls.)
Screen printing	Screen print a liquefied TlBr compound onto the IC and laser anneal it to minimize defects
Hot Wall evaporation	Standard method now used to make 1" and 9" films

The most promising techniques that will be investigated first include straight-line evaporation and/or hot wall evaporation, as they have the potential to be the most effective and have the fewest materials compatibility and temperature issues. Perhaps the most compelling reason to utilize this method is that they can be easily accomplished with the limited resources available for this project.

There are three material compatibility issues that must be resolved before this process can be made to work.

1) adhesion of the photoconductor to the integrated circuit,
2) chemical compatibility with the passivation layer of the integrated circuit
3) identifying a suitable intermetallic contact material that is compatible with the photoconductor and the metallization on the integrated circuit.

In addition, a material must be found that can act as a bond pad material for the bond wire required on the top surface of the photoconductor to apply a bias voltage. A number of materials have been identified that show promise as being suitable for both the intermetallic contact and bond pad material. These materials will be studied in connection with the proposed effort to determine optimum performance.

The proposed research effort will be carried out in three tasks. Task 1 will be devoted to establishing the viability of the straight-line evaporation technique and will address the most fundamental materials compatibility issues. Task 2 will be devoted to determining the best materials to use for intermetallic contacts between the photoconductor and the bond pads on the IC and for making a bond pad on the top surface of the photoconductor. Task 3 will be devoted to testing coated ICs in a prototype slot-scanning mammography system developed by PGI and described in further detail in the attached appendix.

Task I

In this task, a straight-line evaporator system will be assembled with the capability of depositing Thallium Bromide films on the readout IC. The readout IC is 26 mm x 8 mm and has a row of bond pads on one end that must be masked off. Initially, ICs will coated that are not functional to prove out the process of applying a uniform coating with a thickness of about 50 microns. ICs coated in this manner will have the photoconductor stripped off and a visual inspection will be made to determine if the passivation layer of the IC has been compromised by the Thallium Bromide. Another concern to be addressed here is the mismatch of the thermal coefficients of expansion of the thallium bromide and the integrated circuit. Thermal stress testing will be performed to determine under what conditions the thallium bromide coating will de-laminate from the IC.

Task II

In this task, the bond pads of the readout ICs will be coated with conductor materials that will prevent the thallium bromide from attacking the aluminum bond pads on the IC. This will be accomplished by sputtering the material on to the IC using a shadow mask previously developed by PGI. At this time materials such as copper oxide and indium-tin-oxide (ITO) are being considered for this purpose. An RF adaptor kit will be purchased to upgrade a DC sputtering system presently owned by Xicon to accomplish this task.

Once the materials have been properly deposited on the IC, they will be put into the straight-line evaporator to have the thallium bromide coated. A bond pad probably made from ITO will be applied to the top layer of the photoconductor as well. Several tests will be conducted including visual inspection, electrical continuity and circuit function on the IC.

Task III

In this task, successfully coated ICs will be packaged and inserted into the slot-scanning camera developed by PGI and exposed to light and x rays. Images and data can be accumulated in this way. Images will be acquired of the ACR Accreditation phantom and the image quality parameters of the coated IC will be obtained.

This task is facilitated due to the fact that PGI has already developed this equipment and has recently characterized its silicon-based diode sensors to provide a benchmark of performance. Image quality parameters will be obtained and analyzed by Dr. Hans Roehrig, a consultant to this project. Dr. Roehrig has previously taken these measurements for the silicon-based diode sensors and will provide good continuity to the previous body of work.

Schedule

The program schedule will be revised to permit the completion of the analysis and demonstration of this alternative. A schedule summary is presented below, with the months from project restart indicated across the top:

```
Task #  1  2  3  4  5  6  7  8  9  10 11 12 13 14
Task 1  ←--------------→
Task 2           ←--------------→
Task 3                          ←-----------→
Report                                      ←--→
```

The research effort proposed above represents a best-case scenario to produce an effective coating process. There are a number of alternative approaches that could be implemented in the event that one or more of the individual process steps prove to be unfeasible. For example, if there is excessive corrosion of the passivation layer on the IC by the thallium bromide, an additional passivation layer could be applied to protect the IC. In a worst case scenario, the thallium bromide could be deposited on a ceramic layer that has a patterned metallization layer to act as a barrier and provide electrical contact to the IC.

If any of these approaches is required during the proposed effort, resources will be taken from task III, to devote more effort to the coating process. In this event, a less elegant process will evolve and a smaller testing and evaluation effort will ensue.

Budget

Detailed Cost Estimate

A budget summary chart for the proposed modification to this IDEA project is shown below. It includes a roll-up of the proposed costs for each cost element. It should be noted that a significant cost share is being contributed to the project by the participants due to the team's intense desire to see the program achieve commercialization success and to stay within the budget constraints suggested by this proposal. In particular,

Xicon, has developed the technology of producing a high-quality Thallium Bromide photoconductor layer. Xicon has contributed over $1M of effort in related work which will serve to accelerate this program, reduce the risk and lead to faster commercialization. Xicon will contribute all indirect costs as a cost share element of the program. This includes the cost to administrate the sub-contracts to the other organizations.

PGI Corporation has developed its CMOS-based slot-scanning mammography detectors in connection with an existing army grant. The CMOS readout integrated circuits are fully developed and require no further development to accomplish the tasks set forth in the proposed effort. Moreover, the x-ray generator, camera electronics and software required to test and evaluate the sensors for mammographic applications has already been developed. Approximately, $2M of private and government sponsored development effort has been previously spent in connection with the development of these components.

Total Budget:

Category	Total
Direct Labor	56,800
Fringe Benefits	14,200
Labor Costs, Total	71,000
Major Equipment	44,000
Materials, Supplies, Consumables	12,000
Subcontracts – PGI	59,000
Travel	3,600
Publications and Reports	1,000
Consultants	30,000
Other Direct Costs	0
Indirect Costs	0
Total Costs	219,600

Statement of Work

PrimeX General Imaging Corp

Scope – This statement of work shall cover activities for PrimeX General Imaging Corp (PGI) in connection with a sub-contract between Xicon Technologies, LLC and PGI in support of a contract between Xicon Technologies, LLC and the U.S. Army (contract No. DAMD17-97-1-7016)

Purpose of the sub-contract – The purpose of the sub-contract between PGI and Xicon is to assist Xicon in the development of a technique to apply thallium-bromide photoconductor material to integrated circuits in order to realize a compact, x-ray sensitive, mammographic sensor. PGI has previously developed a suitable CMOS integrated circuit that has the capabilities of integrating signals produced by a photoconductor, performing an on-chip TDI and clocking out an analog pixellated signal that can be formatted into a bit map image.

Tasks – PGI will provide integrated circuits, camera electronics, x-ray sources and expertise required to evaluate the materials compatibility issues and optimize a deposition process. PGI will develop a process to pattern a deposited barrier metal on the bond pads of the CMOS integrated circuit. PGI will also evaluate the electrical and x-ray imaging properties of the thallium-bromide coated integrated circuit.

Task 1 – Preliminary Compatibility Evaluation

- Remove indium bumps from CMOS integrated circuits
- Prepare, package and ship 25 damaged and 4 functional CMOS integrated circuits to Xicon facilities.
- Participate in initial thallium-bromide compatibility tests on CMOS integrated circuits.

Task 2 – Functional Evaluation

- Prepare, package and ship functional CMOS integrated circuits to Xicon facilities
- Develop process for masking the CMOS integrated circuit so that a barrier metal can be patterned on the bond pads.
- Deposit barrier metal on CMOS integrated circuits
- Perform continuity tests for barrier metal on bond pads to determine electrical function as required.
- Participate in thallium-bromide compatibility tests on barrier metals.
- Develop process to attach bond wire to top metal contact.
- Mount coated CMOS integrated circuits on ceramic substrates. Wirebond IC to ceramic substrates.
- Produce test fixtures for electrical testing of the CMOS integrated circuit as required.
- Participate in the electrical testing of the CMOS integrated circuits.

Task 3 – Imaging Performance Evaluation

- Install packaged ICs in the prototype DXM-1 digital mammography camera and acquire x-ray images and data
- Assist Dr. Hans Roehrig in the acquisition and analysis of x-ray images and data.

Appendix B

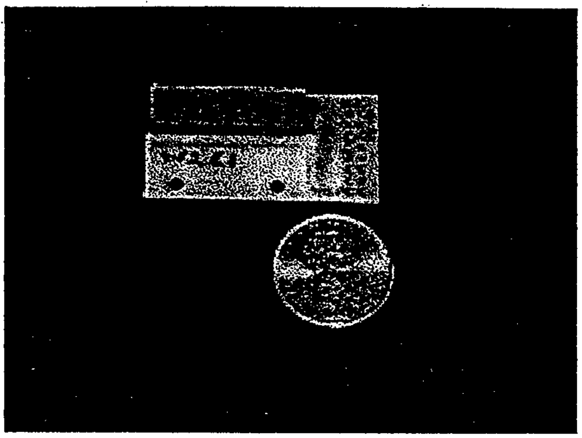


Figure B-1: Silicon-Based Hybrid PIN Diode Array

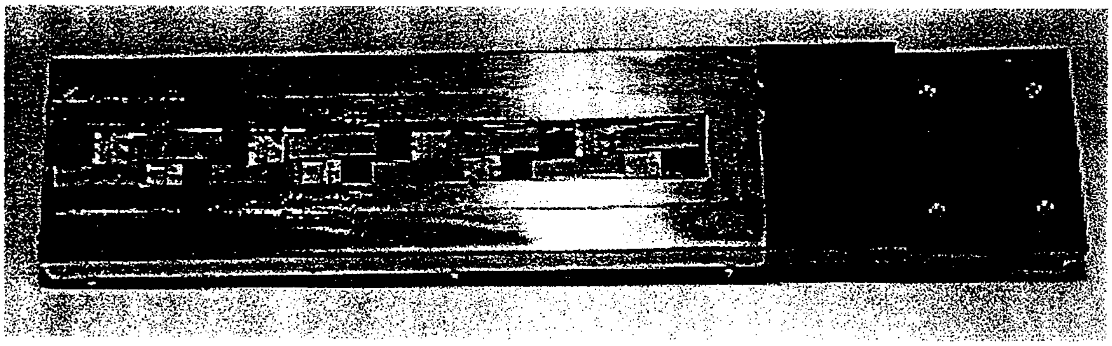


Figure B-2: DXM-1 Detector Module

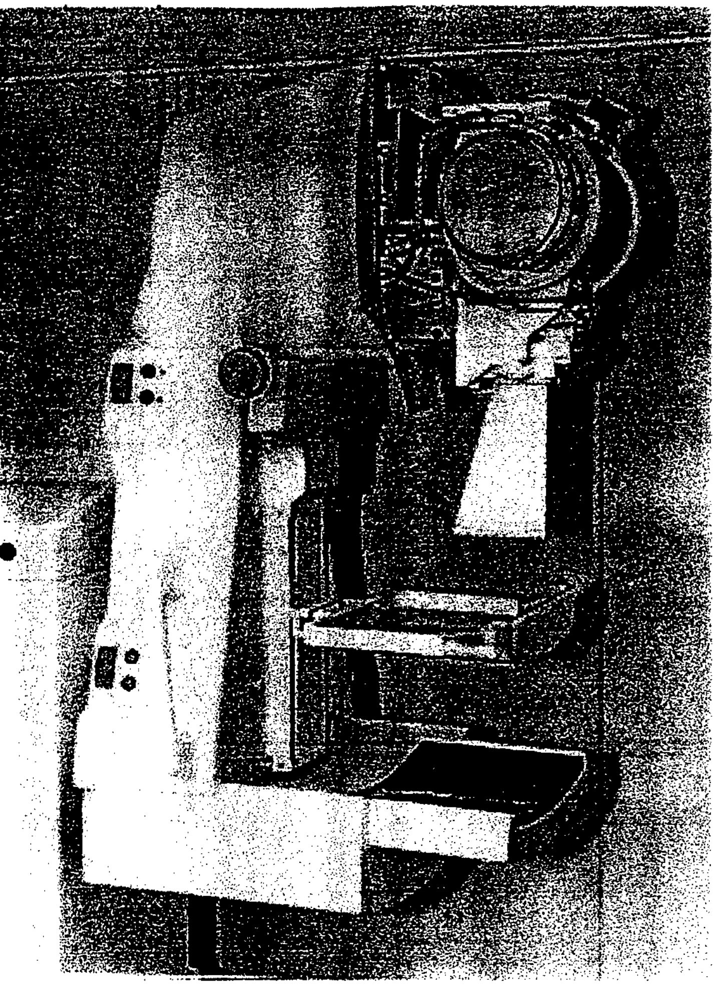


Figure B-3: Fischer Imaging Corporation's Sensoscan
Digital Mammography Gantry – Side View
Tube Head Exposed

Figure B-4: Fischer Imaging Corporation's Sensoscan
Digital Mammography Gantry – Front View
Tube Head Exposed

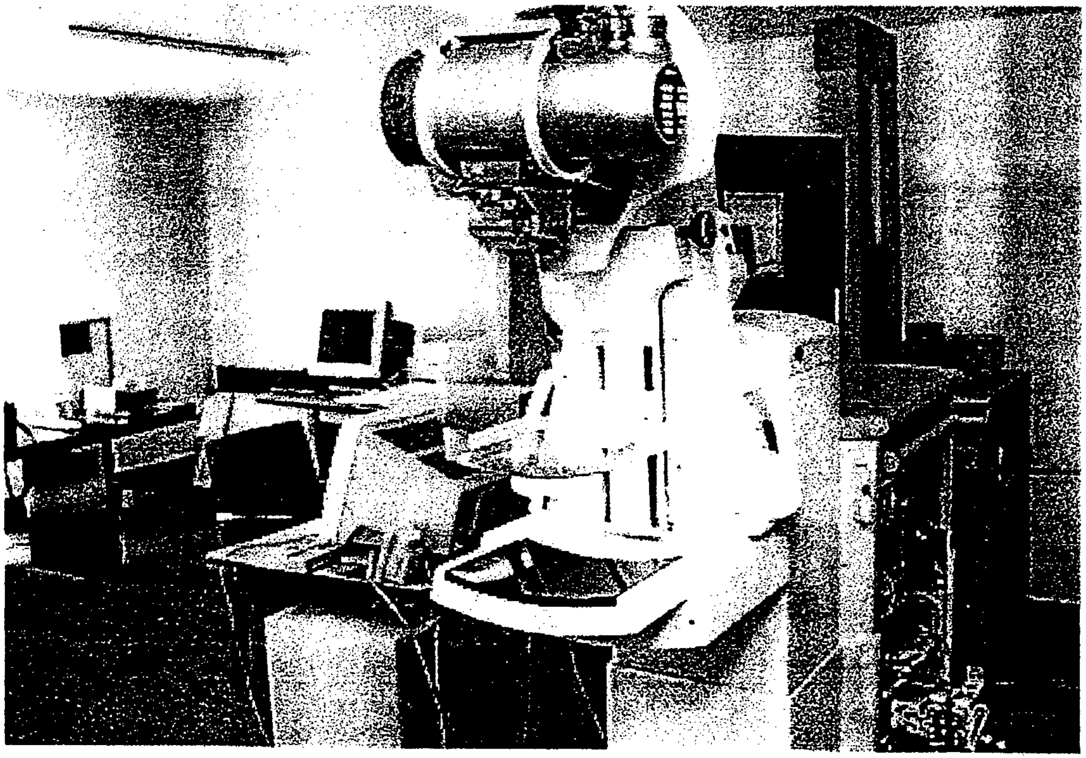


Figure B-5: Fischer Imaging Corporation's Sensoscan Digital Mammography Gantry – Front View

Figure B-6: Fischer Imaging Corporation's Sensoscan Digital Mammography Gantry – Side View

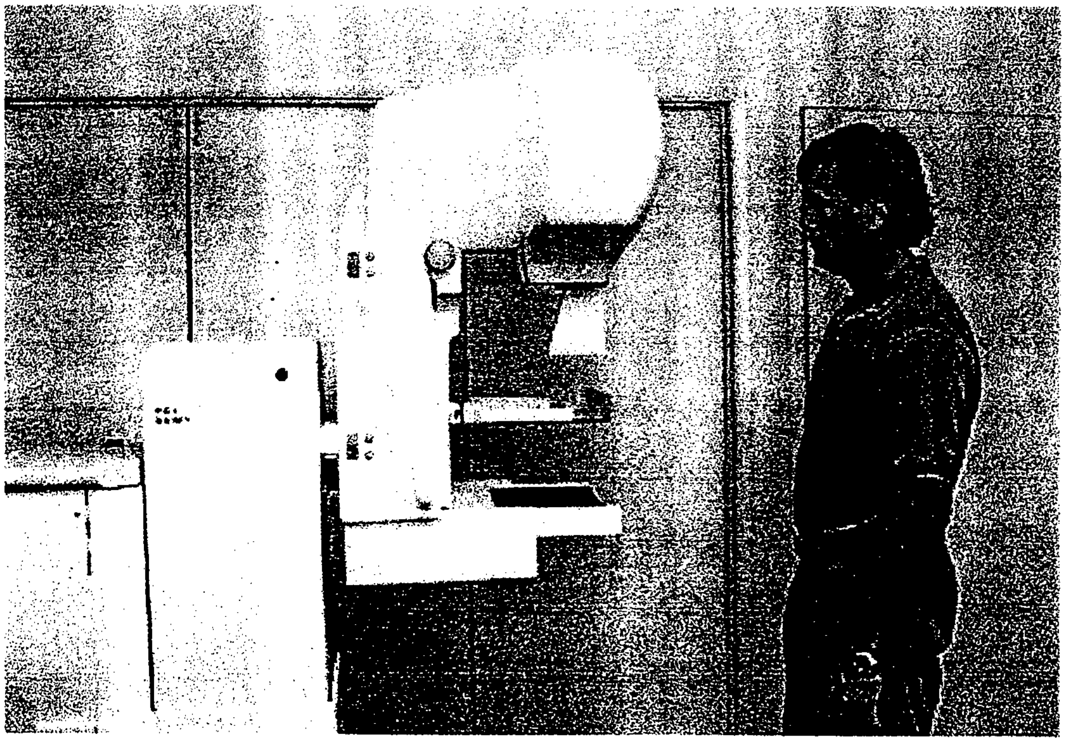


Figure B-7: Prototype 2-channel DXM-1 DSP

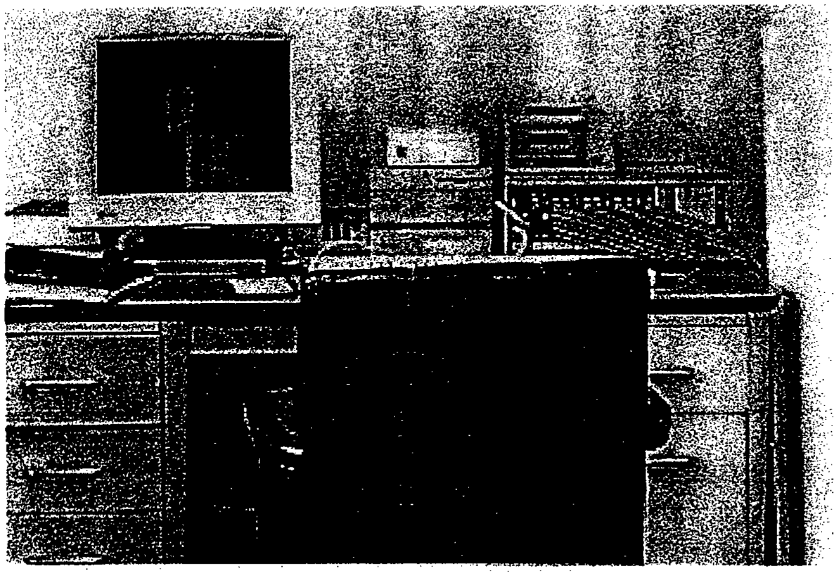


Figure B-8: Prototype 2-channel DXM-1 Gantry

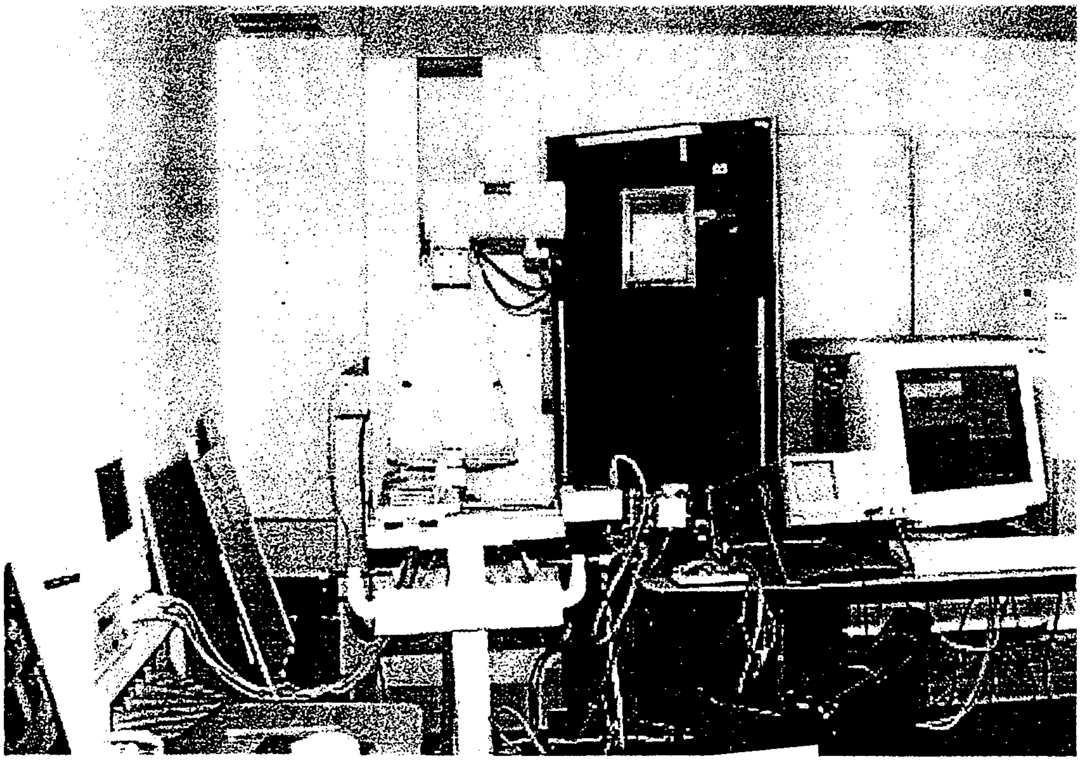


Figure B9: Cadaver Breast Image Acquired with the DXM-1

Figure B10: Cadaver Breast Image Acquired with the DXM-1
Area of Interest Showing Microcalcifications

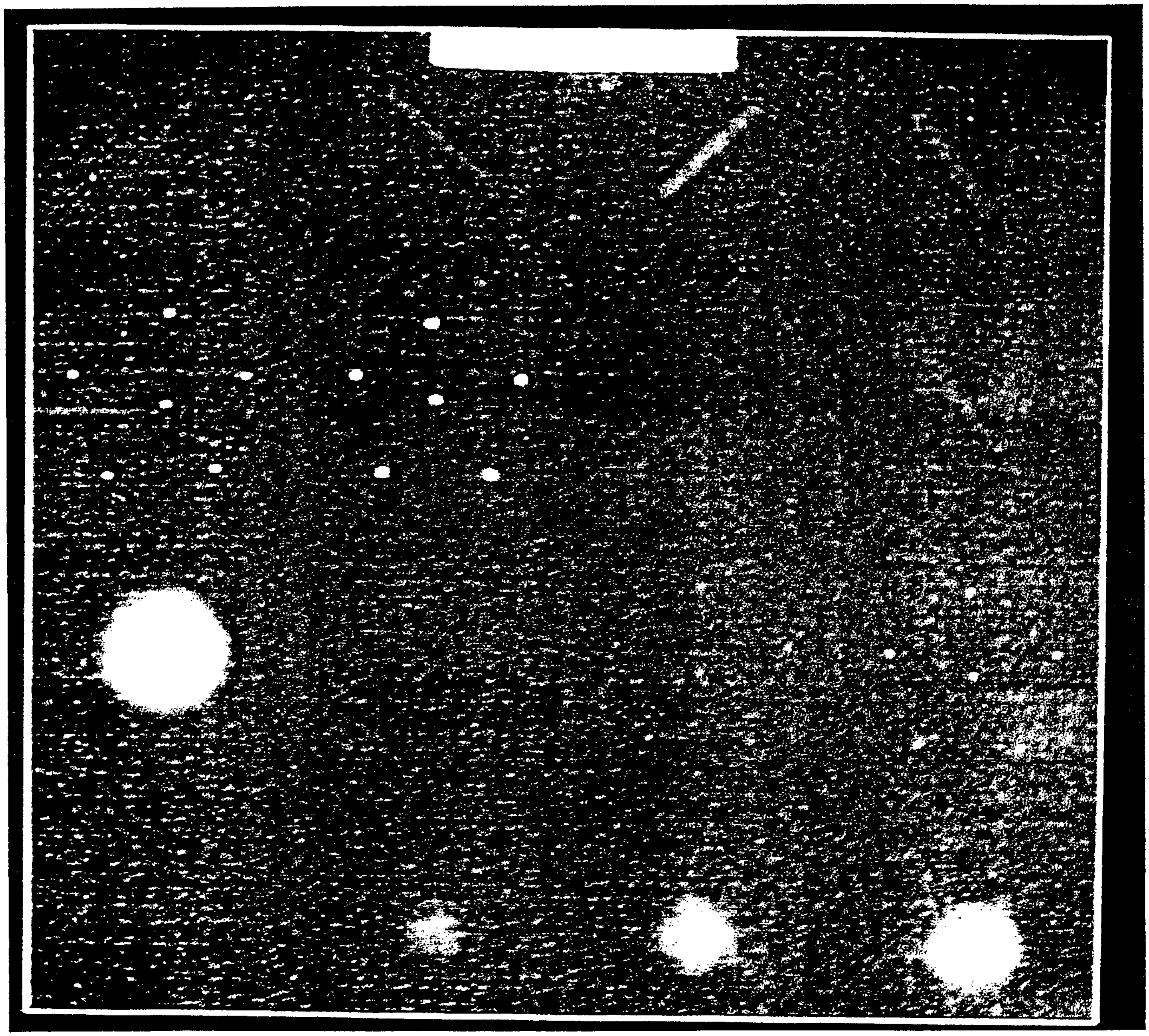


Figure B11: ACR Accreditation Phantom Image Acquired with the DXM-1

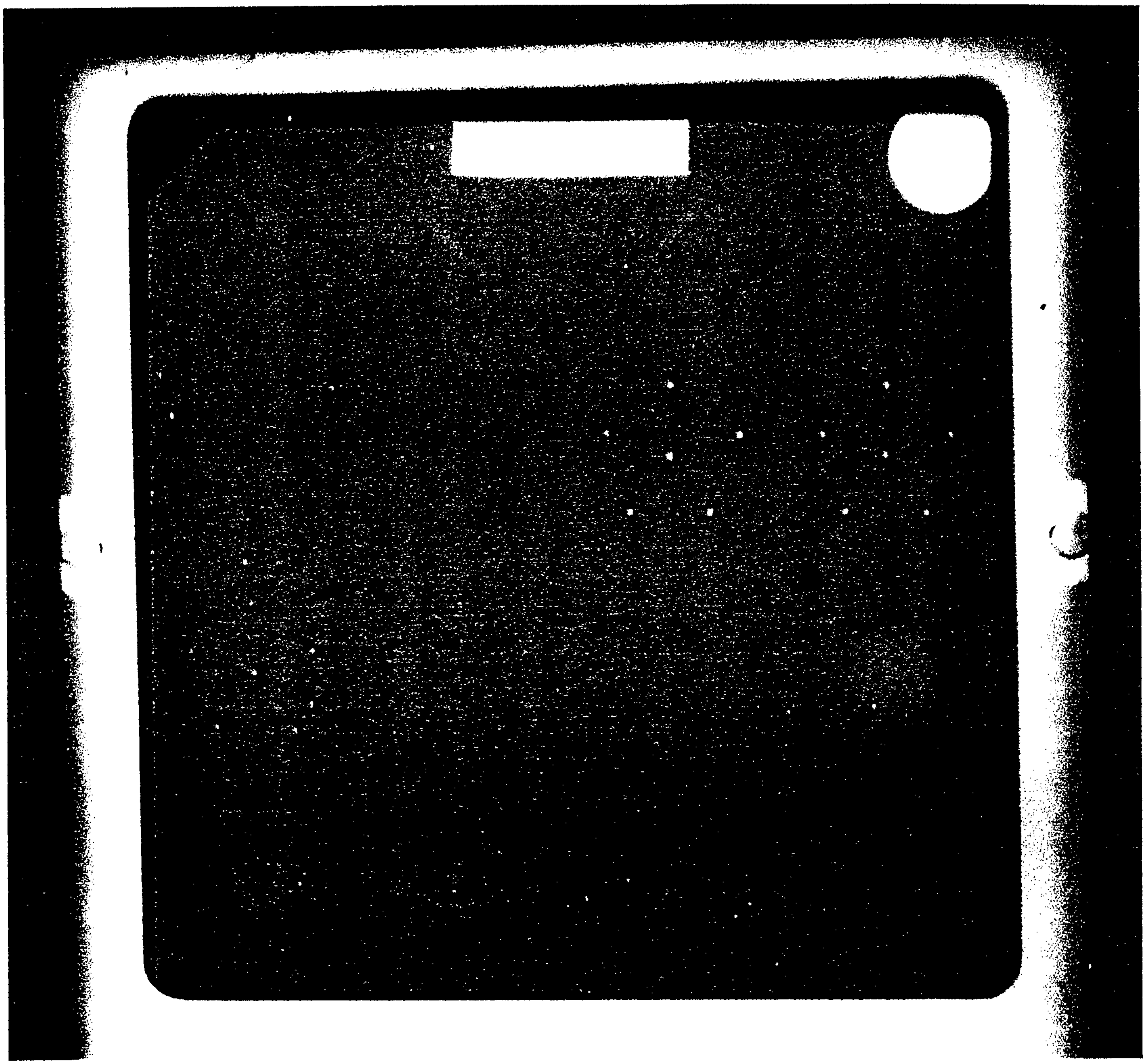
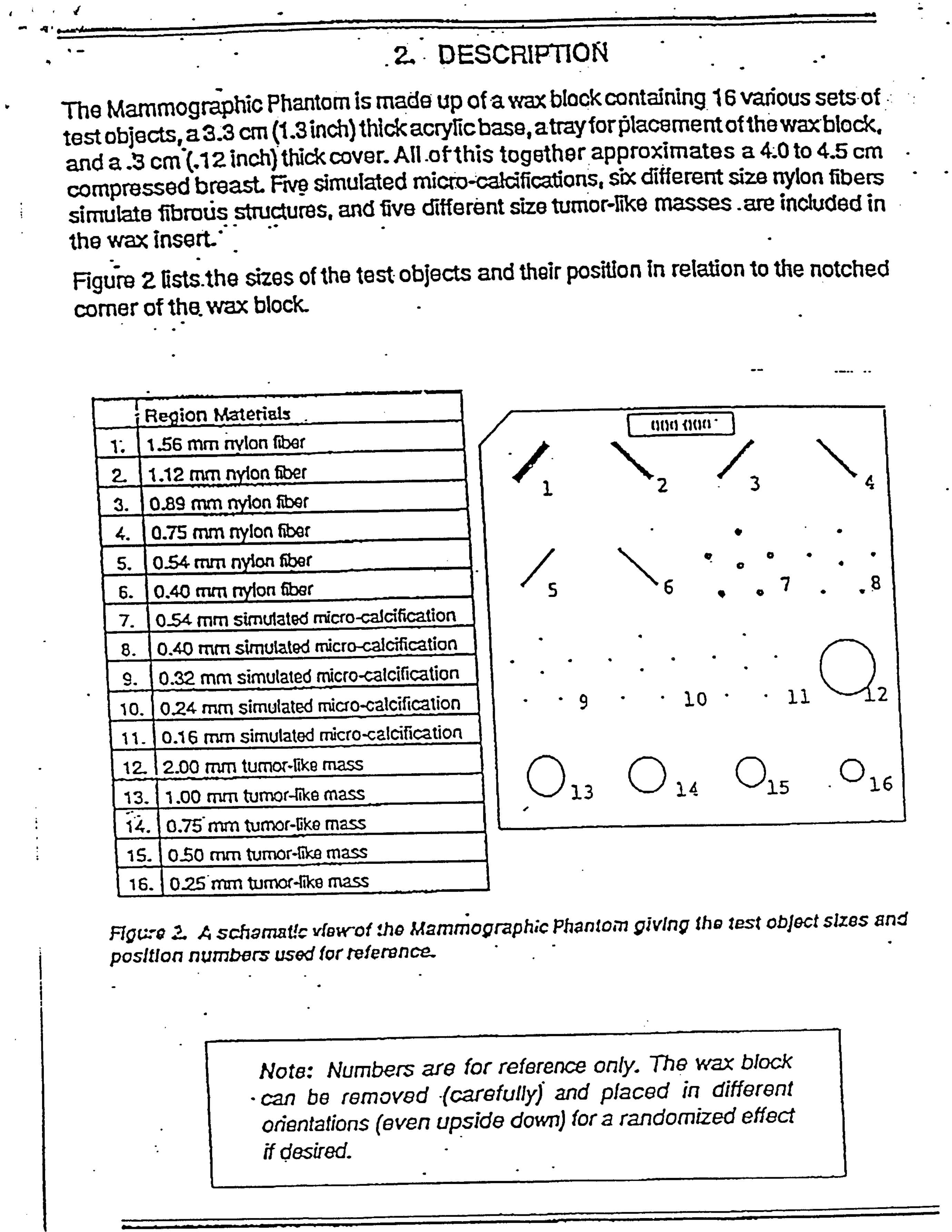


Figure B12: ACR Accreditation Phantom Image Acquired with Film/Screen



2. DESCRIPTION

The Mammographic Phantom is made up of a wax block containing 16 various sets of test objects, a 3.3 cm (1.3 inch) thick acrylic base, a tray for placement of the wax block, and a .3 cm (.12 inch) thick cover. All of this together approximates a 4.0 to 4.5 cm compressed breast. Five simulated micro-calcifications, six different size nylon fibers simulate fibrous structures, and five different size tumor-like masses are included in the wax insert.

Figure 2 lists the sizes of the test objects and their position in relation to the notched corner of the wax block.

	Region Materials
1.	1.56 mm nylon fiber
2.	1.12 mm nylon fiber
3.	0.89 mm nylon fiber
4.	0.75 mm nylon fiber
5.	0.54 mm nylon fiber
6.	0.40 mm nylon fiber
7.	0.54 mm simulated micro-calcification
8.	0.40 mm simulated micro-calcification
9.	0.32 mm simulated micro-calcification
10.	0.24 mm simulated micro-calcification
11.	0.16 mm simulated micro-calcification
12.	2.00 mm tumor-like mass
13.	1.00 mm tumor-like mass
14.	0.75 mm tumor-like mass
15.	0.50 mm tumor-like mass
16.	0.25 mm tumor-like mass

Figure 2. A schematic view of the Mammographic Phantom giving the test object sizes and position numbers used for reference.

Note: Numbers are for reference only. The wax block can be removed (carefully) and placed in different orientations (even upside down) for a randomized effect if desired.

Figure B13: ACR Accreditation Phantom Image Schematic

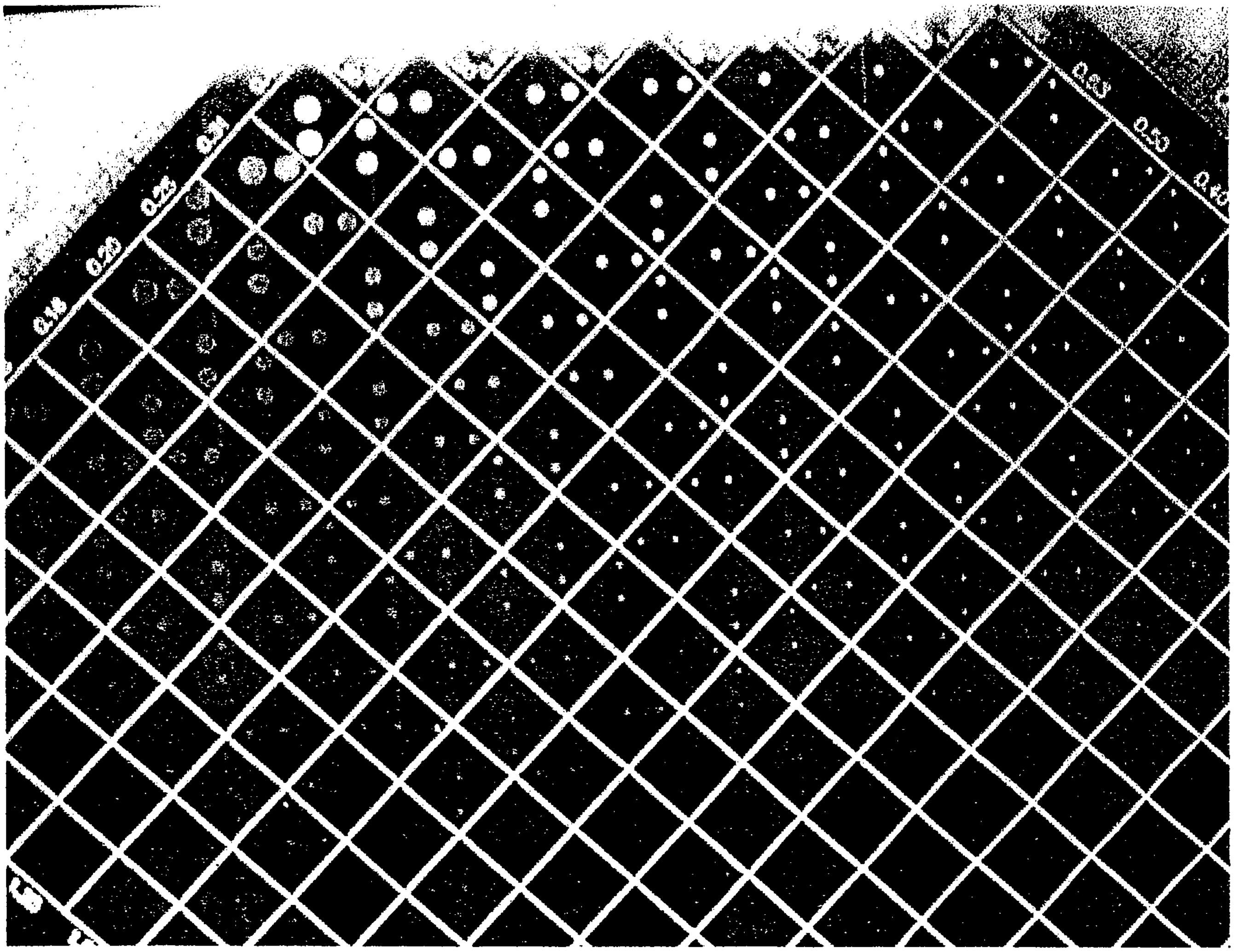


Figure B14: CDMAM Phantom Image Acquired with the DXM-1

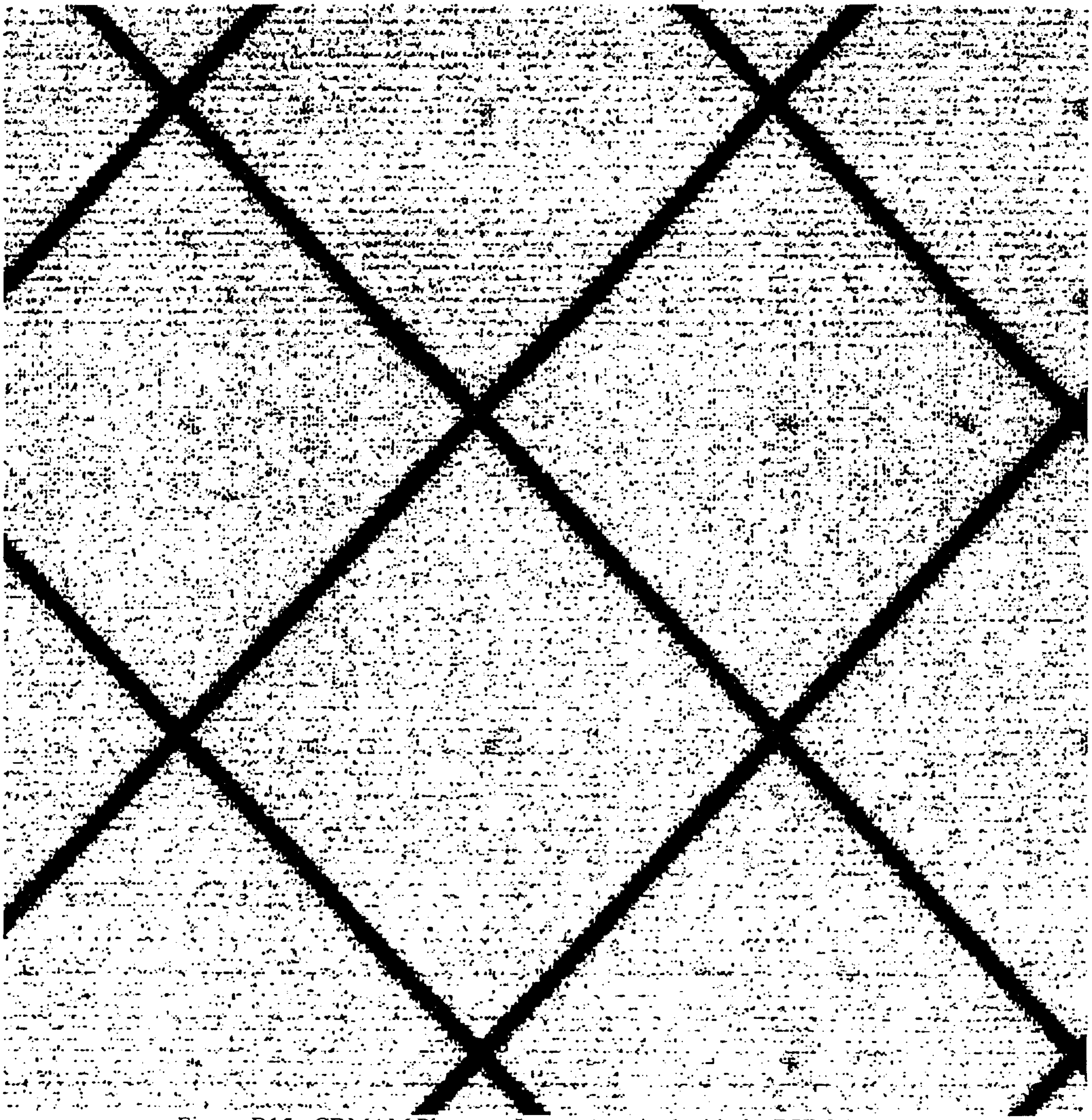


Figure B15: CDMAM Phantom Image Acquired with the DXM-1
Area of Interest Showing High Resolution

Appendix C

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www.sni.net/BFE/

BFE 124
On-chip TDI Error Investigation

Executive Summary

A careful analysis of the BFE124B circuitry, as implemented, has revealed two obviously serious design errors in the digital control logic. Two additional issues have been identified that may cause problems in certain (high) signal conditions.

The first major error (**read order**) is an error in the order of the pixel readout within a row, and the second (**o/n timing**) involves the timing of the state machine increment.

1. The logic that selects which capacitor to read out is not in the proper phase relative to the advance of the image across the detectors. The net result is that a capacitor gets part of it's charge due to one image pixel and the rest due to an image pixel four pixels away creating a ghost image.

2. The state machine that steers charge from each detector to the appropriate integration capacitor for a given row is supposed to advance as soon as that row is read out. An error in the logic results in all rows advancing simultaneously when the last row is reached. For rows near the far end of the chip the effect is minimal, since the actual advance is occurring close to where it is supposed to. But as the addressed row moves away from the end of the chip, the capacitor that was just read out continues to view the wrong image pixel (one located four pixels away from where it should be looking) until the end of the sub-frame. Similarly, the capacitors that were not read out continue to view the wrong image pixel, but in these cases it is the adjacent pixel. The net effect is a blurring of the image with a ghost image.

The read order error can be corrected on the present die using Focussed Ion Beam Milling/Epitaxy to cut and bridge 4 traces. However, the o/n timing error involving the state machine timing can only be corrected by modifying several of the layout masks and refabricating the entire chip. For evaluation purposes, the imaging capabilities of the BFE124B may be demonstrable using a FIB modified die provided only rows near the end of the chip are viewed.

General Summary

Note: The schematics that apply to this part of the circuit are structured in a way that makes them unhelpful to understanding the problem, so are not included.

The BFE124 is a 480 row Read-Out IC with two banks and 64 detector channels in each row of each bank. The two banks are located side-by-side and are offset vertically by one half the height of a pixel. The effect of the two banks thus oriented is to create a virtual 960 row array.

While it is technically a 2D area array, it is designed to function as a 1D scanning-mode linear array. The purpose of the 64 detector channels is to improve the signal-to-noise ratio without sacrificing image scan-time. This is done using Time Delayed Integration (TDI) where the signal from adjacent detector channels are added together with the appropriate time delay so that the signal from each detector channel corresponds to the same picture element (pixel) for all 64 channels. Appropriate post processing can also create the effect of having a 480-row linear array with 128 channels combined via TDI.

The TDI is performed in two stages. First, 4-channel TDI is performed on chip. Second, the output data is post-processed to perform another sixteen stages of TDI resulting in the final 64-channel TDI output.

The 4-channel on-chip TDI is performed within each unit cell where there are four detectors and four signal-integration capacitors. At any moment in time, each detector is mapped to one of the four capacitors. As the image scans across the chip, and hence moves from one detector to the next, this mapping is altered so that the detector that is viewing a particular region in the image is always mapped to the same capacitor until the image moves beyond that family of four detectors.

In order to maximize the amount of time that a given signal is integrated while allowing continuous scanning and readout, each row of pixels works independently. As the row counter reaches a particular row, one of the four pixels is sampled for readout. The corresponding capacitor is then reset and, when the row counter advances to the next row, the detector/capacitor mapping is advanced. Each complete cycle of the row counter thus reads out one-fourth of the pixels in the array and is referred to as a sub-frame. It therefore takes four sub-frames to read out all pixels and complete an entire image frame. The partial image read out with each sub-frame consists of every fourth pixel in the image. Subsequent sub-frames also read out every fourth pixel, offset by one from the prior sub-frame, such that the four sub-frames that make up a complete image are interleaved.

Conceptual Event Pipeline (implementation details ignored):

When the row counter reaches a particular pixel's row:

- Route the signal on the terminal capacitor (the capacitor connected to the trailing detector) to the column sample and hold circuitry.
- Capture the signal.
- Reset the charge on the terminal capacitor.

When the row counter advances to the next row:

- Shift the detector/capacitor mapping so that the just-reset capacitor becomes the initial capacitor (the capacitor connected to the lead detector). All other capacitors shift to match the motion of the image across the detectors.

Detector/Capacitor Mapping:

The on-chip TDI is capable of integrating either an image traveling left-to-right across the chip or right-to-left. However, since the detector to capacitor mapping is sensitive to the scan direction, the chip must be aware of the direction. This is accomplished through the Pleft input signal. If Pleft is HI, then the image scans across the chip from left-to-right.

In the following tables, the alphabetic entries denote image pixels. Imagine an image that consists of the letters of the alphabet in ascending order that is scanned across the chip: (XYZABCDEFGH)
The table indicates which letter is being viewed during a given Time Step by each detector.

Pleft = HI: Pixel seen by each detector as the image scans left-to-right:

Detector	D1	D2	D3	D4	
Time Step 1	A	Z	Y	X	
Time Step 2	B	A	Z	Y	
Time Step 3	C	B	A	Z	
Time Step 4	D	C	B	A	Read out pixel A and reset capacitor
Time Step 5	E	D	C	B	Read out pixel B and reset capacitor
Time Step 6	F	E	D	C	Read out pixel C and reset capacitor
Time Step 7	G	F	E	D	Read out pixel D and reset capacitor
Time Step 8	H	G	F	E	

In order to integrate the appropriate signal, the following detector to capacitor mapping must be implemented (based on pixels A-D and extending forward and backward for all others):

Detector	D1	D2	D3	D4	State
Time Step 1	C1	C4	C3	C2	S1
Time Step 2	C2	C1	C4	C3	S2
Time Step 3	C3	C2	C1	C2	S3
Time Step 4	C4	C3	C2	C1	S4
Time Step 5	C1	C4	C3	C2	S1
Time Step 6	C2	C1	C4	C3	S2
Time Step 7	C3	C2	C1	C4	S3
Time Step 8	C4	C3	C2	C1	S4

Pleft = LO: Pixel seen by each detector as the image scans right-to-left:

Detector	D1	D2	D3	D4

Time Step 1	X	Y	Z	A	
Time Step 2	Y	Z	A	B	
Time Step 3	Z	A	B	C	
Time Step 4	A	B	C	D	Read out pixel A and reset capacitor
Time Step 5	B	C	D	E	Read out pixel B and reset capacitor
Time Step 6	C	D	E	F	Read out pixel C and reset capacitor
Time Step 7	D	E	F	G	Read out pixel D and reset capacitor
Time Step 8	E	F	G	H	

Detector	**D1**	**D2**	**D3**	**D4**	**State**
Time Step 1	C4	C3	C2	C1	S4
Time Step 2	C3	C2	C1	C2	S3
Time Step 3	C2	C1	C4	C3	S2
Time Step 4	C1	C4	C3	C2	S1
Time Step 5	C4	C3	C2	C1	S4
Time Step 6	C3	C2	C1	C4	S3
Time Step 7	C2	C1	C4	C3	S2
Time Step 8	C1	C4	C3	C2	S1

If the Read and Reset capacitor mapping is ignored for now, there are four Detector/Capacitor Mapping States:

State	**D1**	**D2**	**D3**	**D4**
S1	C1	C4	C3	C2
S2	C2	C1	C4	C3
S2	C3	C2	C1	C2
S4	C4	C3	C2	C1

Since each row is independent, each row needs two Finite State Machines (FSM). The choice of which state machine to use is determined by the status of the Pleft signal. Each row's state machine is advanced as soon as a capacitor is read out and reset. This occurs once per Sub-frame, when the row counter points to that particular row (actually, the next row).

Pleft = HI:	FSM#1:	S1►S2►S3►S4►repeat
Pleft=LO:	FSM#2:	S4►S3►S2►S1►repeat

Physically implementing two FSM's in each row is not desirable and can be avoided by operating four global state machines that are clocked once per Sub-frame:

Pleft = HI:	FSM#1A:	S1►S2►S3►S4►repeat
Pleft = HI:	FSM#1B:	S2►S3►S4►S1►repeat
Pleft=LO:	FSM#2A:	S4►S3►S2►S1►repeat
Pleft=LO:	FSM#2B:	S3►S2►S1►S4►repeat

As can be seen, the only difference between the A and B state machines is that the B state machine leads the A state machine by one state. In fact, the A and B state machines can be (and are) implemented as a single FSM with twice as many output signals.

To see how these are used to create the virtual state machines in each row, consider a row R such that 0<R<(N-1) where N is the total number of rows (i.e., N=480). If x is the row currently pointed to by the row counter, then (as an example) we want the following behavior:

Upon each row clock: If x<(N-1) then x▶x+1 else x▶0

x=R:	Read out and reset the terminal capacitor.
x=R+1:	Advance FSM from S1 to S2

This behavior can be synthesized as follows:

x=R:	Read out and reset the terminal capacitor.
x=R+1:	Switch from FSM#1A (S1) to FSM#1B (S2).
x=0:	Advance FSM#1A (to S2) and FSM#1B (to S3) Switch from FSM#1B (S3) to FSM#1A (S2)

The effect of the two events that occur at x=0 is to keep the row in S2.

To implement this behavior, generate the proper state signals and route them globally to each row. Since only one state machine (FSM#1 or FSM#2) is used at a time, their outputs can be multiplexed onto a bus according to the Pleft signal. This serves to minimize the routing and logic.

Since the bus contains both the A and the B families of signals, a simple latch in each row can use the row decoder (which must already be present) to select between the two families. When the row decoder advances to the next row, the B family is selected. When the row counter wraps around to row zero, the A family is selected.

Synchronization of the Finite State Machines to the Pixel Readout and Reset Logic

As mentioned previously, it takes four sub-frames to read out and to reset all four capacitors in each unit cell, one capacitor per sub-frame. Since the FSM's that determine the detector to capacitor mapping also have a period of four sub-frames, it is only natural to use the same FSM for all three purposes. But care must be taken to properly establish the relative phases between the three operations, otherwise pixel mixing (resulting in ghost images) will occur.

To establish the necessary relationships, the event sequences used to establish the detector to capacitor mappings for both scan directions are reproduced below, along with the additional mapping information necessary for the Read & Reset (R&R) event. It must be kept in mind that each Time Step listed below is a sub-frame and lasts for one complete cycle of the row counter. In each Time Step, the capacitors are integrating the signal from their respective detectors for the entire sub-frame. At the end of the sub-frame, one of the capacitors is selected for read out. It is sampled and then reset just prior to advancing the detector mapping. The state machine only needs to select which capacitor will be read out at the end of the sub-frame. The row and column decoders control the fine timing of the actual sample and reset events.

Pleft = HI:

Detector	D1	D2	D3	D4	State	R&R
Time Step 1	C1	C4	C3	C2	S1	C2
Time Step 2	C2	C1	C4	C3	S2	C3
Time Step 3	C3	C2	C1	C2	S3	C4
Time Step 4	C4	C3	C2	C1	S4	C1
Time Step 5	C1	C4	C3	C2	S1	C2
Time Step 6	C2	C1	C4	C3	S2	C3
Time Step 7	C3	C2	C1	C4	S3	C4
Time Step 8	C4	C3	C2	C1	S4	C1

Pleft = LO:

Detector	D1	D2	D3	D4	State	R&R
Time Step 1	C4	C3	C2	C1	S4	C4
Time Step 2	C3	C2	C1	C2	S3	C3
Time Step 3	C2	C1	C4	C3	S2	C2
Time Step 4	C1	C4	C3	C2	S1	C1
Time Step 5	C4	C3	C2	C1	S4	C4
Time Step 6	C3	C2	C1	C4	S3	C3
Time Step 7	C2	C1	C4	C3	S2	C2
Time Step 8	C1	C4	C3	C2	S1	C1

As can be seen, which capacitor is read and reset is dependent not only on the state, but on the scan direction as well.

				Pleft:	HI	LO
State	D1	D2	D3	D4	R&R	
S1	C1	C4	C3	C2	C2	C1
S2	C2	C1	C4	C3	C3	C2
S3	C3	C2	C1	C2	C4	C3
S4	C4	C3	C2	C1	C1	C4

Signal Polarities

In order to simplify the decode logic located in each row, the state machines are One-Hot encoded. Furthermore, the outputs must be conditioned to ensure that they are non-overlapping in order to prevent unwanted transfers between the signal integration capacitors.

PoX/PnX: These are two families of signals with four signals in each family (the X is a wildcard which stands for {A,B,C,D}). These state signals determine the detector/capacitor mapping and are Active-LO One-Hot encoded. PoX is the old state (the A state machine) and PnX is the new state (the B state machine).

PselX: This family of four signals selects which capacitor is routed to the sample and hold circuitry and then reset. They are Active-HI One Hot encoded.

ModeS/ModeR: These two signals control the set and reset of the SR latch that determines which family of signals (PoX or PnX) is routed to the unit cells in that row. Both inputs are Active-HI. When reset (ModeR taken HI) then PoX is routed out. When set (ModeS taken HI) then PnX is routed out.

Active Signals

The PnX family needs to always precede the PoX family, but the relationship of the PselX family is scan direction dependent. For Pleft=HI, PselX must lead PoX while for Pleft=LO is must equal PoX. The reason is that the terminal detector is located on the opposite side of the unit cell.

Pleft = HI

State	PoX	PnX	PselX
S1	A	B	B
S2	B	C	C
S3	C	D	D
S4	D	A	A

Pleft = LO

State	PoX	PnX	PselX
S4	D	C	D
S3	C	B	C
S2	B	A	B
S1	A	D	A

Known Design Errors/Issues:

(1) The signal that asserts the ModeR lines is not generated on chip. It is the logical OR of the MRST and ROWRST signals which are externally supplied. The intent was for the chip not to require either of these signal and they have default pulldown resistors on them. But, as implemented, the ROWRST signal must.

Corrective Action:
Short term - externally apply the necessary reset signals.
Long term - internally generate a reset signal.

(2) The signal that is routed to the ModeS lines of the mode latches is of the wrong polarity. The signal is supposed to be active-HI and the signal that is actually routed to this circuitry is the Qb output of the row-enable shift register (the rowenb signals). The result is that the Mode Latches are continuously held in a SET state except during the brief time that they are supposed to actually be set. The RESET signal is therefore basically ignored - except during the brief time that it is being asserted in which case both the ModeS and the ModeR are HI which is an undefined state - the consequence is that the PFET in all eight transmission gates are turned ON. As soon as the reset is relaxed, the latch is immediately SET.

Corrective Action:
Short term: None possible.
Long term: Requires an inversion in the ModeS line, either explicitly or by changing the polarity of the RS Latch.

(3) When the Mode Latch changes state, there is approximately a 2ns overlap between the state signals going to the unit cells - both the old and the new signals are asserted simultaneously permitting charge transfer between the signal integration capacitors under high signal conditions.

Corrective Action:
Short term: None possible.
Long term: Requires modification of the Mode Logic to suppress one family until the other family is removed completely. Perhaps the buffers can be modified to take all of the outputs high until during the transition.

(4) The derivations of the PoX and PnX families are basically reversed. As implemented, the PnX signals lead the PoX signals. In addition, the PselX signals equal the PoX signals when Pleft=HI and precede the PoX signals when Pleft is LO. It is the error in the PselX signal that is causing the ghost images.

Corrective Action:
Short term: These can be modified using IBE. Due to Issue #2 above, there is little point in correcting the PoX/PnX relationships. But by correcting the PselX derivation relative to the PoX, it should be possible to eliminate the ghost image (due to this error). Given Issue #2, the PnX family must be treated as being the PoX family for the purpose of establishing the PselX family, since the PselX signal is acted upon just prior to switching from PoX to PnX and the PnX family is (incorrectly) asserted at that time.
Long term: Derive the signals correctly.