Fall 11-2001

Technology in Positron Emission Tomography

Cindy Lee Jones-Shields
University of Tennessee - Knoxville

Cindy, Looks good! See my corrections. HLD

Technology in

Positron Emission Tomography

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Cindy Jones

CTI PET Systems, Inc.

Senior Honors Project

October 26, 2001

Appendix D - **UNIVERSITY HONORS PROGRAM**
SENIOR PROJECT - APPROVAL

Name: Cindy Jones

College: Engineering Department: Nuclear/Radiological

Faculty Mentor: Dr. Harold L. Dodds

PROJECT TITLE: Technology in Positron Emission Tomography

I have reviewed this completed senior honors thesis with this student and certify that it is a project commensurate with honors level undergraduate research in this field.

Signed: [signature], Faculty Mentor

Date: 11-15-01

Comments (Optional):

Technology in

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Abstract

In the past, obtaining accurate medical diagnoses often necessitated surgery, required expensive diagnostic tests, or was completely unattainable. Additionally, the treatments of many medical conditions demanded highly invasive procedures that were frequently ineffective and unsuccessful. With modern developments in Positron Emission Tomography (PET), however, the medical world is becoming revolutionized.

My involvement in PET innovations focused mainly on the development of a new PET scanner at CTI PET Systems, Inc., located in Knoxville, TN. This scanner is original due to its ability to provide greater image resolution, less scanning time, and automated source strength correction. The three major areas of my work included the Coincidence Point Source Interface, the Smart Source Board, and the Smart Source Testware.

My greatest learning experience and most significant contribution to CTI's new PET scanner was the Smart Source Testware development. This task required me to write programs in Microsoft Visual C++, a language I had never used prior to this project. I also learned to read and write EEPROMs for the first time. The Smart Source Testware can be used for other applications in CTI PET scanners as well. My code is well documented and can easily be modified for use in new assignments with similar requirements.

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1 Acknowledgements

I would like to express my gratitude to the following individuals who donated their time and resources to contribute to this project. Dr. Ron Nutt of CTI PET Systems, Inc. offered me a summer engineering internship position in his Research and Development Department. Additionally, Carlyle Reynolds, Mark Overbay, and John Young provided technical guidance and suggestions during my internship. Jenny McCann, also of CTI, extended advice and guidelines concerning environmental and other regulatory requirements pertaining to this project. Lastly, I would like to thank Dr. Harold L. Dodds, University of Tennessee Nuclear Engineering Department Head, for his guidance in developing this report.

2 Introduction

During the summer of 2001, I worked as an engineering intern at CTI PET Systems, Inc. My main tasks involved electrical and computer design work for a new Positron Emission Tomography (PET) prototype. Since my academic major and interests are within the field of Nuclear Engineering (concentrated in Radiological Engineering), I wanted to continue this type of work for my Senior Honors Project. This project was supervised by engineers and management at CTI PET Systems, Inc. and by Dr. Harold L. Dodds.

3 Positron Emission Tomography

In the past, obtaining accurate medical diagnoses often necessitated surgery, required expensive diagnostic tests, or was completely unattainable. Additionally, the treatments of many medical conditions demanded highly invasive procedures that were frequently ineffective and unsuccessful. With modern developments in Positron Emission Tomography (PET), however, the medical world is becoming revolutionized.

3.1 What is PET?

PET is an emerging non-invasive, diagnostic imaging technique used for measuring the metabolic activity of cells in the human body. It is approved by many insurance carriers and used by physicians to diagnose and manage patient treatment plans for numerous diseases.

Traditional diagnostic techniques, such as x-rays, computed tomography (CT) scans, or magnetic resonance imaging (MRI), produce images of the body's anatomy or structure. The premise with traditional techniques is that disease causes a change in structure or anatomy that can be observed. PET is unique because it produces images of the body's basic biochemistry. These biochemical processes may be altered by disease before there is a change in anatomy. For example, even in diseases such as Alzheimer's, where there is initially no gross structural abnormality, PET is able to show a biochemical change.

In addition to imaging and measuring metabolic processes, there are other reasons that PET is a vital addition to the clinician's diagnostic toolbox. PET can validate and/or modify patient management and care. Furthermore, it reduces patient risk and improves patient outcome. Lastly, PET decreases overall healthcare costs and defines appropriate pathways of medical care.

3.2 PET Applications

PET's uniqueness and value lie in its ability to quantitatively measure biochemical, metabolic, and functional activity in well defined, localized regions of the body. PET is primarily used in cardiology, neurology, and oncology. Specifically, it can be utilized to access the benefit of coronary artery bypass surgery, identify causes of childhood seizures and adult dementia, and detect and classify tumors (CTI PET Systems Patients' Info).

3.2.1 Cardiology

PET has several promising clinical applications among patients with known or suspected heart ailments. PET allows physicians to screen for coronary artery disease and to assess flow rates and flow reserve. It has also proven useful in distinguishing viable from nonviable myocardium tissue – knowledge which can be used to predict the therapeutic success of a cardiology patient after undergoing bypass, angioplasty, or transplant procedures.

3.2.2 Neurology

PET provides information for evaluating numerous neurological diseases such as Alzheimer's and other dementias, Parkinson's, Huntington's, and Down's Syndrome. Additionally, it offers assistance to epilepsy patients by localizing epileptic foci in order to qualify and identify the site for surgical intervention. It also enables the characterization, grading, and assessment of possible brain tumor recurrence.

3.2.3 Oncology

PET is the only modality that can accurately image many organs of the body with a single pass to allow discrimination between benign and malignant tissues. It can also provide information to determine whether a primary cancer has metastasized to other parts of the body. PET has demonstrated its usefulness in the early detection of recurrent tumors, grading of existing tumors, and the selection and evaluation of therapy treatments. PET offers further assistance in the following ways: providing whole-body metastatic surveys, avoiding biopsies for low grade tumors, differentiating tumors from radiation necrosis non-invasively, determining the need for early change in course of ineffective chemotherapy, and avoiding unnecessary diagnostic and therapeutic surgeries. PET has proven a high degree of accuracy for determining the presence or spread of many malignant tumors including: lung cancer, ovarian cancer, breast cancer, lymphomas, head/neck tumors, colorectal cancer, melanoma, brain tumors, and pancreatic cancer.

Whole body PET scan of patient with metastatic disease

Figure 3.2. PET Image Used in Oncology

3.3 How Does PET Work?

The PET scan is a simple procedure involving the use of a small amount of a short half-lived radiopharmaceutical (produced by a cyclotron or generator), comparable to the amount used in other nuclear medicine procedures. A radioactive element is incorporated into a compound that is familiar to the body, such as glucose, water, ammonia, or certain drugs. The radioactive compound is then administered to the patient, usually by injection, and a specially designed PET scanner images how the body processes the introduced material. The radiopharmaceuticals discharge positrons from wherever they are located in the body. As these positrons encounter elements within the body, gamma rays are produced from resulting reactions.

A patient preparing to undergo a PET scan must first lie on a table that slides into the middle of the scanner (see Figure 3.3.1). Inside the scanner are rings of detectors constructed with special crystals that produce light when struck by a gamma ray. The internal electronics of the scanner record the detected gamma rays and map an image of the area where the radiopharmaceutical is located. Because the radiopharmaceutical contains a chemical that is regularly used by the body, PET enables a physician to see the location of the metabolic process. For example, glucose (a sugar which the body uses to produce energy) combined with a radioisotope shows where glucose is being utilized in the brain, the heart muscle, or a growing tumor (CTI PET Systems Patients' Info).

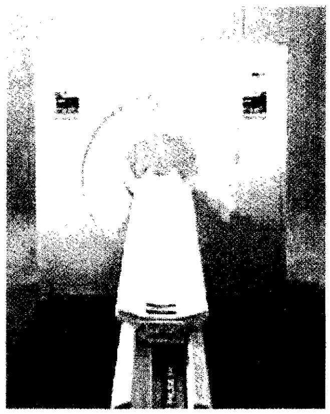

Figure 3.3.1. CTI ECAT® Tomograph (PET Scanner)

In summary, a PET patient receives an intravenous injection of a radioactive tracer. The radioactive compound is then distributed throughout the body and processed by the organs being studied. The PET scanner records the position of the tracer as the emitted positrons interact with electrons in the body (positron annihilation), creating gamma radiation that can be detected by detectors outside the body. A computer reconstructs the pattern of detected radioactivity into three-dimensional pictures of the body.

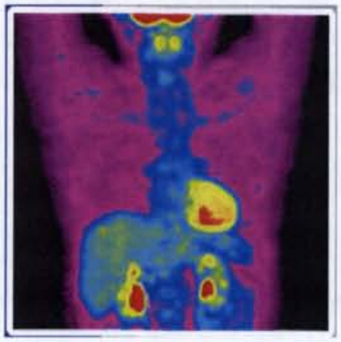

Figure 3.3.2. PET Image of Upper Body

3.4 PET Cost Effectiveness

PET is responsible for improved accuracy in diagnosis, avoidance of unnecessary surgeries, and significant savings for surgeries not performed. Gambhir et al report that the use of both PET and CT scans provides a savings of $1154 per patient over the use of the CT scan alone (1432).

The ICP Cardiology Task Force contends that the myocardial viability assessment is more accurate with PET than with the Thallium stress test. They note that PET is capable of screening out patients without viable tissue who would not benefit from surgery. Such knowledge has allowed the number of unnecessary catheterizations to reduce by 28% and the number of unnecessary CABGs (Coronary Artery Bypass Grafting) to reduce by 12%. Fewer surgeries ultimately result in a reduction in the number of potential post-surgical complications. Lastly, PET is useful in determining viable candidates for cardiac transplants (ICP Cardiology Task Force).

4 CTI PET Systems, Inc.

CTI is the leading supplier of products and services for the Positron Emission Tomography market. CTI's product line includes the RDS cyclotron products, the RDS chemical synthesis units, and the ECAT® tomograph (i.e., PET scanner) products. Cyclotrons are particle accelerators that generate positron emitting isotopes. The chemical synthesis units incorporate these isotopes into radiolabeled compounds which, through injection or inhalation, are taken up in body tissue in proportion to biochemical activity. A scanner then detects this radiation emitted from positron decays and forms images of the labeled compound distribution. Together they work to provide significantly more valuable diagnostic information for physicians compared to conventional anatomical imaging techniques. CTI also provides other PET-related products and services, including the distribution of selected PET compounds in major metropolitan areas.

5 Project Outline

My involvement in CTI's PET innovations was focused mainly on the development of a new PET scanner, currently termed the "P39 Project." The electronics and programming involved with this project are extremely complicated and require the combined efforts of the entire Research and Development department at CTI. I contributed to a small portion of this network by focusing on an electronic board termed the "Coincidence Point Source Interface" and an EEPROM (Electrically Erasable Programmable Read Only Memory) chip termed the "Smart Source". This report only includes the results of my research and contributions since most of the other components of the P39 Project have yet to be completed. The three major areas of my work include the Coincidence Point Source Interface, the Smart Source Board, and the Smart Source Test Hardware/Software.

5.1 PET Transmission Overview for the P39 Project

In addition to collecting *emission data* by detecting gamma radiation produced within a patient who has received a radiopharmaceutical injection, *transmission data* must also be collected to correct a large source of error in the emission data. This error is caused by the attenuation of gamma radiation within the body or entity being measured. This means that some gamma radiation will interact with elements within the body, and thus, will never reach a detector. The radiation that does not interact with a detector is not accounted for unless physicians are able to determine the number of gammas that are typically "lost" to interactions within the body. By accurately measuring the gamma radiation attenuation, a simple normalization can be made to correct the acquired emission data for a given attenuation.

The P39 transmission source will utilize a transmission system in which a point source is loaded with a positron isotope (either ^{68}Ge or ^{22}Na), and ten of these point sources will be loaded into a Point Source Assembly (Overbay). When an isotope within a point source emits a positron, positron annihilation will occur as soon as the positron combines with an atomic electron. As positron annihilation occurs, two

0.511-MeV gamma photons are emitted 180 degrees from one another. In order to insure that only the annihilation photons are counted, two detectors are placed 180 degrees apart. A high-speed detector is placed adjacent to the source in order to collect one of the gamma photons produced by the positron annihilation. Fast signal processing electronics record these detector events and perform coincidence measurements. Coincidence measurements include only those events in which the two annihilation gammas are detected simultaneously within their respective detectors. If the detector that is adjacent to the source detects an annihilation gamma, but the second detector does not, the undetected gamma photon has most likely been attenuated within the body.

This system has the ability to acquire emission and transmission data concurrently, which permits better registration of emission and transmission data since there is less opportunity for a patient's body to shift between the transmission and emission acquisitions.

5.2 Definitions

Smart Source	Dallas Semiconductor EEPROM which enables the storage of activity and manufacture date for each of the ten point sources
Smart Source Board	Small pc-board to which Smart Source EEPROM is mounted
Point Source Assembly	Assembly containing all components of the point source mechanism; includes a rod with ten windows, ten point sources and photomultiplier tubes, sensors, motor, and Smart Source Board
Coincidence Point Source Interface	Interface board between the Smart Source Board and the Detector Head Interface; use of several connectors
Detector Head Interface	Board that communicates with the Coincidence Point Source Interface and reads the Smart Source contents

5.3 Acronyms and Abbreviations

BOM	Bill of Materials
CPSI	Coincidence Point Source Interface Board
CRC	Cyclic Redundancy Check
DHI	Detector Head Interface
ECAT	Emission Computerized Axial Tomography
EEPROM	Electrically Erasable Programmable Read Only Memory
ESD	Electrostatic Discharge
PET	Positron Emission Tomography
PMT	Photomultiplier Tube
PSA	Point Source Assembly
SSB	Smart Source Board
SS	Solid State (Relays)
UDP	Universal Data Packet

6 Coincidence Point Source Interface

This section describes the initial specifications that I wrote for the P39 Project Coincidence Point Source Interface board. The Coincidence Point Source Interface board (CPSI) provides communication between the detectors, Point Source Assembly (PSA) motor and sensors, power supplies, and detector electronics of the P39 PET scanner. The CPSI resides adjacent to the PSA.

6.1 Functionality

The CPSI provides convenient connection points for power, detectors, signal cables to the detector electronics, motor, and motion sensors. It provides high voltage for the photomultiplier tubes (PMTs), and the CPSI has preamplifiers for each PMT output. Two relays on the CPSI are responsible for switching the 220 VAC to the motor on the PSA. When the relay circuits close, current flows to the PSA motor in order to drive it forward. As the motor rotates, it extends the PSA point source rod outward using a "rack and pinion" drive, until a mechanical stop is reached (each of the ten point sources is aligned with its respective window at this point). The outward movement of the rod causes a powerful spring, attached to the rod assembly, to stretch and gain tension. Once rod motion ceases, the motor stalls while data is being collected since it is still receiving power (the proposed motor can stall indefinitely without resulting in damage or burn-up). After all data collection is complete, the relay circuits open and terminate current flow to the motor. The spring begins to recoil as soon as the motor loses power, and as a result, it drives the motor backwards. This reverse drive causes the rod to retract to its original position such that the point sources are no longer exposed. The electronics assembly mounts within the cover of the PSA mechanical assembly.

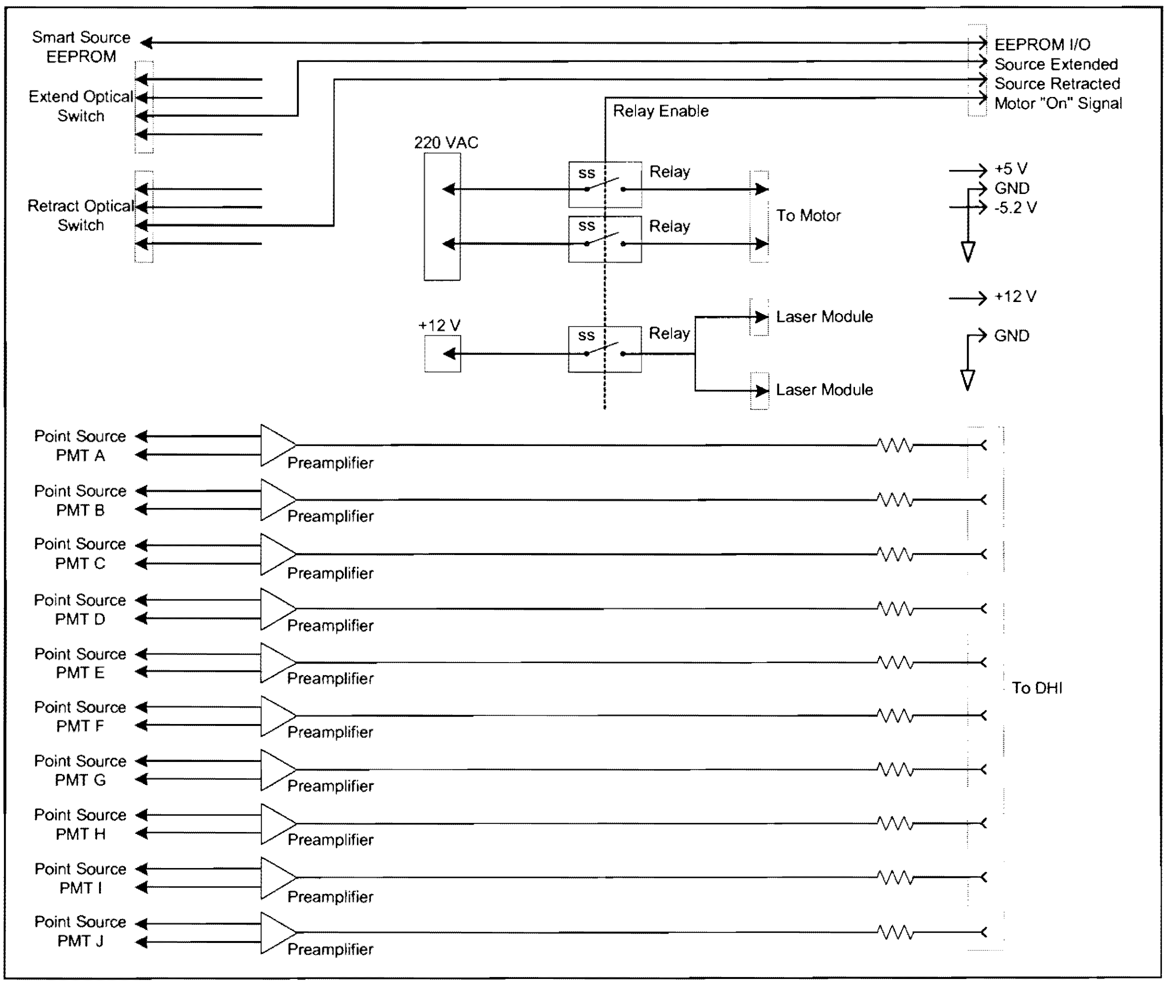

Figure 6.1 Block Diagram of Coincidence Point Source Interface Board

6.2 Components

The CPSI contains several electrical components, and the descriptions of the preamplifiers and relays are discussed below.

6.2.1 Preamplifiers

The PMTs of the PSA have to run at a low gain. This is due to the high count rates expected as a result of the detector proximity to the point source. Considering this count rate and the overall light output from the detector crystal, low PMT gain is the only way to avoid damaging high average anode current in the tube (Moyers). Because of the low PMT gain, preamplification is required to boost the signals to levels required by the analog processor. The preamplifier circuit will be a simple one- or two-stage (depending on the gain needed) current feedback operational amplifier design. The amplifier gains have yet to be determined. A delay line may be required to correct for the short time of flight of the PSA PMTs. Output is differential, reducing noise at the analog processor. The block diagram of the preamplifier/delay circuit is shown in Figure 6.2.

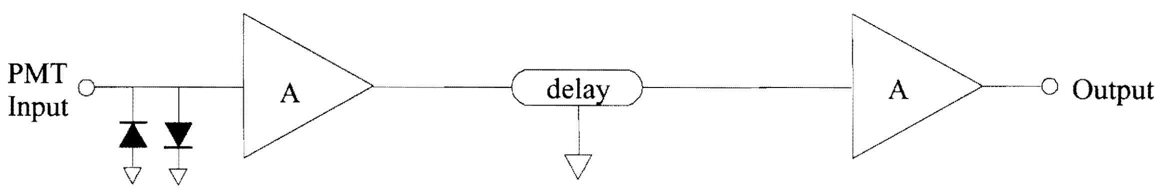

Figure 6.2. PMT Preamplifier/Delay Circuit

6.2.2 Relays

Two Solid State (SS) single pole relays will be used on the CPSI to control current flow to the PSA motor. Once the relays receive an enabling signal from the Detector Head Interface (DHI), the relay circuits will close allowing current to flow to the motor. The relays will have an input of 220 VAC. They are paired for redundancy purposes - if one fails, opening one leg of the motor power will still allow the sources to retract.

6.3 Risk Assessment & Hazard Analysis

A comprehensive Risk Assessment and Hazard Analysis will not be considered at this level unless an assembly or subassembly analysis shows that it is warranted. High voltage is not present on the board, and no board components are high current. Therefore, the risk of fire is minimal on the CPSI.

6.4 Initial Production, Verification, & Validation

6.4.1 Initial Production

Initial Production Units of the CPSI will be built prior to Release to Production of the Coincidence Point Source Interface assembly. These units will be assembled by Benchmark Electronics. The Responsible Engineer will be accountable for testing the units built prior to Release to Production. All documentation pertaining to the assurance of these units' functionality will be retained in the Coincidence Point Source Interface design notebook. Changes to the initial design will be documented in the P39 project notebook.

6.4.2 Verification

At least six units will be built first. These units will be visually inspected for consistency to the schematics and bill of materials (BOM). All power connections will then be checked for shorts with an ohmmeter. The unit will be powered on the bench, and desired operation of all circuits will be verified and documented.

6.4.3 Validation

Validation of the assembly will be performed through integration with the detector panel and the detector electronics. The detectors are assembled and attached to the Detector Panel Interface board, which is connected to the detector electronics. System setups will be performed, and the performance of the overall detector/electronics documented.

6.5 Additional Requirements

6.5.1 Labeling & Packaging Requirements

All boards will have CTI part numbers, serial numbers, and revision levels clearly marked. They will be handled and shipped according to the usual Electrostatic Discharge (ESD) precautions.

6.5.2 Environmental Limitations

The CPSI will be enclosed in the gantry, which is sealed and environmentally controlled.

6.5.3 Applicable Standards & Regulatory Requirements

- European Union Medical Device Directive (MDD), 12 July 1993, 93/42/EEC.
- Quality System Regulation, 21 CFR Part 820 Medical Devices; Current Good Manufacturing Practice (CGMP).
- ANSI/ASQC Q9001-1994 (ISO) Quality Systems Model for Quality Assurance in Design, Development, Production, Installation, and Servicing.
- IEC 601-1-4, Medical Electrical Equipment - General Requirements for Safety.

6.6 Cost Goal

Each Coincidence Point Source Interface Board will cost approximately $300 to build.

6.7 Tentative Schedule

TASK	Duration (days)
Develop the P39 CPSI Board	***25***
Initial Specifications	2
Design	13
Schematics	5
Choose Parts / Create BOM	3
Design Review	2
P39 CPSI Board Layout	***14***
PCB Placement/Routing	13
Placement/Routing Review	1
P39 CPSI Board Verification	***10***
Verify six boards	5
Develop Validation/Test Procedure	5

7 Smart Source Board

This section describes the initial specifications that I wrote for the P39 Project Smart Source Board. The Smart Source Board (SSB) connects to the CPSI to relay source strength information to the Detector Head Interface. The SSB stores source strength and other general information in an EEPROM, and it connects to the CPSI via a flexible cable.

7.1 Functionality

The P39 system will employ positron isotopes for radiation sources. These positron-emitting isotopes suffer from relatively short half-lives of either 0.740 years (for ^{68}Ge) or 2.66 years (for ^{22}Na). This diminishing source activity can lead to errors in quantification in PET scanning if not accounted for. Thus, it is important that the transmission sources be replaced at regular intervals to ensure adequate isotope activity to support quality transmission imaging. Present coincidence transmission systems lack an automated way to account for source activity each time the sources are changed. When new sources are placed in the tomograph, a manual notation must be made of the source manufacture date and activity of each source. This burden would be significant while trying to maintain the twenty different sources of the two P39 point source assemblies.

In order to determine when the sources decay below a minimum useful activity without manual treatment, the P39 PSAs will be assembled with a Dallas Semiconductor Smart Source EEPROM. This EEPROM contains enough memory to store the measured activity and date of the source manufacture for each of the ten point sources within a PSA. Data encryption methods will be applied to the data stored in the chip to allow error checking when reading the chip contents.

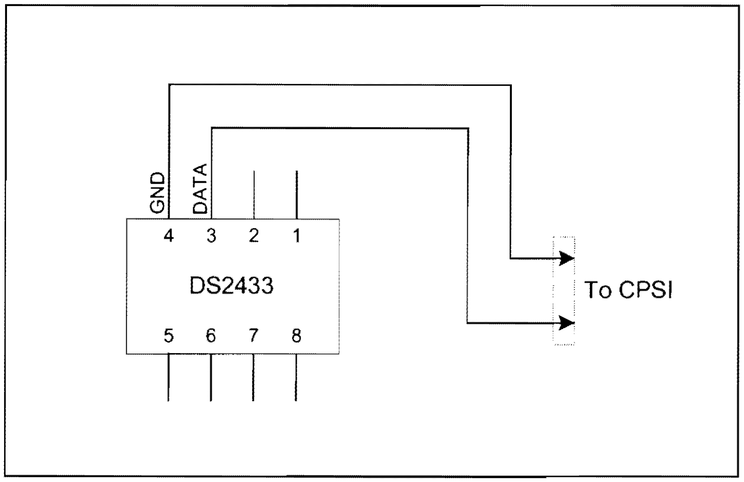

Figure 7.1. Block Diagram of Smart Source Board

The SSB will interface with the CPSI. The DHI will then communicate with the CPSI, allowing interrogation of the Smart Source EEPROM. Firmware on the DHI will read the contents of the EEPROM and make this data available to the Emission Computerized Axial Tomography (ECAT) software. This will permit the capability of automatic transmission source-strength correction as well as notification of the operator when sources are nearing replacement time. The unique serial number in each Smart Source chip permits source traceability for regulatory purposes.

Physically, the Smart Source EEPROM will be mounted on a small pc-board (SSB) with a flexible cable terminated by a connector that will plug into a connector on the CPSI. Since the head of the SSB moves approximately one-half inch when the source extends, a flexible cable is important.

7.2 Components

The Smart Source Board contains an EEPROM and a connector. The EEPROM is described below.

7.2.1 Smart Source EEPROM

The Dallas Semiconductor Smart Source EEPROM is a self-contained electronic chip that has a permanent unique serial number as well as 4k-bits of non-volatile memory. The chip will be programmed by a PC interface at the time of source manufacture.

Each Smart Source chip is loaded with the measured activity and date of source manufacture for each of the ten point sources in the P39 point source assembly. An 8-pin, 4-kbit EEPROM (DS2433) will be used in this application. The EEPROM will be programmed using a DS9097U-S09 serial port adapter and a modified DS1402D-DR8 blue dot receptor. The programming connector from the computer can be the same type of connector used to connect the pc-board to the CPSI (DS2433 4k-Bit 1-Wire™ EEPROM Data Sheet).

7.3 Risk Assessment & Hazard Analysis

A comprehensive Risk Assessment and Hazard Analysis will not be considered at this level unless an assembly or subassembly analysis shows that it is warranted. High voltage is not present on the board, and the DS2433 EEPROM is a low current component. Therefore, there is essentially no risk associated with the SSB.

7.4 Initial Production, Verification, & Validation

7.4.1 Initial Production

Initial Production Units of the SSB will be built prior to Release to Production. These units will be assembled by Benchmark Electronics. The Responsible Engineer will be accountable for testing the units built prior to Release to Production. All documentation pertaining to assurance of these units' functionality will be retained in the Smart Source design notebook. Changes to the initial design will be documented in the P39 project notebook.

7.4.2 Verification

At least six units will be built first. These units will be visually inspected for consistency to the schematics and BOM. All power connections will then be checked for shorts with an ohmmeter. The unit will be powered on the bench, and desired operation of all circuits will be verified and documented.

7.4.3 Validation

The Smart Source board will be connected to a host processor such that correct read and write operations may be verified by someone other than the responsible engineer. Any problems encountered will be fixed before release.

7.5 Additional Requirements

7.5.1 Labeling & Packaging Requirements

All boards will have CTI part numbers, serial numbers, and revision levels clearly marked. They will be handled and shipped according to the usual ESD precautions.

7.5.2 Environmental Limitations

The SSB will be enclosed in the gantry, which is sealed and environmentally controlled.

7.5.3 Applicable Standards & Regulatory Requirements

- European Union Medical Device Directive (MDD), 12 July 1993, 93/42/EEC.
- Quality System Regulation, 21 CFR Part 820 Medical Devices; Current Good Manufacturing Practice (CGMP).
- ANSI/ASQC Q9001-1994 (ISO) Quality Systems Model for Quality Assurance in Design, Development, Production, Installation, and Servicing.
- IEC 601-1-4, Medical Electrical Equipment - General Requirements for Safety.

7.6 Cost Goal

Each Smart Source Board will cost approximately $50 to construct.

7.7 Schedule

TASK	Duration (days)
Develop the P39 Smart Source Board	***17***
Initial Specifications	2
Design	5
Schematics	4
Choose Parts/ Create BOM	4
Design Review	1
Verify Components/ Netlist	1
P39 Smart Source Board Layout	***3***
PCB Placement/ Routing	2
Placement/Routing Review	1
P39 Smart Source Board Verification	***7***
Verify two or three boards	2
Develop Validation/ Test Procedure	5
Develop the Windows programming software	***22***
Find/Design an Encryption/ Decryption Algorithm	5
Create GUI Framework	2
Add Programming functionality	10
Test/ Debug	5
Develop DHI Firmware to Support the Smart Source Board	***20***

8 Smart Source Testware

This section describes the P39 Smart Source test hardware and software, which are used to store the source information in the Smart Source EEPROM. I developed the Smart Source dialog interface software, which can be used with associated hardware to quickly write an EEPROM and test it for proper operation.

8.1 Need for Product

PET scan operators must be able to determine when sources decay below a minimum useful activity. Therefore, the P39 PSA will be assembled with a Dallas Semiconductor Smart Source EEPROM mounted to the SSB. While the EEPROM contains sufficient memory to store activities and manufacture dates, both software and hardware are needed to write the necessary information to the EEPROM. The Smart Source information results in the capability of automatic transmission source-strength correction as well as notification of the operator when sources are nearing replacement time. Ultimately, this interface allows a user to quickly write to an EEPROM and to test whether or not the EEPROM is working properly.

8.2 Structure & Interfaces

As sources are generated in the laboratory, a software interface is needed to allow technicians to enter the appropriate source data into the EEPROM. This user interface utilizes dialog boxes for simplicity and was constructed in Visual C++. An example of the dialog interface is shown in Figure 8.2.

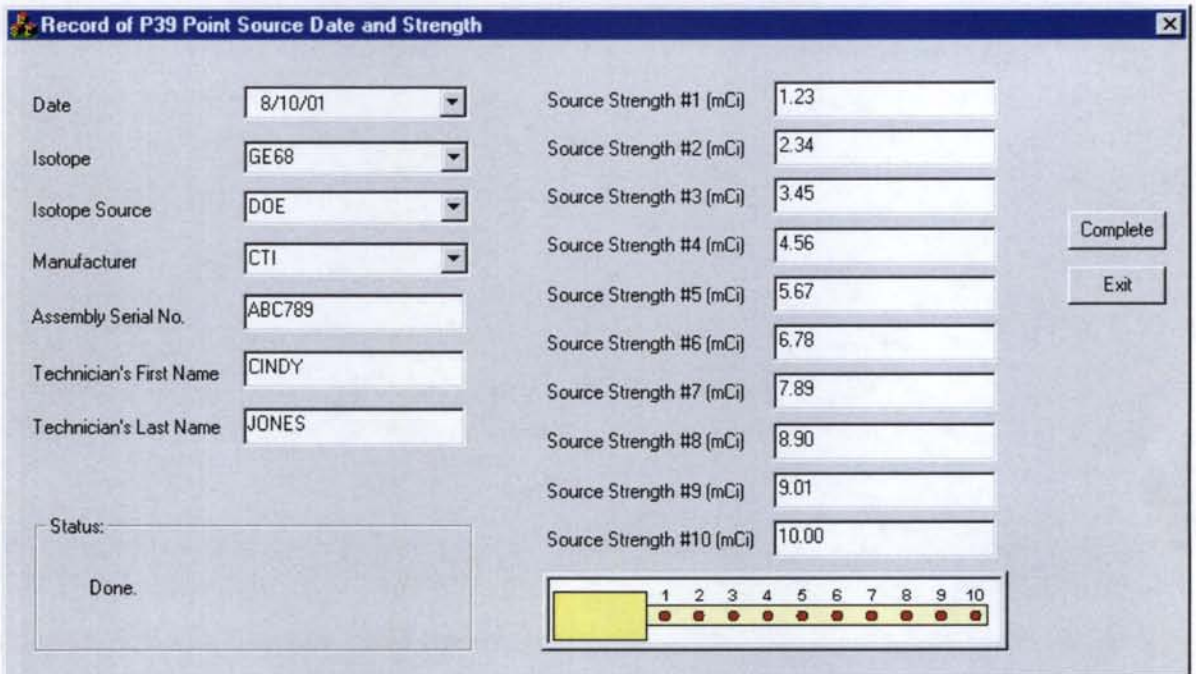

Figure 8.2. User Dialog Interface

Also, if there are problems during or prior to writing, specific error messages appear to help the user correct the problem. Once the user has entered valid information, the interface encrypts the date and activity source data, and then writes the data to the EEPROM with other general information. This information is then read back, in decrypted form, and verified before completion.

8.3 Hardware & Software

This section contains descriptions of the hardware and software components associated with the Smart Source.

8.3.1 Pentium PC with Windows 95, 98, or 2000

This component is used both in the development of the interface software and in the actual application of the interface software. The sources lab technician needs the PC to execute the interface dialog software for writing to the EEPROM.

8.3.2 Microsoft Visual C++

Visual C++ and the Dallas Semiconductor Software Developer's Kit were used to develop the code to read and write the Smart Source EEPROM. The C++ code provides the means to encrypt and download the desired source data into the EEPROM and to test whether or not the EEPROM is working properly. Firmware on the DHI utilizes the same decryption algorithm to correctly decode the data. The encryption/decryption code is used to encrypt and decrypt the data to be stored in the EEPROM. This algorithm employs a key, which will be unique for each device by using certain combinations of the EEPROM serial number. The method of key generation is a secret among CTI's Research and Development engineers and is not needed by the user (Jones). (Due to a CTI confidentiality contract, further details cannot be provided about the encryption code I wrote for Smart Source applications.)

8.3.3 DS2433 EEPROM

The Dallas Semiconductor Smart Source EEPROM is a self-contained electronic chip that has a permanent unique serial number as well as 4k-bits of non-volatile memory. The chip is programmed by a PC interface at the time of source manufacture. Each Smart Source chip is loaded with the measured activity and date of source manufacture for the ten point sources of the P39 PSA.

8.3.4 DS9097U-S09 Universal Serial Port Adapter

This adapter connects to the PC serial port and to a blue dot receptor. The adapter enables a PC to directly read and write the 1-wire EEPROM (DS9097U-S09 Universal Serial Port Adapter Data Sheet).

8.3.5 DS1402D-DR8 Blue Dot Receptor

This device contains an 8-foot coiled cable with two blue dot receptors on one end to provide touch communication with an iButton™ EEPROM. The other end has a

RJ-11 connector to connect to the serial port adapter. Since this receptor is manufactured to support iButtons™, it will have to be slightly modified to provide interface for non-metal can packaged EEPROMs. This modification will be documented so that it can be reproduced (DS1402D-DR8 Blue Dot Receptor Data Sheet).

8.4 Overview of EEPROM Storage

8.4.1 64-Bit Lasered ROM

Each DS2433 contains a unique ROM sequence that is 64 bits long. The first eight bits are a 1-Wire family code, and the next 48 bits are a unique serial number. The last eight bits are a Cyclic Redundancy Check (CRC) of the first 56 bits. The 1-Wire CRC is generated using a polynomial generator consisting of a shift register and exclusive OR gates, modeled by the polynomial $x^8+x^5+x^4+1$. The shift register bits are initialized to zero. Then, starting with the least significant bit of the family code, one bit at a time is shifted in. After the 8^{th} bit of the family code has been entered, then the serial number is entered. After the 48^{th} bit of the serial number has been entered, the shift register contains the 8-bit CRC value. This CRC value is verified by an independent C++ calculation before writing to the EEPROM (Application Note 27 – Understanding and Using Cyclic Redundancy Checks).

8.4.2 EEPROM Memory Map

The EEPROM contains a 32-byte page called the scratchpad and sixteen additional 32-byte pages called memory. The DS2433 contains pages 0 through 15, which compose the 4096-bit EEPROM memory. The scratchpad is an additional page that acts as a buffer when writing to memory. For this application, only pages 0-6 store data.

8.4.3 Universal Data Packet

The Universal Data Packet (UDP) is a structure used to store data on the EEPROM. It includes 1-2 bytes representing the string length of the data it contains, followed by the data string, and then two inverted CRC bytes. This CRC value is 16 bits, rather than 8, and it is generated according to the standardized polynomial function

$x^{16}+x^{15}+x^2+1$. In contrast to the 8-bit CRC, the 16-bit CRC is always returned or sent in inverted form.

UDPs always start on page boundaries but can end anywhere. The first 1-2 bytes representing string length contain the number of data bytes excluding the length byte(s) and the CRC16 bytes. There is only one length byte when the number of data bytes is less than 255 (always the case in this application). If there are 255 or more data bytes, then the first length byte is 255 and the next length byte is 0 to 253. The first and second length bytes added together provide the total number of data bytes. The CRC16 is first initialized to the starting page number in order to verify that the correct page is being read. The CRC16 is then calculated over the length and data bytes. It is then inverted and stored low byte first followed by the high byte (DS2433 4k-Bit 1-Wire™ EEPROM Data Sheet).

8.4.4 Location of data in the EEPROM

** Specific encryption data has been omitted to protect confidentiality agreement with CTI. **	
Page 0	
Byte 0	Length of Identification String (including null character) = 21
Bytes 1-20	Identification String = CTI PET Systems Inc.
Byte 21	Null Character = 0
Bytes 22-23	16-bit CRC Value = 6, 64
Bytes 24-31	Empty
Page 1	
Byte 0	Length of Serial Number String (including null character) = x
Bytes 1 - (x-1)	Serial Number String
Byte x	Null Character = 0
Bytes (x+1) - (x+2)	16-bit CRC Value
Bytes (x+3) - 31	Empty
Page 2	
Byte 0	Length of First Encrypted Source String (including null character)
Bytes 1-8	Encrypted Data Set #1
Byte 9	Encrypted Character Divider
Bytes 10-14	Encrypted Data Set #2
Byte 15	Encrypted Character Divider
Bytes 16-20	Encrypted Data Set #3
Byte 21	Encrypted Character Divider
Bytes 22-26	Encrypted Data Set #4
Byte 27	Null Character = 0
Bytes 28-29	16-bit CRC Value
Bytes 30-31	Empty

Page 3	
Byte 0	Length of Second Encrypted Source String (including null character)
Bytes 1-5	Encrypted Data Set #5
Byte 6	Encrypted Character Divider
Bytes 7-11	Encrypted Data Set #6
Byte 12	Encrypted Character Divider
Bytes 13-17	Encrypted Data Set #7
Byte 18	Encrypted Character Divider
Bytes 19-23	Encrypted Data Set #8
Byte 24	Null Character = 0
Bytes 25-26	16-bit CRC Value
Bytes 27-31	Empty
Page 4	
Byte 0	Length of Third Encrypted Source String (including null character)
Bytes 1-5	Encrypted Data Set #9
Byte 6	Encrypted Character Divider
Bytes 7-11	Encrypted Data Set #10
Byte 12	Encrypted Character Divider
Bytes 13-17	Encrypted Data Set #11
Byte 18	Encrypted Character Divider
Bytes 19-21	Encrypted Data Set #12
Byte 22	Encrypted Character Divider
Bytes 23-26	Encrypted Data Set #13
Byte 27	Null Character = 0
Bytes 28-29	16-bit CRC Value
Bytes 30-31	Empty
Page 5	
Byte 0	Length of Combination Isotope String (including null character) = 21
Bytes 1-5	Isotope (stored as 5 bytes; empty bytes appear as space char.)
Byte 6	Space Character
Bytes 7-16	Isotope Source (stored as 10 bytes; empty bytes appear as space char.)
Byte 17	Space Character
Bytes 18-20	Manufacturer (stored as 3 bytes; empty bytes appear as space char.)
Byte 21	Null Character = 0
Bytes 22-23	16-bit CRC Value
Bytes 24-31	Empty
Page 6	
Byte 0	Length of Entire Encrypted Name String (including null character) = x
Bytes 1 - y	Encrypted Data Set #14 (length = y)
Byte (y+1)	Encrypted Character Divider
Bytes (y+2) - (x-1)	Encrypted Data Set #15
Byte x	Null Character = 0
Bytes (x+1) - (x+2)	16-bit CRC Value
Bytes (x+3) – 31	Empty

8.5 Version Control & Validation

8.5.1 Version Control

Version control of this software is handled by PVCS version control software by Merant. The PVCS currently in use is version 6.7. The first working version of the software was stored using PVCS. Any modifications will be shown in the description of the new PVCS version.

8.5.2 Validation

The Smart Source EEPROM will be connected to a host processor such that correct read and write operations may be verified by someone other than the responsible engineer. Any problems encountered will be fixed before release.

8.6 Schedule

TASK	Duration (days)
Develop the Windows programming software	***22***
Find/Design an Encryption/ Decryption Algorithm	5
Create GUI Framework	2
Add Programming functionality	10
Test/ Debug	5

9 Conclusion & Recommendations

My greatest learning experience and most significant contribution to CTI's P39 Project was the Smart Source Testware development. This task required me to write programs in Microsoft Visual C++, a language I had never used prior to this project. I also learned to read and write EEPROMs for the first time.

My C++ programming efforts enabled CTI technicians to enter source data into a dialog interface (shown in Figure 8.2). The technician then clicks the "Complete" button, and the program proceeds to check for errors in the submitted data, improper connections between the PC and EEPROM, and failures of the EEPROM itself. If problems do arise prior to or during writing, specific error messages appear to help the user correct the problem. When no errors are present, the program encrypts the source and technician identification data, and then writes the data to the EEPROM along with other necessary information. This information is then decrypted and verified before completion. The technician is notified when writing is complete and successful.

The Smart Source Testware can be used for other applications in CTI PET scanners as well. My code is well documented and can easily be modified for use in new assignments with similar requirements. Currently, the encryption/decryption portion of the code is of particular relevance and value to other CTI products.

My experiences with CTI were exciting and beneficial to my education in nuclear engineering. Furthermore, the CTI employees were friendly and willing to share their expertise. I gained practical knowledge during this internship that far surpassed any of my experiences during previous jobs or university courses. I would definitely recommend that future engineering students take advantage of an opportunity to work with CTI and its innovative PET technology.

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