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The PCI compatible junction temperature monitor

Adrian L. Marshall

The PCI Compatible Junction Temperature Monitor

A THESIS

Presented to the

Honors College at Southern University
Baton Rouge, Louisiana

In Partial Fulfillment of the Requirements for the
Electrical Engineering Degree

By

Adrian L. Marshall

May 2002

Honors College

Southern University
Baton Rouge, Louisiana

CERTIFICATE OF APPROVAL

HONORS THESIS

This is to certify that the Honors Thesis of Adrian L. Marshall has been approved by the examining committee for the thesis requirement for the Honors College degree in Electrical Engineering

Advisor

Chairman, Honors Advisory Committee

Dean, Honors College

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ABSTRACT

The purpose of this research project is to give a precise temperature reading of various semiconductor devices. An accurate junction temperature measurement could allow you to eliminate heat sinks and fans if they are not needed or it could prevent your system from going down on a hot day. Nearly all integrated circuits contain input protection diodes to protect against static electricity. These diodes can be used to make the measurement process simple. The only procedure that is required is to disconnect one wire leading to the device to be tested. The junction temperature monitor is then connected to the two ends of the disconnected wire and ground. The voltage change across the diode is measured and related to a mathematical temperature equation. The Junction temperature monitor does not affect the operation of the device.

AUTHOR'S ACKNOWLEGEMENTS

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Thanks goes to Southern University and A&M College for providing the educational background to undertake this project. Sincere appreciation goes to the faculty and staff of the Honor's College that gave so much guidance in completing this thesis. Special thanks to Dr. Charles Singleton (Advisor), Dr. E. Shaban, Dr. J. Luo, and the entire Electrical Engineering department for any assistance provided in the completion of this project.

Sincere appreciation goes to Raytheon Inc. for introducing a real-world problem that needed to be resolved, providing all the equipment, and believing in the students to complete this project. The author would especially like to thank Mr. Veikko Kanto (Raytheon Advisor) for all the ideas, assistance, and patience that were all vital in a successful project.

Much love goes to Larry Wright, Patrick Candler, Patrick Carpenter, Mark Lazard, Spencer Pace, and any student that spent countless nights studying until the wee hours of the morning, provided encouraging words, or telling good jokes. The author would like to thank all his peers in the Department of Electrical Engineering, Southern University, and Tallulah for their Support.

Last but certainly not least, the author would like to grant the sincerest of thanks to his mother, Ms. Dorothy Marshall, for all her love, encouragement, and prayers. To my brother, Marquette Marshall, thanks for the guidance and support. To my brother

Darryl, much love for always having my back. To everyone everywhere that encouraged, assisted, or prayed for me during the good times and bad times, I am who I am today because of each of you.

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CHAPTER I
BACKGROUND OF STUDY

Introduction

Semiconductor p-n (positive-negative) junctions offer many useful properties which are excellent for determining the temperature of that device. These properties form the basis for the electrical method of junction temperature measurement and are used for measurement of junction temperatures within semiconductor devices. They offer the unique capability to measure temperatures deep inside solid-state devices, without direct mechanical or optical contact. Methods based on these properties can be applied to virtually all semiconductor device types. In addition, the limiting measurement bandwidth is high enough to capture all but the fastest thermal device-transients. For these reasons, electrical measurement of semiconductor junction temperatures offers many advantages over other measurement techniques.

Statement of the Problem

The purpose of this research project is to give a precise temperature reading of various semiconductor devices. An accurate junction temperature measurement could allow you to eliminate heat sinks and fans if they are not needed or it could prevent your system from going down on a hot day. Nearly all integrated circuits contain input protection diodes to protect against static electricity. These diodes can be used to make the measurement process simple. The only procedure that is required is to disconnect one wire leading to the device to be tested. The junction temperature monitor is then connected to the two ends of the disconnected wire and ground. The voltage change across the diode is measured and related to a mathematical temperature equation. The Junction temperature monitor does not affect the operation of the device.

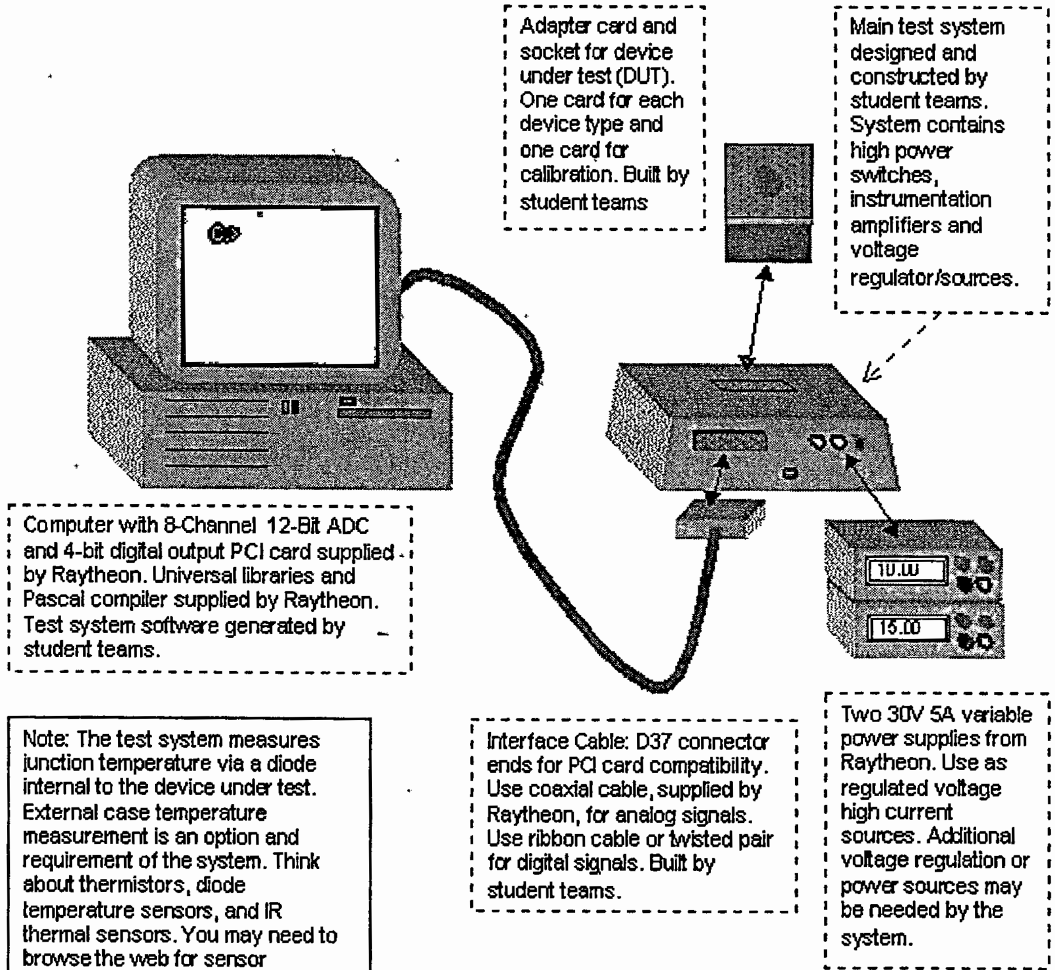
Hypothesis

Veikko Kanto, the advisor for this project, already has a similar project to this one. His project includes an analog-to-digital converter within the test box, and it is limited to testing the diode and NPN and PNP transistors. However, the setup for this research differs in that the analog-to-digital conversion will be taken care of inside the PCI card and additional semiconductors such as the power mosfet, Darlington transistor, and integrated circuit will be able to be tested. Therefore, modifications will need to be made to the software.

For this project, temperatures will be read across diodes within the semiconductor devices that will be tested. The diode is any p-n junction in the device under test (DUT). If it is a diode, then the diode will act as the temperature sensor. If it is a bipolar transistor, then the base to emitter or base to collector diodes will serve as the temperature sensor. In integrated circuits (ICs), the temperature sensor might be a body diode, input protection diode, or an isolation diode in the output stage. A large amount of power heats up the device, and is quickly cut off as the measurement diode is forward biased. The temperature measurement diode is biased with a low current and the measurement is performed rapidly to prevent cooling of the device die. There is a relationship that is close to 2mV per degrees Celsius drop in forward voltage. The change is dependent on the doping concentrations and the type of junction diffusion. Most diodes are graded in the diffusion. Hence, the voltage-temperature relationship is device dependent.

For accurate temperature measurements, the test diode junction must be measured at room temperature then heated to a known temperature and measured again. The measurement at both temperatures is performed with the same forward test current that is in the milliamp range so that the test is accurate. A 2-point measurement and calibration is adequate for this project to maintain accuracy. The test system does not have to provide a heat source but an external case measurement sensor can be used to obtain the calibrated device temperature. In this case, the diode in the device under test does not dissipate much power and the junction is at the same temperature as the case. [4]

This problem will be solved by a test system broken into four parts. The first part is the test card. Different circuits will be set up on various edge-card sockets. The circuit is totally dependent upon the semiconductor device and the location of the diode within the device. The second section of our project is the test box. The edge-card connects to this box. The test system is solely responsible for amplifying analog signals from the test card, reducing noise, and producing the test currents that will drive the semiconductor device. The final part of the test system is the PC, or personal computer. Software will be installed and programmed so that the computer receives information from the test box through the PCI card, analyzes it, and displays usable information regarding the temperature of the device. A block diagram of the test system is given below in Figure 1.



Note: The test system measures junction temperature via a diode internal to the device under test. External case temperature measurement is an option and requirement of the system. Think about thermistors, diode temperature sensors, and IR thermal sensors. You may need to browse the web for sensor candidates.

Figure 1.

Definitions/Key Terms/Abbreviations

1. **Sensitive:** TSP (Temperature Sensitive Parameters) sensitivity should be "sufficiently high". This sensitivity is expressed in terms of the ratio of voltage change to temperature change and is the TSP temperature-derivative. High sensitivity improves the electrical signal-to-noise ratio and thus the temperature measurement accuracy. Insufficient sensitivity yields excessively noisy data.

2. **Non-Invasive**: There should be minimal parasitic electrical heating of the semiconductor associated with the measurement technique. This situation eliminates the need to compensate for self-heating artifacts. Ideally, the temperature to be measured is not influenced by the measurement method.

3. **Uniform**: There should be sufficient uniformity in the TSP relationship within a production lot of "identical" devices to avoid the need to perform a complete device calibration for every individual device tested.

4. **Linear**: The TSP should ideally be a linear or nearly linear function of temperature versus voltage. More non-linear TSPs are usually less accurate and more difficult to use.

5. **DUT**: Device Under Test

6. **PCI**: Peripheral Controller Interface

7. V_{BE}: Voltage across the base and emitter junction.

8. V_{CE}: Voltage across the collector and emitter junction.

General Hardware Parameters/ Constraints:

- Analog to digital conversion and readout: < 50us per channel
- Temperature sensor diode voltage measurement resolution: 1mV
- Device voltage measurement resolution: 10mV or better
- Device current measurement resolution: 10mA or better
- Current voltage switching time on/off 50us maximum
- Switched voltage source: Linear adjustable 0 to 15V up to 1.5 amps
- Switched current source for diode testing: 0.1A, 0.2A, 0.5A, 1A, 2A
- Bipolar transistor switching configuration: NPN or PNP 0.1W, 1W, 10W
- Power MOSFET switching configuration: N-channel or P-channel 0.1W, 1W, 10W

General Software Restraints:

- Device power, die temperature and external temperature acquisition intervals: 500us, 1ms, 2ms, 5ms, 10ms, 20ms, 50ms
- Data point storage : 1 to 32768 per channel
- Software Coding *: Microsoft Visual Basic 6.0 or Delphi ver 6
- Temperature calibration of diode sensors
- Plotting of device power, device temperature, case temperature and thermal resistance Vs time

- Plot cursors for extracting point data
- Export of test data to text file
- Import of text data for plotting

Possible Hardware Configurations:

Option 1:

- PC Workstation
- Printer port digital I/O control
- External AtoD conversion with dumb hardware

Option 2:

- PC Workstation
- Internal PCI bus AtoD digital I/O card

Option 3:

- PC Workstation
- Serial or parallel port communication
- Intelligent micro-controller for control of timing, reading AtoD, and communication

CHAPTER II
REVIEW OF LITERATURE

The fist reference used for this research was entitled "Thermal Diode." [3] This information was retrieved from the website http://support.intel.com. This site mostly tells about the Intel processors. However, its use to this project is its temperature-voltage relationship equations. This site also gives us critical specifications of semiconductor devices so that mishaps can be held to a minimum.

The second reference used was a package put together by Veikko Kanto of Raytheon.[4] This handout is the basis of the Junction Temperature Monitor project. This references basically describes a similar prototype constructed by Mr. Kanto. The prototype includes the test card, test box, and computer software. In addition, this material contains important hardware and software parameters that must be adhered to. There are also many descriptive block diagrams and ideas that we might be able to use for our project.

The next reference used was "Electrical Temperature Measurement Using Semiconductors". [6] The author of this publication is Dr. John W. Sofia of the Massachusetts Institute of Technology. This information gives insight on the junction temperature and voltage relation ship. It also gives informative data on temperature-sensitive parameters and their characteristics. Most importantly, it provides information about device calibration, which is useful in getting the most accurate temperature and voltage reading each and every time.

Another reference I used was "Electronic Design: From Concept To Reality". [9] This textbook is co-authored by Martin S. Roden and Gordon L. Carpenter. This book is used primarily to understand the theory behind the various semiconductor devices to be tested. It gives the physical make-up of each component, uses for the component, and theoretical equations that help determine voltages and currents at certain levels in the circuit. Furthermore, this book helps design circuits to fit the specific need of this project.

Another article used was "Power Mosfet Basics" by Vrej Barkhodarian.[8] This article was chosen to get detailed information on the power mosfet, which was one of the semiconductor devices to be tested that is not extensively covered in the electronic design book. This publication gives a background on the device including the physical make-up of the component. It gives the current/voltage characteristic curve and schematics for the device. In addition, this article covers the breakdown voltage, threshold voltage, and power dissipation. There are many graphs and figures included in this publication that help explain some of the concepts.

"Electronic Circuits Digital and Analog" was another reference used.[10] This book is by Charles A. Holt. This reference, much like "Electronic Design: From Concept To Reality", is used mostly to understand the theory behind the various semiconductor devices. It gives design specifications for different operational amplifiers and switches. Moreover, this book elaborates on the make-up, uses, and related equations for each device. There is also detailed information on temperature measurement and useful thermal equations.

CHAPTER III
METHODS AND MATERIALS

Materials

Instrumentation Amplifier (LF356): The instrumentation amplifier is the part of the test box that receives the signal from the DUT card. The LF356 then amplifies the signal precisely while rejecting large values of noise. This is needed because the signals received from the DUT are on the mV scale, and amplification is needed to make a good reading. Elimination of noise is always a plus.

Power MOSFET (metal oxide semiconductor field effect transistor): The Power MOSFET is one of the devices that we will be testing. It differs from other MOSFETs in that it can switch at least 1A of current. It also has higher breakdown voltages than regular MOSFETs. A large base drive current as high as one-fifth of the collector current is required to keep the device in the ON state.[8].

The logic gates are used as switches within the circuit and switch on or off depending on the test. Voltage regulators keep voltage levels between a set minimum and maximum value. [9] Also included in the test box are the load resistors. The purpose of these resistors is to provide various currents used to power different DUTs.

PCI bus A-to-D (analog to digital) I/O (input/output) card: Although the PCI card is not designed by the team, it is very critical to the project. This card is connected to the test box through a coaxial cable that is attached to a D37 connector. This is simply a connector with 37 pins used for compatibility with the PCI card. The main purpose of this card is to change the analog signal that is received from the test box into a digital signal so that the computer may interpret it. The PCI card also supplies a voltage of 12 V to drive the logic gates. The PCI card is connected to the PC.

Personal computer: The PC is responsible for analyzing the digital signals, maintaining the software, and running the tests. Once the digital signal is received from the PCI card is must be read and interpreted by the PC. This is mostly taken care of by the Delphi 6 software that is used. This software must be programmed to make the appropriate readings of voltage and temperature and successfully display usable information on the computer monitor.

Darlington Transistor: The Darlington transistor is the second device that will be tested in this project. This transistor is composed of two cascaded transistors. It has high imput impedance and high current gain. However, the second transistor in the Darlington pair amplifies the leakage current of the first transistor.

Integrated Circuit (IC): The integrated circuit is the device that will be tested for thermal characteristics. ICs are just devices that contain an internal circuitry of resistors, capacitors, op-amps, logic gates and more. For the extent of this project, operational amplifiers will be the only integrated circuits tested.

Voltage Regulators (LM317): Voltage Regulators set a maximum and minimum voltage and a specific Voltage output. For this project, the voltage regulator will output 9.5 volts. This 9.5 volts is connected to the DUT card which essentially drives the device under test.

Load Resistors: The load resistors only serve to vary the current to the DUT. Various semiconductor devices require different currents to drive them. They are set up with a switch so that the current will vary according to the setting of the switch.

Methods

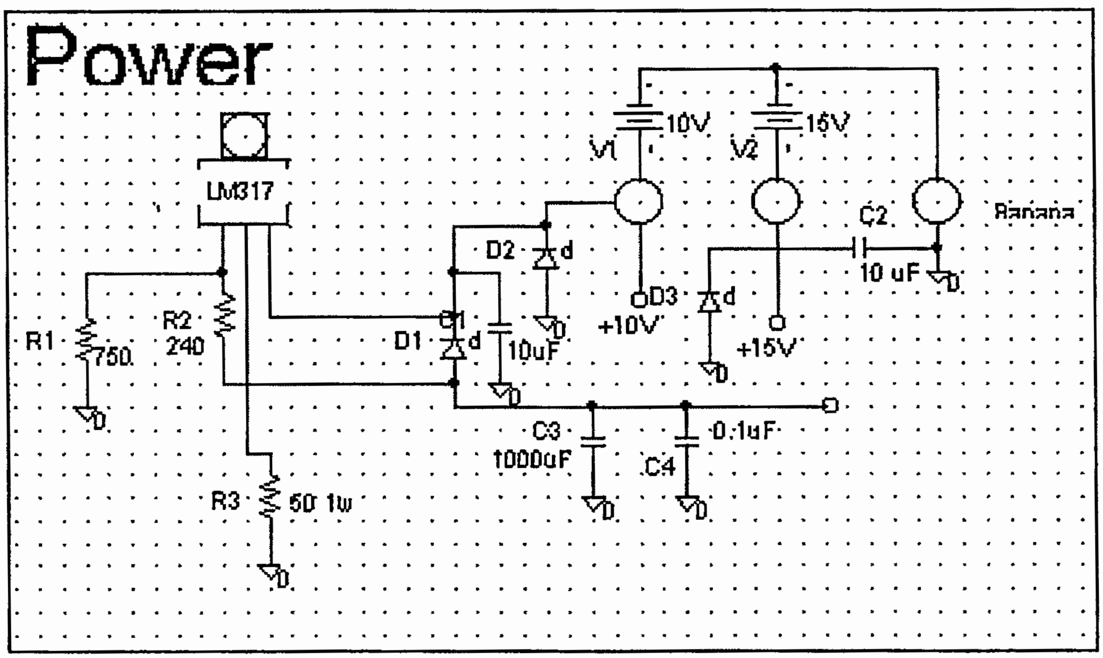
Delphi 6 installation: This project was set up in a series of stages. The first task accomplished was the installation of the Delphi 6 software onto the hard-drive of the computer. Delphi 6 is a visual programming environment for rapid application development. With this software highly efficient applications for various Windows operating systems can be created with a minimum of manual coding.[1] Delphi supplies all the tools needed to develop, test, debug, and deploy applications with the aid of a large library of reusable components. These tools simplify prototyping and reduce development time.

PCI card installation: The next item handled was the installation of the PCI DAS08 card. This card had to be manually installed by opening the central processing unit (CPU) and connecting the PCI card to the motherboard. Software also had to be installed to so that the PCI card can interface with the computer terminal. Furthermore, there were additional universal libraries installed in order to make the PCI card user-friendly. It also aids in the process of writing programs for data acquisition.

Test box construction: After installing the PCI card, the initial setup of the test box was started. The test box is very similar to the prototype built by Mr. Kanto. However, there will be no analog-to-digital converter inside the box. The primary function of the test box is to serve as a liaison between the test card and the PCI card. This box sends voltages to drive the test card and receives analog signals from the test card. It then prepares the analog signals to be sent to the PCI card. The test box contains instrumentation amplifiers, logic gates, voltage regulators, and other devices. The instrumentation amplifiers are basically used to amplify the analog signals and reduce noise at the same time.

The test box was broken into steps in order to place various parts of the circuit on different breadboards so that the circuit would be easier to troubleshoot if any problems arose. The first step was the power setup. This part of the design supplies power to the various components within the test circuit. In this stage, two DC regulated power supplies were set up to supply voltages of +10V and +15V and a current of up to 5 amps. This part of the circuit also contains a voltage regulator (LM317T), which supplies a voltage of +5V. The schematic is shown below.

Figure 2.



In the second step of the test box was the instrumentation amplifier stage. Instrumentation amplifiers (LF356) are used for precision amplification of differential dc or ac signals while rejection. large values of common mode noise. They are also used to eliminate floating points by acting as a differential amplifiers and removing common mode signals. Voltage gains are found by calculating the ratio of the feedback resistance divided by the output resistance. There are +/- 12V connected to all supplied to all the amplifiers.[4] Capacitors are also placed near the component to cancel inductance in the power feed lines. Capacitors also eliminate voltage drops for transients.

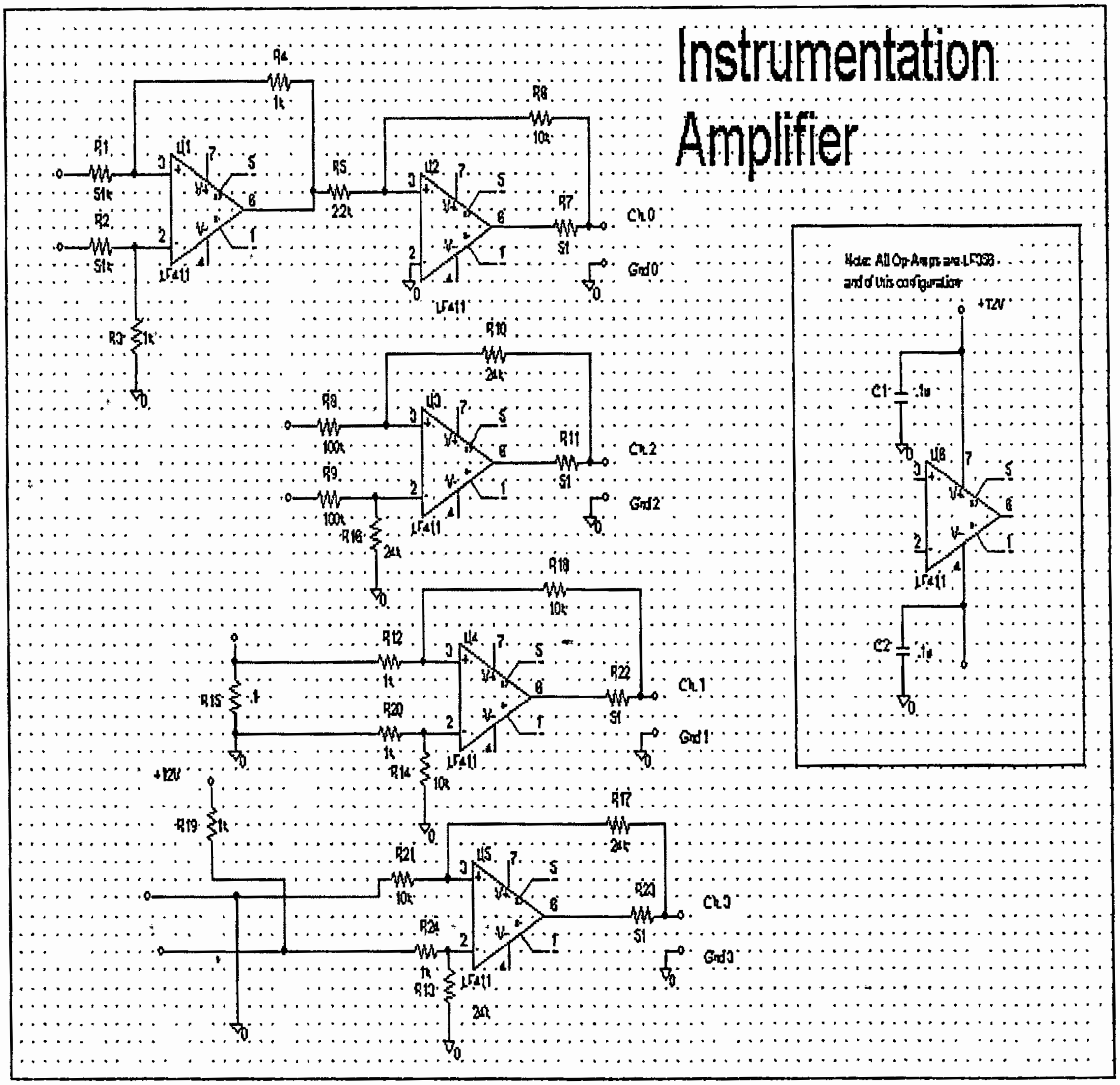
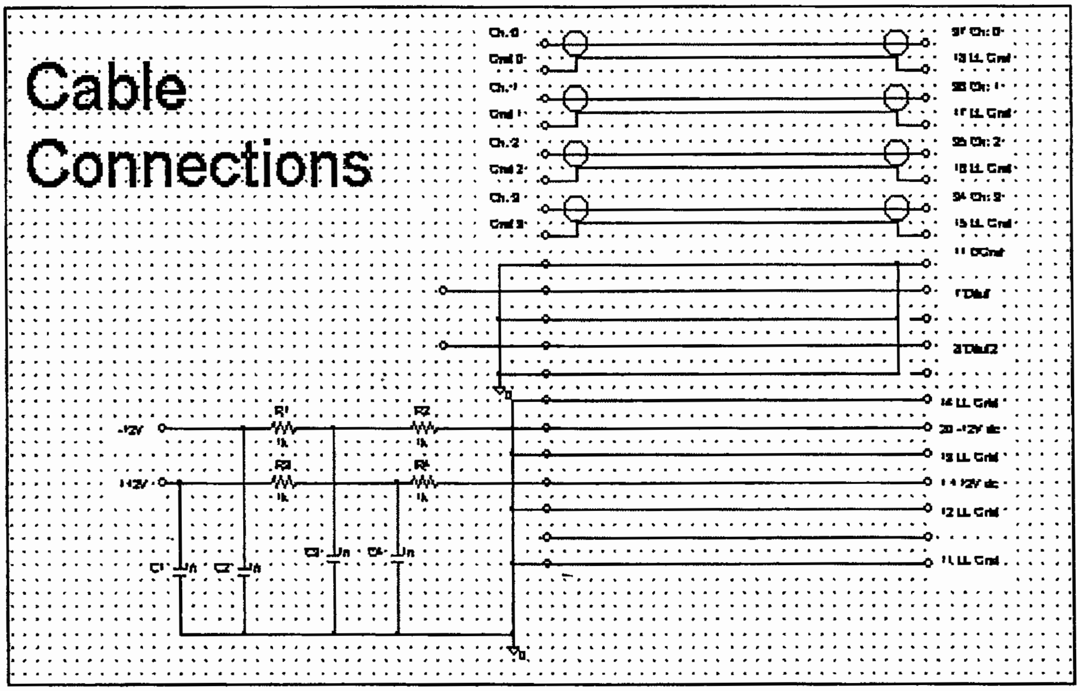

Instrumentation Amplifier
Note: All Op-Amps are LF358 and of this configuration
+12V
C1 .1u
C2 .1u
U1
U2
U3
U4
U5
U8
LF411
R1 51k
R2 51k
R3 1k
R4 1k
R5 22k
R7 51
R8 10k
R9 100k
R10 24k
R11 51
R12 1k
R13 24k
R14 10k
R15 .1
R16 24k
R17 24k
R18 10k
R19 1k
R20 1k
R21 10k
R22 51
R23 51
R24 1k
Ch.0
Gnd0
Ch.1
Gnd1
Ch.2
Gnd2
Ch.3
Gnd3
+12V

Figure 3.

The next step is the Voltage switch stage. This stage is control of the forward bias place on each diode during the testing. Since the DUT will only be measured for a short period of time (50 milliseconds), the diode need to be forward biased and switched to ground very quickly. The switch is first closed to allow a current to pass through the diode. The switch then opens, which breaks the circuit and cuts off all current through the DUT.

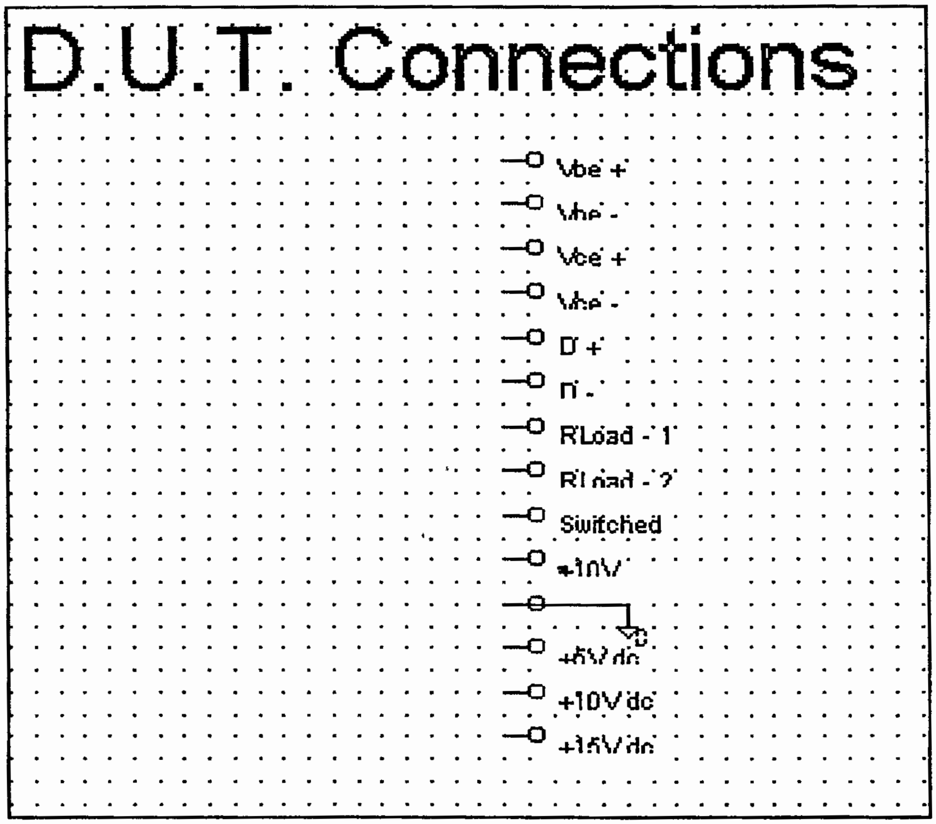
Cable Connections: The fourth step is the cable connection stage. In this stage we used coaxial cables to connect the analog inputs to the test set. The outer wires of the cables were connected to ground. The coaxial cables were used to connect four channels. The digital outputs from the test set are connected through twisted pair cable. This gives a better impedance match. For the ribbon cables, alternate signal and ground lines were ran to isolate digital signals. 220pF capacitors are used in series with 100-ohm resistors to cut down on cable capacitance. The cables used were 3 ft. long to further decrease cable capacitance. [4] The cables are connected to the PCI card as shown below.

Figure 4.



Device Under Test Design: The last stage of the project was the DUT stage. In this stage, three test cards were designed to take measurements from the Darlington transistor, power MOSFET, and integrated circuit. The basic concepts are common for all the test circuits. The voltage must be read across the base-emitter (or gate-source) junction so, V_{be} sense pins are connected at the base and emitter or the anode and cathode ends of practical diodes within the circuit. The same concept applies for the collector-emitter junction. For the integrated circuit, the forward current must be kept less than .5 amps to prevent device damage. In the Darlington transistor, the only practical diode to use is the base to collector diode. Finally, in the power MOSFET, the body diode is used for temperature sensing.[9] The pins for the test card are set up as follows:

Figure 5.


D.U.T. Connections
Vbe +
Vbe -
Vce +
Vbe -
D +
D -
RLoad - 1
RLoad - 2
Switched
+10V
+5V dc
+10V dc
+15V dc

A test card must be designed for each semiconductor device to be measured. The test card is an edge card/socket configuration with gold plated fingers on the edge of the card. In each test, we are measuring the p-n junction, which is located in different locations of the various devices. A forward biased voltage is applied to each device and quickly shut off. The test card must be designed so that this voltage is applied to the appropriate pin and readings are taken at the correct locations. For the transistors, the V_{be} + and V_{be} – pins are connected to each end of the base-emitter or gate-source diode. Each load resistor is connected to a switched ground so that the diode is forward biased and quickly shut off. The base to each diode is connected to a voltage source in order to drive the junction. The card will connect to the test box. The design of the Darlington transistor, Power MOSFET, and Integrated Circuit test cards, are shown below:

Figure 6.

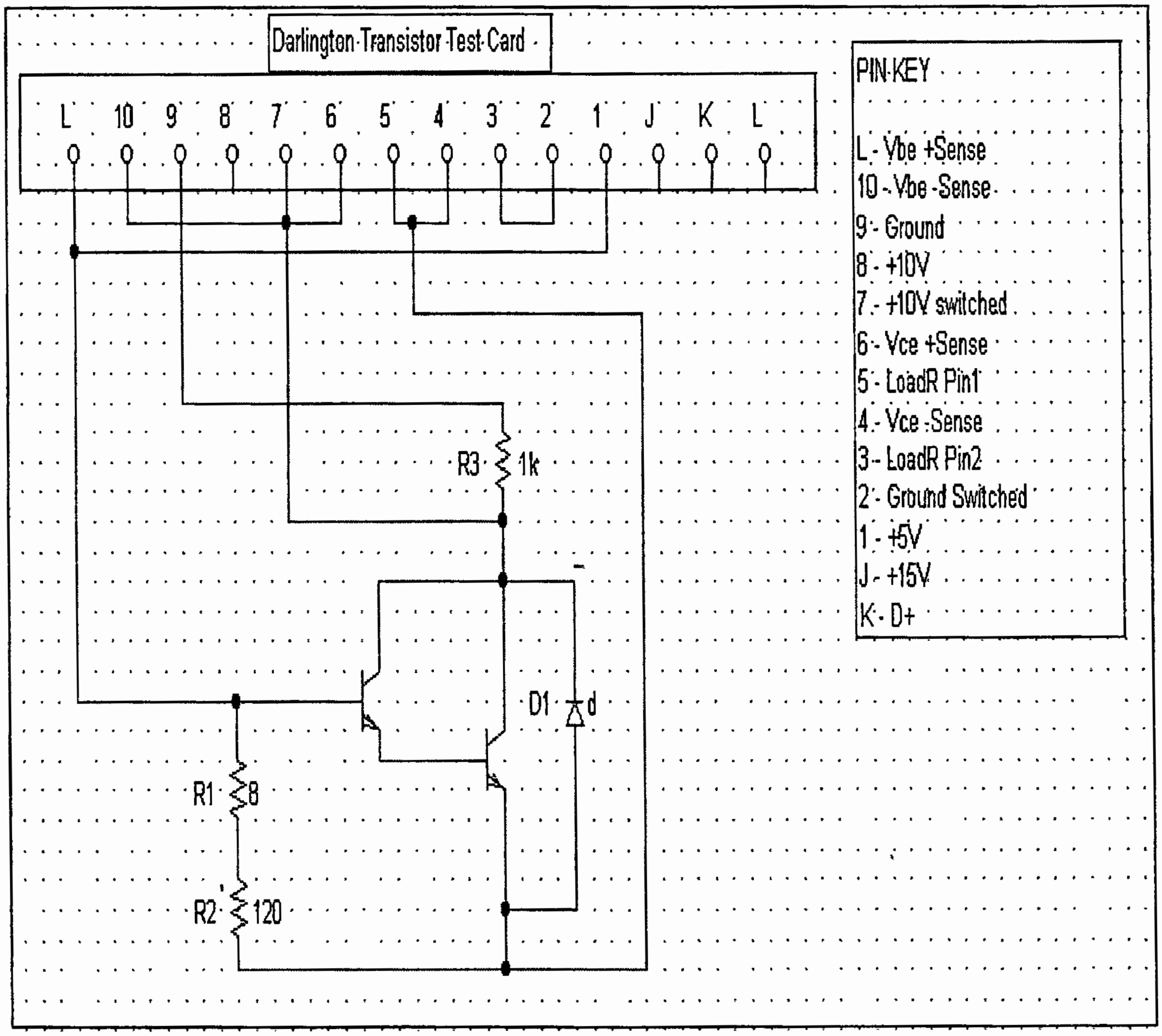

Darlington Transistor Test Card
L 10 9 8 7 6 5 4 3 2 1 J K L
PIN KEY
L - Vbe +Sense
10 - Vbe -Sense
9 - Ground
8 - +10V
7 - +10V switched
6 - Vce +Sense
5 - LoadR Pin1
4 - Vce -Sense
3 - LoadR Pin2
2 - Ground Switched
1 - +5V
J - +15V
K - D+
R3 1k
D1 d
R1 8
R2 120

Figure 7.

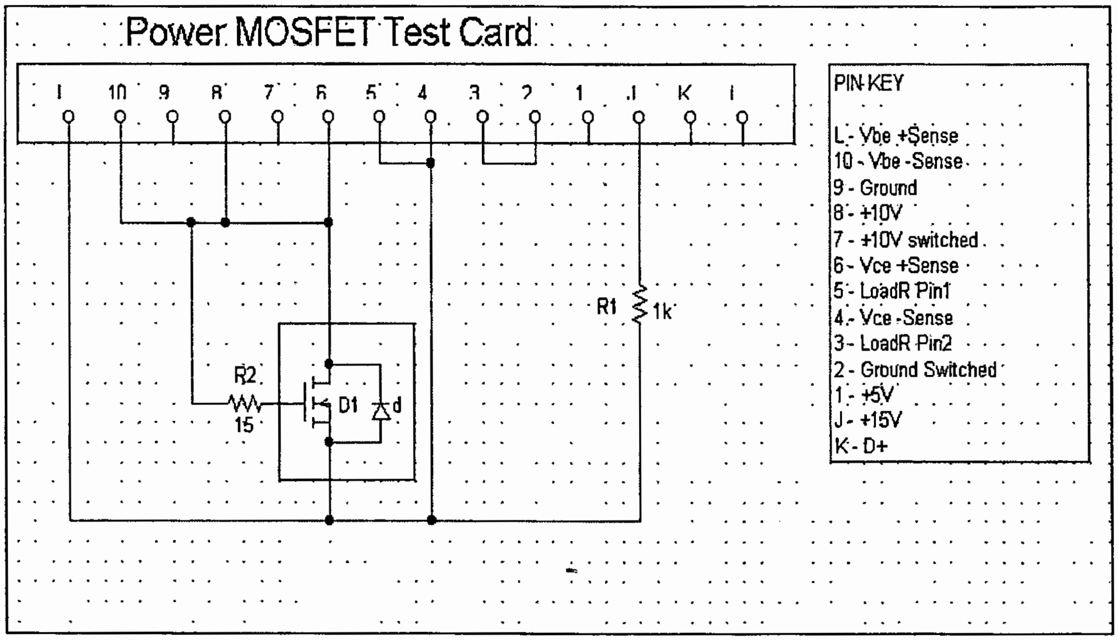
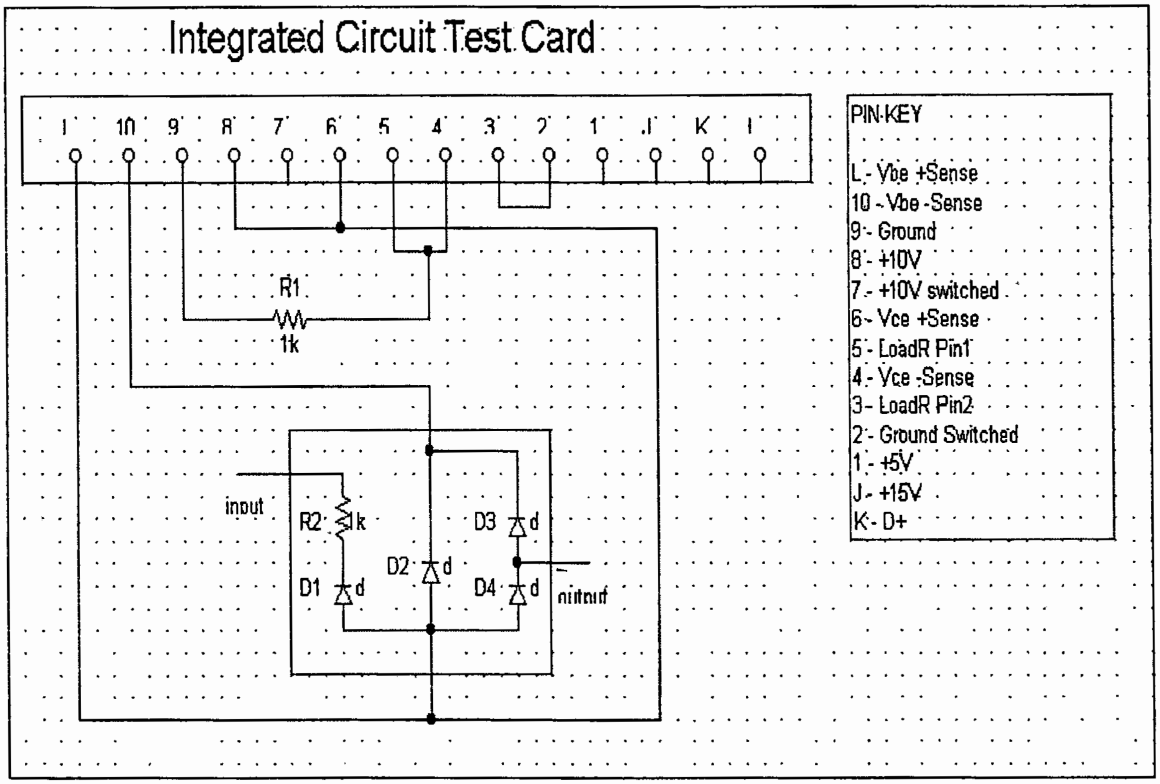

Power MOSFET Test Card
L 10 9 8 7 6 5 4 3 2 1 J K I
R1 1k
R2 15
D1
d
PIN KEY
L - Vbe +Sense
10 - Vbe -Sense
9 - Ground
8 - +10V
7 - +10V switched
6 - Vce +Sense
5 - LoadR Pin1
4 - Vce -Sense
3 - LoadR Pin2
2 - Ground Switched
1 - +5V
J - +15V
K - D+

Figure 8.


Integrated Circuit Test Card
L
10
9
8
7
6
5
4
3
2
1
J
K
L
R1
1k
input
R2
1k
D3
d
D2
d
D1
d
D4
d
output
PIN KEY
L - Vbe +Sense
10 - Vbe -Sense
9 - Ground
8 - +10V
7 - +10V switched
6 - Vce +Sense
5 - LoadR Pin1
4 - Vce -Sense
3 - LoadR Pin2
2 - Ground Switched
1 - +5V
J - +15V
K - D+

CHAPTER IV

RESULTS AND CALCULATIONS

Instrumentation Amplifier Gains:

Voltage gain = A_v =

A_{V1} = 27k/51k = 0.529

A_{V2} = 10k/2.2k = 4.545

A_{V3} = 24k/100k = 0.24

A_{V4} = 10k/1k = 10

A_{V5} = 24k/10k = 2.4

Translation from Gain to Analog to Digital Units:

ADU = Voltage Range / 2^(# bits) / gain = 10V / 2^12 / gain = 2.44mV / gain

ADU1 = 2.44mV / 0.529 / 4.545 = 1.015mV / ADU

ADU2 = 2.44mV / 0.24 = 10.17mV

ADU3 = 2.44mV / 10 = .244mV / ADU

ADU4 = 2.44mV / 2.4 = 1.017mV / ADU

Load Current:

Current = Voltage / Resistance ; Voltage = 4.4 V

Load1 Current = 4.4V / 44 = .1A

Load2 Current = 4.4V / 22 = .2A

Load3 Current = 4.4V / 8.8 = .5A

Load4 Current = 4.4V / 4.4 = 1A

Load5 Current = 4.4V / 2.2 = 2A

V_{BE} Changes ≈ -2mV / °C [3]

Figure 9.

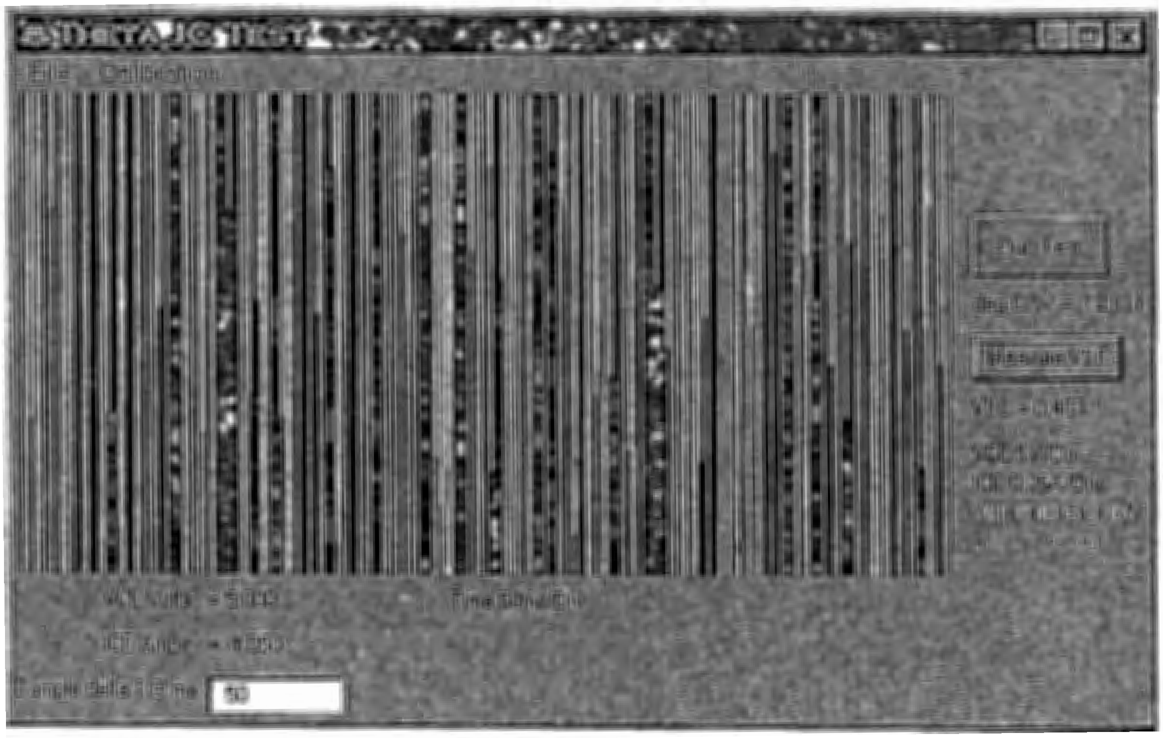
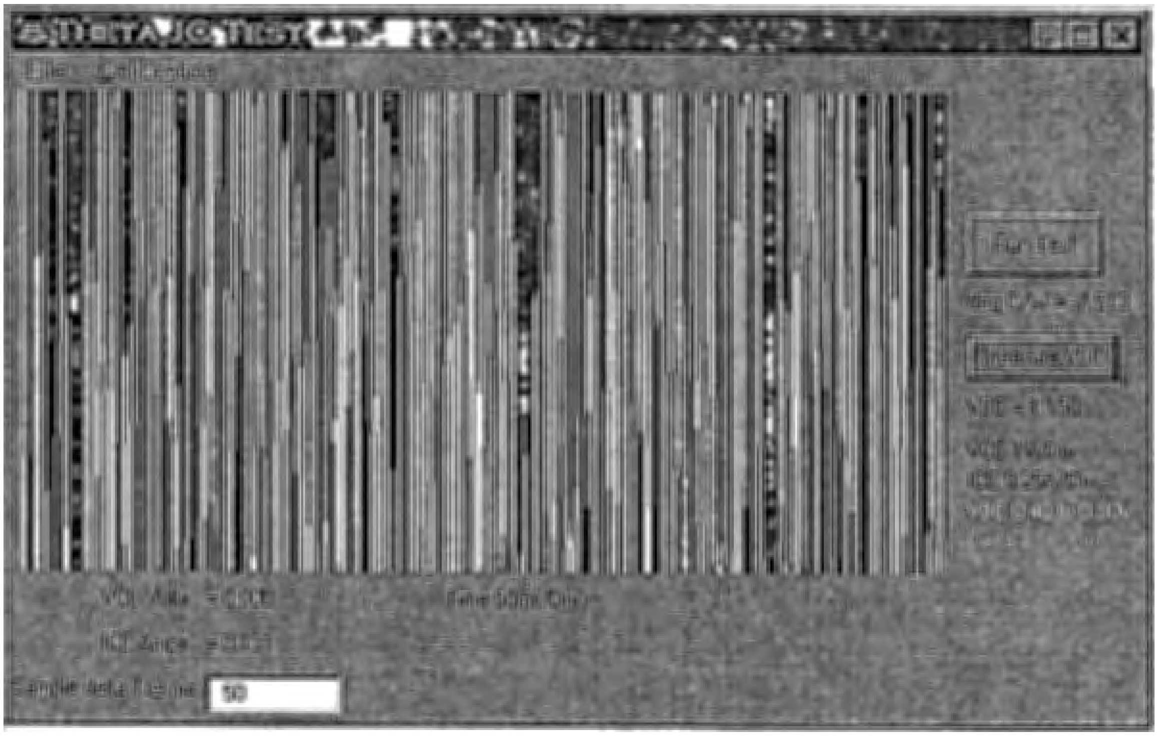


Figure 10.



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VITA

Adrian Lamar Marshall was born on the 26th of May of Nineteen-hundred and eighty in Monroe, Louisiana to the parents of Miss Dorothy Marshall and Mr. Alex Summerville. He completed high school at Reuben McCall High School in Tallulah, Louisiana in 1998. He joined Southern University's Honors College to get a degree in Electrical Engineering in August of 1998.

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