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DESIGN OF FACTORY FLOOR TESTER FOR HVAC CONTROLLER AND REMOTE MONITORING UNIT

A PROJECT REPORT

Submitted in partial fulfilment of the requirement for the award of the Degree of

MASTER OF TECHNOLOGY
in
SENSOR SYSTEMS TECHNOLOGY

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CERTIFICATE

This is to certify that the thesis titled "***Design of Factory Floor Tester For HVAC Controller and Remote Monitoring Unit***" that is being submitted by **Suresh Kumar Gadi (07MSS025)** is in partial fulfillment of the requirements for the award of MASTER OF TECHNOLOGY DEGREE, is a record of bonafide work done under my /our guidance. The contents of this thesis, in full or in parts, have neither been taken from any other source nor have been submitted to any other Institute or University for award of any degree or diploma and the same is certified.

Mr. Loganathan Joghee **External Guide** **Honeywell**	**Mrs. Elizabeth Rufus** **Internal Project Supervisor** **VIT**

The thesis is satisfactory / unsatisfactory

Internal Examiner **External Examiner**

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PROJECT COMPLETION CERTIFICATE

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ABSTRACT

In a factory, final product needs to be thoroughly inspected before delivering to customer. This is achieved by factory floor tester. Factory floor tester is responsible for automation of testing final product’s completeness, assembly exactness and correct functionality. The project deals with design of the factory floor tester. This includes the hardware design, software design, integration of software with fabricated hardware and testing the whole setup. Hardware design includes the design of electronic circuit and simulation. Software design is development of a GUI interface to the designed hardware. This includes the coding in embedded C, embedded C++ and Visual C++. The software code and other data is dumped in the fabricated unit’s memory, the unit is allowed to interface with the PC for the GUI module to take control over it. The final phase is to test and debug the software to assure the proper integration between both software and hardware setup.

The advancement of virtual instrument allows us to perform more complex testing operations. This project also deals with developing an test equipment which is responsible of testing complex functionalities like GSM communication (multi threading operations), handling multiple grounds effectively (implementing complex algorithms), connecting database and making database available for analysis (manipulating database over network).

Identifying the System transfer function gives the detail information of the system. In this project we have attempted to automate the process of identifying the transfer function of an electrical system.

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NOMENCLATURE

Ω	Ohm (unit for electrical resistance)
AHU	Air Handling Unit
’’H2O	Inches of water (unit of pressure)
A	Ampere
AI	Analog Input
AO	Analog Output
ASTM	American Society for Testing and Materials
atm	Atmospheric pressure units for pressure
AV	Analog Value
AWG	American wire gauge
BACnet	Building Automation and Control Networks
BI	Binary Input (also known and Digital Input)
BO	Binary Output (also known as Digital Output)
BTC	BACnet Testing Labratories
BV	Binary Value
CAV	Constant Air Volume
CE	Conformité Européenne
DDC	Direct digital control
DegC	Degree Centigrade
DegF	Degree Fahrenheit
DI	Digital Input (also known as Binary Input)
DMM	Digital Multi Meter
DO	Digital Output (also known as Binary Output)
FCC	Federal Communications Commission
FFT	Final Functional Tester
FRAM	Ferroelectric non-volatile Random Access memory
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communication
GTF	Graphics Toolkit Framework
HOA	Hands-Off-Automatic
HVAC	Heating, Ventilation and Air Conditioning

JTAG	Joint Test Action Group
MS/TP	master slave / token passing
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NOC	Network Operation Center
PSIA	Pounds per Square Inch (Atmospheric Pressure)
PSIG	Pounds per Square Inch (Gauge Pressure)
RH	Relative Humidity
RoHS	Restriction of Hazardous Substances Directive
RPC	Remote Programmable Controller
RS232	Recommended Standard 232
RS485	Recommended Standard 485
RMU	Remote Monitoring Unit
SCC	Signal Conditioning Circuit
SIB	Sensor Interfacing Board
SIM	Subscriber Identity Module
SPI	Serial Peripheral Interface
UI	Universal Input
UIB	User Interface Bus
UL	Underwriters Laboratories
USB	Universal Serial Bus
V	Volt
VAC	Alternating Current Voltage (RMS value, if not mentioned)
VAV	Variable Air Volume
VDC	Direct Current Voltage
WDT	Watch Dog Timer
WEEE	Waste Electrical and Electronic Equipment Directive

SI PREFIXES

Symbol	Prefix	Value
y	yocto	10^{-24}
z	zepto	10^{-21}
a	atto	10^{-18}
f	femto	10^{-15}
p	pico	10^{-12}
n	nano	10^{-9}
μ	micro	10^{-6}
m	milli	10^{-3}
c	centi	10^{-2}
d	deci	10^{-1}
da	deka	10^{1}
h	hecto	10^{2}
k	kilo	10^{3}
M	mega	10^{6}
G	giga	10^{9}
T	tera	10^{12}
P	peta	10^{15}
E	exa	10^{18}
Z	zetta	10^{21}
Y	yotta	10^{24}

1 INTRODUCTION

1.1 *Need for Factory Floor Tester (FFT):*

In an industry delivering high quality product to customer is ultimate goal. This goal is achieved continuous quality inspection. Even after the continuous monitoring of unit at the time of production, the final inspection is important to make sure the proper assembly, completeness, meeting functionality etc. In a mass production plant, it is necessary to minimize the human intervention in the process and testing for achieving high productivity with fewer defects. There is a requirement for Automatic Test Equipment (ATE) which monitors product at each stage and Final Functional Tester (FFT) at end of all tests. FFT is a fully or semi automatic test equipment, which is capable of performing tests which make sure proper assembly and functionality. This project deals with design of one such FFT for HVAC Controller and Remote Monitoring Unit.

1.2 *Introduction to HVAC Controller:*

In modern day every field is under a great demand of automation. Building automation is one such field which also requires integration of many fields of engineering. One of the major parts in a building automation system is Heating, Ventilation and Air Conditioning (HVAC). HVAC basically contains an Air Handling Units (AHU), chillers, heaters, sensors, actuators, pumps, fans etc. A Controller is required to co-ordinate all the units to work as an efficient system. As the system is very big and the units are far from each other, we have to divide the complete system into small blocks. Each block is then integrated with other blocks through electronic signals sent and received by controller. So, controllers work is not only to control the units but also to communicate with other blocks. For centralized monitoring, we have to communicate with all these blocks via a protocol which is universally accepted. The universally accepted protocol of communication is important because each block may be procured from different manufacturers. One such protocol is BACnet (Building Automation and Control Networks), which is widely used

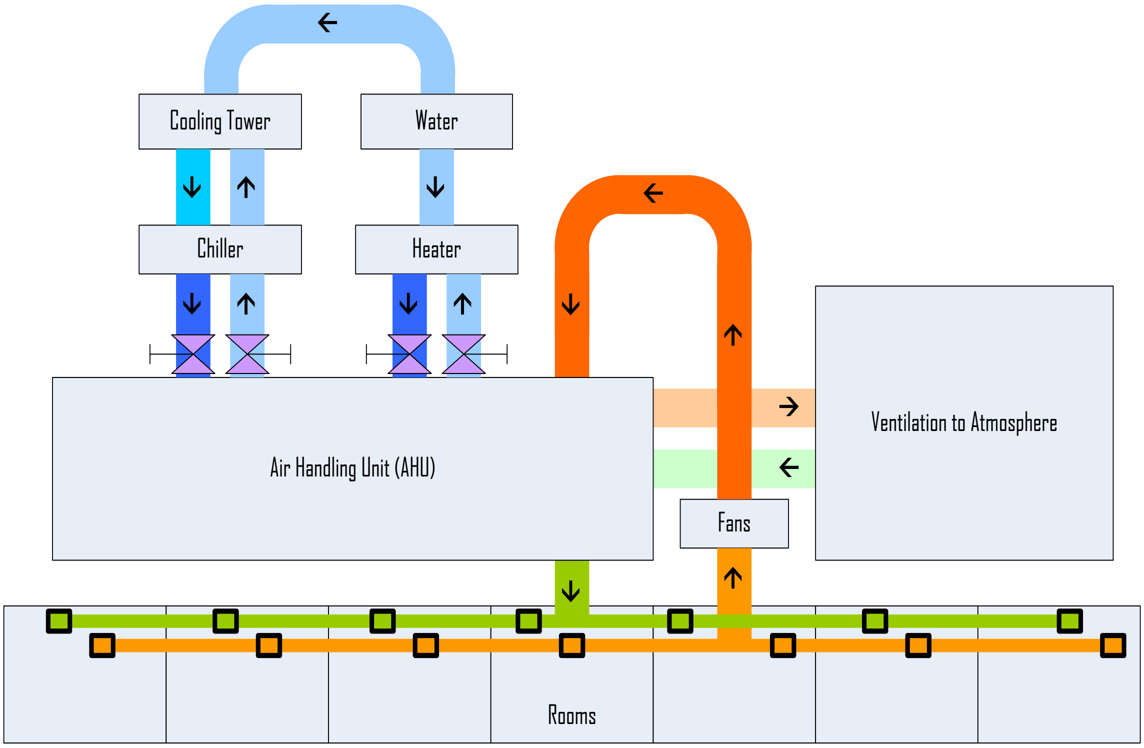


Figure 1.1 - Block Diagram of HVAC system

Figure 1.1 shows a block diagram a typical HVAC system. Air is circulated through rooms and AHU with the help of fans. Heat exchange happens in AHU, treated air is sent back to the rooms. AHU also monitors the composition of the air received form the rooms and add required atmospheric air to maintain the good composition of air supplied to rooms. There are two ways in maintaining the temperature of the rooms. First one is Constant Air Volume (CAV) where AHU outlet temperature is varied according to the requirement of the user. The other method is Variable Air Volume (VAV), where the AHU outlet temperature is maintained constant and opening of ducts inside room is varied to obtain controlled volume of air enter into room to maintain required temperature.

As we can notice that there are many parameters to monitor and many actuators to control, the controller is made in general with remote programming capability. The controller is to be designed such that it can capture any kind of signal (analog voltage, analog current, resistance, and digital signal) and generate any kind of output signal (digital signal, analog voltage, analog current) for actuator.

1.3 Introduction to Remote Monitoring Unit (RMU):

In industries monitoring the parameters of equipments is a very essential. The traditional method is to take readings manually. The development of wireless communication allows us to transmit the information from the remote location to the centrally located server. This RMU deals with monitoring remote tanks located in the field using GSM technology. The parameters like temperature, humidity, pressure, level, position of valves are monitored remotely. A step ahead to this, there is another provision of controlling the valves remotely. This allows the device to work more than a simple monitoring tool. RMU allows monitoring and controlling the valves at remote places (GSM network need to available). Like any other device the manufactured RMUs need to be tested at factory level before shipping to customer. The RMU unit contains several sensors like thermistors (monitoring temperature of fluid in tank and ambient temperature), level sensor (for monitoring fluid level), contact type switch (for detecting valve position), pressure sensor (for monitoring tank pressure) and it contains digital outputs which are capable of giving signals to the actuators to operate for manipulating valves.

The test equipment needs perform functional test of complete device and also need to calibrated most of the sensors like level sensors and pressure sensors.

2 DEVICE UNDER TEST STUDY

2.1 HVAC Controller:

General architecture of the HVAC controller is shown in below block diagram.

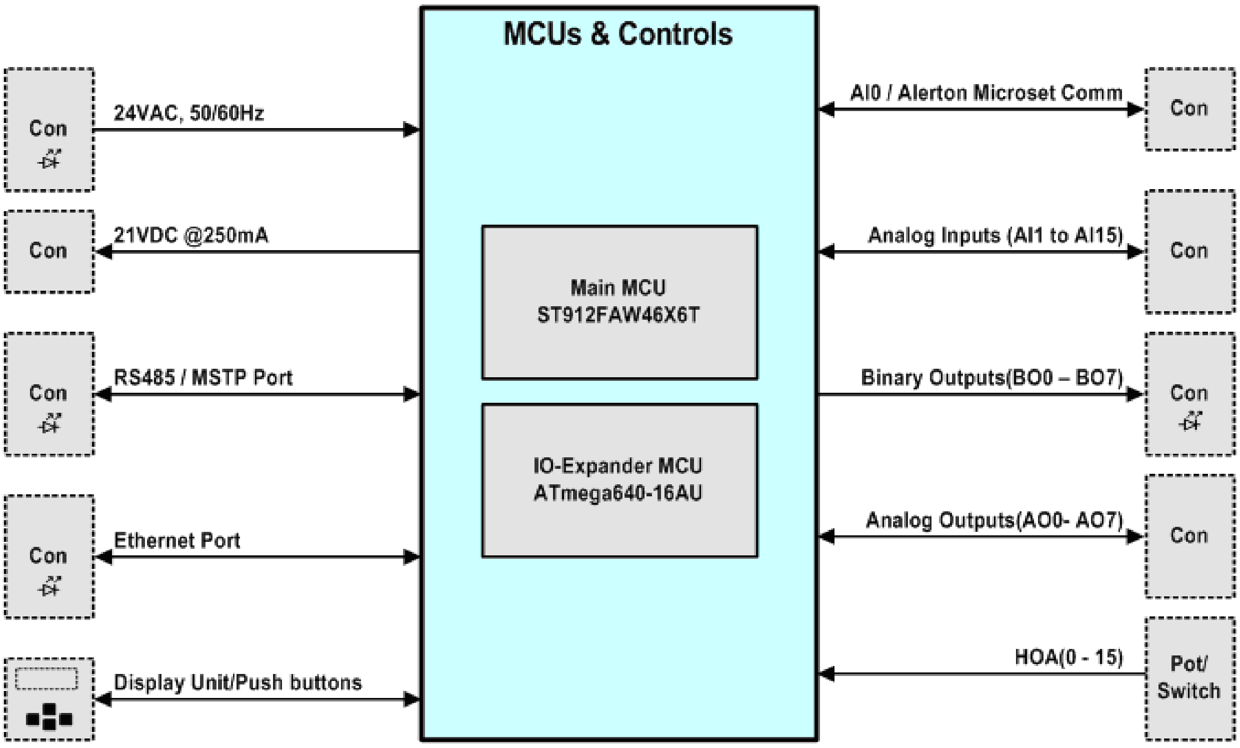


Figure 2.1 - Block diagram of the HVAC controller

2.1.1 BACnet MS/TP:

Communications shall conform to the ASHRAE BACnet standard.

- The controller shall use BACnet MS/TP for network communications
- The MS/TP physical interface shall be via a ¼ unit load RS485 transceiver.
- The controller shall handle the following BACnet object types for an AAC-certified controller.
- This set of features qualifies the controller as a B-ASC device with some extra services supported.

BACnet Objects	***Number of Objects Allowed***
(M) Device	1
(M) Program	10 (based on segmentation of configuration files required)
(M) File	10 (based on segmentation of configuration files required)
(M) Analog Input	(hardware dependant ~6)
(M) Analog Value	up to 256 (300 total of AV, MV and BV combined)
(M) Analog Output	(hardware dependant ~3)
(M) Binary Input	(hardware dependant ~4)
(M) Binary Value	up to 256 (300 total of AV, MV and BV combined)
(M) Binary Output	(hardware dependant ~6)
(M) Multistate Value	up to 256 (300 total of AV, MV and BV combined)
(D) Schedule	1 (4 entries per day)
(D) Calendar	1

Table 2.1 - BACnet Objects available in HVAC Controller

The controller will support the following BACnet Standard Application Services for satisfying profile AAC-certified controller:

Service	***Initiates***	***Responds to***
(M) ReadProperty	✓	✓
(M) ReadPropertyMultiple		✓
(M) WriteProperty	✓	✓
(M) WritePropertyMultiple		✓
(M) AtomicReadFile		✓
(M) AtomicWriteFile		✓
(M) Who-Is	✓	✓
(M) I-Am	✓	✓

(M) Who-Has		✓
(M) I-Have	✓	
(M) DeviceCommunicationControl		✓
(D) TimeSynchronization		✓
(D) UTCTimeSynchronization		✓

Table 2.2 - BACnet Services available in HVAC Controller

2.1.2 General Hardware Requirements:

Controller shall have the following input and output configuration:

a. 16 Universal Inputs with at least 12 bits of resolution. On board 250 ohms resistor for 4-20mA inputs.
b. 8 Digital Triac outputs.
c. 8 Analog Outputs
d. 1 RS485 MS/TP interface.
e. Ethernet 10/100 Base T connectivity.
f. Hand-OFF-Auto (HOA) support on all Digital and Analog Outputs.
g. 1 UIB. This will be part of Analog Input 0.
h. 20 VDC power output to external sensor with 250mA capability
i. Improved input filtering (input that maintains the integrity of high precision sensors) similar to the new EXP’s.
j. Real Time Clock (RTC) support for Trend logs.

2.1.3 Input Circuit Requirements:

It is desired the universal input circuits have improved analog input circuit performance as define below:

Input Type	*Room/Zone Discharge Air Outdoor Air Temperature*	*Outdoor Air Temperature*	*Resistive*	*Voltage Input*	*Current Input*
Sensor Type	3K, 10K, 20K Ohm NTC	PT1000 IEC751 3850	Custom resistive	Transducer, Controller	
Operating Range	-40°C to 93°C (-40°F to 199°F)	-40°C to 93°C (-40°F to 199°F)	100 ohms to 100Kohms	(0 – 10.24 volt)	4 to 20 mA
Resolution (max.)	0.03°C (0.05°F), (-2°C, 43°C) (28°F, 110°F) 0.5°C (1.0°F), (-40°C, 60°C) (-40°F, 140°F)	0.5°C 1.0°F, (-40°C, 60°C) (-40°F, 140°F)	100 – 1K, 0.5 ohms 1K – 10K, 4 ohms 10K -50K, 50 ohms 50K – 100K, 350 ohms	0.0025 volts	

Table 2.3 - Input Circuit Requirements for HVAC Controller

2.1.4 Digital Triac Output Requirements:

Voltage Rating	20 – 30 VAC, 50-60 Hz
Current Rating	25 mA to 500 mA (AC), continuous; 800 mA (AC rms) for 60 milliseconds.
Switching Type	Optically isolated, high-side switching to 24 VAC. (Controller and loads must be powered from the same transformer.)
Protection	Outputs must pass a 75VA transformer short circuit test without fire, explosion, or splatter of molten metal. Output triacs are allowed to fail during this test.

Table 2.4 - Digital Output Circuit Requirements for HVAC Controller

- All the Binary outputs shall have hard HOA support.

2.1.5 *Analog Output Requirements:*

- Analog outputs shall operate in ether current or voltage mode.
- Operating mode for each output shall be automatically selected based on its load resistance.
- When load resistance is less than 600 Ohms current mode shall be selected.
- When load resistance is greater than 1000 Ohms voltage mode shall be selected.
- All the Analog Outputs shall support hard HOA

Current Output Range	0 mA – 20 mA DC;
Tolerance	The null output value shall be ≤ 3 mA DC. The full scale output value shall be ≥ 21.0 mA DC
Output Load Resistance	550 Ohms (maximum)
Resolution (min)	0.05% of full-scale.
Short Circuit & Miswire Protection	The Analog outputs shall survive short circuit to ground or 24VAC without failure.

Table 2.5 - Current-Mode Analog Output for HVAC Controller

Voltage Output Range	0.0 – 10 VDC
Tolerance	The null output value shall be ≤ 70 mV DC. The full scale output value shall be ≥ 10.24 VDC
Maximum current output	10.0 mA DC
Resolution (min)	0.05% of full-scale.
Short Circuit & Miswire Protection	The Analog outputs shall survive short circuit to ground or 24VAC without failure.

Table 2.6 - Voltage-Mode Analog Output for HVAC Controller

2.1.6 Velocity Pressure Sensor:

The table below lists the performance specifications of the velocity pressure sensing circuitry.

Operating Range	*0” to 1.5” H2O* *(0 – 374 Pa)*
Accuracy	*±2% of full scale @ 25℃;* *±1% of full scale at null pressure @ 25℃;*
Resolution (min)	*0.0001” H2O* *(0.025 Pa)*
Thermal Drift	*0.25% per degree C (typical)* *Measured @ 0.25” over 0℃ - 50℃.*
Overpressure rating (transient)	*25 psi (172 kPa)*

Table 2.7 - Velocity Pressure Sensing Requirements for HVAC Controller

2.1.7 Communication Circuit Physical Requirements:

2.1.7.1 MS/TP Interface Requirements:

- The MS/TP physical interface shall use a ¼ unit load RS485 transceiver.
- Either or both terminals shall survive short circuit to ground or 24VAC without failure.
- MS/TP shall support the following serial baud rates: 9600, 19200, 38400, and 76800.
- Auto baud rate sensing shall be implemented.

2.1.7.2 Ethernet Requirements:

- Controller shall support 10/100 Base T Ethernet.

2.1.8 User/External Interface Requirement:

2.1.8.1 Triac Output Status LEDs:

- Each triac output shall have one green status LED that indicates ON/OFF status.
- Each LED shall illuminate when its triac is conducing current (switched on).
- Each LED shall be positioned on the PCB just to the left of its associated screw terminal.

- All LEDs shall be visible to the user when the PCB assembly is installed in its plastic cover.

2.1.8.2 Power and Communications Status LED:

- The controller shall provide one green LED be used to provide MS/TP communications status to the user.
- The LED shall be positioned near the MS/TP terminal block pins.
- The LED shall be visible to the user when the PCB assembly is installed in its enclosure.
- Controller shall support “Activity” & “Status” LED for Ethernet link based on the IO availability from the STR Microcontroller.
- Controller shall provide a LED to indicate the power supply status. It shall be on 3.3V supply rail.

2.1.8.3 MAC Address DIP Switch

- The controller shall provide an eight position DIP switch to allow the user to set the controller’s MS/TP MAC address.

2.1.8.4 Field Service Tool Interface

- The controller shall provide a standard 3-pin header for connection of field service tools (such as Alerton’s FST-100) to the MS/TP interface during equipment commissioning.

2.1.9 Power-up And Power-down Considerations

2.1.9.1 Default I/O State

The default I/O state shall be as follows:

- All Analog Outputs shall be driven to zero volts
- All Binary Outputs shall be turned OFF

2.1.9.2 Power On/Off Criteria

Await Power State: This is the first state entered following application of power. The controller shall drive all outputs into the default state and wait until 17VAC has been present for 3.6 seconds continuously.

Power On State: The controller shall consider power to be "on" whenever 17VAC has been present on the power supply terminals for 3.6 seconds or more.

While in the "Power On" state, whenever the voltage falls below 15VAC, the controller shall save all nonvolatile data to flash, place all I/O into a default state, and go into the "Await Power" state.

2.1.9.3 Initial Data Values

Upon detection of invalid nonvolatile backup data, the controller shall set the corresponding nonvolatile data to default values, according to the following table:

Item	**Default State**
AO	Priority arrays set to NULL
BO	Priority arrays set to NULL (output set to Relinquish Default)
AV	All set to 0.0
BV	All set to Inactive. All Relinquish defaults set to inactive
BV40	Priority array all set to NULL. Relinquish default set to inactive.

2.1.10 Direct digital control (DDC)

- The strategy engine will be executed once every second..
- If the DDC takes longer than 1 second to execute, then DDC shall execute continuously.
- Hardware inputs shall be sampled immediately prior to DDC execution.
- Hardware outputs shall be written immediately following DDC execution.
- All hardware inputs and outputs shall remain static (from the point of view of the DDC code) during DDC execution.

2.1.11 Electrical & Mechanical Requirements

2.1.11.1 Environmental Ratings

- The Operating Temperature Range shall be -40°C to 65.5°C (-40°F to 150°F).
- The Storage/Shipping Temperature Range shall be -40°C to 65.5°C (-40°F to 150°F).
- The controller shall be rated for operation in the humidity range 5% to 95%, non-condensing.
- The controller shall have an environmental (dust and water spray) rating of NEMA-1.

2.1.11.2 Electrical & Performance Ratings

- The input voltage rating of the controllers shall be 20 – 30 VAC, 50/60Hz.
- The controller shall be classified as a NEC Class II (power limited) device. This requires that the combined load of the controller plus any connected customer loads be no more than 100 VA.

2.1.11.3 Mechanical Requirements

- The controller shall have a vibration rating of “V2”, per Honeywell ASTM 4169 standard.
- The controller shall have a corrosion rating of “Class I -Office Environment”, per Battelle Labs Manufacturing Test Methods.

2.1.11.4 Reliability In-Warranty Return Rate Requirements

- The six sigma score shall be greater than 5.0.
- The hardware shall have a projected ten (10) year life.

2.1.11.5 Styling / Marking Requirement

- Labels shall match the Alerton branding of the other unitary controllers (i.e. font, colors, placement, copy, location of copy)
- The controller shall have labeling for the Order Specification (OS), series number and date code.
- The controller shall have the appropriate UL labeling.
- The controller shall have the CE Mark for the EU market.

2.1.12 Safety Standards and EMC Standards Approval Requirements

- The controller shall meet FCC EN-55024.
- The controller shall be CE – EN-61000 compliant.
- The controller shall be UL 864 listed.
- The controller shall be UL listed per UL916 (Standard for Open Energy Management Equipment) with plenum rating.
- The controller shall be tested with unshielded wire, with the exception of MS/TP.
- The controller shall be RoHS/WEEE compliant.

2.1.13 Open Systems Requirements

The controller shall be tested and approved by BTL as an Advanced Application Controller (B-AAC).

2.1.14 Packaging Requirements

- The controller shall have a new case
- The controller shall have a new over pack cartons
- There is no requirement for bulk or pallet pack.

2.1.15 Field Installation Requirements

2.1.15.1 Mounting and Orientation

- The controller shall provide a method to mount with external sheet metal screws.
- The controller shall mount in any orientation.
- The controller shall provide DIN rail mounting features.

2.1.15.2 Literature

- No pack instructions will be packaged with the controller.
- A Data sheet shall be created
- A BACnet PICS statement shall be created
- An image library shall be created

2.1.15.3 Field Wiring

- The controller package shall allow quick change out of the electronics with out rewiring.
- The controller shall provide a method to reconnect the field wiring to the proper location without mix up.
- The controller shall provide screw terminals, minimum slot size of 3 mm (0.118”), for all I/O connections.
- Each terminal shall be capable of holding two (2) 18 stranded AWG wires and a ¼ watt wire-wound resistor.
- Each terminal shall be capable of accepting 22 AWG wire.
- All field wiring connecting locations shall have identifying marking for the appropriate function.
- All screws shall allow the same screwdriver to be used.

2.1.15.4 Serviceability / Field Repair

- The controller shall be field replaced as a single unit.
- The controller shall provide access to the terminals while the controller is operating.
- The controller shall provide a method to upgrade the host processor firmware in the field.

2.1.16 Implementation Considerations

2.1.16.1 Testability & Manufacturability

- The controller shall cooperate with factory testers such as In-Circuit Test (ICT) and Final Functional Test (FFT) to verify its functionality. The JTAG port shall be available for the factory to program the Flash and test the device.
- The controller shall be designed such that 100% of the inputs and outputs can be tested in the factory.
- The controller shall provide a method to command each output, report the model type, report the Universal and Digital Input values to the factory tester.

2.1.16.2 Unusual Material, Process, Quality Requirements

No unusual material will be used. The product requires factory calibration of universal inputs and analog outputs. Factory calibration parameters will not be field adjustable.

2.1.16.3 Future Considerations

- Unit should be designed with sufficient processor resources to support future firmware upgrades.
- Wireless communications.
- Inputs with 16-bits resolution
- Binary outputs with Relays
- Incorporate a small text display.
- Incorporate the ability to have two pressures transducers for dual duct applications.
- Faster MS/TP baud rate support.

2.2 Remote Monitoring Unit (RMU)

2.2.1 Overview:

The device contains basically 3 individual boards (PCBs). The functions of the boards are as given below.

1. Base Board
2. Sensor Interfacing Board (SIB)
3. GSM Board

2.2.2 Base Board:

- This board contains basic power supply circuitry and the micro controller for interfacing with Sensor Interfacing Board and GSM board.
- The communication between Base Board and SIB is RS485.
- The communication between Base Board and GSM Board is SPI bus.
- For field maintenance an RS232 port is made available for updating calibration details.

2.2.3 Sensor Interfacing Board (SIB):

This board contains SCC and interfaced with a microcontroller. The onboard microcontroller of this board will be responsible for measuring data from sensors, applying proper control signals to actuators, and communicating with base board.

2.2.4 GSM Board:

GSM Board’s function is to communicate with the GSM network with the instructions of Base Board. GSM Board contains microcontroller, which help in interfacing with Base Board and GSM Module (SIM300)

2.2.5 Sensors which are interfaced to the SIB are as follows.

1. Fluid Temperature Sensor (-55 to 125DegC)
2. Ambient Temperature Sensor (-55 to 125DegC)
3. Tank Pressure Sensor (1 – 1.5 atm)
4. Fluid level Detector (sensing range of 15 cm)
5. Tank Humidity Sensor (0 to 100% RH)
6. Valve position sensor (Open / Close)

The actuators which are interfaced with SIB are basic open / close type of valves.

2.2.6 Requirements of Device:

RMU will require external power supply for its operation. RMU will take unregulated RAW AC supply of 3 different voltages:-

- 12 V AC, 500mA, +/- 10% voltage variation.
- 9 V AC, 100mA, +/- 10% voltage variation.
- 9 V AC, 100mA, +/- 10% voltage variation.

RMU will have an RTC which will be used to time stamp the alarm. The accuracy of RTC will be 1 second. Power to the RTC will be provided by a coin type lithium-ion cell battery with at least 10 years life

RMU will have one visual indication LED. This LED will flash at different rates to indicate:

- Power Supply to RMU. → continuously ON (Green color LED A, software controlled)
- GSM/GPRS Data Communication. → flash rate dependent on configured baud rate of GSM modem. (Green color LED B)
- Health of the RMU. → 2 sec with 50% duty cycle (Green color LED A, software controlled)

A GSM/GPRS Tax disc antenna (900Mhz-1800Mhz) shall be used for wireless communication between RMU and NOC.

A rudimentary host (NOC) which shall serve the following basic purpose to demonstrate functionality:-

- Identification of RMU.
- Configuration of RMU.
- Monitoring of RMU parameters.
- Logging RMU parameters to the database.
- Time (used for time stamp events posted to NOC) synchronization across different RMUs.
- Help in RMU installation process, will have user guides, terminal connection diagrams, user manuals.

RMU will be able to log last 5 critical alarm conditions.

The following is the list of alarm conditions:-

- Power Failure.
- Not able to send data to NOC when the GSM/GPRS communication failed. This alarm will be sent whenever the communication link is restored.
- Low Fluid Level fault.
- Measured voltage parameters out of predefined safe range.
- Measured temperature (ambient/top of fluid) out of pre-defined safe operating range.
- Measured pressure parameters out of predefined safe range.
- Measured Humidity parameters out of predefined safe range.
- Actuator faults (when a command is issued to switch on/off the valve, the commanded status is not reflected via the feedback path).

The RMU should be able to store event history log of last 25 events. Events, along with parameters, will be sent twice daily.

RMU supports an execution engine that shall offer to build custom logic using the function blocks for the controlling and monitoring of site infrastructure.

- The execution engine will be capable of running maximum of three execution strategies.
- Each execution strategy can use maximum of 10 function blocks.
- Each execution strategy should execute in maximum of 1 minute.

RMU will have a separate PC/laptop based tool and corresponding appropriate RMU firmware for calibrating its 1/3-phase energy measurement interfaces. This will be an offline calibration tool, which will be used during the manufacturing of the RMU.

3 DESIGN OF FACTORY FLOOR TESTER

FFT contains industrial computer, electrical circuitry, and mechanical fixture. Industrial PC is responsible for running the complete test in the desired manner by integrating the software with the hardware. Electrical connections from the DUT are taken through the pogo pins. These pins connect the DUT's PCB at required test points. The mechanical fixture plays very important role in FFT. The fixture is nested with all the sensors and actuators required to test the DUT. The fixture also has provision for holding the DUT tightly at right place for exact pogo pin contact.

In this design process, we have developed individual modules then integrated into one complete system. These individual modules are combination of software, hardware and firmware. We made sure that appropriate drivers are available for all the selected hardware. Hardware and software requirement study is been made after thoroughly understand the DUT's specifications. We prepared a list with all the possible tests and operations to perform on the DUT. The complete system is then reviewed meticulously by an organised review team of Honeywell, the review comments were again set as goals for second stage of design. This iterative process helped in keeping design close to requirement, optimizing resources, minimizing cost, use of latest technology and improving time taken for testing each DUT.

In the design of HVAC Controller, we used Agilent relays, multiplexers, DMM with interface with the Borland C++ programme. The multiplexers, relays, DMM, Ethernet, USB, Programmers (for flashing firmware) and barcode scanner are connected to the PC directly. Other analog values are measured by DMM routed through relays and multiplexers.

RMU contains three PCBs. We have a requirement where, we need to test each module individually and all PCBs combined. We made design for two different test fixtures for meeting the requirement of both cases. In the first case, we used NI's DAQ card for digital and analog voltage input, output. In the second case, we were required to use only one RS232.

3.1 FFT DESIGN OF HVAC CONTROLLER

Verify voltages of DUT at various stages of circuit:

DUT's PCB contains very complex circuitry. Verifying voltages at various stages is required to ensure that DUT is powered on without mistake. The test points of DUT's PCB are taken out using pogo pins which allow interfacing DUT's PCB with test hardware. The voltages are directly connected to Digital Multi Meter (DMM). A multiplexer is used to switch between different test points. Voltage is measured from DMM and its final value is determined by the algorithm discussed in section 4.1.

Verifying model using barcode:

A barcode resistance need to be provided to read the serial number of the DUT. Recording serial number is required for marinating the database. The barcode also provide the information about the product. Same product with slightly modified specifications is available, which can be recognised by the barcode. So, we need to identify the barcode before commencing the test.

Flashing firmware to DUT:

Pogo pins are taken out of controller's programming pins. There are three different processors to flash. Three separate twenty pins JTAG connectors are used to program. The first processor is a mixed signal processor used for running DDC, second one is a 16 bit microcontroller used for implementing communication protocols and third is a microcontroller used to measure flow from flow sensor.

Calibrating flow meter:

The flow meter used here is a hotwire type one. We need to measure temperature during calibration process. An infrared thermometer is used to measure the temperature of the flow-sensor. Alicat device (PC3 - 1PSIG-D \ 5P) is used to control pressure precisely. The input pressure (~4 PSIG) is to be given to Alicat device, this will allow us to vary output pressure from 0''H2O to 2''H2O. One end of the flow-meter is open and another end is maintaining the pressure as per set-point value. The pressure difference between upstream and downstream of the flow-sensor is due to the back pressure. This back pressure is related to the flow through the flow-sensor. The back pressure is maintained constant by Alicat device. A RS232 cable is to be connected to Alicat Device for changing set-point of the controller. The temperature measured by the infrared sensor is taken into computer using RS232 cable. The calibrated result is basically the gain adjustment and offset adjustment information. This data needs to be written into the allocated memory. Writing of calibrated data is done using the BACnet connection. Testing flow-meter can only be performed after writing calibration information into the memory. During calibration and testing of flow-meter, we need to use BVs and AVs. This can be again achieved by BACnet connection.

Testing flow meter:

One end of the flow-meter is kept open to atmosphere and another end is connected to precisely controlled compressed air. The Alicat device (PC3 - 1PSIG-D \ 5P) which is also mentioned in the calibrating flow-meter is used for calibration purpose. Different flow rates through the flow-sensor can be obtained by varying the Alicat device set-point between 0-2’’H2O. The setup done for calibration is sufficient for the testing, so no additional hardware setup is required for testing. BACnet connection is required for monitoring the measured flow-rate.

Calibrating universal input:

Calibration of universal inputs is done in 3 stages. First one for resistance, second is for voltage and lastly for current. Same input can be used to measure resistance, voltage or current. The selection of the unit under measurement is done by varying the binary values associated to it. Example is given in the following table.

Universal Input – (UI00)	Binary value – (BV200)	Binary Value – (BV400)
Resistance Mode	0	0
Voltage Mode	0	1
Current Mode	1	1

Table 3.1 - Selection of modes in Universal Input of HVAC Controller

From above table, we can see that by changing BV’s we can configure the universal input as any one of the available modes. We need a BACnet enabled communication between controller and our PC. This can be achieved by MS/TP (more details are provided in 16. Testing BACnet functionality) *a. Calibrating resistance mode:*

The calibration of UI for resistance mode is done by three point calibration. We need to externally provide three different resistances for the calibration process. This can be achieved by connecting a resistance array with relays to select appropriate resistance or we can emulate desired resistance using the circuit shown in appendix – 1. The resistances required for calibration are 0 Ω (short circuit), 10 kΩ, and infinite resistance (open circuit).

b. Calibrating voltage mode:

The calibration of UI for voltage mode is done by two point calibration. We have to provide two different voltages at the input terminal. Lower and higher limits are provided for the better calibration. So, we selected to give 0V and 10V at the input terminal. For generating 0V and 10V, we used an Agilent 34952A (±12V with 1mV resolution). The Agilent device is connected to the computer using RS232.

c. Calibrating current mode

The calibration of UI under for current mode is also same as voltage mode. We use two-point calibration technique. We provide different two different electrical currents using same DAC, which is used for Voltage calibration. The DAC is capable of supplying only 10mA, so we made software such that only 1 UI channel connect to the DAC during current measurement.

After calibration, a set of values are generated. These need to be flashed into the allocated memory. This can be done through BACnet bus.

Testing universal input:

For testing UIs, we need to connect different values of resistance, voltage or current based on the mode of the operation. By meeting hardware requirement for calibration, in turn meets the hardware requirement for testing. There is no separate hardware setup required.

Calibrating analog output:

For calibrating analog output, we connect external resistance to the analog output. The mode of operation in voltage mode or current mode is determined by the value of the resistance connected. The output will be in current mode, if the external resistance is less than 500 Ω. The output will be switched to voltage mode when the resistance connected is more than 1 kΩ.

a. Calibrating voltage mode:

In voltage mode, we give two different voltages to the output resistor and measure the DMM’s reading. We calibrate the AO for voltage mode using those to readings. The controller voltage is changed using the BACnet communication between DUT and computer.

b. Calibrating current mode:

Similar to voltage mode, we change the DUT’s output current through BACnet communication. The current is measured using the DMM, and calibration information is extracted.

The calibration information obtained from the voltage mode and current mode are written into the specified location to finish the calibration.

Testing analog output:

We used same hardware setup of calibration for testing also, so there was no separate hardware requirement.

Testing digital output:

The digital output of the DUT should be capable of producing a current of 500mA at 25VAC, when it is enabled. Digital output can be controlled using BACnet communication. We connected an external resistance (50Ω, 25w) for each channel of the DO to test all DOs in full load condition.

Testing Ethernet:

For testing Ethernet connection, we used an Ethernet cable connected to DUT and the HUB, which in turn connected to the testing PC. Communication is verified by sending and receiving a code.

Testing USB:

For testing USB, we connected the USB of DUT directly to the testing PC. Similar to the Ethernet port, code is sent and received from USB. Successful receiving of code confirms the proper working of USB

Testing HOA switch functionality:

HOA is a feature, which enables user to control output directly without programming DUT. For testing this, no separate hardware setup is required. The setup available for analog and digital output will be sufficient for testing this functionality. Operator manually needs to switch the HOA position.

Testing LED's colour and intensity:

Each LED is connected to an optical fibre coming out of LED sensor (Optomistic's Trident Smart LightProbe™). We have total 12 LEDs and each sensor is capable of testing 3 LEDs. So, we used four Trident Smart LightProbe™ sensors. LEDs can be switched on and off using the BACnet communication. Each Trident gives tow analog outputs. One is intensity another is for colour. All these analog outputs are connected to the DMM

Testing LCD screen's and its background light's brightness:

A command is issued by BACnet, which will generate different patterns in the LCD screen. The light brightness is monitored by LUX meter. LUX meter is connected to test PC using RS232.

Testing keypad:

Pneumatic figures are connected to each key of the keyboard. Pneumatic fingers are actuated by compressed solenoid. The solenoid is controlled by Agilent 34980A. Agilent 34980A is connected to computer by USB.

Testing BACnet functionality:

For testing BACnet functionality, we are using RS485 communication line with MS/TP. This two wire line is connected to Alerton's BACnet router. Alerton BACnet router converts the RS485 MS/TP to Ethernet protocol. This Ethernet is connected to hub, which in turn connects to the test PC.

Testing User Interface Bus (UIB):

A device with UIB is made available on the test fixture. The UIB pins from the DUT are taken and directly connected to the UIB available on the FFT Fixture. This connection will allow us to test UIB.

Testing internal memory:

The internal memory of the DUT is tested by sending and receiving the bulk of information. Sending and receiving of data is done by BACnet communication.

Testing processor functionality:

A command is sent through BACnet to the firmware of the processor. This will run the test firmware within DUT and response code is generated from DUT and sent to test PC via BACnet communication.

Test for connector's presence:

DUT contains plastic connectors for terminals. For making sure that DUT is placed with all the required plastic, we connect pogo switches, these pogo switches are connected to the Agilent 34952A. Agilent 34952A is connected to PC using USB. We can monitor the pogo switches status from PC. The status of pogo switches determine presence of plastic.

Testing dip-switch:

Ground is connected to the dip switches of DUT via relays. By operating relay, we can generate different positions for DIP switches. We can monitor the DIP position from the computer using BACnet communication.

Testing for additional labels like FCC etc., and marking device:

An optical sensor (Keyence fiber sensor) is used to monitor the presence of different labels like FCC, CE. The output of the Keyence sensor is analog voltage. This is analog voltage is given to the DMM. Also a mark is made on the DUT indicating that it passed FFT. The marker is generally a sharp object making tiny mark at one end of DUT. The marker is operated using solenoid. The solenoid is actuated using Agilent 34952A.

Following figure shows the block diagram of complete hardware setup of the FFT

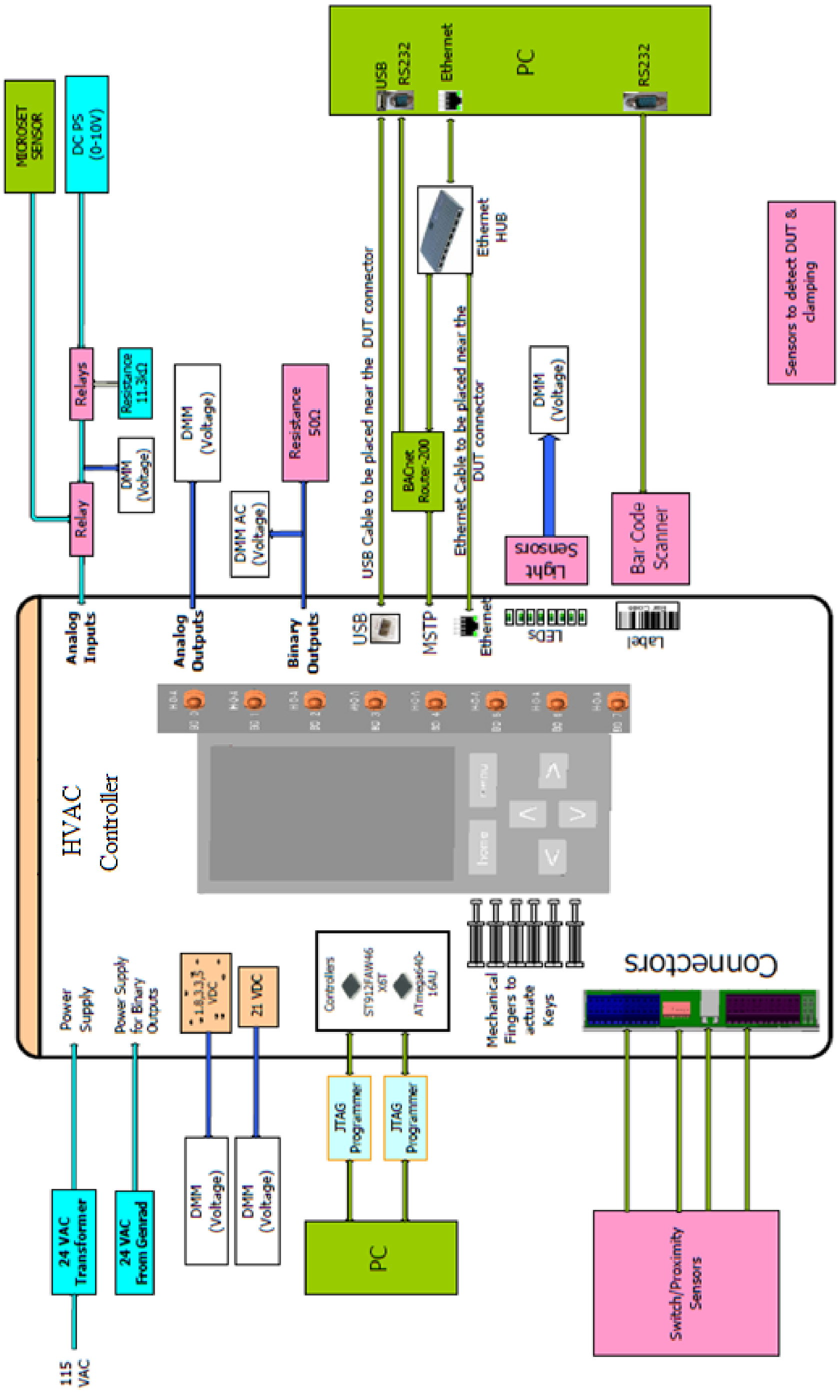


Figure 3.1 - Complete Hardware setup of the FFT for HVAC Controller

3.2 FFT DESIGN OF RMU

3.2.1 Stage-1

Following block diagram shows the complete setup of the hardware connections:

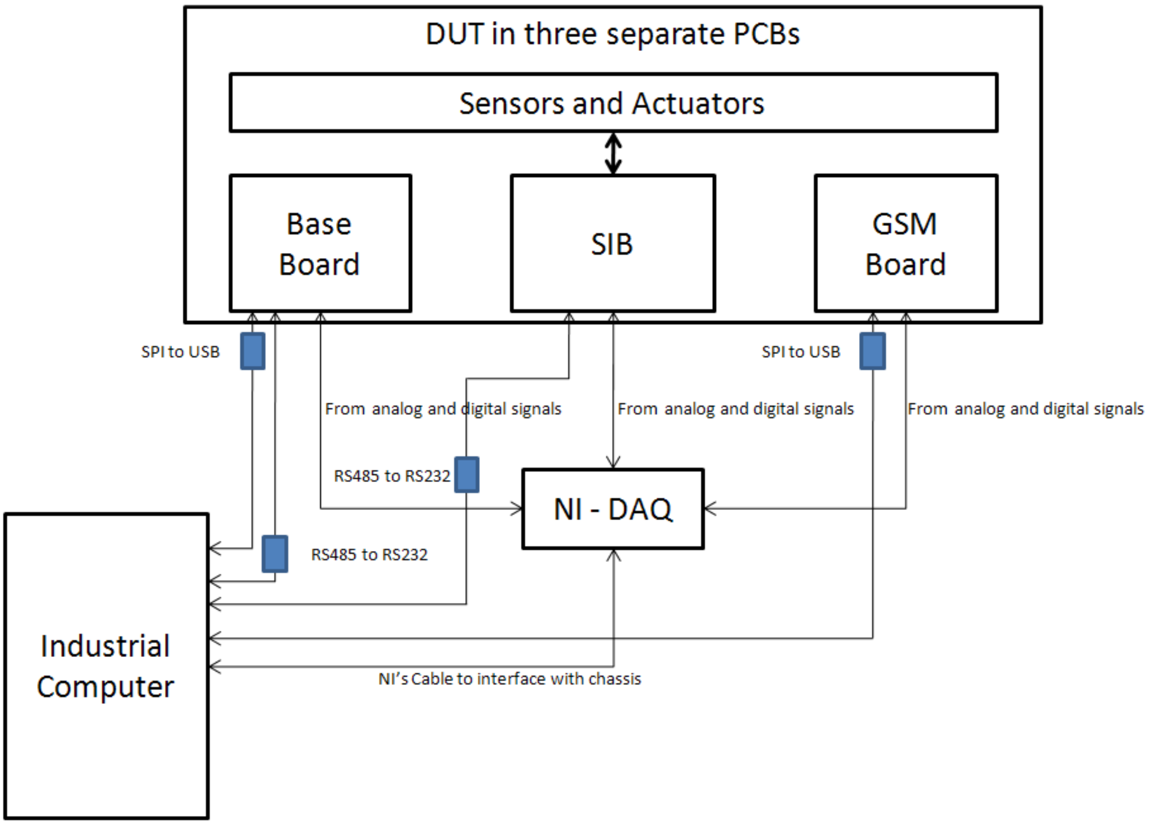


Figure 3.2 - Block diagram of Design setup of Stage-1 FFT for RMU

In this stage DUT is in three separate PCBs namely Base Board, Sensor Interface Board and GSM Board. All boards are to be placed in the test fixture. The test fixture contain proximity sensor which automatically detect the presence of DUT and start execution of test when the test fixtures door is closed. The electrical contacts from the DUT are taken using pogo pins. DUT Sensors (pressure sensor, two temperature sensors, humidity sensor and level sensor) are to be connected manually. The sensor inputs of valve position detector and actuator operation is emulated with the NI DAQ card. The communication protocols like RS485 and SPI are tested via converter external hardware. The ADAM converter is used to convert the RS485 to RS232. SPI to USB conversion is accomplished via NI USB-8451.

Powering up of DUT:

Program is made to continuously monitor the status of the DUT door and proximity sensor values. The NI LabVIEW will actuate the relays which connect the transformer output to the DUT power supply pogo pins.

Verify voltages of DUT at various stages of circuit:

After powering up of DUT, we need to verify the voltages at various stages of power supply to make sure the DUT is power correctly. This is achieved by measuring the analog voltages at the selected pogo pins and comparing measured voltage with the limiting values (higher and lower).

Flashing firmware to DUT:

DUT will be flashed with the test firmware (Appendix contains more details about test firmware). We send a command to DUT through RS232 and receive feed back through same. By comparing feedback, we will make sure that flashing is done properly.

Handling multiple grounds:

Multiple grounds are available in this device. NI DAQ contains only one ground for all digital I/O, analog inputs and analog outputs. The grounds are routed to the ground of DAQ via relay network. From the software made sure that proper ground is connected.

Testing temperature and Humidity sensors:

Command is sent to DUT to read the temperature from the DUT to the LabVIEW via RS232. The read temperature is compared with the available temperature sensor mounted test fixture. The test will be declared pass, if the error is below 1ºC. Similarly DUT sends read Humidity sensor information to LabVIEW. It is then compared to test fixture's sensor.

Calibrating level sensor with 3 point calibration:

A three point calibration is adopted for calibrating level sensor. The level sensor is allowed to change its position manually. User needs to inform PC by pressing button during calibration process to confirm the level sensor's position. The calibrated data is saved into the memory location allocated.

Testing level sensor:

A command will be sent to firmware to read the position of the level sensor. The same is displayed to the user. User need to manually verify the level sensors position and give appropriate input to the PC for determining result for this test.

Testing digital outputs for valve operation:

A resistance is connected to the output for valves operation. The command is sent to the SIB to open and close the valve. The voltage across the resistance is measured with the help of NI DAQ.

Testing digital inputs:

The Analog output of the DAQ is routed to the digital input of the RMU. The analog voltage 5v is to be generated from the AO of NI DAQ. Command is sent to SIB to read the digital input status. Message is to be read from SIB to verify for the digital input.

Testing communication between base board and SIB:

For testing the communication between two boards, we verify the communication between individual boards. The communication between SIB and the Base Board is RS485. This RS485 is converted to RS232 by using ADAM converter. We send command to SIB and receive the acknowledgement from firmware. Similar to SIB, the base board will also tested by sending and receiving message.

Testing communication between base board and GSM board:

Similar to the above, these communication lines also be tested by testing individual board separately. The communication between GSM and Base Board is SPI. We used SPI to USB converter NII's USB-8451.

Testing GSM functionality:

SIM is placed into DUT. Test fixture also contains one SIM 300 (GSM Module), which contains RS232 communication with the industrial computer. DUT is allowed to call the number SIM present in test fixture. The SIM 300 will verify the caller with the SIM of DUT. The caller identification facility of the subscriber is utilized to for testing GSM functionality.

Testing memories of each device:

A test command is sent to each board. Test firmware run a program which copies memory with all “1” and reads back to verify the memory is working. Upon successfully retrieving data, firmware sends code indicating test passed.

Capturing barcode information for database operation:

Barcode value is read via USB for all the boards, sensors and actuator. The read values are to be stored in a table to verify that these boards are integrated together.

3.2.2 Stage-2

Following is the block diagram showing connections for the stage2 FFT:

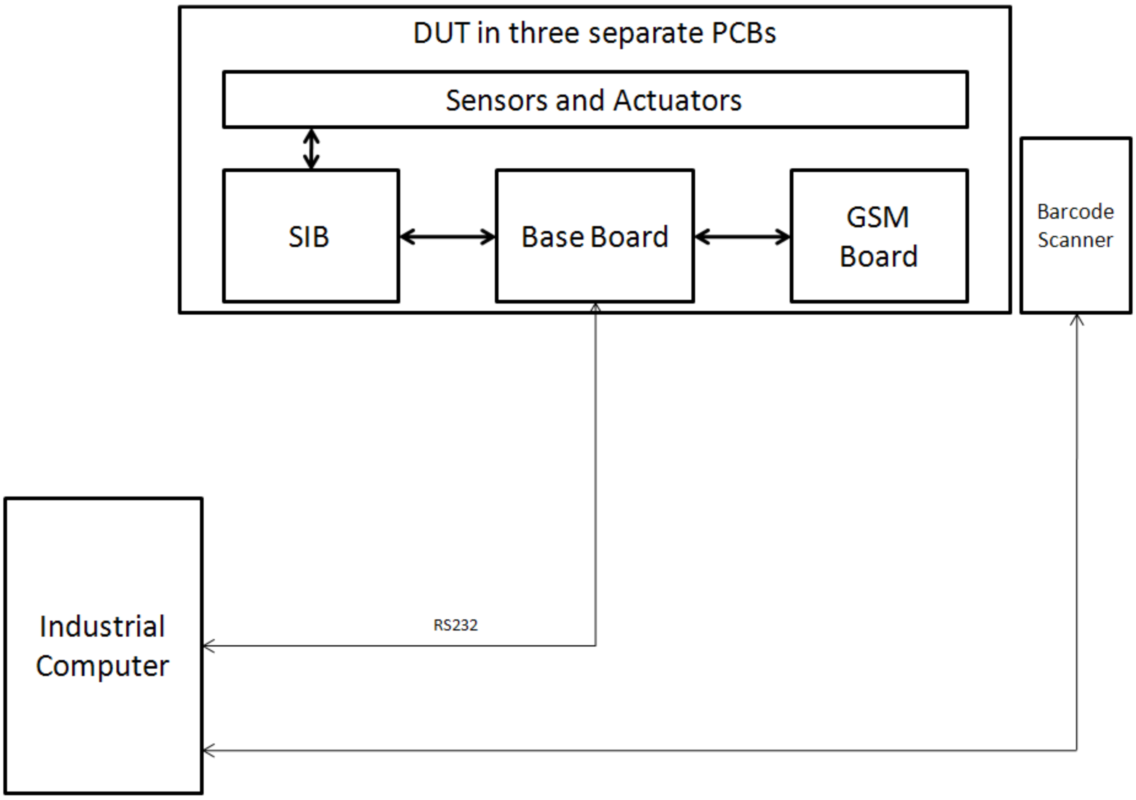


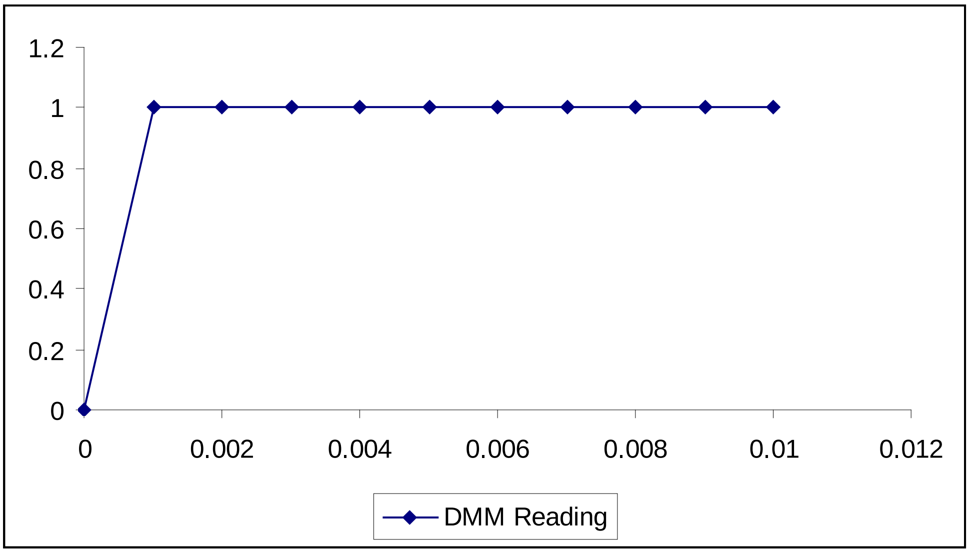
Figure 3.3 - Block diagram of Design setup of Stage-2 FFT for RMU

In this stage all the boards are to be connected together. Only one RS232 is connected to PC. We designed the process in which, firstly test firmware is to be flashed. Commands for different tests will be sent to board via connected RS232. Base Board runs tests like communication between each board and then sends feedback code to the computer. Computer verifies the code to declare the device pass or fail.

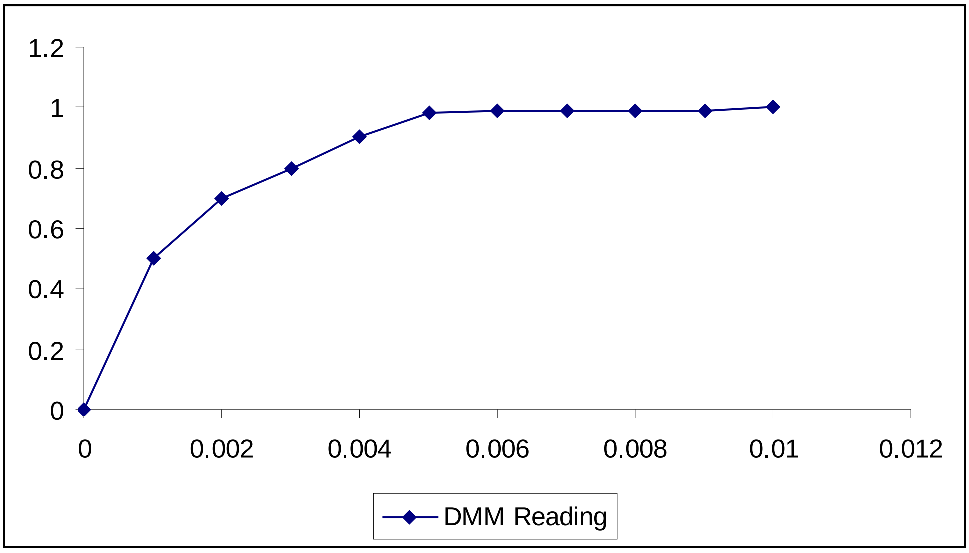
4 INDIVIDUAL MODULES USED IN FFT DESIGN

4.1 Measuring Voltage through DMM

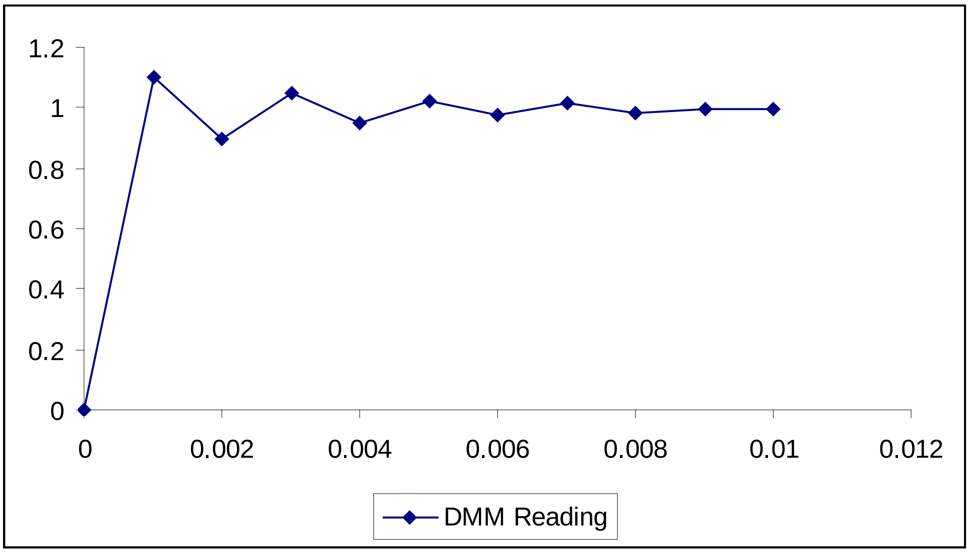
Measuring voltage from the DMM is a very simple task. We connect the terminals to the required point and measure the reading of DMM directly or through RS232.The process becomes complex when it comes to the real time. In real time, we need to measure voltage from DMM in the less possible time. When we connect DMM to the terminal and observe the reading. We may observe any of the following transition in the DMM.



Graph 4.1 - Voltage measurement by DMM : Type 1



Graph 4.2 - Voltage measurement by DMM : Type 2



Graph 4.3 - Voltage measurement by DMM : Type 3

For fast and the sufficiently accurate measurement, following rule can be adopted.

- Select the reading of the DMM as the voltage, if the previous two values are same.
- Select the reading of the DMM as the voltage, if the slope between the last two samples is less then required accuracy requirement.
- Select the reading of the DMM as the average of the last two samples, if the DMM's reading is oscillating (or slope is changing its polarity).

4.2 Measuring Resistance

Electrical resistance is important parameter to measure. The general method used in DMM is shown here.

The voltage is divided across the resistance by ordinary voltage divider rule. The voltage measured at net-1 is converted to resistance by following well known formula.

$$R_2 = \frac{v_1 \times R_1}{V_{cc} - V_1}$$

Equation 4.1 - Resistance Measurement by Voltmeter

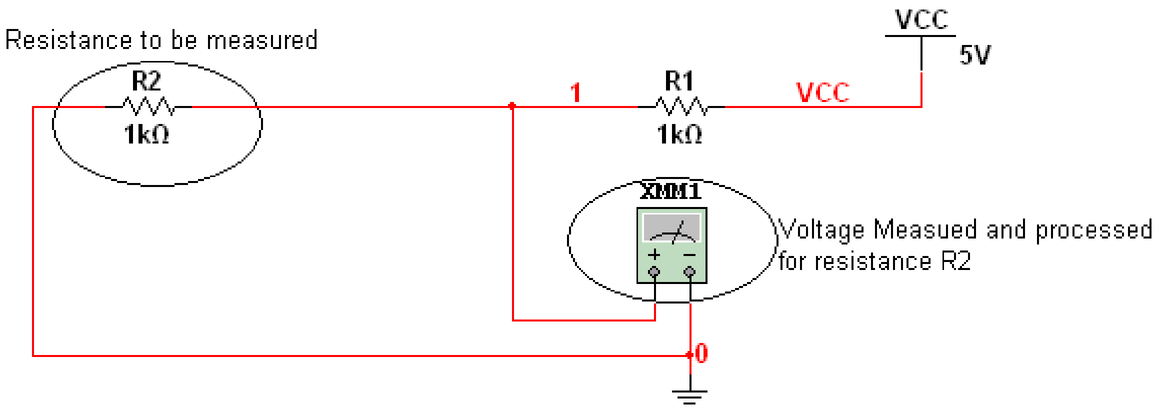


Figure 4.1 - Circuit Diagram for Resistance Measurement by Voltmeter

4.3 Measuring Current using Voltmeter

Measuring current is similar task as that of resistance. Electric current is allowed to flow through a resistor and the voltage across the resistor is measured using DMM. The measured voltage is proportional to the current through the resistance. The current is thus deduced from the famous Ohms law.

$$I = \frac{V}{R}$$

Equation 4.2 - Ohm's Law

4.4 Emulating Resistance

Resistance can be emulated by following circuit. This will be useful for testing purpose. This circuit is useful for emulating resistance for DC supply only.

In the following circuit, the circuit inside the rectangular block will simulate the resistance.

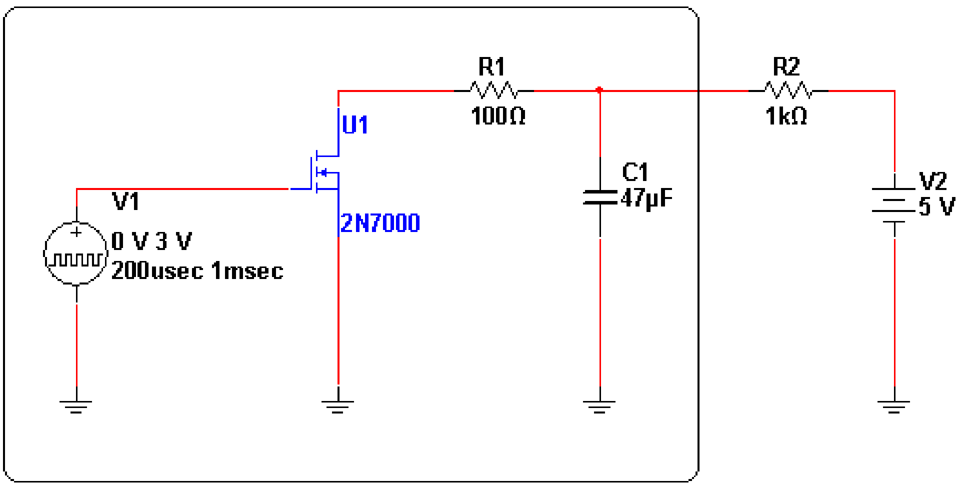


Figure 4.2 - Circuit Diagram for Emulating Resistance

Lets first study the circuit with no capacitor. Then we check the circuit. As indicated in the “Measuring Resistance”, the circuit outside rectangular block is general arrangement made for measuring the resistance. FET will act as a switch operated by the PWM signal. The PWM signal can be generated by an ordinary microcontroller. The voltage between R1 and R2 resistances is 5V when FET is open and 0.4545V when FET is closed. When PWM signal is applied with duty cycle of “x”, the voltage will be 5V for x% time and 0.4545V for (1-x)% time.

So, the average voltage (voltmeter measured average value in DC mode) is

$$V = 5 \times x + 0.4545 \times (1 - x)$$

Equation 4.3 - Average voltage measured in DC mode

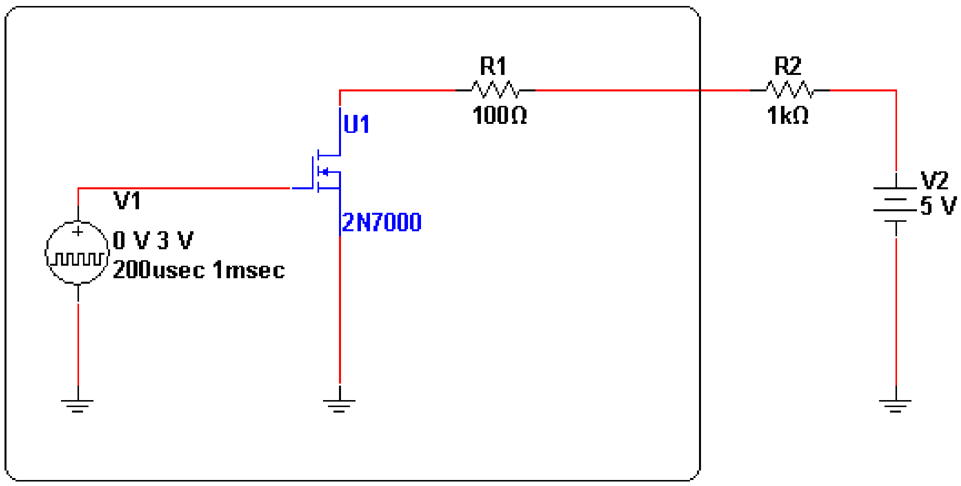


Figure 4.3 - Simplified Circuit Diagram for Emulating Resistance

Corresponding resistance to the measured voltage is given by following formula as discussed above

$$R = \frac{V \times 1000}{5 - V}$$

Equation 4.4 - Resistance corresponding to the Measured voltage

As we can see, we can generate the resistance from the table that resistance can be generated from 100Ω to 100 kΩ, by controlling PWM.

Voltmeter averages the signal over a period decided within the voltmeter. This may not give good result as we need to average the signal over one complete period. This can be achieved by averaging the signal at the circuit level itself. Capacitor is placed to divert all the AC voltage to ground and give the DC voltage to the voltmeter. Thus placing capacitor will remove all the frequency components and allow only the DC value appear at the Voltmeter.

Following table shows the emulated resistance for different duty cycles of the PWM signal in the above given circuit.

Duty Cycle	V	R
0.00	0.455	100.000
0.01	0.500	111.111
0.02	0.545	122.449
0.03	0.591	134.021
0.04	0.636	145.833
0.05	0.682	157.895
0.06	0.727	170.213
0.07	0.773	182.796
0.08	0.818	195.652
0.09	0.864	208.791
0.10	0.909	222.222
0.20	1.364	375.000
0.30	1.818	571.429
0.40	2.273	833.333
0.50	2.727	1200.000
0.60	3.182	1750.000
0.70	3.636	2666.667
0.80	4.091	4500.000
0.90	4.545	10000.000
0.91	4.591	11222.222
0.92	4.636	12750.000
0.93	4.682	14714.286
0.94	4.727	17333.333
0.95	4.773	21000.000
0.96	4.818	26500.000
0.97	4.864	35666.667
0.98	4.909	54000.000
0.99	4.955	109000.000

Table 4.1 - Resistance vs. Duty Cycle

4.5 Test Firmware

Test firmware is a firmware which allows the tests to perform on the DUT. This firmware may never be used in the device life cycle. The example of one such firmware is that all pixels of LCD screen on a digital watch can be made on to make sure that all the pixels are working. Usually the test firmware will not having any complex algorithms of controlling etc. Test firmware can be placed with the actual device firmware provided the device is having enough space for holding additional code. When the device contains both test firmware and operational firmware, the device can be switched from one mode to another by triggering certain hardware or software command (like pressing keys in predefined order or sending certain signal at the input terminal).

In few cases, the memory of the device is very small so, it is not possible to club both the firmware in one package. In this situation we flash the test firmware before conducting any test. After finishing of the test, device’s operational firmware will be flashed. This process is also done to make user ignorant of internal operations because most of the test firmware are in debug mode, which may allow tester to understand the internal process. But, it will make the process complex as many firmware versions need to be maintained.

4.6 Managing multiple electrical grounds

Reason for many grounds:

1. In a circuit when AC source is converted into DC using full-wave bridge rectifier, the DC and AC supplies common will be shifted by a DC voltage (half of its rectified voltage)
2. When electrical isolation is required between two parts of the circuit within same PCB, designer maintains different grounds. Transformer needs to be used for getting completely isolated grounds. The both grounds have no relation. So, the voltage between both the grounds is not defined. Still the circuits with different grounds can be interacted by using optocoupler (also known as Photo-isolator).
3. Analog and digital grounds are usually not shorted in the many points of PCB. The reason being that high frequencies signals of the digital signal interfere with the analog signal. The digital and analog grounds are shorted at only one point (i.e. at the power supply stage).

Handling grounds:

In PCB, we should make sure that all the grounds are given different names and not shorted. For connecting measuring instrument, we need to measure voltage with respect to the corresponding ground. We can use a relay network for achieving best isolation among the grounds. We have conducted experiment connecting grounds through the Analog multiplexer. We found that the analog multiplexer is not giving good isolation to the grounds for the first reason mentioned above.

4.7 Pogo Pins

A Pogo pin is a device used in electronics to establish a (usually temporary) connection between two printed circuit boards. Named by analogy with the pogo stick toy, the pogo pin usually takes the form of a slender cylinder containing two sharp, spring-loaded pins pressed between two electronic circuits.

4.8 Temperature sensor

We have developed a module to measure the temperature to the accuracy of 1 DegC. We used an 20K Thermistor. The LabVIEW program is used for calculation part.

Following is the experimental setup

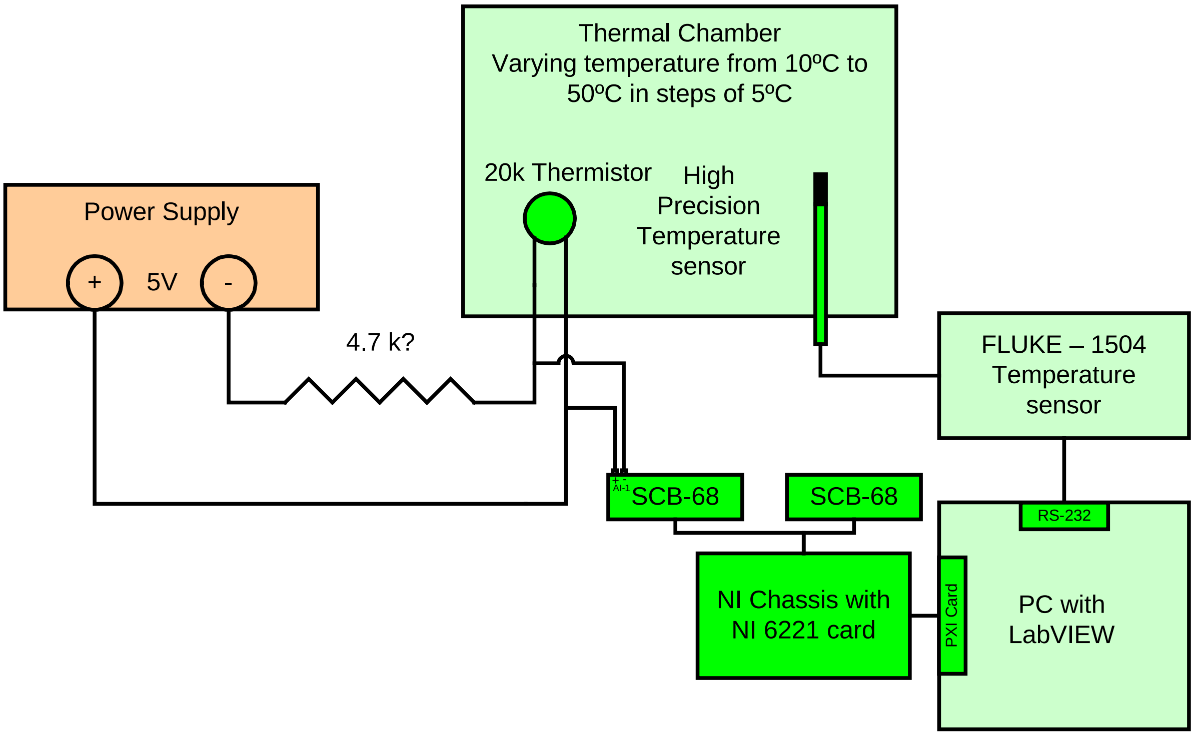


Figure 4.4 - Experimental setup for temperature sensor characterization

Measuring temperature from sensor:

- Got voltage across the 20k Thermistor into LabVIEW using NI DAQ Card
- Calculated resistance of the Thermistor in LabVIEW using formula shown below

$$R_t = \frac{4700 \times V_t}{5 - V_t}$$

Equation 4.5 - Formula for calculating Resistance of Thermistor

- Calculated temperature using following beta formula of Thermistor

$$R_t = R_0 \times e^{\left(\beta \times \left(\frac{1}{T_t} - \frac{1}{T_0}\right)\right)}$$

Equation 4.6 - Relation between Resistance and Temperature

- Used temperature table to calculate the beta value. Formula for calculating beta from measured temperature is

$$\beta = \ln\left(\frac{R_1}{R_2}\right) \times \frac{T_2 - T_1}{T_2 \times T_1}$$

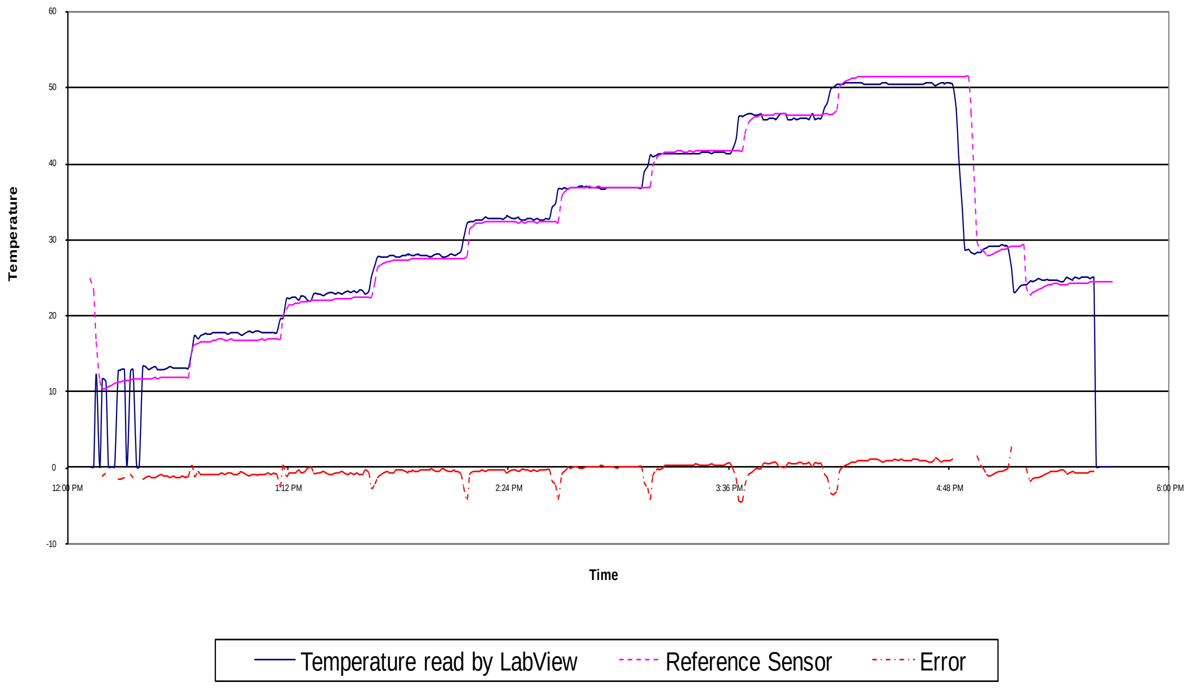
Equation 4.7 - Obtaining Beta value from the resistance vs. Temperature chart

- Formula for measuring temperature is as below

$$T = \frac{\beta}{\frac{\beta}{T_0} + \ln\left(\frac{R}{R_0}\right)}$$

Equation 4.8 - Obtaining temperature from resistance value

Following is the output of the designed sensor and reference sensor



Graph 4.4 - Designed sensor vs. accurate reference sensor

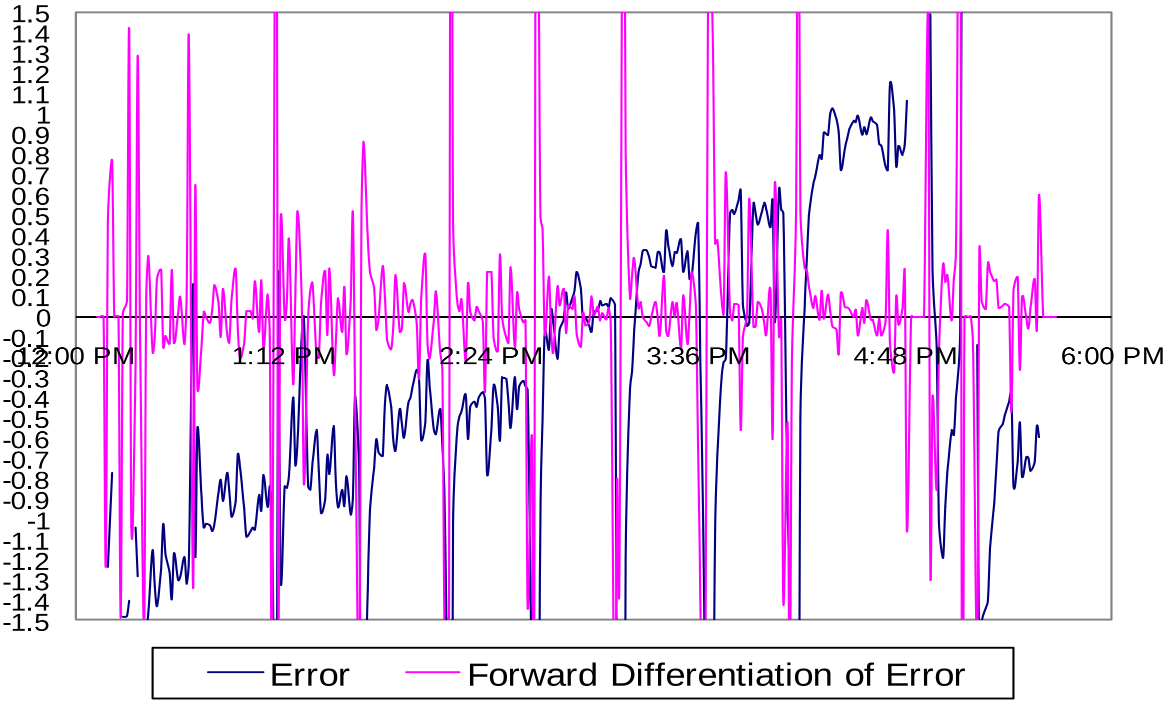
Observation from the measured graph:

- From the graph, it is observed that there is a linear error in the measured value.
- A correction algorithm is developed to eliminate the linear error by subtracting calculated error from measured value.

Error estimation:

- For estimating the error, we have to interpolate the error based on the available data
- All the captured data can not be used, only the readings which attain final stability can be used. For extracting this information, I have selected the points whose differentiation falls with in range (seen from graph as ~±0.5) slope value (the range of values).

Following is the error and its differentiation



Graph 4.5 - Error and forward differentation of error for temperature sensor

Error estimation and correction :

- From the selected data points, we have used statistical method of interpolation with following formula.
- Error equation

$$E = m \times t + c$$

Equation 4.9 - Straight line equation

- Following equations were used solved to get “m” and “c”

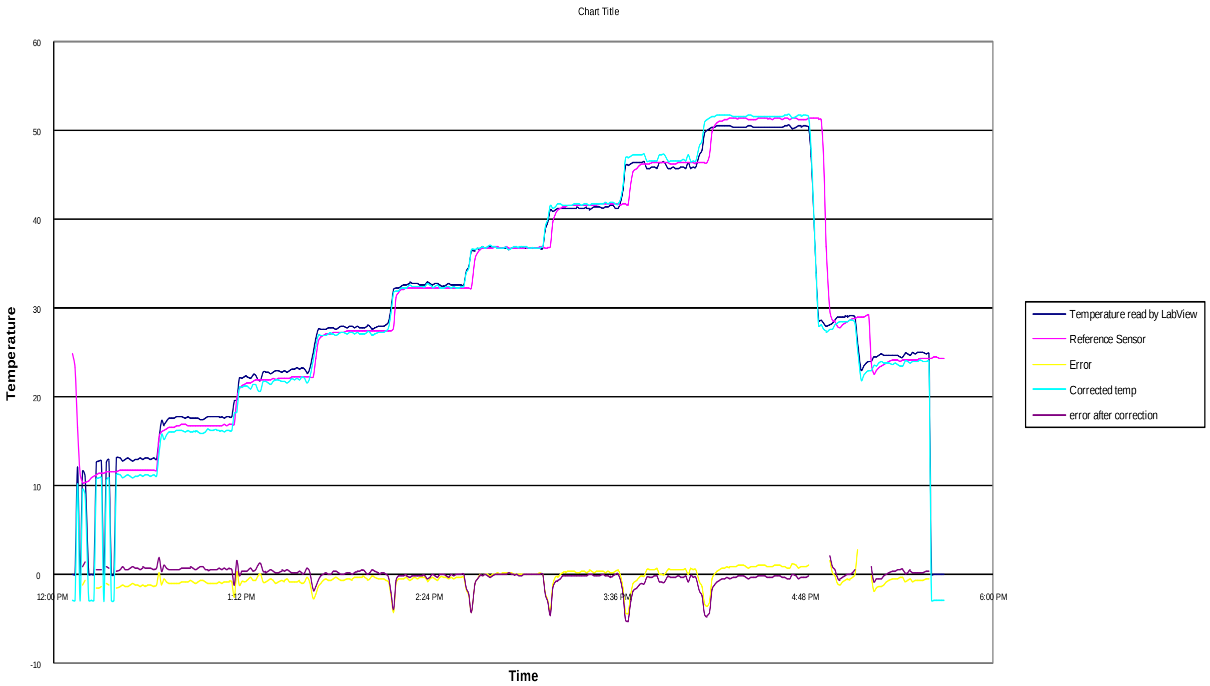
$$\sum_{i=1}^{n} E_i = m \times \sum_{i=1}^{n} t_i + n \times c$$

$$\sum_{i=1}^{n} (E_i)^2 = m \times \sum_{i=1}^{n} (E_i \times t_i) + c \times \sum_{i=1}^{n} E_i$$

Equation 4.10 - Simultaneous equations to be solved for linear estimation constants

The above formula uses all the points to interpolate the error. From the graph, we observed that few points are not valid during transaction. We have separated these values from the valid points by accepting only the values whose absolute value of error differentiation is less than 0.5.

Following is the graph after correction; we can see that the error is less than 1 DegC



Graph 4.6 - Corrected vs. measured temperature

LabVIEW program for temperature calculation from the Thermistor resistance is given below:

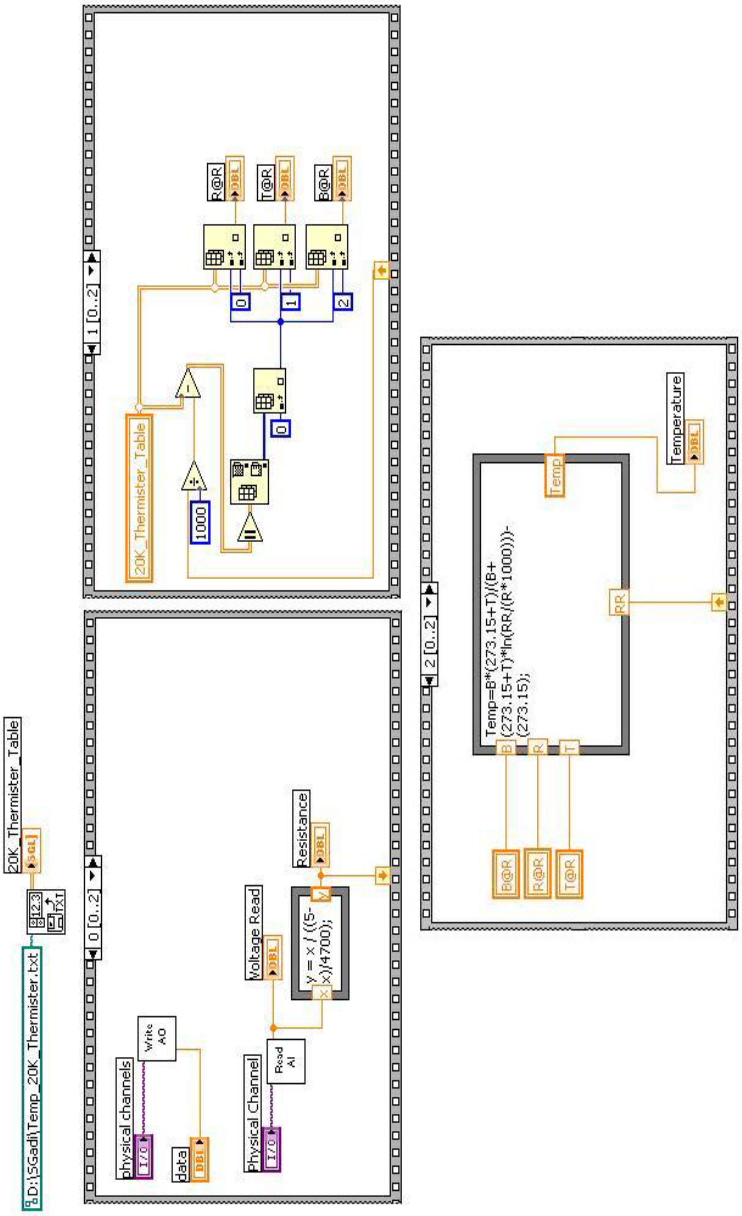


Figure 4.5 - LabVIEW block diagram showing temperature sensor calculations

5 SYSTEM IDENTIFICATION

As a part of the project we made and setup with function generator and oscilloscope. This setup is capable of estimating the transfer function of the connected electrical system. Also this setup is capable of obtaining accurate Bode plot of the connected electrical system.

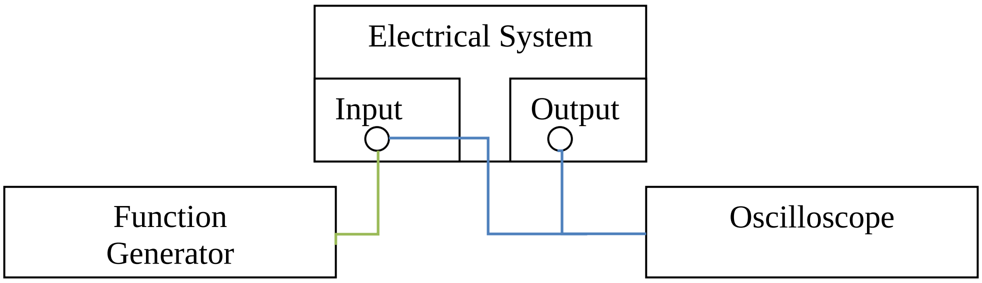


Figure 5.1 - Block Diagram of the setup

5.1 Estimating Transfer Function

In this program a triangular wave is passed though the circuit and the response is captured along with the input from the Oscilloscope. Obtained waveform information is fed to the NI's System Identification tool kit. This toolkit is capable of estimating the characteristics of the circuit for wide range of frequency and generates a transfer function which closely matches the behavior of the connected circuit

5.2 Obtaining accurate Bode Plot with real time data

With the same setup as above, we can use this program to obtain the accurate Bode Plot by giving sine wave of different frequencies and measuring its gain and phase difference.

LabVIEW screenshots are shown in the following pages with program and front panel. We integrated both estimating transfer function and bode plot into a program to make ease in navigation.

5.3 *Screen shots of Front Panel with results*

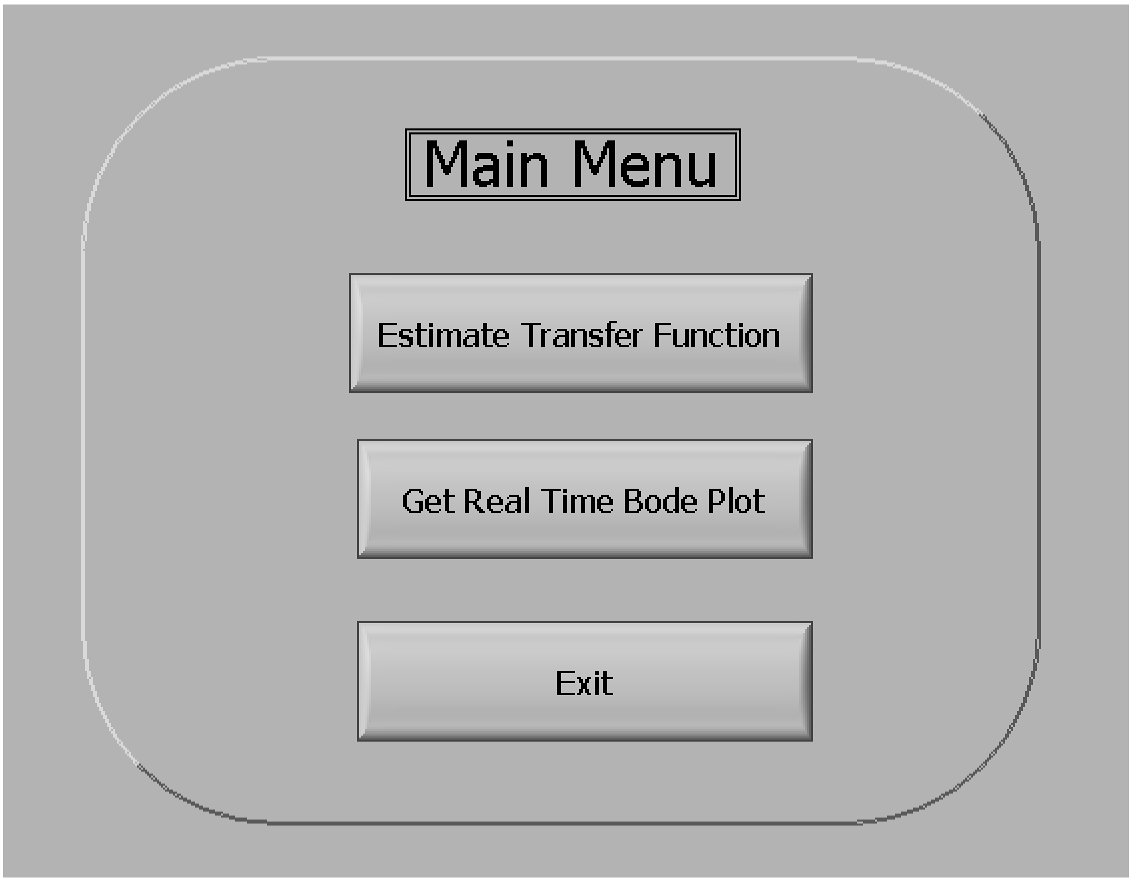


Figure 5.2 - Main Menu for system identification tool

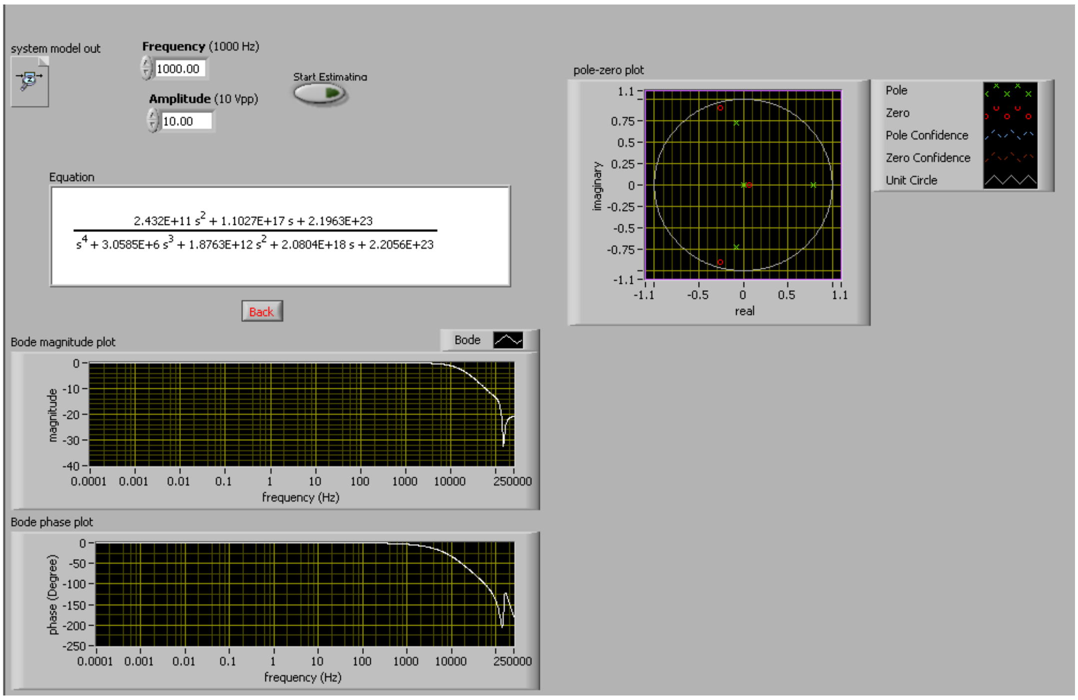


Figure 5.3 - Front Panel of Estimating Transfer Function (filter with time RC = 8e-6 sec)

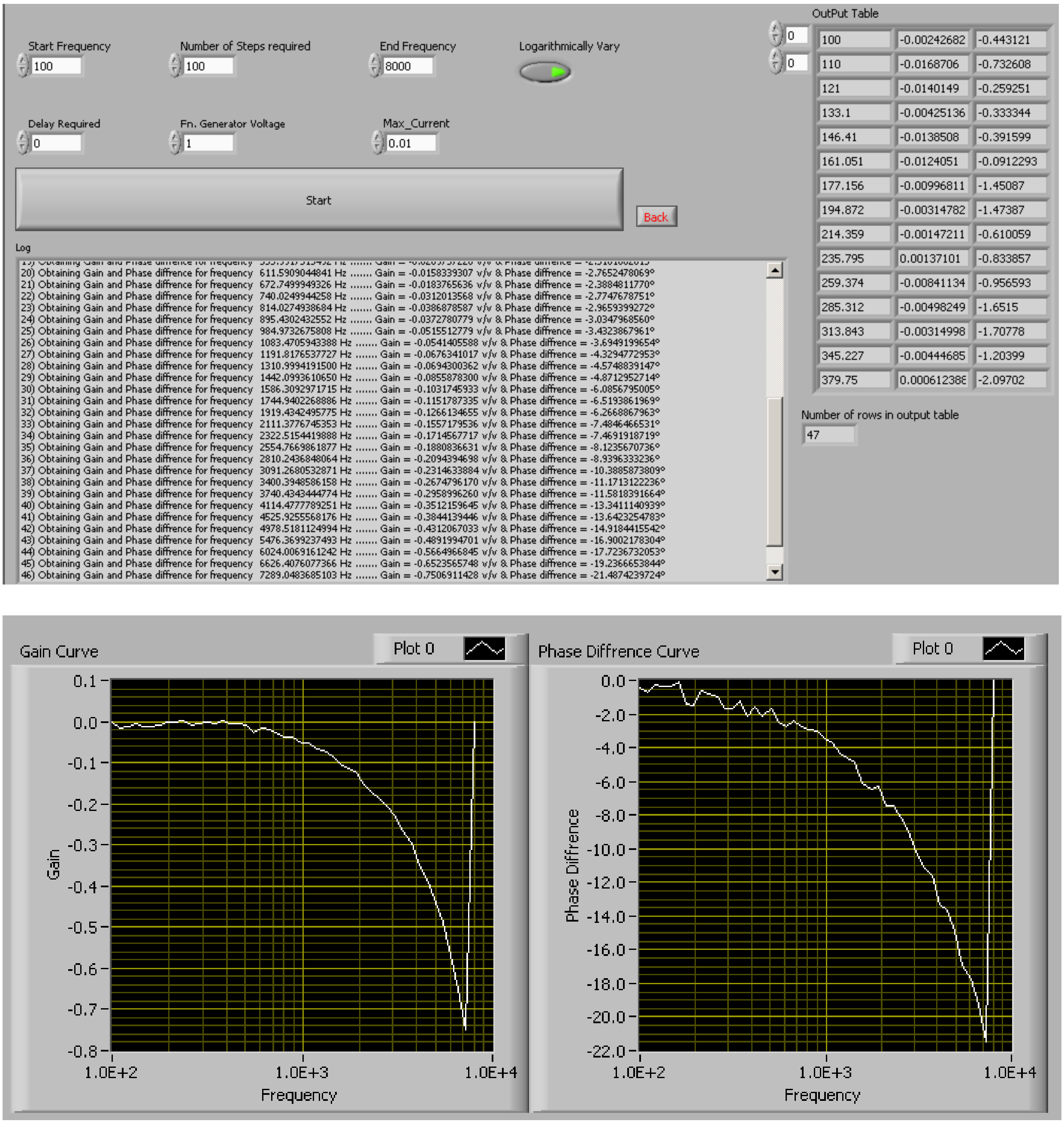


Figure 5.4 - Front Panel of Real Time Bode Plot (filter with RC = 8e-6 sec)

5.4 Block diagram and Front panel for generating theoretical Bode Plot

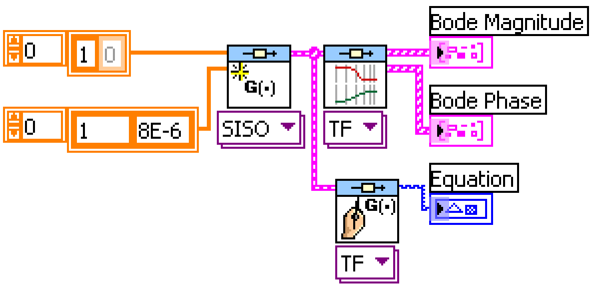


Figure 5.5 - Block Diagram of the theoretical calculation for Bode Plot

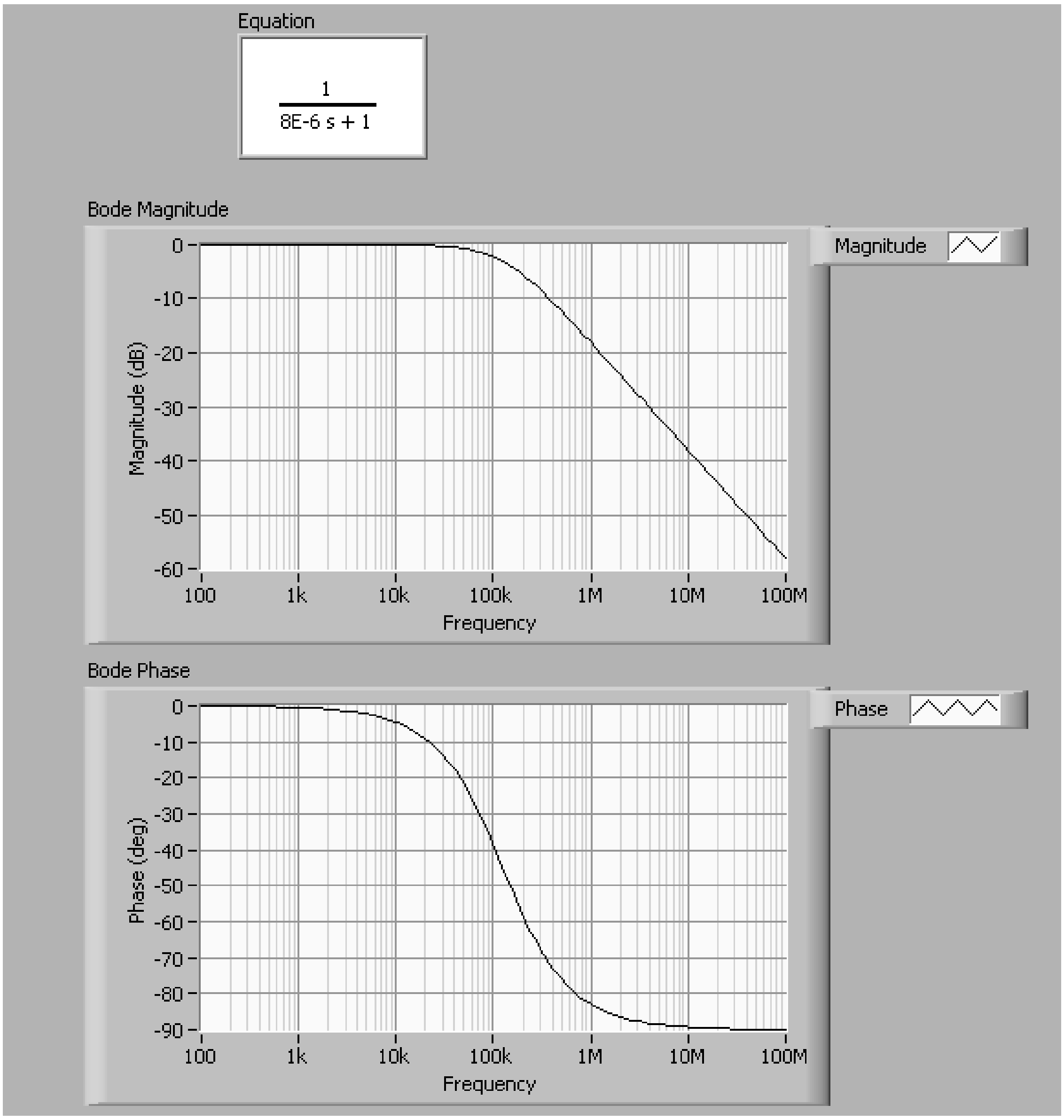


Figure 5.6 - Front Panel of the theoretical Bode Plot

5.5 Screenshots Block diagram showing program in detail

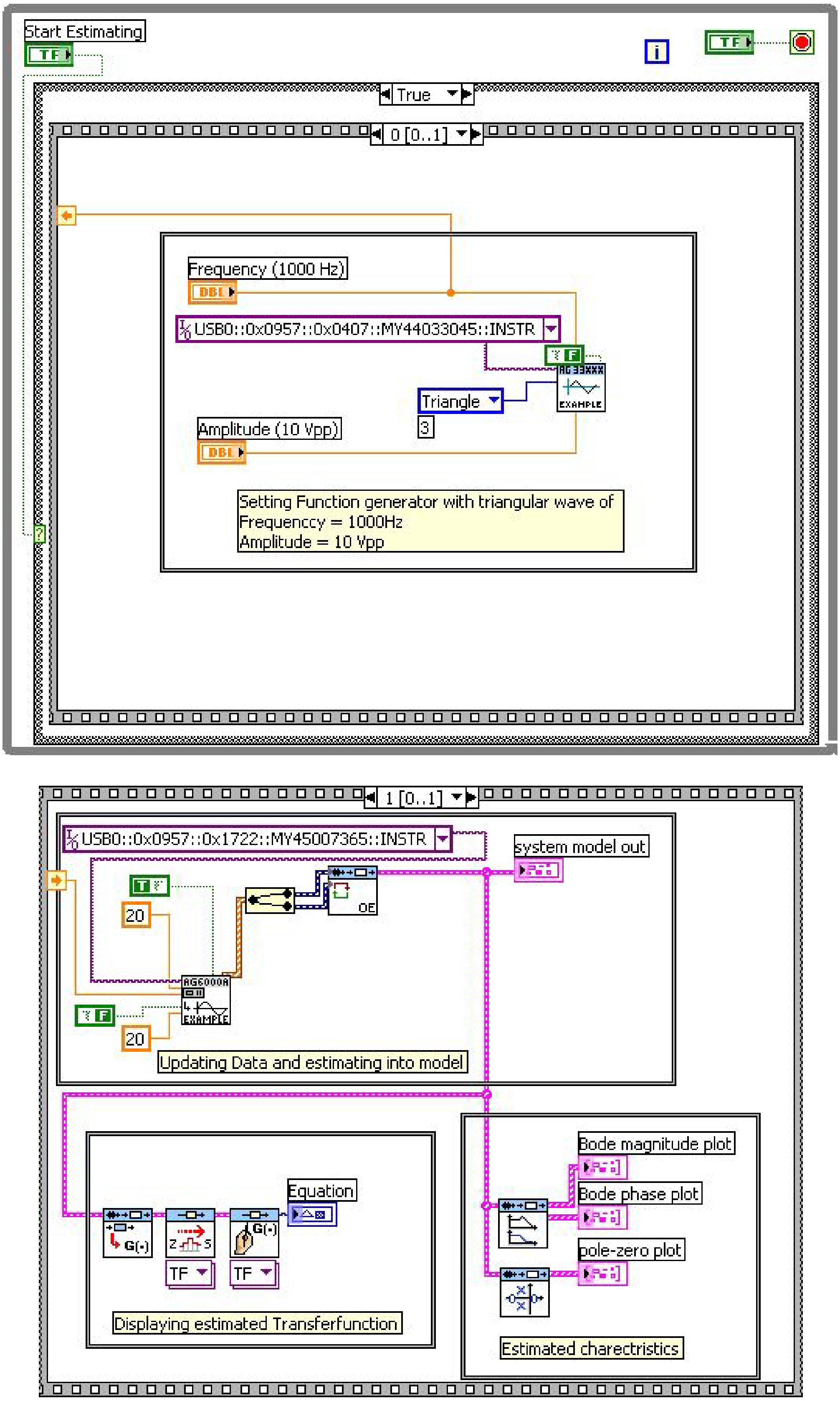


Figure 5.7 - Block diagram showing program for estimating Transfer Function

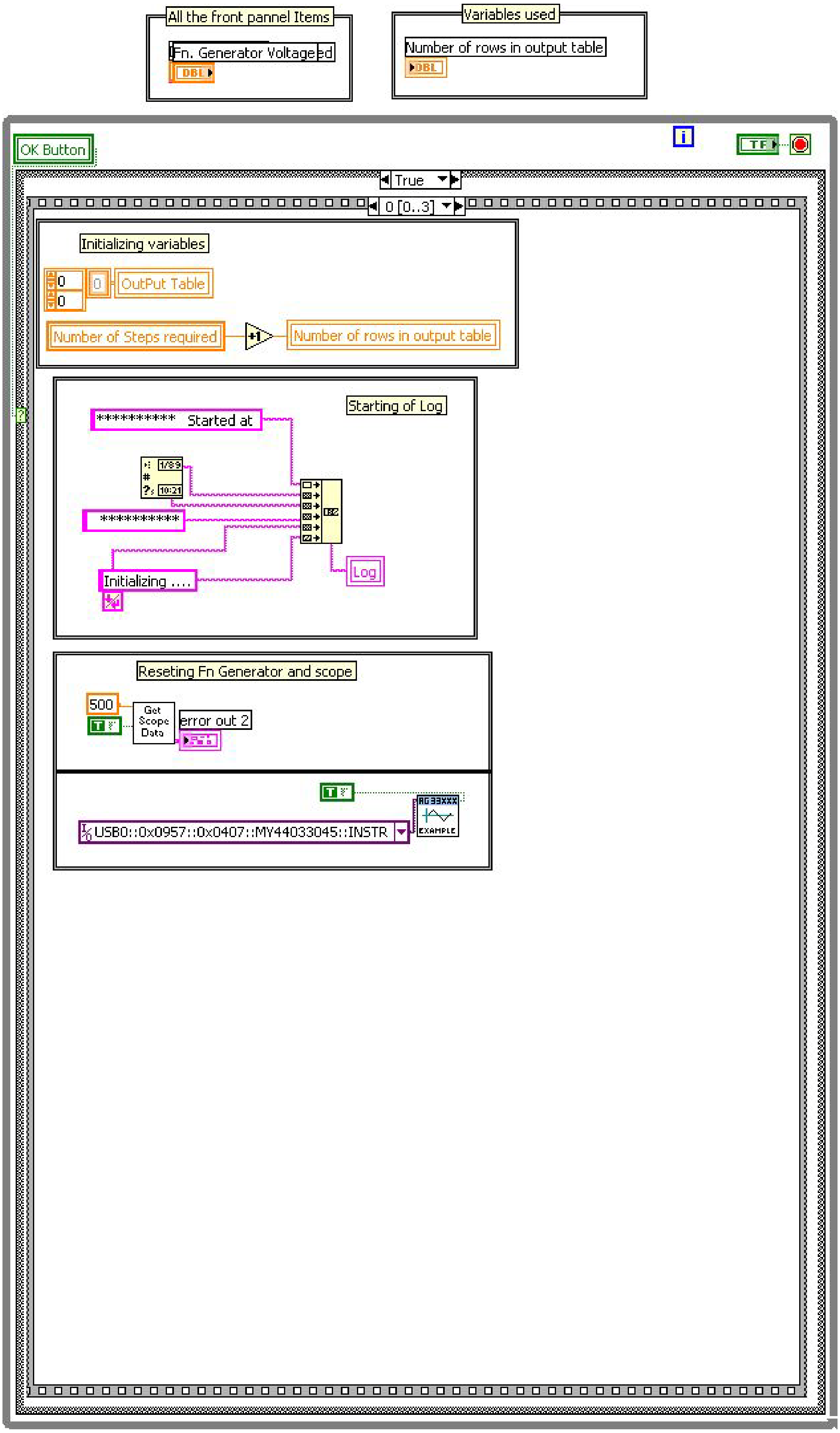


Figure 5.8 - Block Diagram showing program for real time Bode Plot (part 1 of 8)

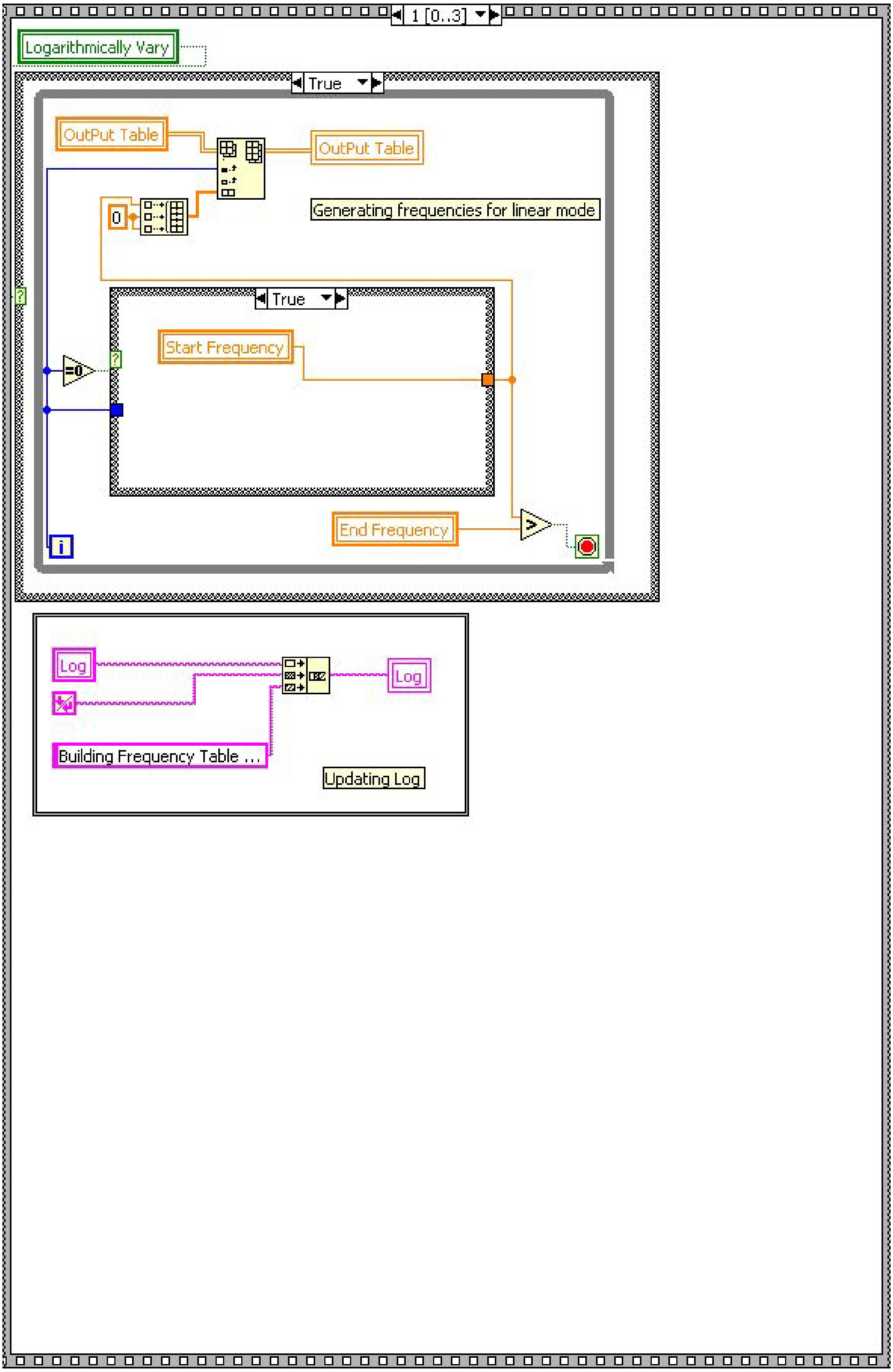


Figure 5.9 - Block Diagram showing program for real time Bode Plot (part 2 of 8)

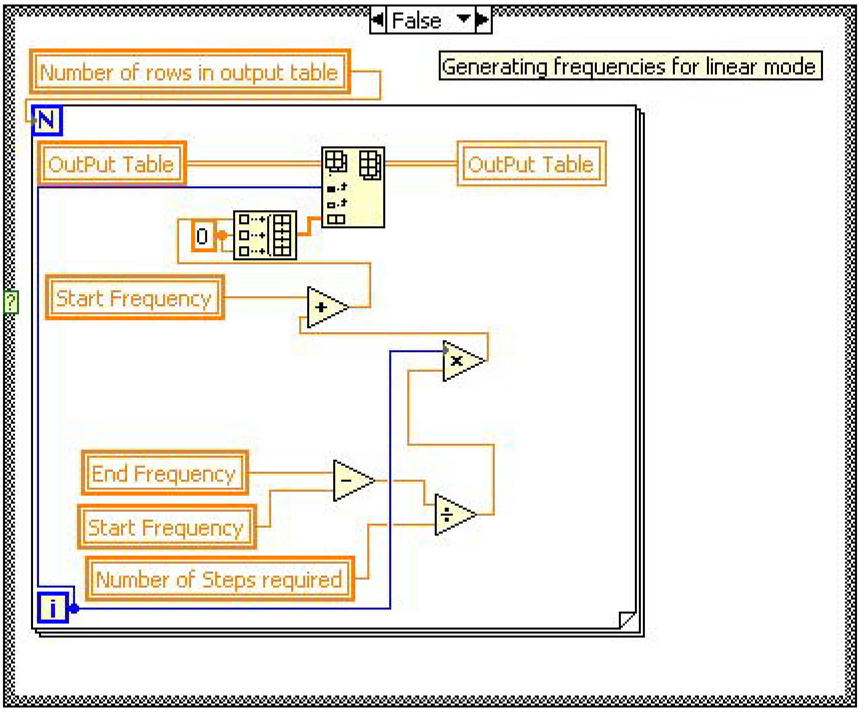


Figure 5.10 - Block Diagram showing program for real time Bode Plot (part 3 of 8)

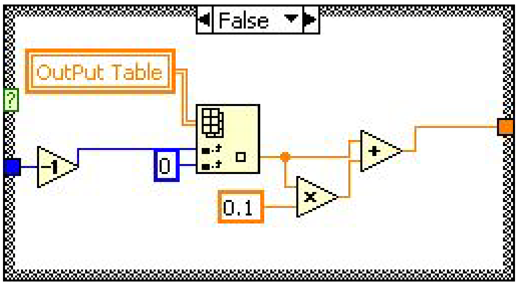


Figure 5.11 - Block Diagram showing program for real time Bode Plot (part 4 of 8)

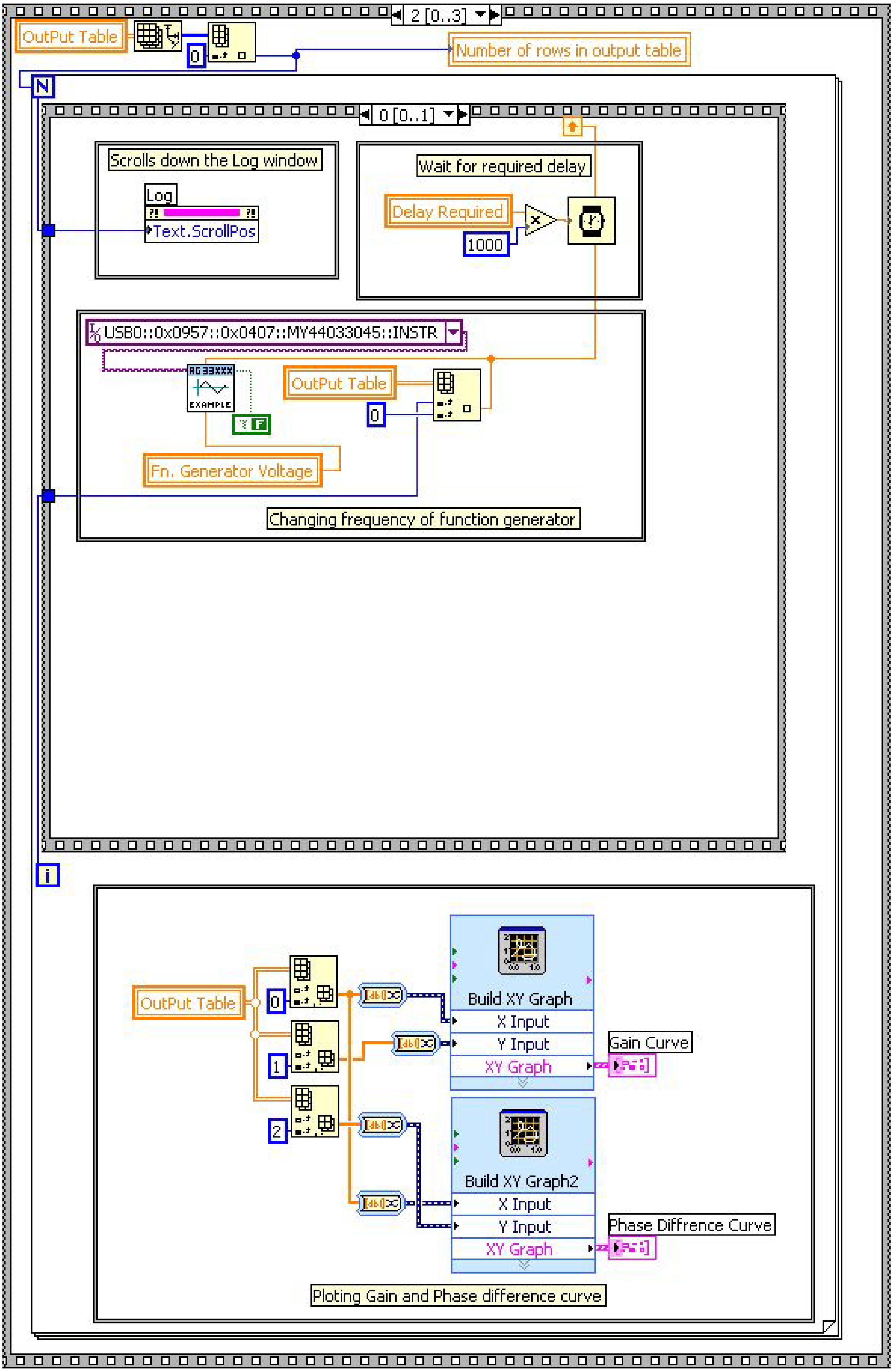


Figure 5.12 - Block Diagram showing program for real time Bode Plot (part 5 of 8)

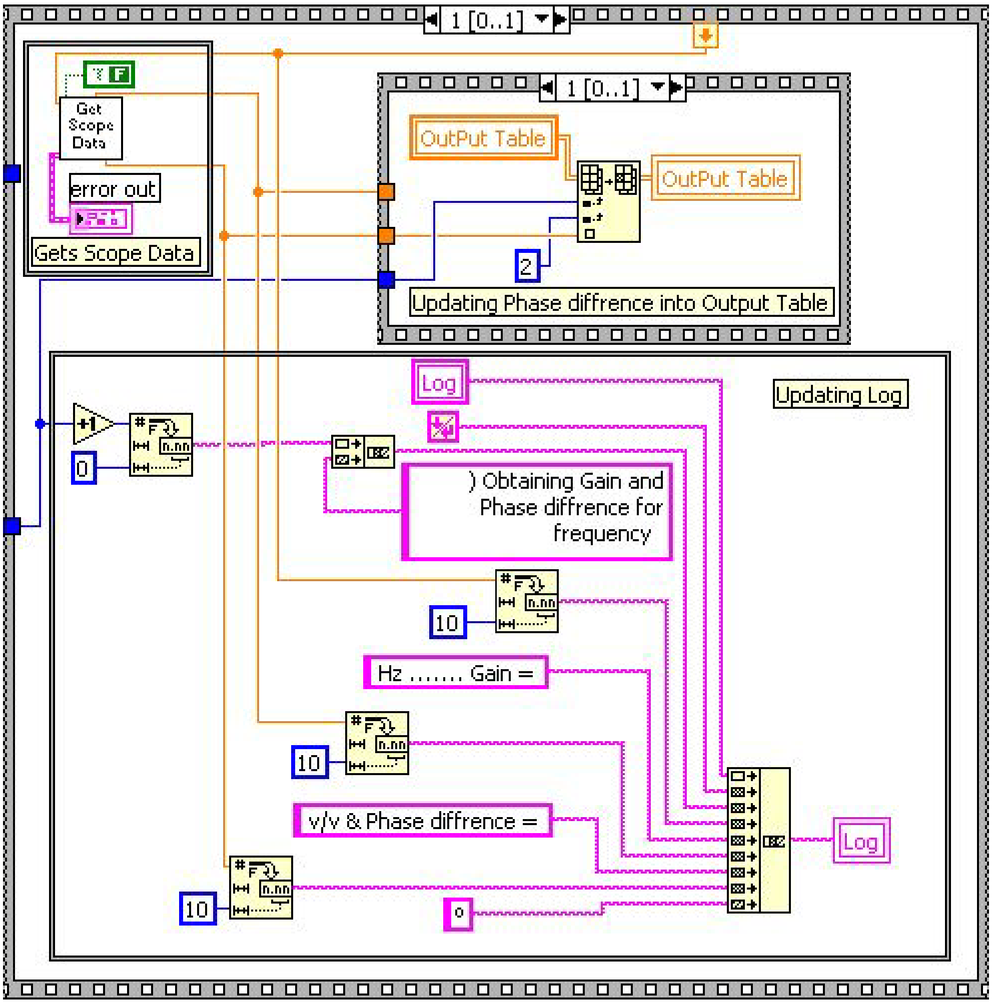


Figure 5.13 - Block Diagram showing program for real time Bode Plot (part 6 of 8)

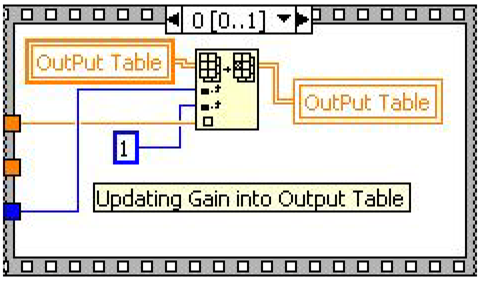


Figure 5.14 - Block Diagram showing program for real time Bode Plot (part 7 of 8)

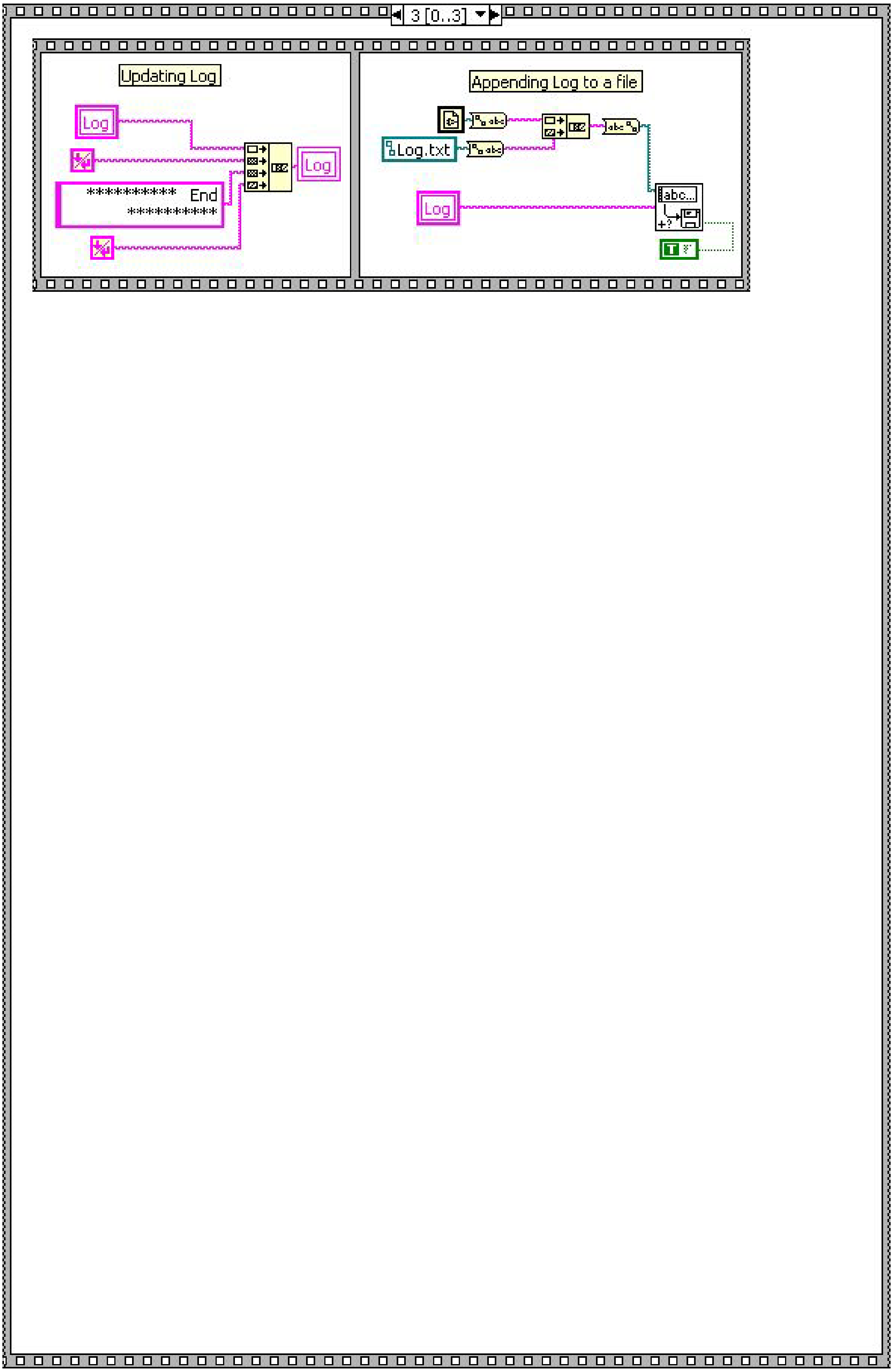


Figure 5.15 - Block Diagram showing program for real time Bode Plot (part 8 of 8)

6 RESULTS AND DISCUSSIONS

The designed FFT is capable of testing the almost all possible functions of the DUT. Design is reviewed by the people of both internal and external to the team. The suggestions given by experienced people made the design robust. The design is given for the fabrication process. A small prototype was made to test several electrical functionalities. This prototype does not have mechanical parts automated. With the available prototype, we have verified out test setup is working as per expectations.

As most of the testing process is same of all various HVAC controllers, the electrical part of the test fixture is made in common so that the same setup can be reused for another device. The mechanical fixture with sensors and actuators will change with the device.

The FFT design met the goal, but still there is a chance of improvement in terms of the time of completion of test. The present design is testing the DUT in a single treaded operation. The time taken for testing one DUT can be greatly reduced by multithreaded operations i.e. more than one function can be tested in parallel.

The experiment conducted for system identification was verified against the theoretical results and found satisfactory. The transfer function identified by the program is 4^{th} order with coefficients very high values. The program can be further developed to simplify the transfer function to the order specified by user.

The setup used for system identification is not able to read the values of the voltage when output of the system falls below 100 mV. High sensitive oscilloscope can be used to obtain good results.

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