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Virtual Instrumentation and It's Applications

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Abstract:—The development and use of programmable measurement systems have been widely explored. The possibility of modifying the measurement procedure simply by changing the algorithm executed by the computer-based architecture without replacing the hardware components makes any experimental activity easier. Virtual measurement systems has been introduced to simplify the design and implementation of programmable measurement systems by adopting a visual interface. In this report, the overview of virtual instrumentation has been discussed. The reasons for a wide acceptance of LabVIEW have been highlighted. The applications and field where LabVIEW has been widely used are reviewed. In the end, small implementations on LabVIEW have been demonstrated.

Keywords:—LabVIEW,VIs,DAQs

I. INTRODUCTION

A virtual instrument consists of an industry-standard computer or workstation equipped with powerful application software, cost-effective hardware such as plug-in boards, and driver software, which together perform the functions of traditional instruments. Virtual instruments represent a fundamental shift from traditional hardware-centered instrumentation systems to software-centered systems that exploit the computing power, productivity, display, and connectivity capabilities of popular desktop computers and workstations. With virtual instruments, engineers and scientists build measurement and automation systems that suit their needs (user-defined) exactly instead of being limited by traditional fixed-function instruments (vendor-defined). Thus development time is reduced and higher quality products with lower design costs are designed.

Virtual instrumentation combines mainstream commercial technologies, such as the PC, with flexible software and a wide variety of measurement and control hardware.

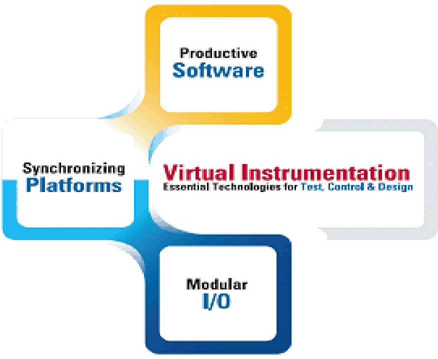


Figure 1.1. *Virtual instrumentation combines productive software, modular I/O, and scalable platforms.*

National Instruments introduced virtual instrumentation in the year 1995, changing the way engineers and scientists measure and automate the world around them. In 2004, National Instruments sold more than 6 million channels of virtual instrumentation in 90 countries. Today, virtual instrumentation has reached mainstream acceptance and is used in thousands of applications around the world in industries from automotive[1]-[2],aerospace[3],nuclear physics[4],biomedical science[5] etc to consumer electronics, to oil and gas.

The main categories of virtual instruments:

- i) Graphical front panel on the computer screen to control the modules or instruments
- ia) controlled module is plug-in DAQ (data acquisition)board,
- ib) controlled instrument is based on GP-IB (general purpose I/O) board,
- ic) controlled instrument is connected via serial port,
- id) controlled instrument is VXI (VME extension)-board (or system).

ii) Graphical front panel with no physical instruments at all connected to the computer. Instead, the computer acquires and analyses the data from files or from other computers on a network, or it may even calculate its data mathematically to simulate a physical process or event rather than acquiring actual real world data.

1.1 Basic components of a virtual instrument

The basic components of all virtual instruments include a computer and a display, the virtual instrument software, a bus structure (that connects the computer with the instrument hardware) and the instrument hardware[6].

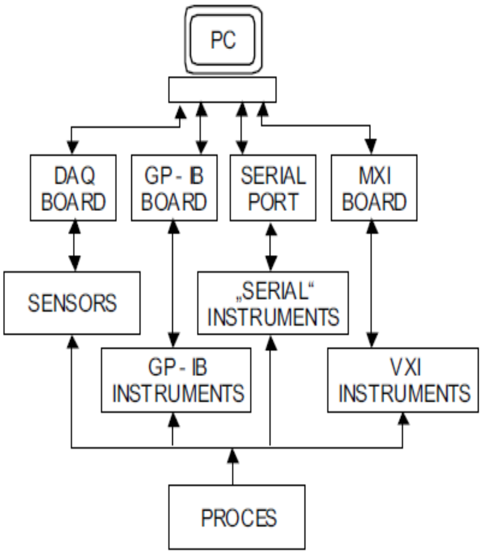


Figure 1.2: *Block diagram of a virtual instrument*

- **Computer and Display:** The computer and the display are the heart of virtual instrument systems. It is important for the chosen computer to meet the system requirements specified by the instrumentation software packages. Rapid technological advancements of PC technology have greatly enhanced virtual instrumentation. Moving from DOS to Windows gave the graphical user interface and made 32-bit software available for building virtual instruments. The future of virtual instrumentation is tightly coupled with PC technology.

- **Software:** The software uniquely defines the functionality and personality of the virtual instrument system. Most software is designed to run on industry standard operating systems on personal computers and workstations. Software implemented can be divided into several levels, which can be described in a hierarchical order:

▪ *Register level software:* Register-level software requires the knowledge of inner register structure of the device (DAQ board, RS 232 instrument, GP-IB instrument or VXI module) for entering the bit combination taken from the instruction manual in order to program measurement functions of the device. It is the hardest way in programming. The resulting program is strongly hardware dependent and it is rarely executable on systems with different hardware.

▪ *Driver level software:* Device drivers perform the actual communication and control of the instrument hardware in the system. They provide a medium-level easy-to-use programming model that enables complete access to complex measurement capabilities of the instrument. In the past programmers spent a significant amount of time writing this software from scratch for each instrument of the system. Today, instrument drivers are delivered as modular, off-the-shelf components to be used in application programs. Several leading companies formed (in 1988) the Interchangeable Virtual Instrument (IVI) Foundation. The IVI Foundation was formed to establish formal standards for instrument drivers and to address the limitations of the former approaches.

▪ *High-level tool software:* Currently the most popular way of programming is based on the high-level tool software. With easy-to-use integrated development tools, design engineers can quickly create, configure and display measurements in a user-friendly form, during product design, and verification. The various high level tool software are discussed later in the section.

▪ *SCPI Standard commands for programmable instruments:* SCPI is not a software tool as are former systems, but it is an effective aid enabling easy standardised control of programmable instruments. SCPI decreases development time and increases a readability of test programs. SCPI provides

an easy understandable command set,
guarantees a well-defined instrument
behaviour under all conditions, which
prevents unexpected instrument behavior.
Although IEEE 488.2 is used as basis of
SCPI, it defines programming commands
that we can use with any type of hardware or
communication link. It has an open structure.
The SCPI Consortium continues in
adding commands and functionality to the
SCPI standard.

- **Interconnect Buses:** Four types of interconnect buses dominate the industry: the serial connection (serial port), the GPIB, the PC bus and VXI bus.
- *Serial port:* Serial communication based on RS-232 standard is the simplest way of using a computer in measurement applications and control of instruments. Serial communication is readily available via the serial port of any PC and it is limited in data transmission rate and distance (up to 19:2 Kbytes/sec, recently 115 Kbytes/sec, and 15 m) and it allows only one device to be connected to a PC.
- *GPIB:* It was the first industry standard bus for connecting computers with instrum-entation. A major advantage of GPIB is that the interface can be embedded on the rear of a standard instrument. This allows dual use of the instrument: as a stand-alone manual instrument or as a computer-controlled instrument. The GPIB offers a flexible cable that connects a GPIB interface card in the computer to up to 15 instruments over a distance of up to twenty meters. The interface card comes with software that allows transmission of commands to an instrument and reading of results. GPIB has a maximum data rate of 1 Mbytes/s and typical data transfers are between 100 and 250 Kbytes/s. It depends on the response of the measured subject.
- *PC-bus:* With the rapid acceptance of the IBM personal computer in test and measurement applications, there has been a corresponding growth of plug-in instrumentation cards that are inserted into spare slots. However, high-accuracy instruments require significant circuit board space to achieve their intended precision. Because of the limited printed circuit board space and close proximity to sources of electromagnetic interference, PC bus instruments tend to be of lower performance than GPIB instruments but also of lower cost. Many are simple ADCs, DACs, and digital I/O cards. Since these cards plug directly into the computer backplane and contain no embedded command interpreter as found in GPIB instruments, personal computer plug-in cards are nearly always delivered with driver software so that they can be operated from a personal computer. This software may or may not be compatible with other virtual instrument software packages, so it is recommended to check with the vendors beforehand. Most data acquisition boards are multifunctional, i:e they accept both analogue and digital signals. These plug-in data acquisition boards gain wider acceptance due to their low price and high flexibility obtained from the associated software.
- *VXI bus:* In the late eighties, the VME eXtension for Instrumentation (VXI) standard allowed communication among units with transfer over 20 Mbytes/second between VXI systems. VXI instruments are installed in a rack and are controlled by, and communicate directly with, a VXI computer. These VXI instruments do not have buttons or switches for direct local control and do not have local display typical in traditional instruments.
  It is an open-system instrument architecture that combines many of the advantages of GPIB and computer backplane buses. VXIbus instruments are plug-in modules that are inserted into specially designed card cages.

1.2 Virtual instruments versus traditional instruments.

Stand-alone traditional instruments such as oscilloscopes and waveform generators are very powerful, expensive, and designed to perform one or more specific tasks defined by the vendor.
However, the user generally cannot extend or customize them. The knobs and buttons on the instrument, the built-in circuitry, and the functions available to the user, are all specific to the nature of the instrument. Engineers and scientists whose needs, applications, and requirements change very quickly, need flexibility to create their own solutions. One can adapt a virtual instrument to his/her particular needs without having to replace the entire device because of the application software installed on the PC and the wide range of available plug-in hardware.

Flexibility

Except for the specialized components and circuitry found in traditional instruments, the general architecture of stand-alone instruments is very similar to that of a PC-based virtual instrument. Both require one or more microprocessors, communication ports (for example, serial and GPIB), and display capabilities, as well as data acquisition modules. What makes one different from the other is their flexibility and the fact that one can modify and adapt the instrument to his/her particular needs. A traditional instrument might contain an integrated circuit to perform a particular set of data processing functions; in a virtual instrument, these functions would be performed by software running on the PC processor.
Here are some examples of this flexibility in practice:

1. One Application -- Different Devices

A single application made, using any high level tool software can be used with an M Series DAQ board,
a PXI system and NI USB DAQ product.
Regardless of the choice, he can use virtual instrumentation in a single program in all three cases with no code change needed.

Figure 1.3. *Upgrading hardware is easy when using the same application for many devices.*

2. Many Applications, One Device

A single M Series DAQ device used for measuring motor position can also be used to monitor and log the power drawn by the same motor. The same device can be reused for many applcations even though the task is significantly different.

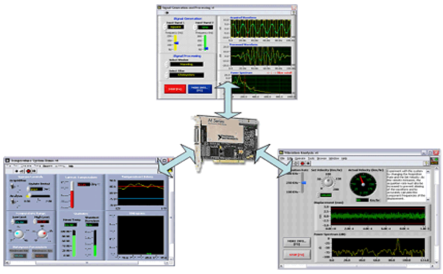


Figure 1.4. *Reduce costs by reusing hardware for many applications.*

Lower Cost

By employing virtual instrumentation solutions, you can lower capital costs, system development costs, and system maintenance costs, while improving time to market and the quality of your own products.

Plug-In and Networked Hardware

There is a wide variety of available hardware that one can either plug into the computer or access through a network. These devices offer a wide range of data acquisition capabilities at a significantly lower cost than that of dedicated devices. As integrated circuit technology advances, and off-the-shelf components become cheaper and more powerful, so do the boards that use them. With these advances in technology come an increase in data acquisition rates, measurement accuracy, precision, and better signal isolation.

II. SOFTWARE IN VIRTUAL INSTRUMENTATION

Software is the most important component of a virtual instrument. With the right software tool, engineers and scientists can efficiently create their own applications, by designing and integrating the routines that a particular process requires. They can define how and when the application acquires data from the device, how it processes, manipulates and stores the data, and how the results are presented to the user.

An important advantage that software provides is modularity. When dealing with a large project, engineers and scientists generally approach the task by breaking it down into functional solvable units. These subtasks are more manageable and easier to test, given the reduced dependencies that might cause unexpected behavior. One can design a virtual instrument to solve each of these subtasks, and then join them into a complete system to solve the larger task.

Virtual instrumentation software can be divided into several different layers:

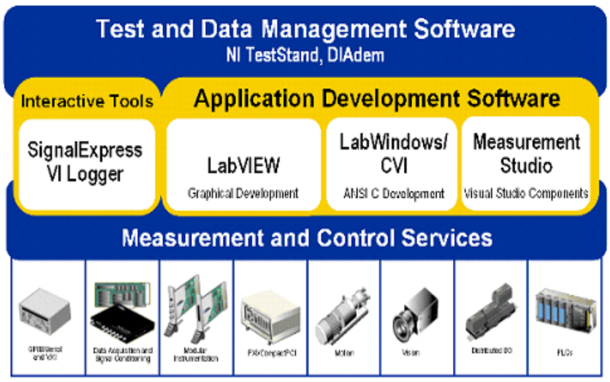


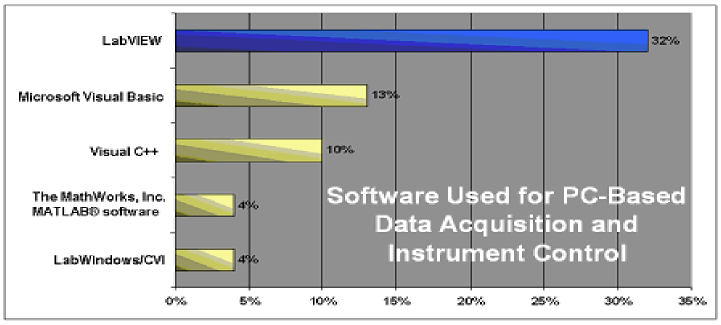
Figure 1.5 *Layers of virtual instrument's software*

- **Application Software:** This is the primary development environment for building an application. It includes software such as LabVIEW, LabWindows/CVI (ANSI C), Measurement Studio (Visual Studio programming languages), SignalExpress, and VI Logger.
- **Test and Data Management Software:** Above the application software layer is the test executive and data management software layer. This layer of software incorporates all of the functionality developed by the application layer and provides system-wide data management. There are many existing Test Management Software and Data Management Software solutions available.
- **Measurement and Control Services Software:** The last layer is often overlooked, yet critical to maintaining software development productivity. The measurement and control services layer includes drivers, such as NI-DAQmx, which communicate with all of the hardware. It must access and preserve the hardware functions and performance. It also must be interoperable .It has to work with all other drivers and the many modular I/O types that can be a part of the solution.

A brief description of all the types of application software used is given below [10]:

- **LabVIEW (Laboratory Virtual Instrument Engineering Workbench)** is a highly productive graphical programming language for building data acquisition and instrumentation systems. To specify the system functionality one intuitively assembles block diagrams - a natural design notation for engineers. Its tight integration with measurement hardware facilitates rapid development of data acquisition, analysis and presentation of solutions makes it the most widely used software.
- **LabWindows/CVI (C for Virtual Instrumentation)** is a Windows based, interactive ANSI C programming environment designed for building virtual instrumentation applications. It delivers a drag-and-drop editor for building user interfaces, a complete ANSI C environment for building test program logic, and a collection of automated code generation tools, as well as utilities for building automated test systems. The main power of CVI lies in the set of libraries.
- **HP VEE (Hewlett-Packard's Visual Engineering Environment)** allows graphical programming for instrumentation applications. It is a kind of Visual Engineering Environment, an iconic programming language for solving engineering problems.
- **TestPoint** is a Windows based object-oriented software package that contains extensive GPIB instrument and DAQ board support. It contains a novel state-of-the art user interface that is easy to use. Objects, called "stocks" are selected and dragged with a mouse to a work area (panel). Logic low is easily established with a point and drag action list.
- **Measurement Studio** is a measurement tool for data acquisition, analysis, visualization and Internet connectivity. Measurement Studio provides a collection of controls and classes designed for building virtual instrumentation systems inside Visual Basic or Visual C++.

The following chart gives a comparative analysis of the usage of software .



Source: Survey of 400 US readers from *T&M World*, *EDN*, *Design News*, and *R&D* magazines, Q1 2004

Figure 1.6 *Usage of Software*

National Instruments has been a virtual instrumentation leader for more than 25 years. As shown in the statistics of (figure 1.6) NI's labVIEW has been the most widely used application software for making virtual instruments. This is due to the following features that NI offers:

1. Express technology

National Instruments created Express technology for LabVIEW, LabWindow/CVI, and Measurement Studio in 2003 to reduce code complexity while preserving power and functionality. Today, more than 50 percent of data acquisition customers use DAQ Assistant to simplify data acquisition tasks.

2. The LabVIEW Real-Time Module and LabVIEW PDA Modules

National Instruments extended LabVIEW for deterministic execution using the LabVIEW Real-Time Module and developed matching hardware platforms to make embedded application deployment a reality. The LabVIEW PDA Module extended virtual instrumentation and the LabVIEW platform to handheld devices.

3. NI SignalExpress

National Instruments created SignalExpress –
a drag-and-drop, no-programming-required environment ideal for exploratory measurements.
In addition to the strong software differentiator, National Instruments offers the most broad and innovative I/O selection among virtual instrumentation companies.

III. APPLICATIONS OF VIRTUAL INSTRUMENTS

Virtual instrumentation has been widely adopted in test and measurement areas. It has gradually increased addressable applications through continuous LabVIEW innovation and hundreds of measurement hardware devices.

3.1 Virtual Instrumentation for Test

Test has been a long-proven field for virtual instrumentation. More than 25,000 companies (the majority being test and measurement companies) use virtual instrumentation. Virtual instrumentation combines rapid development software and modular, flexible hardware to create user-defined test systems. It delivers:

- Intuitive software tools for rapid test development.
- Fast, precise modular I/O based on innovative commercial technologies.
- A PC-based platform with integrated synchronization for high accuracy and throughput.

3.2 Virtual Instrumentation for Industrial I/O and Control

PCs and PLCs both play an important role in control and industrial applications. PCs bring greater software flexibility and capability, while PLCs deliver outstanding ruggedness and reliability. But as control needs become more complex, programmable automated controllers (PACs) are required.
PACs deliver PC software flexibility with PLC ruggedness and reliability. LabVIEW software and rugged, real-time, control hardware platforms are ideal for creating a PAC.

3.3 Virtual Instrumentation for Design

The same design engineers that use a wide variety of software design tools must use hardware to test prototypes. Commonly, there is no good interface between the design phase and testing/validation phase, which means that the design usually must go through a completion phase and enter a testing/validation phase. Issues discovered in the testing phase require a design-phase reiteration.

Figure 1.7. *Test plays a critical role in the design and manufacture of today's electronic devices.*

In reality, the development process has two very distinct and separate stages – design and test are two individual entities. The gap between these two worlds has traditionally been neglected.
As designs iterate through this build-measure-tweak-rebuild process, the designer needs the same measurements again.
NI offers multisim (*.ms 11) for simulation of circuit level design and these simulations can be combined with LabVIEW with the help of LabVIEW Multisim Connectivity Toolkit which is freely downloadable from the website of national semiconductors. Thus one can view the results of simulations on hardware devices.

3.4. Fields of application:

Some fields in which virtual instrumentation are extensively used are:

3.4.1. Virtual instrumentation in automobile engineering: Several researches are going on for optimizing the use of virtual instrumentation in this field. In [1], a vehicle test based system is proposed which does the data collection about the health status of the vehicle after the manufacturing phase (i:e speed,light, emissions, brake, side slipping etc). It stores this vehicle information in an oracle database and this database is compatible with LabVIEW.

In [2] an accurate, automated wind tunnel instrumentation system is presented. Wind tunnel is fundamental for understanding the aerodynamic response and performance of space /road vehicles during the design process. The wind tunnel measuring instrument typically includes the wind speed measurement and control, static and dynamic force measurement, pressure profile measurement, position and motion control for orienting the model with respect to the wind direction.

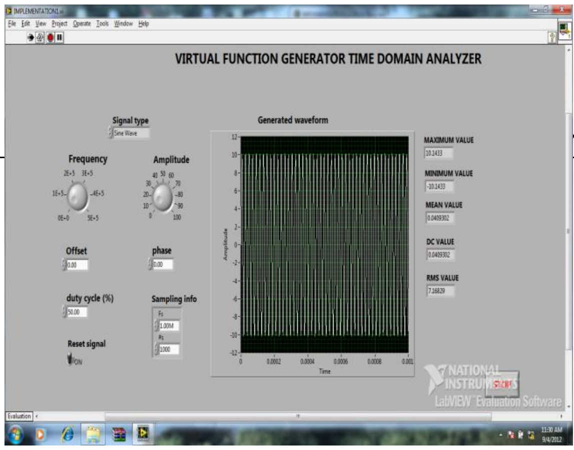


Figure 1.8 *A virtual calculator*

3.4.2. Virtual instrumentation for aerospace engineering: In [3] a fully automated test system is designed that can make static and dynamic unbalanced measurement without human intervention. Thus, it is used as a balancing system for rockets and payloads. The author claims that this new VI based measuring system has the advantages of user friendliness, high precision and accuracy, high efficiency and low cost.

3.4.3. Virtual instrumentation in nuclear physics: In [4], the VI has been applied to develop a system which provides nuclear spectroscopy measurements such as amplitude and time signal analysis. Using the device driver NI scope ,the virtual instrument shows several types of radiation spectroscopes such as gamma ray, X-ray, spectroscopy of charged particles (alpha, electron, proton etc.)

3.4.4. Virtual instrumentation in education: Several VI based teaching tools have been proposed in [5]-[8] which can be used by the UG students. [6]discusses implementation of ammeter, voltmeter, wattmeter so that even important quantities like reactive power and power angle which cannot be which cannot be shown on traditional instruments can also be visualized [7] proposes an educational tool for image recognition which can be used for surface shape recognition, material classification etc.

3.4.5 Virtual instrumentation in biomedical: Several researches are going on in this field.[9] proposes a system for maintaining the database of patients and sending alert messages to the doctors in case of emergency.

Today ,virtual instrumentation has it's spread in nearly all the fields of engineering due to it's easy hardware interface and economic cost. Only some of them have been enlisted above.

IV. IMPLEMENTATIONS

Implementation 1: A user defined calculator has been made which can be used by the engineering students to cross check their answers.

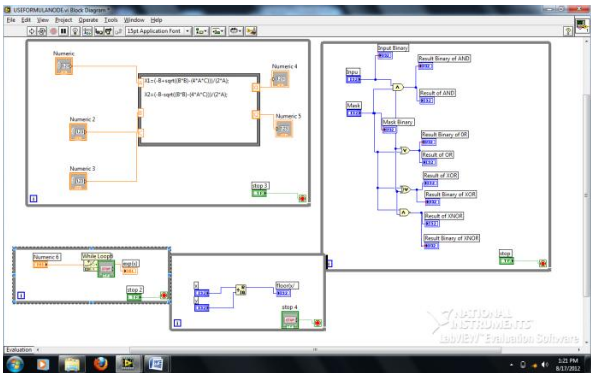


Figure 1.8 *(b): Block diagram*

Implementation 2: A function generator and a time domain analyzer is made which calculates and displays important parameters of the signal such as mean value, RMS value, DC value.

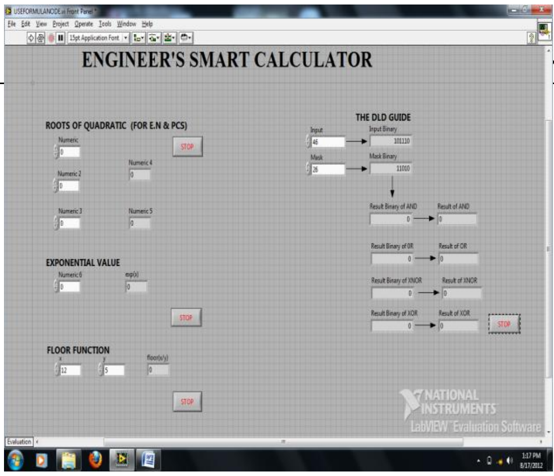


Figure 1.9 *(a)A virtual function generator and time domain analyzer*

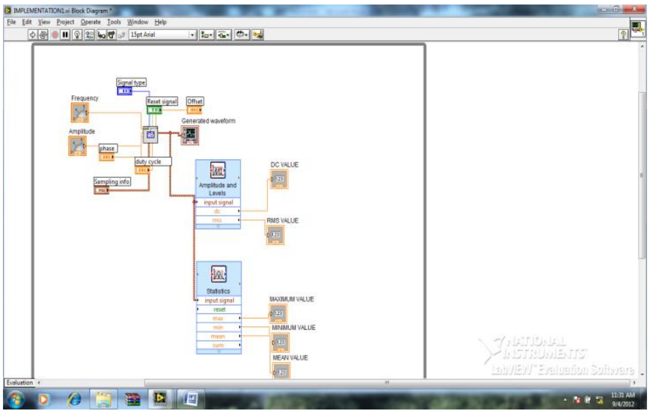


Figure 1.9 *(b). block diagram*

IMPLEMENTATION 3: RF amplifier was simulated in Multisim. The output was converted to LVM file and imported in LabVIEW.

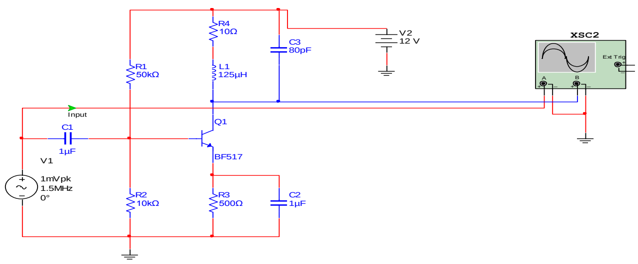


Figure 1.10 *(a). An RF Amplifier simulated in multisim*

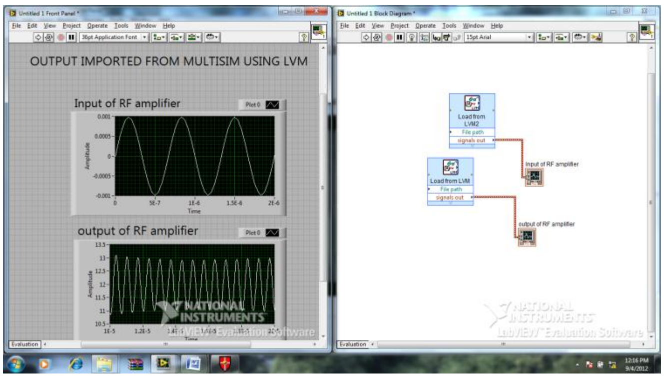


Figure 1.10 *(b) Front panel and block diagram*

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