AN ARCHITECTURAL FRAMEWORK FOR A UNIVERSAL MICROWAVE MEASUREMENT SYSTEM

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Abstract

The complexity of modern antennas has resulted in the need to increase the productivity of ranges by orders of magnitude. This has been achieved by a combination of improved measurement techniques, faster instrumentation and by increased automation of the measurement process. This paper concentrates on automated measurement systems, and describes the requirements necessary to make such systems effective in production testing, and in research and development settings. The paper also describes one such implementation – the MI Technologies Model MI-3000 Acquisition and Analysis Workstation - that was designed specifically to comply with these requirements

The paper discusses several important factors that must be considered in the design of automated measurement systems, including: (1) Enhancing range productivity; (2) Interfacing with instrumentation from a large number of suppliers; (3) Providing a uniform front-end for the measurement setup and operation that must be largely independent of the choice of the hardware configurations or the type of range (near-field or far-field); (4) Making the test results available in a format that simplifies transition to external commercial and user-programmed applications; (5) Providing powerful scripting capability to facilitate end-user programming and customization; (6) Using a development paradigm that allows incremental binary upgrades of new features and instruments. The paper also discusses computational hardware issues and software paradigms that help achieve the requirements.

Keywords: Microwave Measurement Workstation, Measurement Automation, Antenna Measurements, Near-field Antenna Measurements

Introduction

Testing of modern antennas imposes significant challenges on the instrumentation and software needed to complete these measurements reliably and quickly. Modern antennas typically operate in multiple states and over wide frequency ranges. They may consist of multiple input/output ports, and a large number of beam states characterized by beam indices, beam positions and beam configurations. Even with the higher measurement capabilities (10,000 complex measurements per second) of modern receivers such as the MI-1797, it is not unusual for modern antenna ranges to be tied up for extended periods of time just to acquire and store a large amount of measurement data required to characterize the antenna under test [1]. A number of facilities with extensive testing requirements have several antenna ranges with instrumentation from a number of suppliers. Usually these ranges operate differently and have incompatible data output formats, making range interoperability very cumbersome. Modern antenna testing also uses sophisticated post-processing analysis that may have been programmed by the end-user and may in-fact utilize proprietary algorithms. The ease with which an acquisition software package interfaces with proprietary software or with third-party software such as Matlab can enhance or diminish the overall time to acquire data, process and evaluate the results.

Thus, software and hardware designed for use in a universal workstation for microwave measurements shall minimally meet the following requirements:

1. Requirement To Enhance Range Productivity

The workstation shall be designed to enhance the flexibility, usability and productivity of ranges with diverse equipment from independent suppliers. Range productivity is a function of many different factors:

- Choice of measurement instrumentation
- Utilization of appropriate measurement techniques

- Degree of automation afforded by the hardware and software
- Ease with which the resulting acquired data can be used by the user-programmed or legacy post-processing software

If the test facility has several ranges additional factors come into play. For example, the extent to which the usability of the workstation is independent of the choice of the range configuration (such as far-field, compact range, planar near-field, spherical near-field, cylindrical near-field) and instrumentation can enhance or diminish the productivity of range personnel and the interoperability of the ranges.

2. Requirement To Support Commonly-Used Measurement Instrumentation

The workstation shall be capable of supporting microwave receivers, sources, synthesizers, position controllers, switch controllers and other peripherals that are commonly in use in the antenna measurement user community independent of the supplier. The support shall include both normal-speed operations and high-speed operations. Normal-speed operations are typically achieved by interfacing to the instruments using the General-Purpose Interface Bus (GPIB). High-speed operations may require the ability to connect to the instrumentation over a fast parallel digital interface.

Most modern microwave instruments support direct TTL triggering to capture position and receiver measurements. Most receivers make the measurement data available on a digital bus (such as the High-Speed Parallel Interface on the MI-1795 and MI-1797 receivers) or provide an internal buffer to store the measurement data (Agilent 8530 receiver). A number of Microwave Sources/Synthesizers allow direct TTL triggering to change frequencies. Units such as the MI-2180 and the MI-3101 and MI-3102 allow storage of frequency lists either in sorted (ascending or descending order) or in arbitrary order. In order to accommodate the high-speed data acquisition capability of the modern microwave instrumentation, it is essential that the workstation support a programmable device that is capable of reading measured position or receiver data from high-speed digital ports, and writing to the digital output ports to issue triggers and to control external user equipment such as beam-steering devices. It is also essential that such a device have the flexibility of being programmed by the user in a simplified descriptive language or by means of a graphical user interface.

3. Requirement For Concurrent Operations

The workstation shall have the ability to handle a number of services simultaneously (multi-tasking) so that the power of modern desktop computers can be fully utilized. The workstation may utilize the multitasking features of the native operating system, use a separate programmable device dedicated to the acquisition and data collection, and use a software architecture employing independent program modules to allow concurrent execution of different aspects of the software. The workstation shall also be network-ready so that measured raw data can be moved conveniently to other network computers for post-processing.

4. Requirement For a Uniform and Consistent User Interface

The workstation shall present a uniform user interface that is largely independent of the choice of the equipment used to perform the measurements. This is particularly important in facilities where a number of ranges exist, that use instrumentation from independent suppliers. In such facilities the productivity of the range is influenced not only by the speed with which the data can be acquired but also by cross-training requirements and skill transferability imposed on the personnel operating the ranges.

5. Requirement For Data To Be In A Common Format

The workstation shall also make the measurement data available to the user in a uniform commonly available format so that support software needed to evaluate the raw data and generate test results can be programmed to retrieve the data in an efficient manner. The workstation shall provide libraries to support access to the measured data from common software development languages

6. Requirement For End-User Programming

The workstation shall facilitate end-user programming without the necessity of modifying the source code supplied by the workstation vendor. The end-user programming capability shall allow direct execution of user programs including legacy software, and allow a script capability that the user can use to incorporate sequencing of acquisitions, analysis, plotting, connection to other workstations on a Local Area Network, direct instrument control over GPIB, file-handling, branching, etc. It is preferable to use a commonly available commercial or open-source scripting language.

7. Requirement For Expandability

The workstation shall my designed for change and growth. For example, the instrument communication protocol shall allow the ability to add new instruments and update existing services and drivers without the need to re-compile and re-link the base software.

8. MI-3000 - Summary

Microwave Instrumentation Technologies, LLC has recently introduced the MI-3000 Acquisition and Analysis Workstation that meets the requirements identified in the previous sections.

The MI-3000 workstation and software comprises the most advanced hardware and software designed for the fast and accurate acquisition, analysis, and visualization of RF and microwave data in measurement and test applications. Capable of supporting far-field and compact ranges, the MI-3000 includes:

- Workstation - Consists of a high-performance Pentium-based PC, 21-inch monitor, peripherals and an IEEE-488 General Purpose Interface Bus (GPIB) card.
- MI-3041 - Acquisition and Analysis Software - Consists of the Graphical Use Interface (GUI) to set up the measurement system, the modules to perform the data acquisition and collection, the modules to provide real-time visual confirmation of the acquired data, the modules to perform post-acquisition data visualization, modules that can sequence acquisition, analysis and plotting operations, and general utilities to present and print the data.
- MI-3042 - Antenna Analysis Software - Consists of modules to perform standard antenna analysis on the raw measured data and generate reports and plots of the results including Pass/Fail assessment.

The MI-3000 uses an IEEE-488 General Purpose Interface Bus (GPIB) to control Microwave Receivers, Microwave Frequency Synthesizers, Position Controllers and other instruments during the process of conducting measurements. Instrument control drivers are available for a large number of receivers, frequency synthesizers, position controllers and position indicators. New drivers are being added as the need arises. To support the high-speed acquisition capability designed into MI Technologies receivers and synthesizers, the MI-3000 also interfaces with an optional Data Acquisition Coprocessor (DAC) that uses a Digital Signal Processor (DSP) to handle the fast triggering and data collection over parallel digital interfaces. The DAC can also be adapted to provide users with general digital I/O control of external devices such as beam-steering computers.

9. MI-3000 – General Features

Use of Windows NT® - The MI 3001 software is written for the Microsoft Windows NT® operating system. Windows NT® facilitates the structuring of window-based and mouse-enabled Graphical User Interfaces (GUIs), making maximum use of pull down menus and context sensitive help. The MI 3001 GUI enables a natural and intuitive dialogue between the operator and the system.

Windows NT® is a multitasking, multi-threaded, virtual memory operating system that provides the required efficiency to support the real-time data acquisition demands of antenna measurement applications. The advanced preemptive, multitasking and multi-threading features of Windows NT® allow concurrent data acquisition, processing, and display of previously acquired data. Windows NT® also provides a rich set of file and record management operations, which ease the creation, modification, archive, deletion and transfer of measured and processed data. Only the standard features of the Microsoft Windows NT® operating system are used. The operating system is not modified in any way. This ensures that future upgrades of the operating system, if implemented, will not invalidate any of the existing software.

Open Architecture Design Promotes End-User Customization - The MI 3000 software is designed with an open architecture concept to take full advantage of new software technologies such as object-oriented design, data base management, and component technologies. This allows the end-user to extend the capabilities of the system using familiar tools and provides the best blend of a turnkey, fully automated system with common commercial office software (Microsoft Office), scientific software (MATLAB, Mathcad), and laboratory software. The use of a commercial PC with Microsoft Windows NT® ensures that any Commercial Off-The-Shelf (COTS) device with a supplied device driver can be seamlessly integrated into the system. Similarly, COTS software programs written for Microsoft Windows NT® can be routinely loaded and run from the system.

All Definition Files (Sequencer, Acquisition, Analysis and Plot) and raw data files containing the measurement data are created as files that are compatible with Microsoft Access 2000 relational database program. This will provide the advanced end-user the option of analyzing the resultant data and modifying or creating custom reports using Microsoft Access or Microsoft Visual Basic report generation capabilities.

Supports High-Speed Acquisition - MI Technologies receivers, sources, synthesizers, and position controllers utilize high-speed direct digital access and fast TTL triggering to eliminate latencies associated with the IEEE-488 bus (GPIB). An optional hardware module, the Data Acquisition Coprocessor (DAC), is available to ease the connectivity to the high-speed ports of the instrumentation. The MI-3000 provides the device drivers necessary to interface to the DAC and enable acquisition speeds of up to 10000 complex measurements per second with the appropriate equipment.

The optional Data Acquisition Coprocessor (DAC) uses a Digital Signal Processor (DSP) to handle the fast triggering and data collection over parallel digital interfaces. The DAC can also be adapted to provide users with general digital I/O control of external devices such as beam-steering computers

10. MI-3000 – Major Components

The **Installation Module** is used to select the equipment from the available list of receivers, sources, synthesizers, position controllers, and position indicators, and to create a configuration of parameters for each. This module is executed at the time of the installation and subsequently if the equipment is changed. The module uses a series of GUI screens to ease the selection of equipment and to simplify the configuration of instruments. The Equipment Selection screen is shown in Figure 1. The basic MI-3000 software is provided with instrument drivers for a configuration specified by the user. The configuration includes a receiver, a source/synthesizer, an AUT position controller, a source position controller, and an 1885 position indicator. Instrument drivers for other equipment may be purchased separately. The list of currently available instrument drivers is shown in Figure 2.

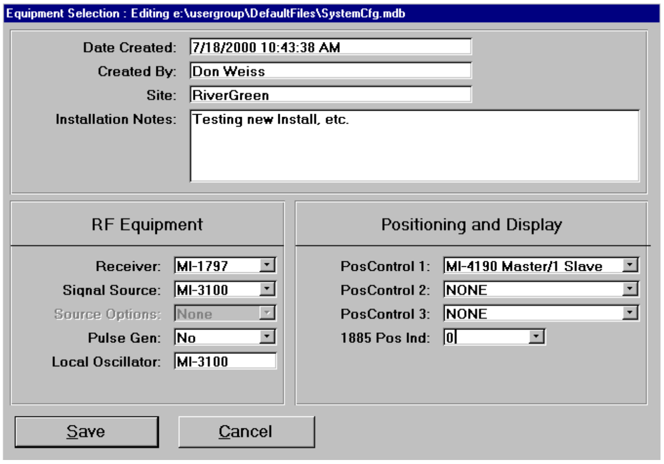

Figure 1: MI-3000 - Equipment Selection Screen

Instrument	Model
Receiver	MI-1797
	MI-1795
	MI-1795P
	MI-1783
	MI-3221 Power Meter
	AGILENT-8530
	AGILENT-8510
	AGILENT-E4408B Spectrum Analyzer
	AGILENT-8566 Spectrum Analyzer
	AGILENT-8753 RF Network Analyzer
Source /Synthesizer	MI-2180/MI-2186
	MI-3101/MI-3102
	AGILENT-83752
	AGILENT-83640
	AGILENT8350
Position Controller	MI-4191
	MI-4192
	MI-4193/MI-4193S
	MI-4194
	MI-4195
	MI-4131
	MI-4139
	MI-2012/MI-4180
1885 Position Indicator	MI-1885/MI-1886

Figure 2: MI-3000 - List of Available Instrument Drivers

The **Acquisition Module** performs two essential functions:

- Creation and maintenance of Acquisition Definition Files (ACDF) via the user interface

- Performing a measurement sequence and collecting data, based on a specific Acquisition Definition File when requested by an operator or called from another program

The creation and maintenance of the ACDF is performed using GUI screens designed to simplify the task of selecting and editing key measurement parameters such as frequencies, scan and step motion ranges, the receiver channels to be recorded, and other required or optional measurement parameters. The ACDF is stored as a Microsoft Access database, and can be viewed, printed, and exported using the supplied Microsoft Office 2000 program. A typical acquisition definition screen is shown in Figure 3.

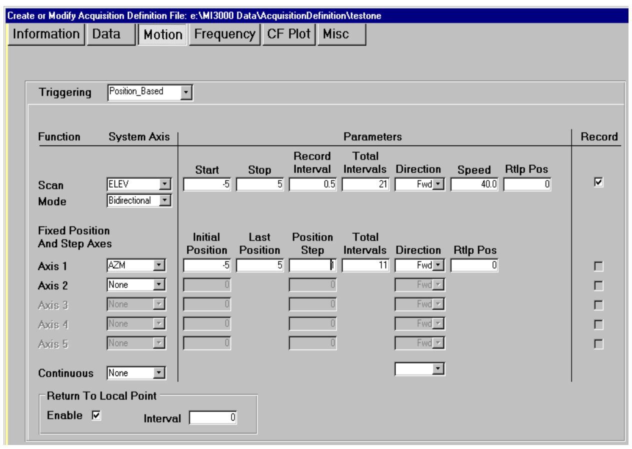

Figure 3: Typical Acquisition Definition Screen

When an acquisition is initiated, a control panel displays a running commentary of events taking place during an acquisition, and exposes a set of command buttons. The command buttons (PAUSE, CONTINUE, END and ABORT) allow the operator to control the status of the acquisition. Clicking on the ABORT button will terminate the acquisition immediately. Clicking on the PAUSE button will halt the acquisition at the end of a scan. Clicking on the CONTINUE button will resume the acquisition at the next scan after PAUSE was initiated. Clicking on the END button will terminate the acquisition at the end of the current scan and will store all relevant information to allow the operator to resume the acquisition at a later time. At the completion of a full or partial acquisition, the EXIT button will be enabled. Clicking on the EXIT button will terminate the acquisition.

The types of data acquisitions needed for the antenna measurements include:

- **Patterns and Principal Plane Cuts**: The radiation pattern or principal plane cut is measured over a range of system-controlled parameters (position axes, frequencies, AUT ports, Polarizations, etc.) as specified in the Acquisition Definition File.
- **Gain Measurements**: The AUT is positioned in the “all axes zero” position or electrical bore-sight and radiation measurements are taken at different frequencies. The process is repeated with a standard gain horn. The gain analysis program is used to calculate the gain of the AUT as a function of frequency.
- **Beam Peak/Null Search:** A series of principal-plane cuts are used in two orthogonal axes, to search for either peaks or nulls as specified by the user.
- **Discrete Point Acquisition:** The radiation pattern is measured over a range of system- controlled parameters (position axes, frequencies, AUT ports, Polarizations, etc.) as specified in the Acquisition Definition File. Positioning along the raster is performed point-by-point.
- **Planar, Spherical and Cylindrical Scans:** With appropriate optional modules, the same software can be used for near-field measurements.

The **Plot** module produces conventional rectangular and polar graphic outputs as well as contour and three-dimensional presentations. The plot module is invoked by clicking on the Plot Icon on the desktop that results in the display of a file selection box. The plot definition characteristics are stored in a Plot Definition File (PDF). A PDF may be selected from a list available in a user directory. A PDF specifies the plotting characteristics that must be applied to a data file or files. The data file may be the result of a previous acquisition or of a previous analysis. The plot specified by the selected PDF may be displayed on the screen or printed on a printer. The properties specified in the selected PDF may be changed. Typical properties allow the selection of the traces to be displayed, the data file associated with the trace, line colors, thickness, type (solid, dashed, dotted), grids, and other visual properties.

A comprehensive set of features and options are provided to generate plots.

- Up to 16 traces can be displayed on a single rectangular plot. The user can distinguish each trace by line colors (from a palette of unlimited number of colors), line types (solid, dashes, etc), and line thickness.
- Amplitude and Phase information can be displayed on the same rectangular plot.
- The plots can be scaled either automatically or to specified ranges.
- Traces can be normalized in x-axis and y-axis.
- The data can be displayed in any of the formats - LOG, Linear or I and Q.
- Two reference lines can be created and displayed on a rectangular plot with the recorded data to permit easy verification of data limits.
- Coordinates of any point in the plot area can be determined by clicking the left button of the mouse
- User-specified labels can be entered in the title (header) area or in the footer area (to specify security labels such as Proprietary, Confidential, etc).
- Significant degree of customization (grids, interior colors, axes labels, etc.) can be performed.
- Interactive Control: Once a plot is displayed, it may be re-scaled by entering limits and scale factors from pull-down menus and dialogue boxes.
- Plots can be printed in color on sizes from standard 8.5 by 11.0 to B-size 11.0 by 17.0.

An example of a isometric plot is shown in Figure 4.

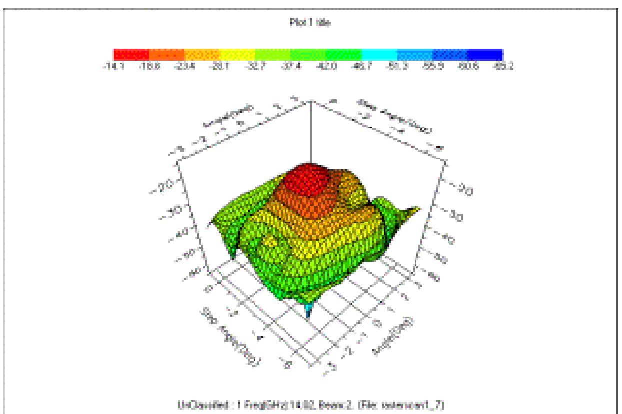

Figure 4: Example of a 3-Dimensional Plot

The **Sequencer** is used to program complex acquisition, analysis, and display/plot sequences that can be linked to create an easy-to-use batch-like process. Sequence mode permits assignment of filenames to variables, relational checks of variable values, display of key parameters, and data entry from the keyboard. The Sequencer is a program that provides a set of commands that the user can use to perform various functions. An editor is used to write Microsoft VBSCRIPT programs to utilize these functions. These programs can be very simple steps to concatenate acquisition, analysis, and plot functions. The programs, however, can utilize the full capabilities of the Microsoft VBSCRIPT language to do complex calculations and control functions. The Sequencer is powerful enough to customize acquisitions and data processing, including operator interaction, and tie the execution of the script to a desktop icon.

The features provided in the Sequencer are:

- The user can build scripts to sequence Acquisition commands, perform analysis, print plots, and export files using simple English-like commands.
- The user can also use a general-purpose scripting language (Microsoft VBSCRIPT) to incorporate control and branching (IF-THEN-ELSE-ENDIF, SELECT-CASE, FOR, WHILE, etc), variables, classes, functions, file management, etc. and other powerful features of a scripting language.
- The user can issue acquisition commands, change acquisition parameters, process the acquired data, export files, run external programs written in C, C++, Visual Basic, MATLAB, or other Windows compatible language.

Summary

The paper described the requirements for a universal workstation suitable for antenna and microwave measurements. The workstation must provide the capability to interface with instruments from a large number of suppliers; provide a uniform front-end for the measurement; present the results in a format that simplifies transition to external commercial and user-programmed applications; provide end-user programming and customization; and simplify the ability to upgrade to new instruments. The paper also described the Microwave Instrumentation Technologies MI-3000, a commercial implementation of such a workstation.

References

[1] O. M. Caldwell, “High Speed, Multi Frequency Measurements”, Proceedings of the Antenna Measurements Techniques Association, 1989