THE EVOLUTION OF AUTOMATED MICROWAVE MEASUREMENTS

John H. Meyer
Hewlett-Packard Company
Palo Alto, California

Abstract

Microwave measurements lend themselves to automation because many readings and much computation is often needed to achieve reasonable accuracies. The expense of automated microwave measurements has limited their widespread use for general measurements. However, an international standard for instrument interfaces, more off-the-shelf programmable instruments, and the advent of inexpensive calculator controllers will dramatically increase the utilization of automated microwave measurement techniques.

I. Introduction

Ideally, one would like to assemble an automatic electronic measurement system from existing equipment without having to design or build additional hardware. This ideal is now being approached thanks to IEC's Technical Committee 66 which has been working on specifying a standard interface for programmable instruments.

It is the purpose of this paper to:

1) Define the reasons for automating measurements and, in particular, why microwave measurements are especially well suited to automation.

2) Explore the drawbacks of early automated systems.

3) Show how the need to overcome these drawbacks has led to an evolution in automatic measurements, in particular the development of an interface standard.

4) Project what the future holds for automated microwave measurements.

II. Reasons for Automating Microwave Measurements

Automated systems offer several significant advantages over manual measurements. These advantages include:

1) Increased speed

2) Computational enhancement

3) Repeatability

4) More complex measurements

Any measurement which would benefit from any of the above advantages is a likely candidate for automation.

Microwave measurements are generally time consuming and often require significant computation to convert from the measured value to the desired answer. Moreover, accuracy on the order of 2% or less can often be achieved only through lengthy calibration procedures and multiple tests. Thus, microwave measurements, especially broadband microwave measurements, can be made significantly faster and more accurately when they are automated.

Hewlett-Packard's 8542A Automatic Network Anlayzer is an excellent example of what automation can do for microwave measurements. This system characterizes the magnitude and phase response of linear networks at frequencies up to 18 GHz. If used manually, the instrumentation in this system would be limited to accuracies on the order of several percent as determined by mismatch, directivity, crosstalk, and frequency response errors. These errors can only be removed through laborious calibration techniques which involve many measurements and considerable computation. It is impractical in broadband measurements to do such calibration manually. However, by putting this instrumentation under control of a mini-computer it is possible to essentially eliminate the previously mentioned errors, leaving only imperfections in the calibration standards, noise, and residual errors, such as connector repeatability, as sources of measurement uncertainty. Errors in some measurements can be reduced to fractions of a percent using these techniques. In addition, once calibrated, this system makes measurements and provides hard-copy output in a fraction of the time it would take to do manually.

Thus, automatic systems, as exemplified by the 8542A Automatic Network Analyzer, have demonstrated the capability to decrease systematic measurement error and simultaneously increase measurement speed.

III. Drawbacks to Early Automated Systems

Until recently, automated systems have suffered from several shortcomings, most notably high price and considerable design effort. These shortcomings in turn, resulted from the desire for ultimate performance in a given application. It has become increasingly apparent that many applications for automatic systems do not require the speed and computational capability of a dedicated automatic system and that a lower cost, although somewhat lower performance, solution is needed.

A careful consideration of the costs involved in putting together an automated system shows that the major contribution to the increased cost (and design effort) of an automated system over its manual counterpart are:

1) The cost of processor/controller (computer)

2) The cost of interfacing various instruments in the system to the computer

3) The cost of writing system software

Decreasing the cost of any one of these components will decrease the cost of the system. The degree to which the cost of each can be decreased will depend, in part, on what degradation in system performance is acceptable.

IV. One Solution-A Standard Interface

A major step towards lower cost, more easily assembled automated systems has been taken by the member nations of Working Group 3 associated with Technical Committee 66 of the International Electrotechnical Commission (IEC). This body voted to accept a proposal defining an instrument interface standard. If adopted by the IEC, this standard would dramatically reduce the cost of interfacing instruments by eliminating interface design as one of the necessary prerequisites to building an instrument system.

Details of the standard are covered extensively elsewhere. However, it is worth mentioning here that one feature of the standard is that it utilizes a bus structure which permits one computer I/O slot to control up to 16 instruments. The implication is that devices much less sophisticated (and less costly) than a mini-computer can be used as a processor/controller.

In fact, desktop calculators costing less than $10,000 are presently available which are compatible with the standard interface. Use of a calculator with its hard-wired high-level language permits control software to be written without reference to assembly level language, thereby further reducirg system implementation costs.

Before proceeding, it should be noted that the interface standard is not a panecea for all system applications. Most notable in the drawbacks of the proposed interface is that it is not as efficient as an interface designed specifically for a particular application would be. This means that in applications where speed is of the utmost importance, special interfaces will still need to be designed and faster controllers used.

Thus, the proposed interface standard will reduce the cost of systems by eliminating the need to design interfaces each time a system is built, and by allowing simpler controllers, such as desktop calculators, to perform the functions previously assigned to more expensive computers.

V. The Future of Automated Measurement Systems

Generally, predicting the future is an uncertain and risky science. However, contrary to this, the future of automated measurement systems is, in my opinion, fairly certain. We have observed in the past two years the rise of the microprocessor. This concept, and the technology it employs, allows much of the computational, and some of the control capabilities of a computer or calculator to be packaged in a very small space. Therefore, the next logical step in automated system design is to place part or all of the controller inside each instrument. This will allow the instrument to perform a series of measurements and computations under microprocessor control and then display the result. This in fact has already been done to a limited extent on the HP 1722A Oscilloscope, which automatically computes frequency, period and voltage information about the waveform being displayed on the CRT. However, control of the instrument is still entirely in the hands of the operator. The next generation of instruments will go one step further and allow the instrument to sequence itself through various measurements, store the results, and then compute the desired answer from these results. For instance, a microprocessor could be included in a frequency counter to allow it to make measurements such as FM peak-to-peak deviation. The user would only need to push a button on the front panel of the frequency counter, and then the microprocessor would cycle the counter through a series of readings at specified intervals, take the maximum and minimum of these readings, compute the difference, and display the result directly as FM deviation.

The next step will be to integrate several system components into one box, along with the microprocessor. As an example, a synthesized signal source and a programmable spectrum analyzer could be put in the same box, or at least could be connected so as to be under control of a single microprocessor, located in one of the instruments. A typical application for this sort of an arrangement would be automated receiver measurements at the push of a front panel button with readout directly in least useable sensitivity, distortion, stereo separation, etc.

So far, I've been talking about applications where the microprocessor is hard-wired to perform a certain measurement. In many cases where a certain class of measurements is commonplace, it may prove feasible to take this approach. Another possibility, however, is to let the instrument "learn" by doing the measurement once manually. This is similar to the approach used to program small calculators where the calculator "remembers" a series of keystrokes. Similar to these calculators, additional buttons, not used in the manual mode, would have to be added to the instrument. Because of their flexibility, these "front panel programmable" instruments may predominate over their hard-wired counterpart.

Thus, the short term trend (next 10 years) will be to remove the controller (calculator or computer) as a system component and move their function inside individual instruments.

Projections further than ten years away get to be risky, but a few developments are highly likely. First, the trend towards miniaturization and increased complexity will lead to a combination of instruments within a single box. I already mentioned the signal synthesizer - spectrum analyzer combination; others are possible. These multiple function units would probably be modular in construction and would be put together at the factory or by the customer, but once assembled, the different instruments would operate, under microprocessor control, as if they were a single instrument. Each individual instrument could be provided with microprocessor control, or one particular instrument could be designated as the controller, depending on the architecture of the "plug-together system".

Finally, where does this path finally lead? The logical, ultimate conclusion of this approach is a system which measures time, voltages and phase and derives all other parameters from these fundamental measurements. Obviously, more is involved here than simply expanding control capabilities, but it is my feeling that this approach may eventually prove feasible, although the question in this case would be, "Does anybody need it?"

VI. Summary

The need for increased speed and improved accuracies has led to automatic measurement systems. These systems are indeed fast and accurate, but they are expensive and difficult to implement. In order to overcome these shortcomings, an interface standard has been proposed and will hopefully be adopted by the IEC. This standard interface will reduce the cost of putting a system together, and will allow the use of less expensive system controllers. In the future, the control function will, in many cases, become internal to particular instruments, obviating the need for a system controller.

VII. Bibliography

(1) Fischer, Walter A., and Risley, William B., "Improved Accuracy and Convenience in Oscilloscope Timing and Voltage Measurements," Hewlett-Packard Journal, Dec. 1974.

(2) Hand, B. P., "Developing Accuracy Specifications for Automatic Network Analyzer Systems," Hewlett-Packard Journal, Feb. 1970.

(3) Longhry, Donald C., "A New Instrument Interface: Needs and Progress Toward a Standard," ISA 74 Paper.

(4) Longhry, Donald C., "What Makes a Good Interface?" IEEE Spectrum, Nov. 1974.

(5) Longhry, Donald C. "The Hewlett-Packard Interface Bus: Current Perspectives," Hewlett-Packard Journal, Jan. 1975.

(6) Rytting, Douglas K., and Sanders, Steven N., "A System for Automatic Network Analysis," Hewlett-Packard Journal, Feb. 1970.