A MICROPROCESSOR CONTROLLED AUTOMATIC NETWORK ANALYZER IN A MICROWAVE COMPUTER-AIDED DESIGN SYSTEM

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ABSTRACT

A microprocessor controlled automatic network analyzer with a frequency range of 0.045-18 GHz with typical accuracies of 0.1 dB and 1° and low cost compared to comparable commercially available systems is described. The software has been designed for ease of use and to allow direct access to the measurement data by other computer programs. A program for processing the data on a graphical terminal is described. Efforts to make the data available to computer aided design programs on a large computer installation are discussed.

Introduction

The automatic network analyzer (ANA) satisfies most requirements for microwave S-parameter measurements in terms of accuracy, measurement speed, and ease of operation. Unfortunately the commercially available Hewlett Packard 8542B ANA has a price tag which is much too high for many potential users. The six-port has thus recently been proposed as a cheaper way of building an ANA, but this remains to be proven.

Computer-aided design (CAD) has become an important tool for the microwave circuit designer. Usually CAD is done with theoretical models while in many cases it would be preferable to use measured data. The measurement accuracy this would require is typically that of an ANA, and as the ANA is computer-controlled, it may also perform very well as a data-collection system. For this purpose it would be very advantageous if the ANA software was designed so that the measurement data could be made available to the CAD program without any physical transportation or recoding of the data.

During the last two years we have designed and built an ANA which became operative by the end of last year. One of the main reasons for building our own ANA was cost, and in addition to a saving of about 30%, a very flexible and versatile system has been obtained. The ELAB ANA presently has a frequency range of 45 MHz to 18 GHz and a typical accuracy of 0.1 dB and 1°. The software fulfills the above demand of CAD compatibility and is interactive and easy to use so that very little training is required to operate the ANA.

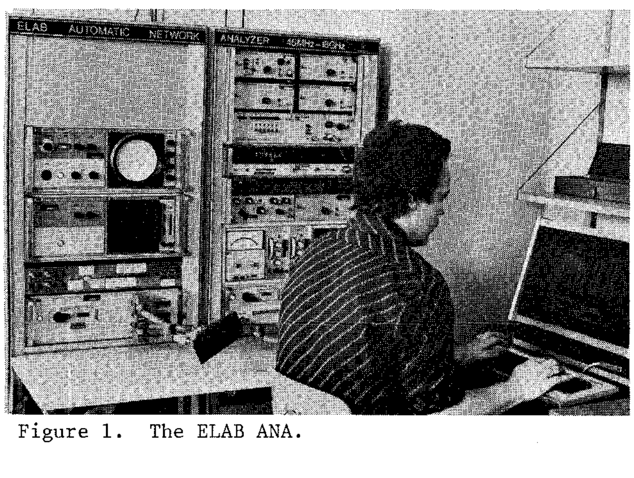

Figure 1. The ELAB ANA.

ANA hardware

The two main instruments of the ELAB ANA is a Hewlett Packard manual network analyzer consisting of a 8410B Network Analyzer, a 8411A Harmonic Frequency Converter, 8743A and 8745A Test Units, and 8412A and 8414A Displays and a Weinschel 4310 A/K-16 0.01-18 GHz Multiband Sweeper System. The network analyzer has been slightly modified to allow digital control of the frequency range switch and use of the displays for plotting corrected measurement data. The sweep generator is standard with 10 dBm power output except for the 12.4-18 GHz range where it is 13 dBm. The instruments are contained in a dual-bay rack as shown in the photograph (figure 1).

The signal detection circuits of the manual network analyzer are too crude for use in an ANA. Instead, we have built a digitally controlled IF-attenuator, a precision demodulator which by it's design eliminates the so-called quadrature error of the network analyzer's polar display, and a precision A/D converter. All instruments are digitally controlled by a microprocessor through BCD interfacing.

The microprocessor which controls all instruments is housed in a 145 mm high rack module. This rack module contains power supplies and a card cage section. The microprocessor electronics occupies two card positions. Its busses and control signals are connected to every card connector in the card cage. Each instrument is connected to a card or group of cards which provides the interface to the microprocessor and circuits like the precision IF demodulator with A/D converter, IF test channel attenuator, sweeper phaselock circuits, and display D/A converters. Spare card positions are provided for future expansions. The ANA operator panel is the front panel of this rack module.

The host computer is interfaced to the microprocessor by a single standard interface card through a 100 m long multiwire cable. This interface is a bit parallel type for fast data transmission, but bit serial types or the IEEE-488 bus may be adopted. Thus, no serious problems would be expected in adopting the ELAB ANA to any type of host computer or even various desk calculators.

The operator communicates with the ANA through an alphanumeric CRT-terminal which is connected to the host computer. Intentionally few possibilities for data manipulation have been made available at the ANA, instead, the offices of the users have been wired up for a terminal connection to the host computer sharing a Tektronix 4010 graphical terminal.

The sweeper in the ELAB ANA is presently free-running with the frequency being set through a D/A converter. By this summer it is intended to replace the local oscillator in the network analyzer with a Fluke 6160B Frequency Synthesizer. This will allow much finer frequency resolution, which is currently not less than 1 MHz, and much more accurate measurement of high-Q devices through phase-locking of the sweeper. In addition harmonic skipping, which is seen in the measurement sample in figure 2 as 0.1 dB peaks, will be eliminated and measurement stability above 10 GHz, which suffers from rapidly varying frequency response, will be greatly improved. The cost of adding the synthesizer is only about 10% of the total instrumentation price which is in the order of $ 50-60,000.-. This is because most of the necessary phase-locking circuitry is already included in the network analyzer.

ANA software

The software of the ELAB ANA has been designed with ease of operation as a primary goal. This reflects the fact that ELAB is a R&D organization and the experience gained here that the microwave designer often profits from doing his own measurements. It has also often been observed that exactly what is to be measured and how the measurement data are to be presented cannot be decided before the measurements are actually done.

The host computer of the ELAB ANA is presently a Hewlett Packard 2100S with 32k memory and a 5 Mbyte disc running under a real time operating system (RTE-II). Program and data memory is restricted to approximately 12k which limited the number of measurement frequencies to 101. All ANA software is modular allowing easy modification and expansion. Almost all software is written in standard FORTRAN IV except for the subroutines which handles the data transfers between the host computer and the ANA microprocessor.

The microprocessor software is designed to save host computer resources. Display refresh and measurement over the specified frequency band are done without intervention. Data transmission is then limited to the passing of preprocessed buffers and macro-like commands. This operating scheme allows an efficient burst processing of the ANA program at the host computer.

ANA operation

A measurement session with the ELAB ANA consists of four phases, a set-up phase, a calibration phase, a measurement phase, and a data output phase. In the set-up and data output phases the operator directs the ANA by giving a command chosen from a menu presented on the terminal, while in the calibration and measurement phases the operator is requested to perform specific tasks such as connecting a calibration component or the device to be measured. However, to cater for any errors made by the user, i.e. connecting the wrong calibration component, he may in the calibration and measurement phases easily stop the normal run of the program. A menu, varying according to where the stop occurred, will then be presented allowing the user to choose from where to restart.

The set-up phase consists of giving an identifier (operator's initials) for file identification purposes, generating a frequency list, and specification of device connector types. A calibration file for each test unit is created, unique to each user, and if the last session

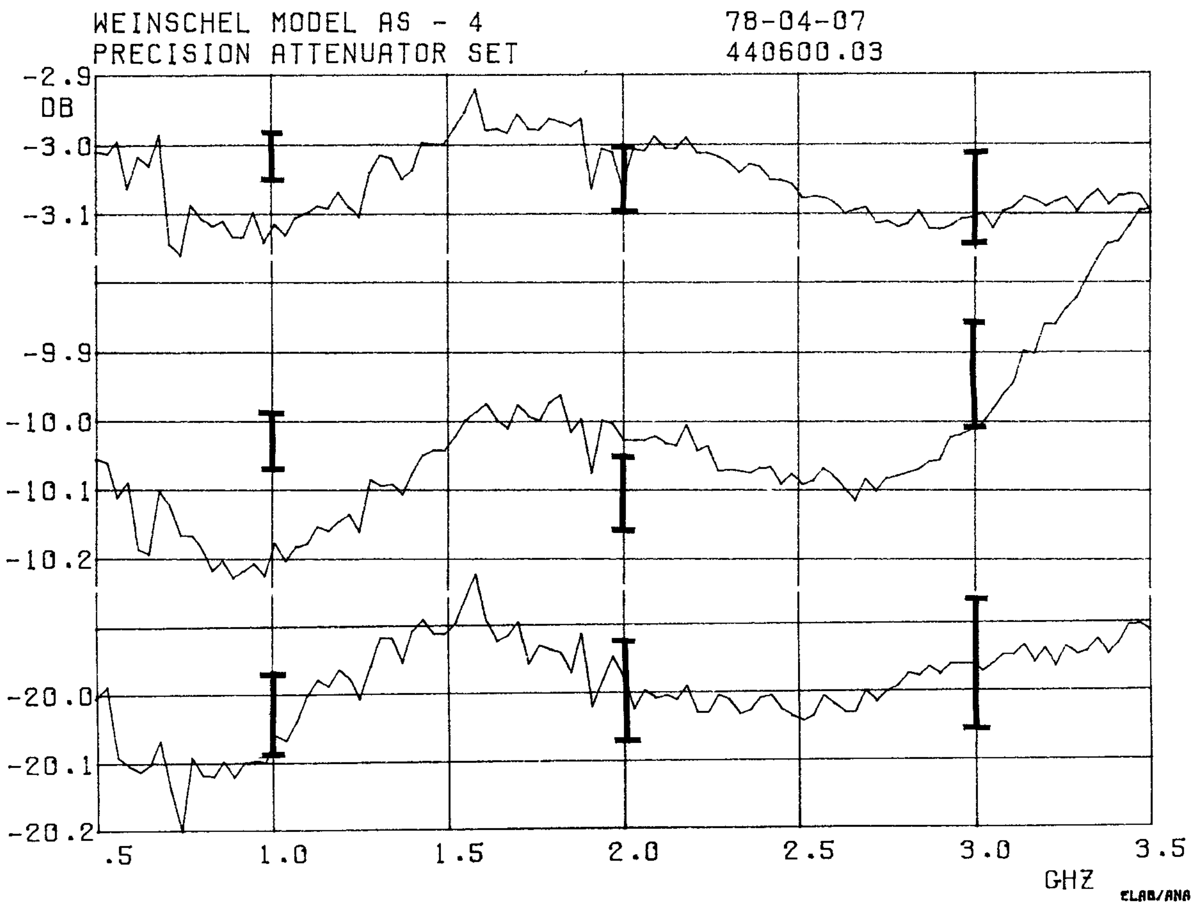

Figure 2. Examples of measurement data plotted by the digital plotter with manufacturer's calibration data added.

was made with the same frequency list and connector types, the old calibration data may be re-used. The frequency list generation is done by choosing one or several (in random order) of the commands in the menu shown in table I, making it very simple to generate complex lists. Presently, different coaxial connectors are allowed while waveguides will be implemented at need. Data for the coaxial calibration components are stored in the program. For microstrip and stripline the user has to input the lengths of the through and the open-circuited lines which he must furnish to calibrate beyond the necessary adapter. A method has been found to allow calibration with negligible error when the device connectors are of different type.

CX: CAL: FILE X [(874)5, (874)3, B(OTH)] LIST,
MX: MEAS. FILE X (Ø-9) LIST,
FI: FILTER LIST (LIN. IN PASSBAND, ELSE LOG.),
SI: LIST OF SINGLE FREQUENCIES,
ST: START-STOP-STEP LIST
LI: LINEAR START-STOP-N LIST
LO: LOG. START-STOP-N LIST
EX: EXIT

Table I. Frequency input menu.

The menu of the data output phase is shown in table II (if the frequency range allows use of only one test-unit, it is shortened accordingly). Outputting of data on the displays and/or terminal is mostly for confirming a successful measurement/calibration to the user. Further manipulation of the data is deferred to another terminal and program thus minimizing the time spent with the ANA. For this purpose, every user has ten files for storing measurement data where each file may contain data from different measurement sessions provided that the frequency list is the same.

XX: PLOT OF SXX (11, 21, 22, 12),
FX: STORE DATA ON FILE NO.X (Ø-9),
LI: LIST OF DATA ON TERMINAL,
PR: LIST OF DATA ON LINE PRINTER,
C5: CAL. OF 8745 AND MEAS. ON BOTH,
C3: CAL. OF 8743 AND MEAS. ON BOTH,
M5: MEASUREMENT ON 8745 ONLY,
M3: MEASUREMENT ON 8743 ONLY,
B5: BOTH CAL. AND MEAS. ON 8745 ONLY,
B3: BOTH CAL. AND MEAS. ON 8743 ONLY,
CA: CALIBRATION AND MEASUREMENT,
ME: MEASUREMENT,
FR: FREQUENCY CHANGE,
CO: CONNECTOR CHANGE,
FC: FREQUENCY AND CONNECTOR C HANGE,
EX: EXIT

Table II. Data output menu.

ANA data processing

For further processing of measurement data a program has been written for use with a graphical terminal. The program is designed to offer the user great flexibility in the presentation form of the measurement data, yet to be as easy to use as possible. The user is guided through the program execution by a short sequence of simple questions until a display of the results is obtained on the screen. The display may be in the form of a rectangular plot, a Smith chart plot, or a table. The following quantities may be plotted/tabulated: The magnitude (in dB on linear scale) or phase of the S-parameters, the VSWR, and the group delay. It is possible to plot the ratios between two parameters, to normalize reflection coefficients/VSWRs to other impedances than the one used in the measurements, and to move the reference planes. Scaling may be done automatically by the program or specified by the user, and he may also choose the frequency range to be plotted/tabulated. All hard copy of any display is easily reproduced on a digital plotter (or on the line printer if a table has been displayed).

A sample of the output from this program is shown in figure 2, where the manufacturer's calibration data on the measured attenuators have also been added. Both test units have been used for this measurement with switch-over at 2 GHz. The accuracy seems to be better on the high-frequency unit, which may be due to wear on the coaxial switches of the other test unit which is several years old.

CAD with ANA data

While CAD has become an important tool for microwave design, it is often of major help only in the paper design, not taking into account the discontinuities and parasitics of real-life circuits. To overcome this deficiency of CAD, accurate modelling of circuit components or measurement data on real-life circuits are necessary, but the efforts required by manual methods have been too large to do this efficiently.

The ANA seems the perfect system for bridging the gap between CAD and real-life, and two methods may be utilized, to have CAD on the host computer or a data link to another (larger) computer including the necessary software to prepare the data for CAD. As a test of the first method a simple optimization program has been written and evaluated. However, experience showed that the limitations imposed by the mini-computer were too many for this to be an efficient solution. Instead work is now underway to exploit the existing CAD programs available on the large Univac 1108 computer installation at the Computing Center of the University of Trondheim.

The first step in this direction was the establishment of a communication link between the two computers. The necessary software (an RJE emulator) was developed under a contract with Hewlett Packard, Norge A/S. The next step will be to develop interactive preprocessors on the ANA host computer to facilitate construction of the input data for the CAD programs and submission of the batch jobs to the Univac computer. These preprocessors will take data from the ANA measurement files and will build files containing circuit topologies. These files may in the future be used by other programs for interactive lay-out and mask generation for stripline and microstrip circuits. For this purpose models of discontinuities prepared by CAD from ANA data will be very useful.

Conclusion

It has been demonstrated that an ANA using the method of harmonic mixing may be produced at a much lower price than existing commercial equipment, a saving of 60% or even more if available instruments may be utilized seems a reasonable estimate. While an ANA may perform reasonably well with a desk-top calculator as controller, the flexibility and ease of operation obtained with a mini-computer more than offsets it's extra cost. This is even more pronounced with a microprocessor controlled ANA whose use of computer resources are so small that it does not appreciably slow down other programs running when the ANA is measuring. Use of ANA measurement data may be expected to have a major impact on microwave CAD, bringing it much closer to real-life circuits.

Acknowledgements

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