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CHECK STANDARD MEASUREMENT AND DATABASE SOFTWARE FOR MICROWAVE NETWORK ANALYZERS†

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ABSTRACT

Vector network analyzers provide a convenient way to measure scattering parameters of a variety of microwave devices. However, these instruments, unlike oscilloscopes for example, require a relatively high degree of user knowledge and expertise. Due to the complexity of the instrument and of the calibration process, there are many ways in which an incorrect measurement may be produced. We routinely use check standards to verify that the network analyzer is operating properly. In the past, these measurements were recorded manually and, sometimes, interpretation of the results was problematic. To aid our measurement assurance, a software program was developed to automatically measure a check standard and compare the new measurements with an historical database of measurements of the same device. The program acquires new measurement data from selected check standards, plots the new data against the mean and standard deviation of prior data for the check standard, and updates the database files for the check standard. The program is entirely menu-driven requiring little additional work by the user. This paper describes the function of the software, including a discussion of its capabilities, and the way in which the software is used in our lab. Finally, some examples are given showing how the software can detect potential measurement problems.

INTRODUCTION

Vector network analyzers are widely used to measure the scattering parameters of a variety of microwave devices. Scattering parameters are related to reflection coefficients and transmission properties of the microwave devices. Typical devices that are measured include attenuators, terminations, mismatches, and directional couplers. The network analyzers require a relatively high degree of user knowledge and expertise and, due to the complexity of the instrument and of the calibration process, poor measurements can be made. Network analyzers must be calibrated or "zeroed" prior to obtaining any measurements. This calibration process entails the measurement a various known components (typically shorts, opens, and loads). This measurement calibration or error correction produces a set of error terms from the measurements of known calibration devices; these error terms are used to mathematically eliminate errors when

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a device is measured. Clearly, a poor measurement calibration of the instrument will give erroneous results.

To eliminate the potential problem and also to insure the highest quality measurement of microwave devices in the Primary Electrical Standards Dept. at Sandia National Laboratories, we have developed a computer program that acquires measurements of check standards and maintains a database of these measurements [1]. Many laboratories have used check standards to verify the proper operation of a measurement system and ensure that the measurement process is under statistical control [2] . This paper describes a unique system that allows a user to check the measurement system, keep a record of these measurements and maintain an historical database of the measurements.

The check standards database program described here may be used with either an HP 8753 or HP 8510 Network Analyzer*. The program itself is written in HP Basic to maintain compatibility with the different systems used in our lab. The program can acquire new measurement data from selected check standards, plot the new data against the mean and standard deviation of prior data for the check standard, and, optionally, update the historical database files for the check standard.

The program may be run stand-alone or loaded as a subprogram to a Basic program already in memory. The software was designed to require little additional work on the part of the user. To facilitate this design goal, the program is entirely menu-driven. In addition, the user is not required to remember file names or directories since this is handled by the software. However, the user does have control of file names and parameters within a definition file which sets up the basic scheme of file names.

The software also acts as a database manager allowing the user to add, delete, or sort records from the database. The database files are DOS text files and, therefore, allow for relatively easy editing or importing into other applications such as spreadsheet programs.

In our lab, we use the software to maintain a database of essentially twenty check standards in four connector types - N, APC-7 mm, APC-3.5 mm, and GR-900. New devices and connector types may easily be added. The software can produce plots of magnitude or phase angle vs. frequency or an historical plot of a device measurement at a single frequency. If desired, both magnitude and phase data for a device may be saved and plotted.

The aim of this paper is to describe the potential of the software. Towards that goal, we begin with an example showing how the software is used. Next, some of the functions of the software

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* Reference to a commercial product is included for completeness only and implies neither endorsement by Sandia National Laboratories or the Department of Energy nor lack of a suitable substitute.

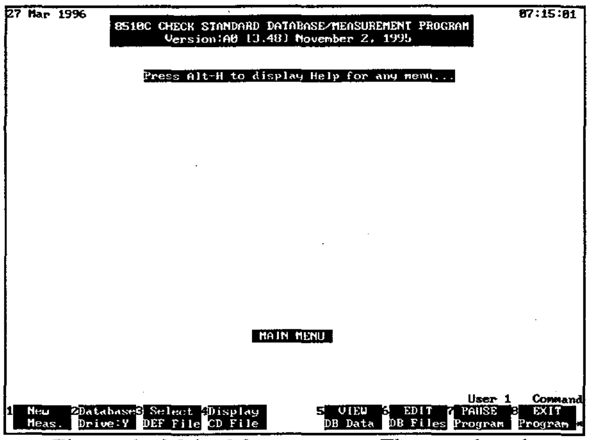

Figure 1. Main Menu screen. The numbered boxes refer to the softkeys labeled F1 through F8.

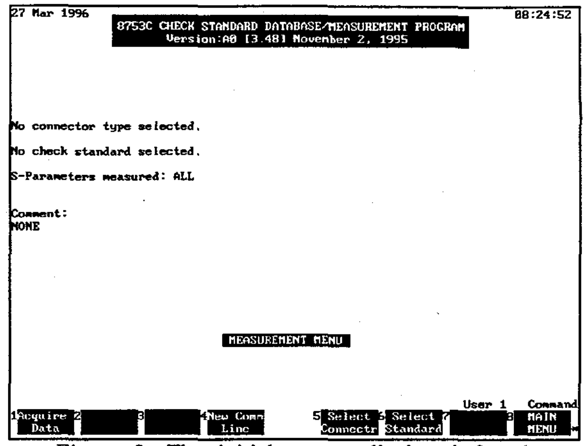

Figure 2. The initial screen displayed for the Measurement Menu. The user must select both a connector type and a check standard device before any measurement data may be acquired.

are described. We conclude by showing some examples of how the software detects problems in the measurement.

EXAMPLE OF USE

Perhaps the best way to exhibit the capabilities of the software is to show an example of typical use. Suppose that you have a 10 dB Type N attenuator that requires calibration. The first thing you must do is to "calibrate" the network analyzer. After this, the check standards program is loaded and started. When the program is started, it detects the type of network analyzer connected to the computer. (It's not necessary to have a network analyzer available. Clearly, if one is not present no new measurements may be obtained. However, the software can still be used to view and/or edit the data in any check standard device's database.) First, the software loads the appropriate definition file. The definition file contains the list of check standard devices as a function of connector type and the names of the files for each device. The Main Menu screen, as shown in Figure 1, is now displayed. Since we desire to measure the check standard devices, key F1, *New Meas.*, is selected. This selection brings up the Measurement Menu as shown in Figure 2.

Before any measurements can be taken, the user must select the check standard device. First, the user chooses the connector type by selecting F5, *Select Connectr*. The program displays a list of connector types as shown in Figure 3. After the correct connector type is chosen, the user selects key F6, *Select Standard*, from the Measurement Menu. The list of check standard devices is displayed as shown in Figure 4.

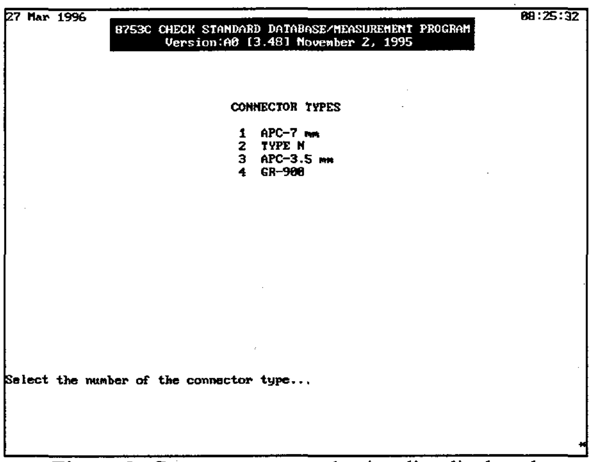

Figure 3. Connector type selection list displayed by the software.

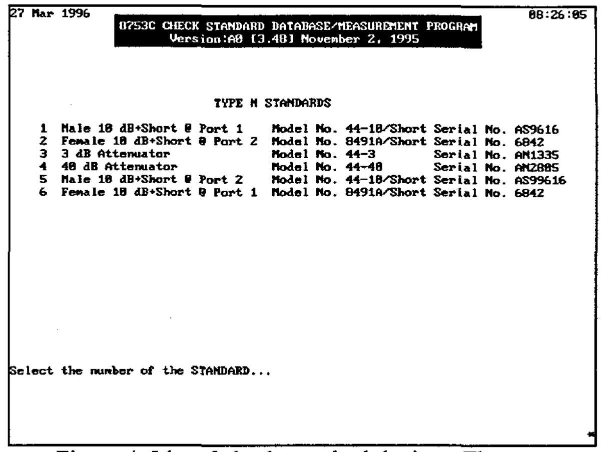

Figure 4. List of check standard devices. The user selects the device which will be measured by the network analyzer.

If the user elects to measure the 3 dB attenuator check standard, the program displays the Measurement Menu screen in Figure 5. Now the screen displays the connector type and the check standard selected. To take measurements, key F1, *Acquire Data*, is selected.

At this point, the software obtains the frequency list from the network analyzer, commands the instrument to do a sweep, and , once the sweep is done, acquires the appropriate S-parameter data. Using the file names provided by the definition file, the software obtains the past measurement history from the database files for the selected check standard device. The newly measured data are plotted along with the standard deviations computed from the previous device measurements. An example of this plot is shown in Figure 6.

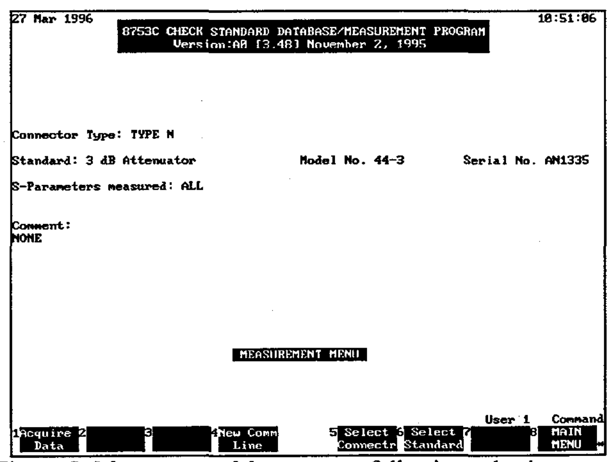

Figure 5. Measurement Menu screen following selection of a check standard.

The data plotted in Figure 6 are not the actual measured values but instead the difference between the measured value and the prior mean value at each frequency. The two curves are the $\pm$ 3 standard deviation (3σ) values calculated from the prior device measurements at each frequency. The solid circles show the current device measurements. Clearly, the user wants the measured values (i.e. the solid circles) to fall between the two 3σ curves. When that happens, the user can safely assume a valid

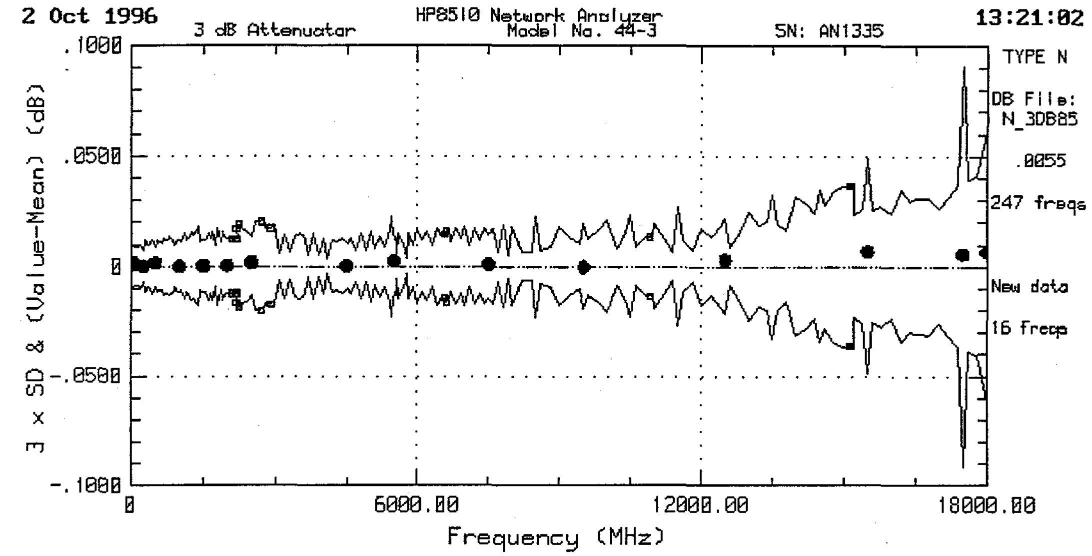

Figure 6. Plot of measured data from the Type N 3 dB attenuator check standard. The solid circles show the measured values. The two solid lines are plus and minus three times the calculated standard deviation of all measurements at each frequency. The measured data points (represented by the solid circles) should fall within the control limit lines to verify that the measurement system is in statistical control.

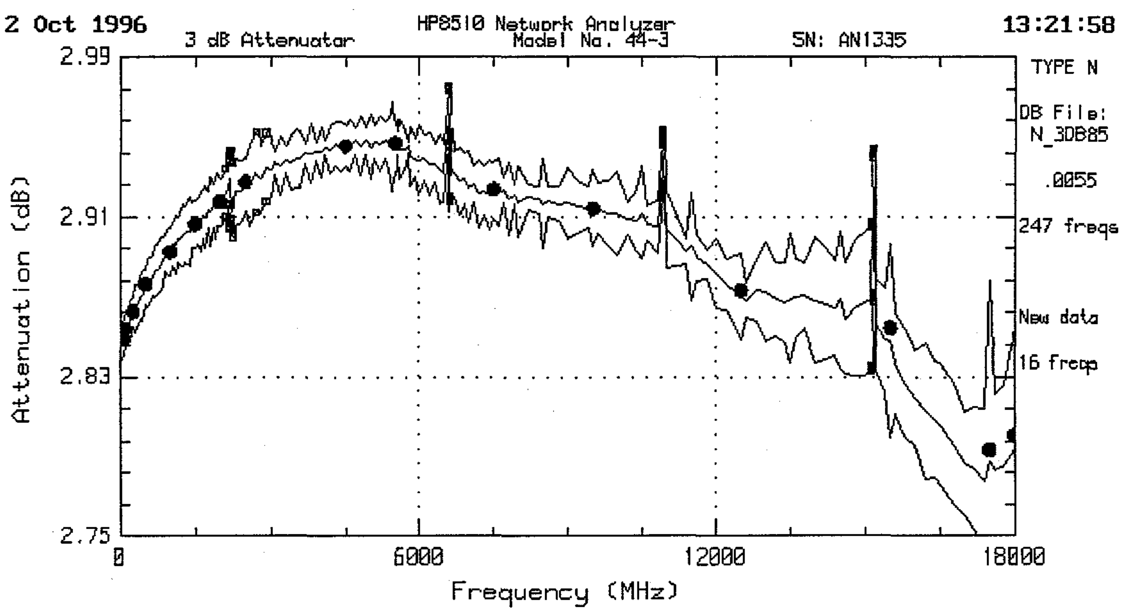

Figure 7. The same data as that plotted in Figure 6 but now the actual values rather than the difference from the means are plotted. The same information is presented but the format is not quite as useful as in Figure 6. This type of plot becomes even less useful for some devices whose measured value can change considerably with frequency

measurement calibration of the network analyzer has been made and subsequent measurements using this measurement calibration will be accurate. Figure 7 shows the same data as in Figure 6 but now displaying the actual measured data rather than the difference from the mean value. This plot shows that it is often difficult to determine whether a valid measurement is obtained when the actual data are displayed. Clearly, to see whether the measurement system is in proper operation, the difference plot, as shown in Figure 6, provides the more useful information. However, the form of plot in Figure 7 is useful when brand new data (data at frequencies not previously measured) are measured. The user can then see whether the new data fits in with the previously measured data.

When the data are acceptable, the user may elect to store the new data. If this is done, the software stores the new measurement data in the correct database files and then updates the summary database file by calculating new mean and standard deviation values at each measured frequency.

The plot in Figure 6 also provides useful information regarding the check standard device and the data. The plot title specifies the network analyzer used to take the measurements and the definition of the device (i.e. device type, model, and serial number). The right margin of the plot lists the connector type, the name of the database file that was accessed, the average standard deviation, and the total number of frequencies in the database for this device. Below the number of frequencies, other information is displayed depending on the type of plot. In the case of Figure 6, the plot is of newly acquired data, so the information line states "New Data" and the number of frequencies measured.

HISTORICAL DATABASE

The check standards measurement and database software not only provide the user with a quick and accurate confirmation of the proper operation of a network analyzer measurement system, it also provides an historical record of each check standard device. The plots shown in Figures 6 and 7 show, in effect, the cumulative measurement variations in the device relative to the calculated mean value at each frequency. The software also allows the user to look at the measurements at a particular frequency over time. Such a plot is shown in Figure 8. In the plot, nineteen measurements at 1,000 MHz are shown with the mean value indicated by the center line. The two other lines again show ± 3 times the standard deviation values of the nineteen measurements. From this plot, the variation over time of the measurements is immediately seen. The right margin displays the mean value and calculated standard deviation. A plot such as this may be used to determine if the check standard value is drifting or if a problem occurred with a particular measurement in the past which produced a larger than expected (or desired) standard deviation.

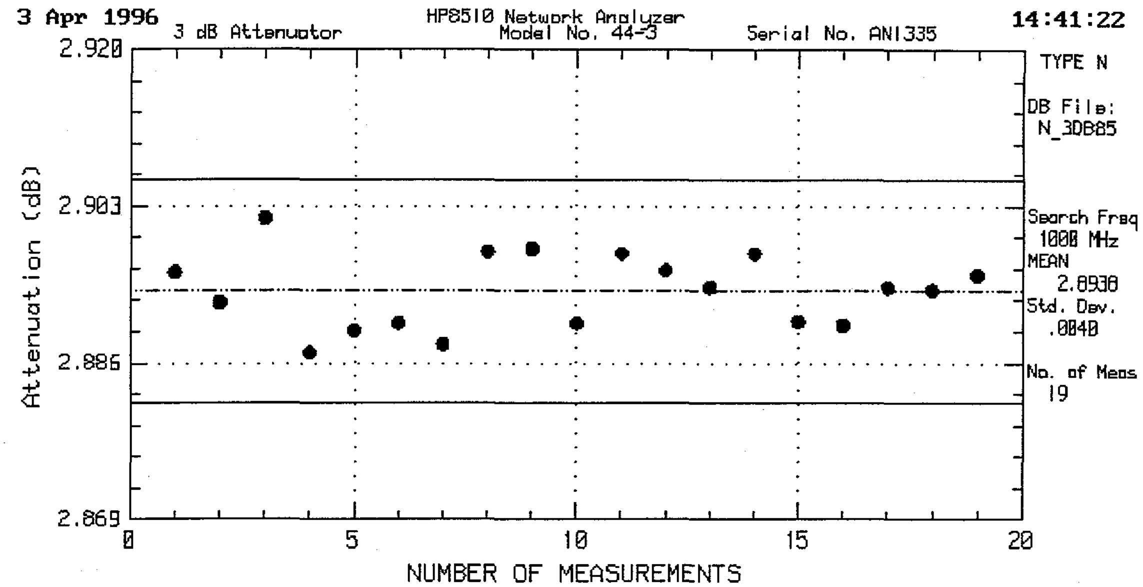

Figure 8. Data from the 3 dB attenuator check standard illustrating the time variation of the measurements at a frequency of 1,000 MHz. .

This time history plot is equivalent to control charts [3] commonly used in statistical process control. Typically, some type of quality characteristic is displayed versus time or sample number. The upper and lower control limits are also displayed to provide the user with some indication whether the process is in control. With this software, the standard control chart can be displayed and this information can be used to determine whether the measurement system and/or check standard is in control *at a particular frequency.* In measuring microwave devices, the *frequency dependence* of the device is important. For this reason, a simple control chart cannot really be used to check the status of the measurement system but, rather, a plot such as in Figure 6 is required.

USING THE SOFTWARE TO DETECT MEASUREMENT PROBLEMS

One of the primary uses of this software is to detect potential problems in the measurement system before a customer's device is measured or before some other type of measurement is made on the network analyzer. In this section, examples are shown where the software indicates the presence of a problem with the measurements or with the measurement system.

Occasionally, the check standard itself may have been poorly connected. The results of such a measurement are shown in Figure 9. Typically, when results such as in Figure 9 are obtained, the check standard device is removed and reconnected. For the case shown here, this simple operation corrected the problem. However, if reconnecting the device does not give acceptable

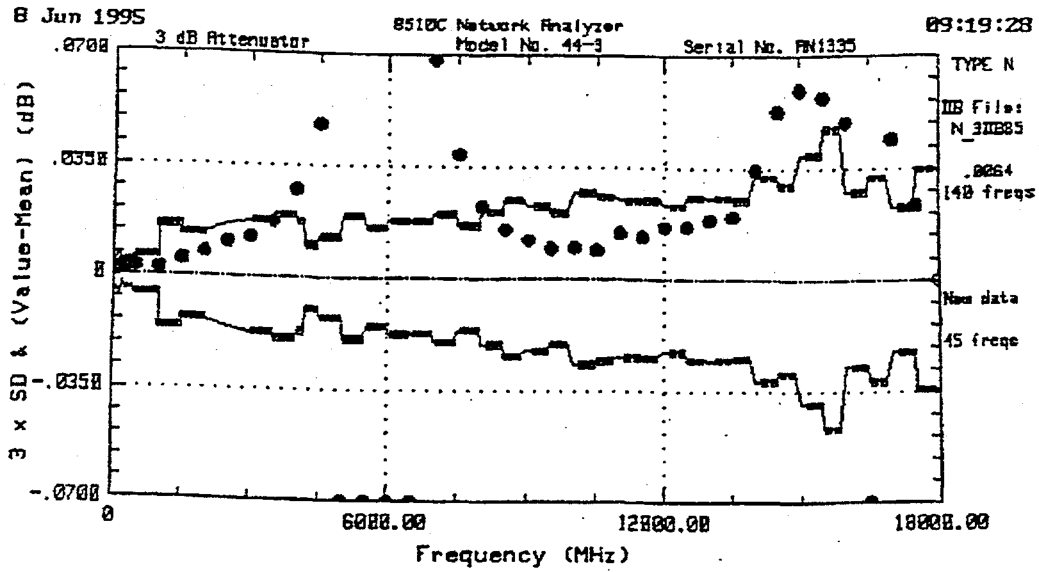

Figure 9. Measurement results showing a poor connection of the device to the network analyzer ports.

results, the only alternative is to recalibrate the network analyzer. Unless there is a hardware problem, re-calibration generally gives good measurements.

Figure 10 shows the data obtained for an APC-7 mm 1-port device when the Port 1 short and open calibration devices were deliberately reversed during the measurement calibration process. When compared to the typical results shown in Figure 6, these data strongly suggest a problem. These data are typical of results obtained with microwave devices. The data at many frequencies appear to be in control but the data at about 2500 MHz, as shown in Figure 10, definitely show some problem. Unfortunately, the data do not really provide any suggestion as to what may be the problem. However, if redoing the measurement calibration produces good results for the check standard measurements, then, clearly, some problem occurred in the measurement calibration process. (The cause of the problem is generally not that important. The network analyzer is usually re-calibrated more carefully to be certain that no errors are again made.)

There are many possible causes of measurement problems with network analyzers. Some may be due to operator error but others could be due hardware problems. Possible reasons for the out of limit measurements illustrated in Figures 9 and 10 include:

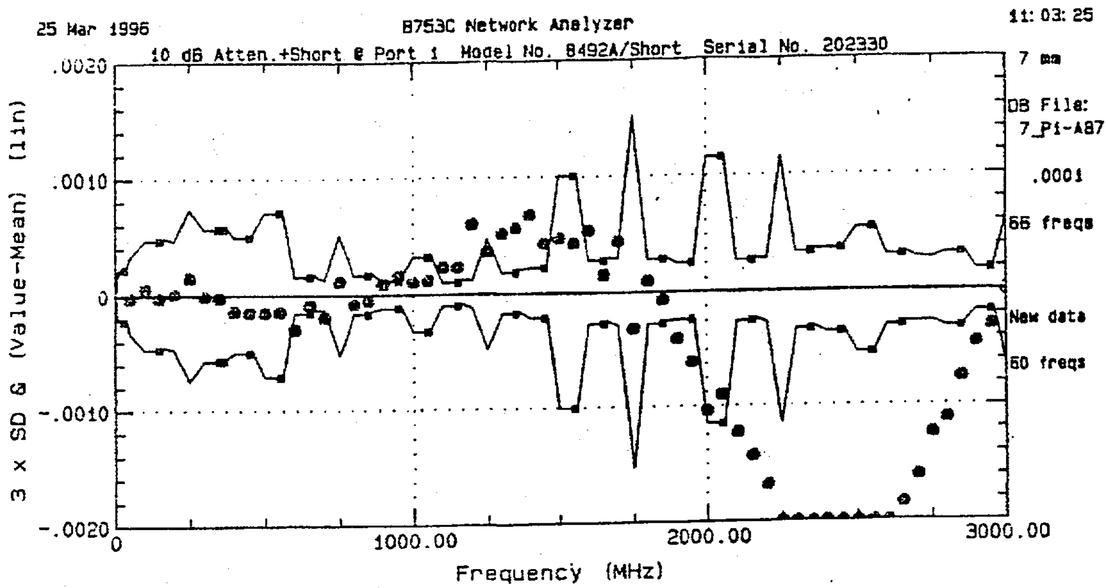

Figure 10. The measurements results for a one-port check standard device with APC-7 mm connectors. The data show the measured values when the short and open calibration devices were intentionally switched during the port 1 calibration. These data give an example of a poor check standard measurement that is due to an error during the network analyzer calibration procedure.

- Poor check standard connection (cf. Figure 9)
- Poor measurement calibration (cf. Figure 10)
    - ◊ Operator error
        - ⇒ Improper device connection
        - ⇒ Incorrect menu selection on the network analyzer
    - ◊ Temporary hardware fault
    - ◊ Hardware problem (synthesizer, test set, phase lock, etc.)
    - ◊ Cal kit device instability or failure
    - ◊ Check standard device instability or failure

Of the reasons listed above, poor check standard device connections and poor measurement calibrations due to operator error are usually corrected by recalibrating the network analyzer. If out-of-limit measurements are due to any of the other reasons listed, isolation of the probable cause becomes more difficult.

The graphical comparison of how well the measured data of the check standard compare with the past history quickly shows possible problems. Looking carefully at the data also shows that in many cases the newly measured data at some frequencies lie well within the standard deviation limits from the database. This shows that by only checking certain frequencies (that is, not <u>all</u>

frequencies at which the network analyzer was calibrated) can certainly give the user a false sense of security regarding the accuracy of the measurement calibration.

SUMMARY

This paper has described a computer program designed to acquire measurements from a microwave network analyzer on check standard devices and maintain a database of these measurements. The program plots the newly measured data together with the calculated mean and standard deviation values of past measurements at each measured frequency. The standard deviation provides statistical limits so that the user can quickly determine whether the measurements are in control.

The paper showed some examples illustrating cases when the measured data for the check standard was not acceptable. This software is used routinely in our lab to verify the performance of the network analyzer measurement systems and thus assure the accuracy and quality of the analyzer performance before carrying out measurements of customer's devices.

REFERENCES

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[3] D. C. Montgomery and G. C. Runger, Applied Statistics and Probability for Engineers, John Wiley & Sons, Inc., New York, 1994.