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Vector Network Analyzer Check Standards Measurements and Database Software

Leonard E. Duda
Sandia National Laboratories
PO Box 5800, MS 0665
Albuquerque, NM 87185-0665

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. Prior to use, the network analyzer must undergo measurement calibration or error correction. Due to the complexity of the instrument and of the calibration process, there are many ways in which a poor measurement calibration or measurement may be produced. Check standards have been used to verify that the network analyzer is operating properly. In the past, the 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 check standard device. 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 update the database files for the check standard. This paper describes the function of the software including a discussion of its capabilities. The way in which the software is used in our lab is also described. 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. These instruments 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. The 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 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 Labs., we have developed a computer program that acquires measurements of check standards and maintains a database of these measurements. Many laboratories have used check standards to check the proper operation of a measurement system. 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 [1]. 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 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

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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 or delete 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 (some may be the same device but used for a different type of measurement) 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 are described followed by a brief description of the computer files used by the program. 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 (DEF) file. The DEF 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.

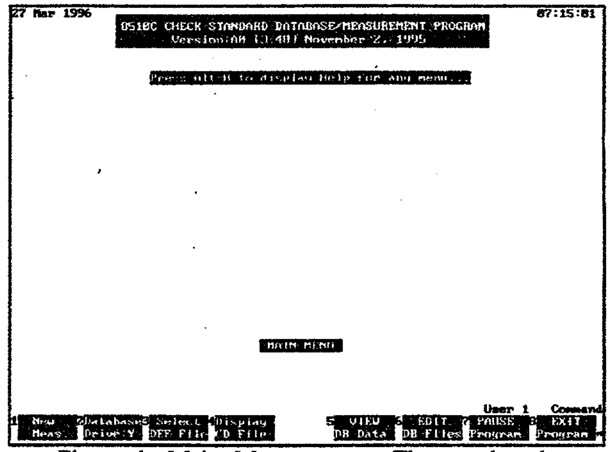

Figure 1. Main Menu screen. The numbered boxes refer to the softkeys labeled F1 through F8.

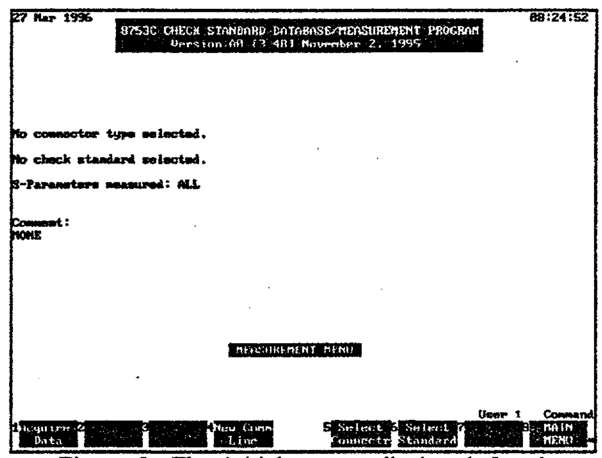

Figure 2. The initial screen displayed for the Measurement Menu. The user must select both a connector type and a check standard device before any measurement data may be acquired.

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 a 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.

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

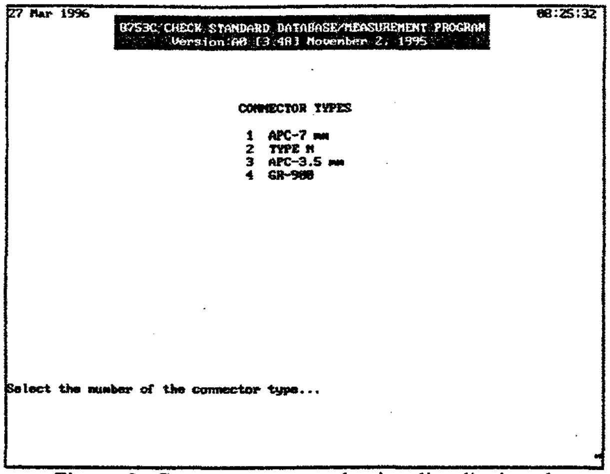

Figure 3. Connector type selection list displayed by the software.

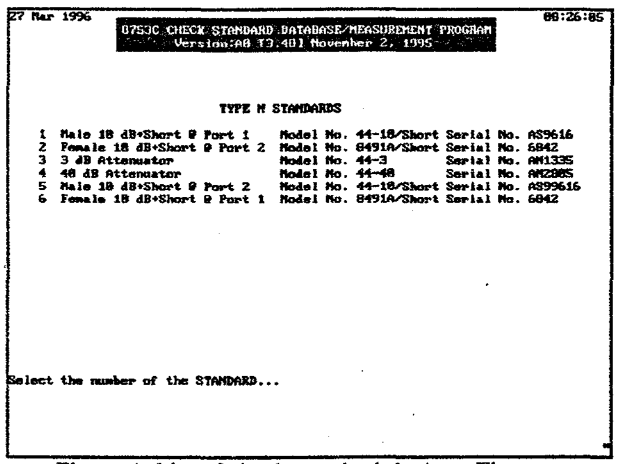

Figure 4. List of check standard devices. The user selects the device which will be measured by the network analyzer.

instrument to do a sweep, and , once the sweep is done, acquires the appropriate S-parameter data. Using the file names provided by the DEF file, the software reads the past measurement history from the database files made for each 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.

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 ±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

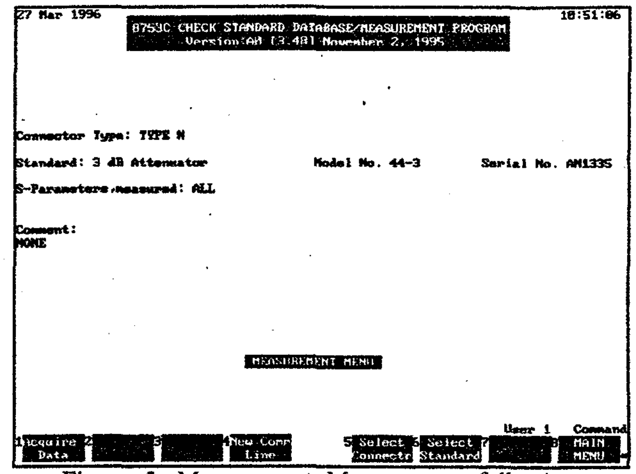

Figure 5. Measurement Menu screen following selection of a check standard.

fall between the two 3σ curves. When that happens, the user can safely assume a valid measurement calibration of the network analyzer has been made and subsequent measurements using this measurement calibration will be accurate.

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.

DATA FILES

There are five different file types used by the software. All these files are stored as simple DOS text files and so may be viewed or edited from any text editor. The two database files, described below, have their file attribute set to read only to prevent inadvertent editing or deletion.

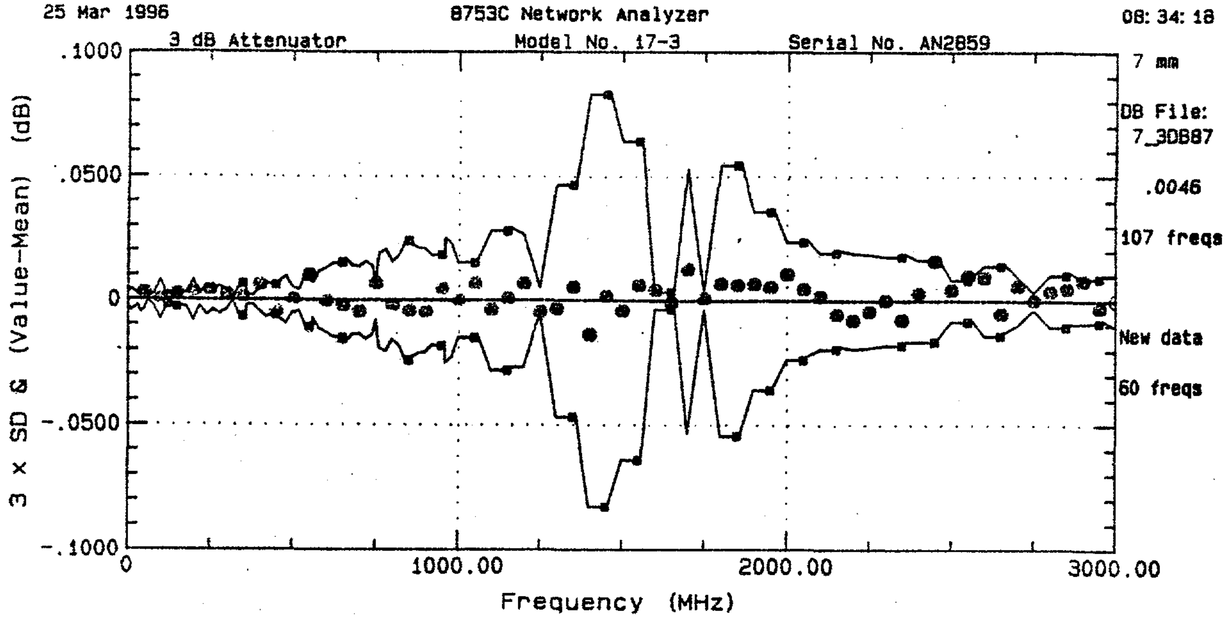

Figure 6. Example of a plot of data from a measurement of the 3 dB attenuator check standard. Some items to note in the plot are described in the text.

The first file type shown is called the database file having an extension of DBF. (Please note: other database programs use similar extensions. The files produced by this program are not directly compatible with these other programs. However, these files, since they are DOS text files, may be imported into many spreadsheet or database programs.) This file stores all the data for the specified check standard measured with a particular network analyzer. Each line in the file constitutes a separate database record. Since all the data are stored on one line, the lines have different lengths depending upon the type of standard and the number of measured frequencies. For devices such as attenuators, only the attenuation value (actually, |S21|) is stored. For one-port devices, both the linear magnitude and the phase angle are stored in the file.

The second database file is called the summary file and has an extension of SUM. This file summarizes the data for a specific check standard at all the measured frequencies. The program allows the user the option of deleting a record in the DBF file or adding a record to the file. When this is done, the related SUM file is updated automatically.

As mentioned earlier, when the software initially starts, the program definition file is read. These files, which have the extension of DEF, provide the information required by the program regarding the number and associated file names of the check standards. The number of DEF files is unlimited but, if more than one is found, the program displays the list of files and instructs the user to select one. Separate definition files are required for each network analyzer. Unlike the database files described above, the DEF files must be constructed by the user.

The fourth type of file is the control data (CD) file which contains the measurements made on a specific check standard on a specific date. Each time a measurement on a check standard is stored, the program also stores a CD file containing the measurement data. The program uses the CD files to add data to a particular database. For example, you may decide to delete a record from the DBF file for a particular check standard. Later, you may decide that you really do want that data included in the check standard's database. The program allows you to add these data from the appropriate CD file.

Finally, the fifth file required by the program is the menu help file that is displayed when the user presses ALT-H at any menu. The help file provides additional information regarding the various softkey choices available at the menu.

HISTORICAL DATABASE

The check standards measurement and database software not only provide the user with a quick and accurate confirmation of the accuracy of a network analyzer measurement system, it also provides an historical record of each check standard device. The

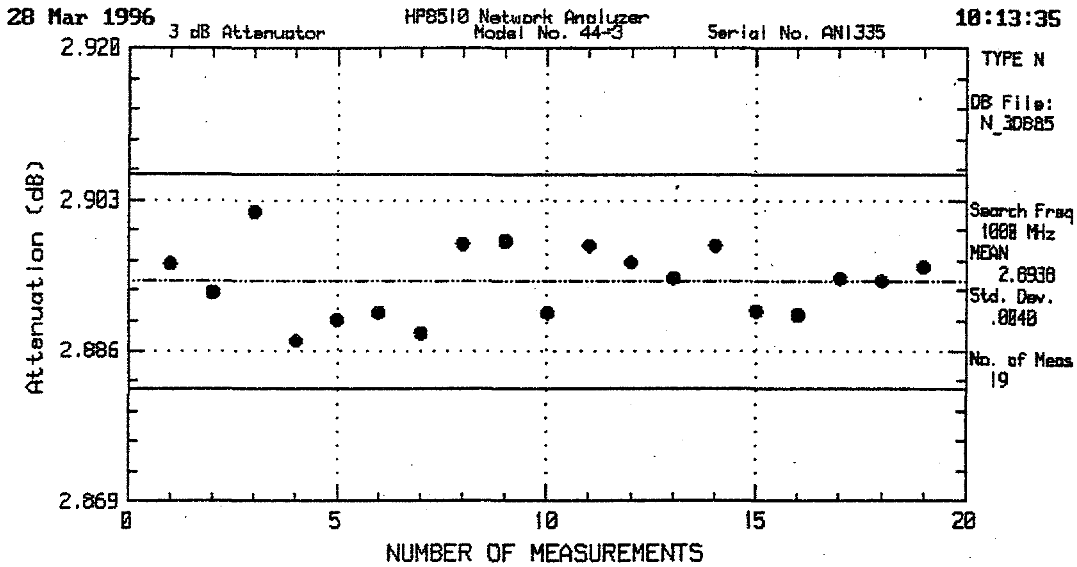

Figure 7. Data from the 3 dB attenuator check standard illustrating the time variation of the measurements at a frequency of 1,000 MHz.

plot shown in Figure 6 shows, 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 7. 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.

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 8. Typically, when results such as in Figure 8 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 results, the only alternative is to recalibrate the network analyzer. Unless there is a hardware problem, re-calibration generally gives good measurements. In the following plots, part of the measurement calibration steps were deliberately done incorrectly so that the results on the check standard measurements could be observed.

Figure 9 shows the data obtained for the 3 dB attenuator 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. Unfortunately, the data do not specify 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.)

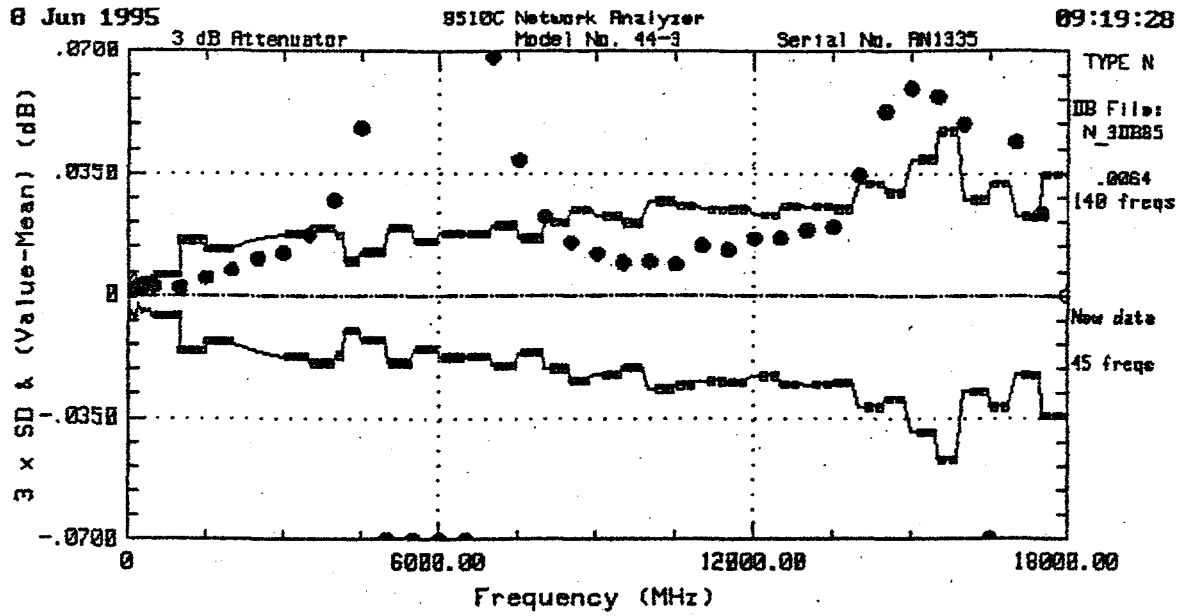

Figure 8. Measurement results showing a poor connection of the device to the network analyzer ports.

Figure 10 shows how the measurements on a simple one-port device appear under the same conditions as in Figure 9. Again, these results clearly show the presence of a problem with the measurement. These data are plotted again in Figure 11 but now the actual measurement values are plotted. In the frequency range of 2 to 3 GHz the measured data (solid circles) clearly lie outside the standard deviation limits of the database data. However, the discrepancy is not as apparent as in Figure 10 where the difference between the mean and measured value are plotted.

Another example of an error during measurement calibration is show in Figure 12. In this example, the sex of the Type N test set port 1 connector was deliberately entered incorrectly when the short

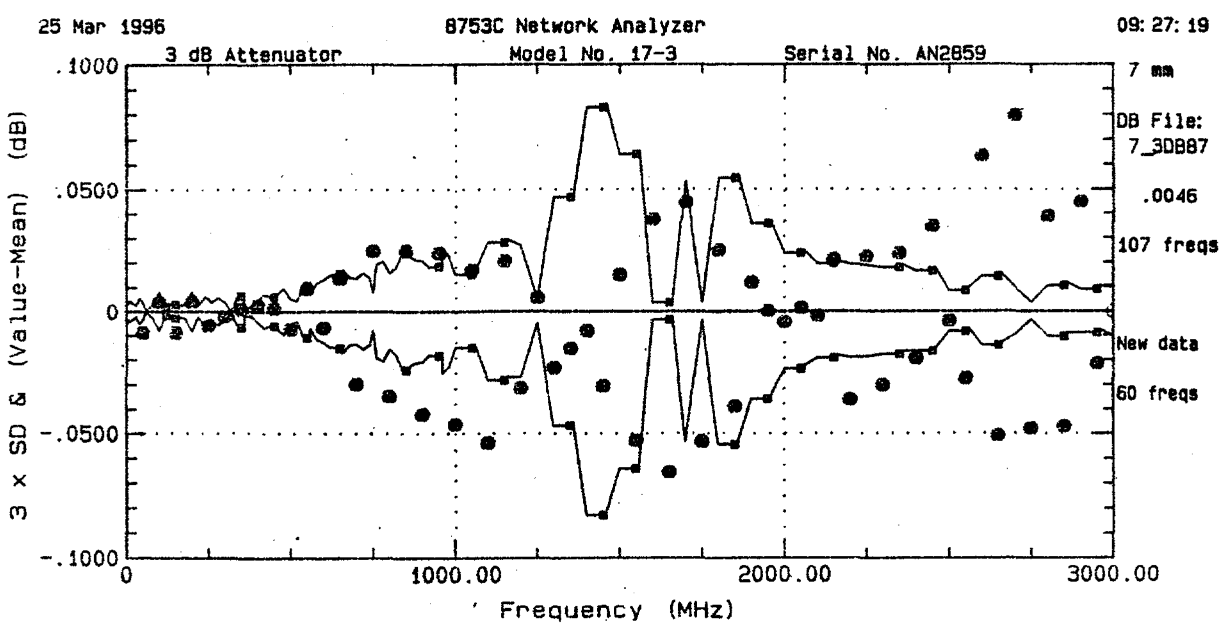

Figure 9. Measurement results on the APC-7 mm 3 dB attenuator check standard when the short/open devices were switched during the port 1 calibration.

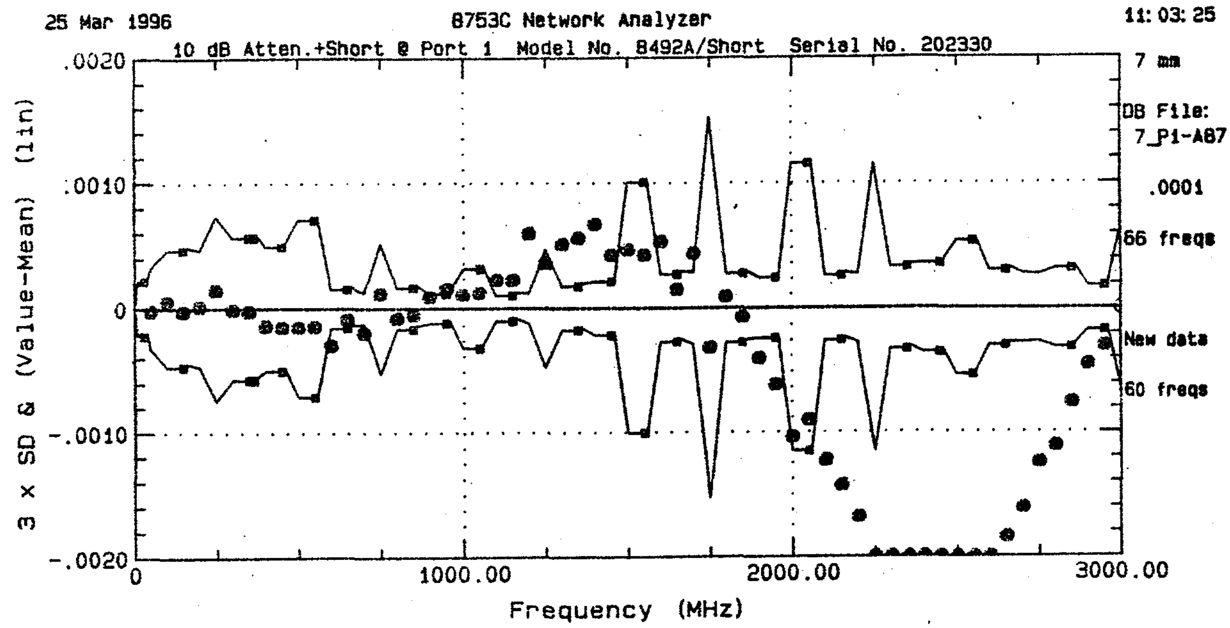

Figure 10. The measurement results for a one-port check standard device under the same conditions as those in Figure 9. The results clearly show a measurement problem.

calibration device was connected. Rather than the correct value of "female", the softkey for "male" was selected. With only this intentional error in the measurement calibration, the measured results for the one-port check standard device clearly show a problem. In fact, most of the data lie outside of the plot limits of 0.02 magnitude units.

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 all 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.

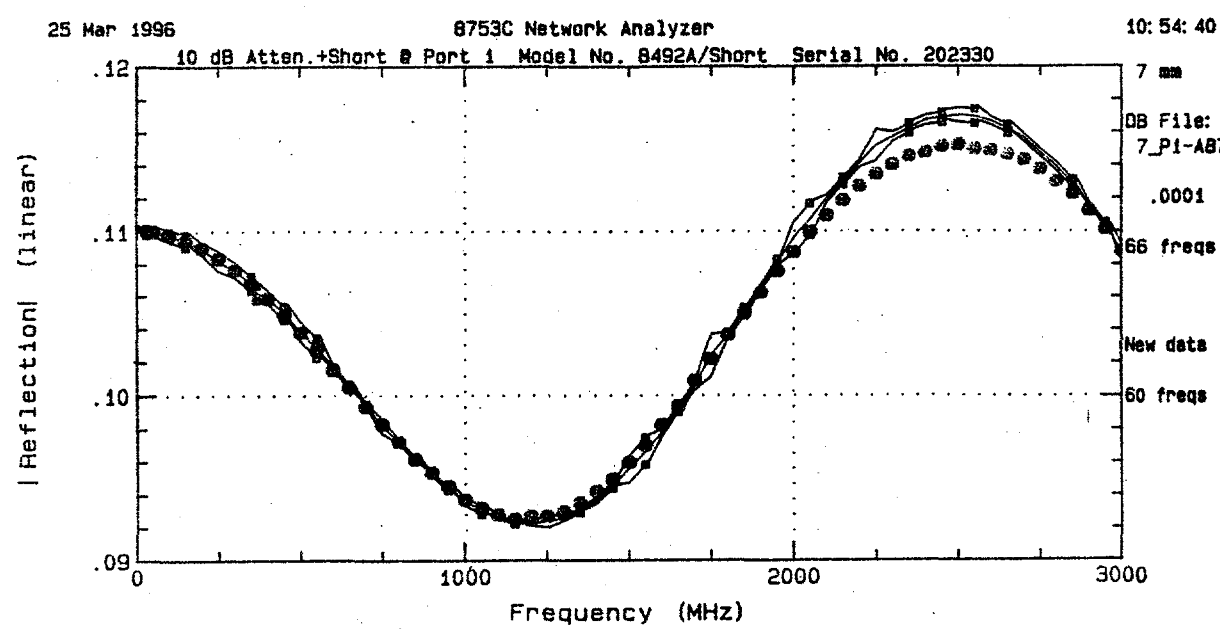

Figure 11. The data from Figure 10 plotted again showing the actual values of the S_{11} magnitude. Note, however, that the measurement problem is not as apparent as in Figure 10.

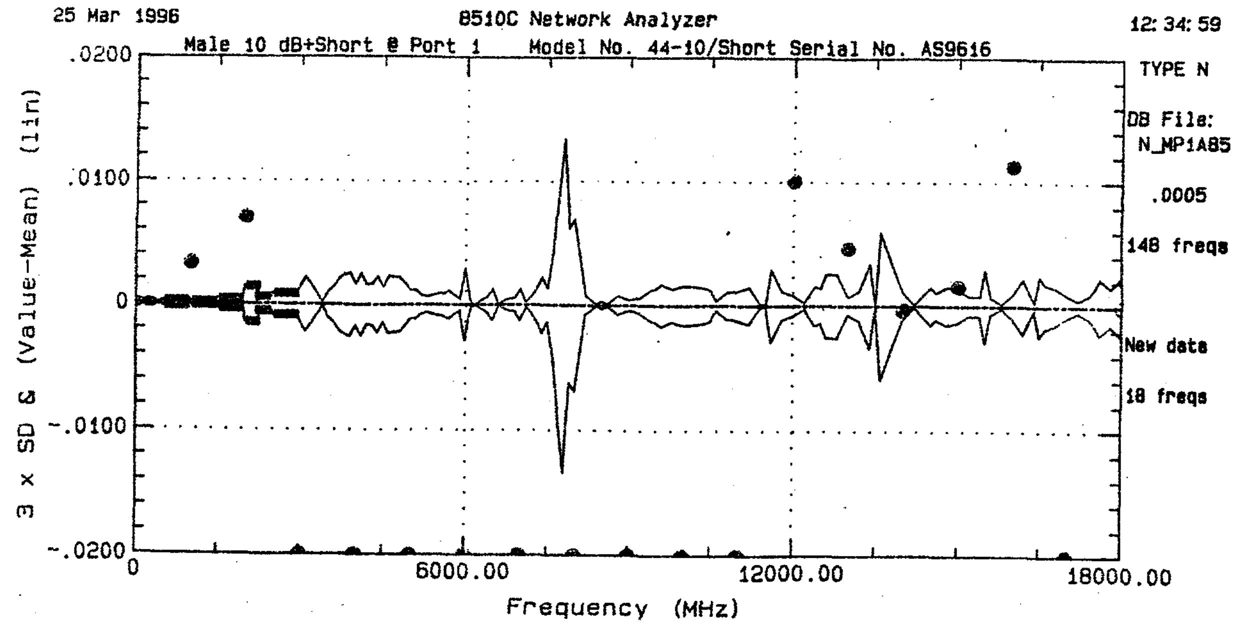

Figure 12. Measurements results for one-port Type N check standard device when the sex of the test port connector was incorrectly specified during measurement of the short calibration device.

SUMMARY

This paper has described a computer program designed to acquire measurements 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.

NOTES

[1] 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.