On-Line Accuracy Assessment for the Dual Six-Port ANA: Experimental Results

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Abstract—When a calibration laboratory such as the National Bureau of Standards (NBS) performs a measurement for a customer, the accuracy the laboratory attaches to its measurements is a significant part of the customer’s report. In some instances, the accuracy statement may be more important to the customer than the measurement itself. Modern automated measurement systems can often perform hundreds of measurements in a fraction of a second. However, few, if any, of these systems attempt to assess the accuracy of these measurements in a real-time or on-line basis.

The accuracy of a modern automatic network analyzer (ANA) is a function of a number of variables. Connector quality, operator technique, system hardware, and system calibration are just a few of the many parameters that affect the day-to-day accuracy of an automated system. This paper describes the results of the current efforts at NBS to implement on-line accuracy estimates for its dual six-port network analyzers. Results are presented showing uncertainty estimates obtained in quasi-real time during the measurement of customers’ devices.

I. INTRODUCTION

THE dual six-port network analyzer (ANA), as implemented at the National Bureau of Standards (NBS), incorporates a significant amount of redundancy. This redundancy, when properly exploited, can be used to provide estimates of the accuracy of any measurement made on the six-port. This report describes the current efforts at NBS to provide on-line accuracy estimates for its dual six-port network analyzers. This capability provides the operator with a quasi-real time estimate of the accuracy of every measurement that is made on the six-port. Examples of on-line accuracy estimates are given for frequencies up to 18 GHz with 7-mm connectors. Details of the theory behind the on-line accuracy estimates are given in companion papers [1]–[4].

Redundancy in the NBS dual six-port network analyzer appears in many forms. For example, four power detectors are used per six-port when, in reality, most measurements can be made with three detectors. The fourth detector is used to supply redundant information on the consistency of the power measurements. Also, the system is implemented with two different six-port heads. Redundant information is obtained by measuring the same termination on both heads. Additional redundancy is obtained by using more devices than necessary in the calibration process and by making multiple connections of those devices during the system calibration. The uncertainty in any measurement is obtained by properly exploiting the redundancy via statistical error propagation techniques.

II. UNCERTAINTY ESTIMATES FOR ONE-PORT MEASUREMENTS

Typical measurements of the reflection coefficient $\Gamma$ of four different one-port devices, at 2 GHz, are shown in Table I. The devices are a 1.05 VSWR mismatch, a 1.5 VSWR mismatch, a short-circuit termination, and an open-circuit termination. Shown for each device is the reflection coefficient as measured on the six-ports as well as the estimated uncertainty of that measurement as obtained from the on-line accuracy assessment software. The entry labeled “random-uncertainty” is a prediction of the random uncertainty in the measurement due to random errors. Throughout this report a convention will be followed of reporting all random values as three standard deviations. The entry labeled “systematic uncertainty” is a prediction of the systematic uncertainty in the measurement due to systematic errors in the calibration standard (beadless air line). The total uncertainty is defined as the systematic component plus the three-standard-deviation random component. Uncertainty predictions, such as those shown in Table I, are obtained for each measurement of the customer’s device. The random uncertainty is a prediction of the random error in the measurement system, not the customer’s device. The random uncertainty of the customer’s device is obtained by making multiple measurements of his device.

As expected with any random process, the random component of the uncertainty varies during the day-to-day operation of the six-ports. On some occasions the various random mechanisms can be expected to result in a random uncertainty below average, while on other occasions they can be expected to be above average. For the devices shown in Table I, much of this random uncertainty is determined by the system calibration.

The typical variation in the uncertainty predictions and the measurements during the day-to-day operation at 2 GHz is shown in Fig. 1. Plotted here is the predicted random uncertainty in $|\Gamma|$ versus $\Gamma$ for the 1.5 VSWR mismatch. This graph is the result of 25 measurements made over a two-week period. Results are shown for both

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while the random variations in the measurements of $\Gamma$ is 0.0004–0.005. The horizontal bars on each graph show the random variability in the actual measurements of each device. For example, the random variability in the measurements of the 1.5 VSWR mismatch is 0.0009.

Fig. 4 shows the same measurements as in Fig. 2, except that the frequency is 12 GHz. Now the random uncertainty for the 1.05 VSWR varies from 0.0008 to 0.007, and from 0.004 to 0.025 for the short-circuit termination. Connector variability is the dominate factor in the random uncertainty at these frequencies.

Fig. 5 summarizes the total uncertainty in $|\Gamma|$ that is typically predicted on the dual six-port network analyzer. Plotted in this figure is the total uncertainty in $|\Gamma|$ versus frequency. The shaded portion denotes the range of values typically predicted in the day-to-day operations. This plot is for devices with 7-mm connectors (six slot collets).
Fig. 5. Predicted total uncertainty in $|\Gamma|$ versus frequency. Results are for devices with 7-mm connectors and $0 \leq |\Gamma| \leq 1$.

and $0 \leq |\Gamma| \leq 1$. The on-line uncertainty software, as currently implemented, tends to overestimate the random uncertainty in some cases. Experiments show that the predicted random uncertainty exceeds the experimental data by a factor of up to 3 for some devices. Efforts are currently underway to improve the predictions in this area.

III. UNCERTAINTY ESTIMATES FOR TWO-PORT MEASUREMENTS

On the dual six-port, the predicted uncertainty in the $S$ parameters ($S_{11}$, $S_{12}$, $S_{21}$, and $S_{22}$) of two-port devices is obtained from the statistical techniques described in [2]. Examples of the predicted uncertainty in $A = -20 \log |S_{12}|$ are shown in Figs. 6–10. As in the previous cases, the total uncertainty is defined as the systematic uncertainty plus the random uncertainty (three standard deviations). The systematic uncertainty in the measurements of $A$ is negligible for all of the examples described in this report.

Fig. 6 shows the predicted random uncertainty in $A$ versus $A$ for a through (0-dB) connection. This graph is the result of 75 measurements made over a two-week period. The six-port was recalibrated 25 times during the period, and the through was measured three times after each calibration, with a disconnect between each measurement. The average predicted random uncertainty is 0.004 dB, while the random variation in the actual measurements is 0.0009 dB. The frequency for these tests is 2 GHz.

Fig. 7 shows similar measurements for a 20-dB attenuator. In these measurements, the average predicted random uncertainty is 0.0053 dB while the random variation in the actual measurements is 0.0018 dB. The measurement procedure is the same as described for Fig. 6. These tests are also for 2 GHz.

Fig. 8 shows the effect of frequency on the predicted uncertainty. Plotted in this figure is the predicted random uncertainty in $A$ versus frequency for a 10-dB attenuator. The horizontal bars on each graph show the random variability in the actual measurements of the device. As in the previous example, the predicted systematic uncertainty is negligible. This plot is the result of 25 measurements over a two-week period with the system recalibrated prior to each measurement. Note that the range of the predicted random uncertainty at 2 GHz is from 0.002 to 0.01 dB, while at 12 GHz the range is from 0.007 to 0.02 dB. The increase in random uncertainty with frequency is largely due to the increase in random errors from connector non-repeatability.

The typical variation of the predicted random uncertainty in $A$ versus $A$ is shown in Fig. 9. For this plot, repeated measurements were made on an 0 (through connection), a 10, 20, and 60 dB attenuator over a two-week period. As in the previous case, the system was recalibrated 25 times during the two-week period and the attenuator was measured three times after each calibration (device disconnected between each measurement). The random variability of the actual measurements is again shown by horizontal bars. The measurement frequency for
It has proven to be a valuable tool in understanding the system and in keeping its operation under control. It can be used to quickly identify system failure, such as a noisy power detector, or a poor connector on one of the calibration standards. Also, it provides the operator with a quasi-real-time indication of the accuracy of any of the measurements. This feature has been particularly useful in training the operator and illustrating the importance of connector care and cleaning.

The on-line uncertainty estimates are dependent on redundancy in the measurement system. Obviously, the form of this redundancy must be judiciously chosen. Inconsistency cannot be detected where no redundancy exists. The negative aspect of the on-line uncertainty estimates is that it adds a significant amount of complexity to the system. The procedure requires more calibration devices than would normally be used on the six-ports. Also, the calibration standards are disconnected and reconnected three times to assess connector repeatability. The software also is significantly more complicated.

The on-line uncertainty estimates, as currently implemented, tend to be slightly pessimistic in that it overestimates the random uncertainty in many cases. The experimental evidence shows that the predicted random uncertainty can be up to a factor of 3 greater than the experimental data. This degree of overestimation is felt to be reasonable considering the complexity of the problem. Some of this overestimation is believed to be due to nonideal connectors and the modeling of connector repeatability in the on-line software. Efforts are continuing to refine the technique and to increase the accuracy of the predictions.

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REFERENCES