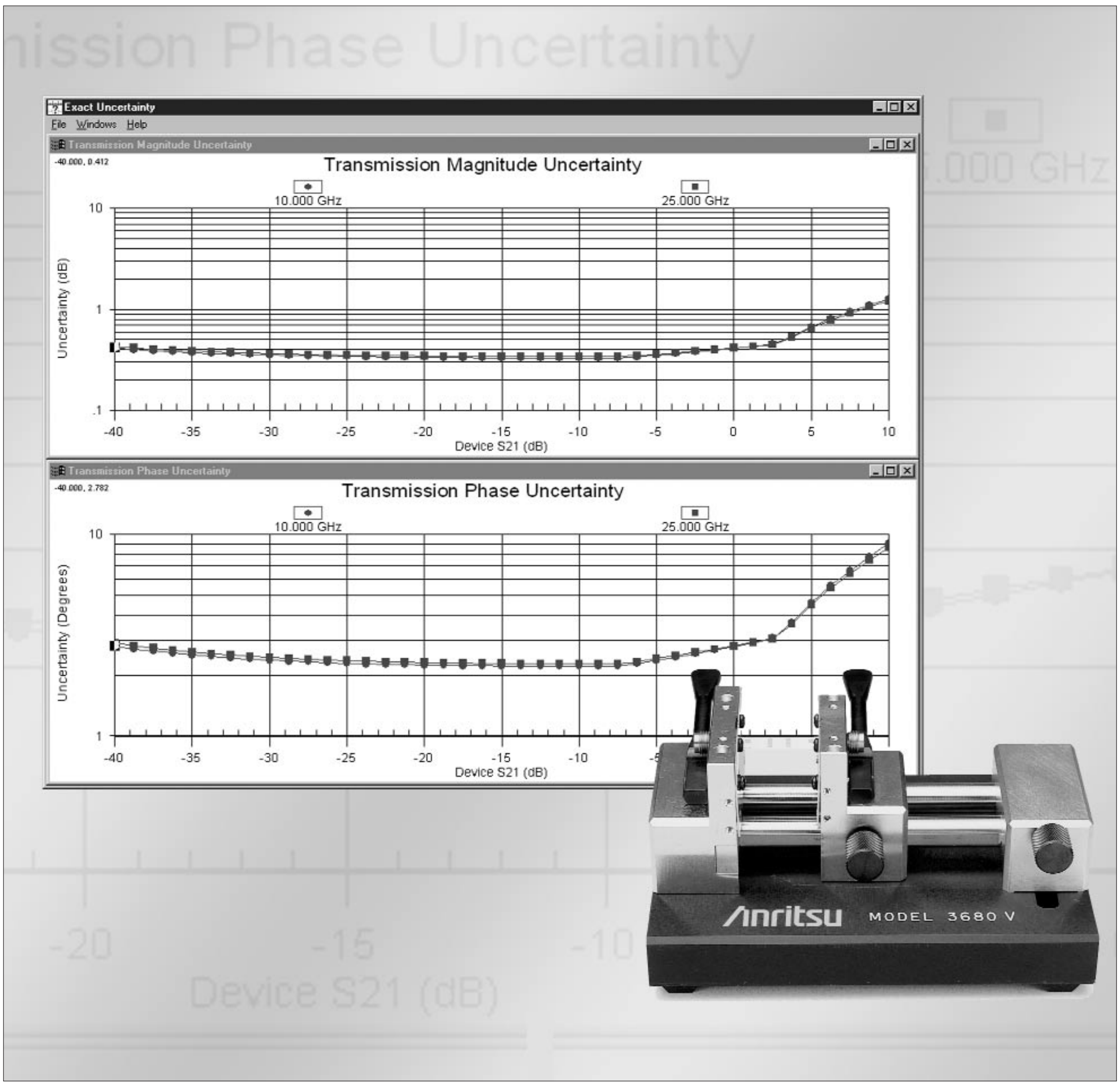
Anritsu

# Application Note

# What Is Your Measurement Accuracy?

## Vector Network Analyzer



# Introduction

Vector Network Analyzers (VNA) are your primary resource when S Parameter information is required for RF and Microwave measurements. They are regarded as accurate measuring instruments; but, it is rare that a user takes a serious look at the quantitative accuracy performance of a VNA in a specific application. VNA specifications are a starting point; but, they are based upon very specific calibration and measurement conditions, which are not applicable for many of your applications. A Windows based program (Model No. 2300-361) is available to help you obtain the uncertainty data that is appropriate for your specific application.

In 1999, the international standards, ISO/IEC 17025, was published as the essential requirements for demonstration of the competence of testing and calibration laboratories. It covers testing and calibration performed using standard methods, non-standard methods, and laboratory-developed methods. The ability to express uncertainty of measurement is the key element of assurance of competence. Section 5.4.6 of the standards specifies the requirements of estimation of uncertainty of measurement. "A calibration laboratory, or a testing laboratory performing its own calibrations, shall have and shall apply a procedure to estimate the uncertainty of measurement for all calibrations and types of calibrations."

## General Considerations

VNA performance specifications are usually presented as numeric data detailing Test Port characteristics and dynamic range parameters as shown in Figures 1and 2. This information coupled with test condition assumptions, such as connector repeatability and cable stability, can be used to develop the measurement uncertainty curves included in VNA technical data sheets such as shown in Figure 3.

It is important to note that that the information included in Figures 1 through 3 is based upon several conditions usually described in footnotes such as:

- 12 Term sliding load calibration required
- IFBW is 10Hz
- Averaging used is 1024
- DUT S11 and S22 = 0

These are not realized in many applications so the question arises: What is the uncertainty that you should apply to your specific situation?

| Model | Frequency (GHz) | Max. Signal Into Port 2 (dBm) | Noise Floor (dBm) | Receiver Dynamic Range (dB) | Port 1 Power (dBm, Typical) | System Dynamic Range (dB)* |
|---|---|---|---|---|---|---|
| 37369C | 0.04<br>2<br>20<br>40 | +30<br>+30<br>+30<br>+30 | -65<br>-93<br>-90<br>-83 | 75<br>123<br>120<br>113 | +5<br>+5<br>0<br>-7 | 70<br>98<br>90<br>76 |

**Figure 1.** Typical VNA dynamic range specifications.

| Connector | Frequency (GHz) | Directivity (dB) | Source Match (dB) | Load Match (dB) | Reflection Frequency Tracking (dB) | Transmission Frequency Tracking (dB) | Isolation (dB) |
|---|---|---|---|---|---|---|---|
| K | 0.0225<br>2<br>20<br>40 | >42<br>>42<br>>42<br>>38 | >40<br>>40<br>>38<br>>34 | >42<br>>42<br>>42<br>>38 | ±0.005<br>±0.005<br>±0.006<br>±0.006 | ±0.030<br>±0.050<br>±0.070<br>±0.080 | >105<br>>115<br>>110<br>>100 |

**Figure 2.** Typical VNA test port parameter specifications.

## References


1) Bill Oldfield, "VNA S11 Uncertainty Measurement - A Comparison of Three Techniques", AEFTG Conf. Dig., June 1992.

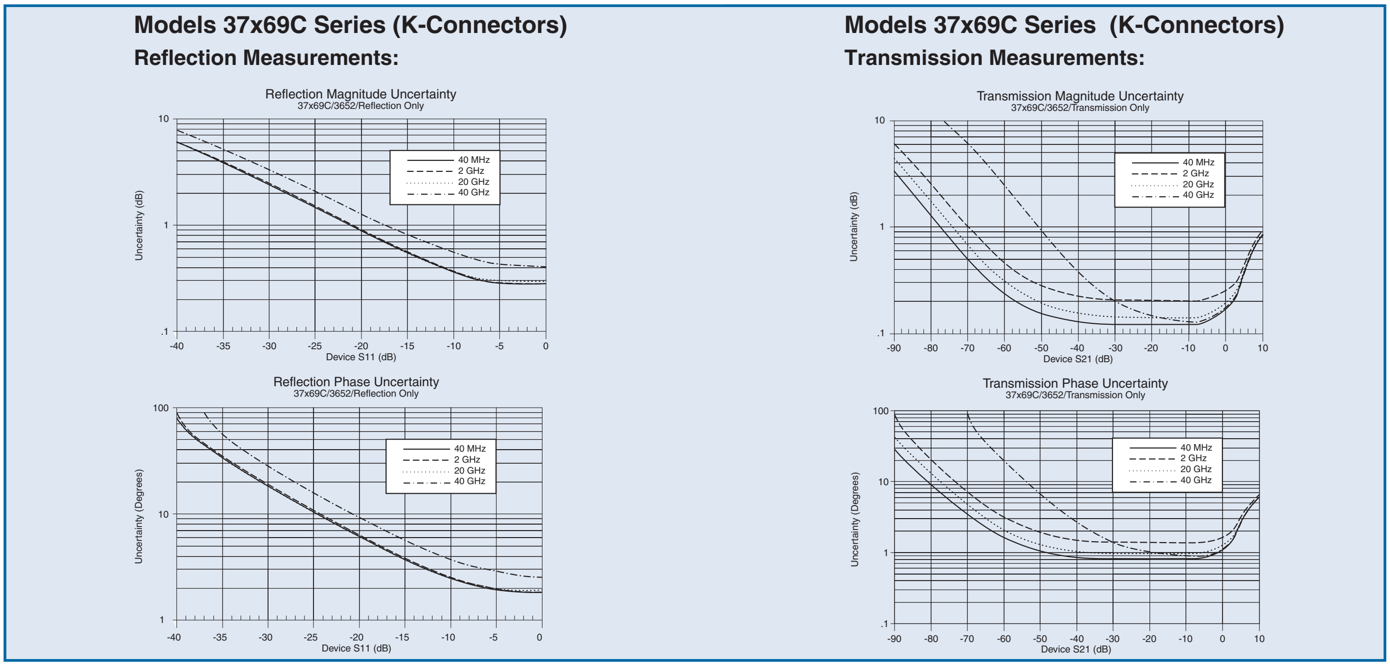



**Figure 3.** Typical VNA Uncertainty specifications.

Uncertainty curves are developed from models of the measurement environment. The model for the Anritsu Uncertainty program is shown in Figure 4. This model includes the important VNA effective parameters, test configuration parameters such as connector and cable performance and the Device Under Test (DUT) parameters. The model leads to equations that are quite elaborate (see Appendix A): but, fortunately computers were designed for this type of calculation and you can focus on the important performance parameters and the result. The user must determine the model parameters for the specific application. In general, the important parameters are test port characteristics: directivity, source and load match, which result from the calibration process, and the noise floor of the measurement system. Directivity, source and load match specifications are available in instrument specifications for specific calibration methods and connector types; however, as mentioned above, they are also dependent upon conditions that may not be appropriate for the application being considered. If in fixture or on wafer measurements are involved, specifications may not be available. It is desirable to actually measure these parameters and this is readily done if a transmission line standard is available which is often the case [1].

The noise floor (NRc) in the model is an important entry that should be carefully considered. This parameter establishes the Signal to Noise (S/N) ratio for a specific measurement.
For example: a 40dB S/N ratio is fine for good operation of many systems; but, for an instrument such as a VNA, a S/N ratio of 40dB results in an uncertainty approaching + /- .1dB, which may be a problem for your measurement requirement. VNA's include menu options to change the IF Bandwidth and Averaging, and these parameters can be changed to reduce the noise floor at the expense or longer measurement time. Published VNA noise floor specifications are usually specified a very narrow IF Bandwidths and/or high averaging factors that require very long and in many cases impractical sweep times. The actual lnoise floor for a specific IF Bandwidth and averaging factor can be accurately estimated by considering port power used during calibration and the system noise floor with both ports terminated.

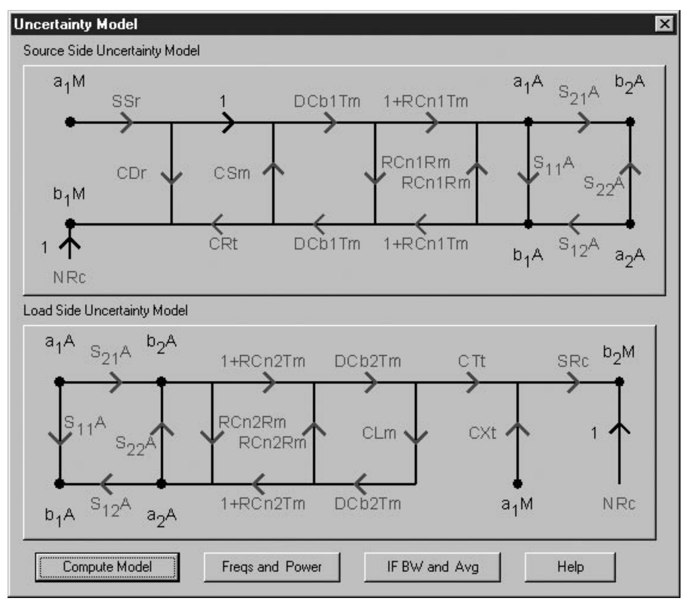



**Figure 4.** Flow graph representation of model.

## Program Operation

There are two paths available to obtain uncertainties for a user application: the CONFIGURATION panel and the MODEL panel. These are available from the WINDOWS popup menu. The CONFIGURATION panel is appropriate for applications using standard calibration kits for which test port specifications are available. The MODEL is used for special situations such as in fixture calibrations or on wafer measurements.

The CONFIGURATION (default) panel is shown in figure 5. The user can select the Anritsu VNA and the calibration kit being used as well as the frequency range of interest. Specified performance parameters are automatically included in the program. It is important to enter the actual IF Bandwidth and Averaging Factor (see figure 6) being used as this establishes the noise parameter used in the computation.

The user can also input the specific frequencies that are important for a given measurement as shown in figure 7. When the appropriate choices have been made, Compute Configuration will lead to the generation of uncertainty curves for the measurement situation. If the full frequency range is specified for the selected VNA, Averaging factor set to 512 and IF Bandwidth set to 10, compute configuration will result in curves similar to the published specifications.

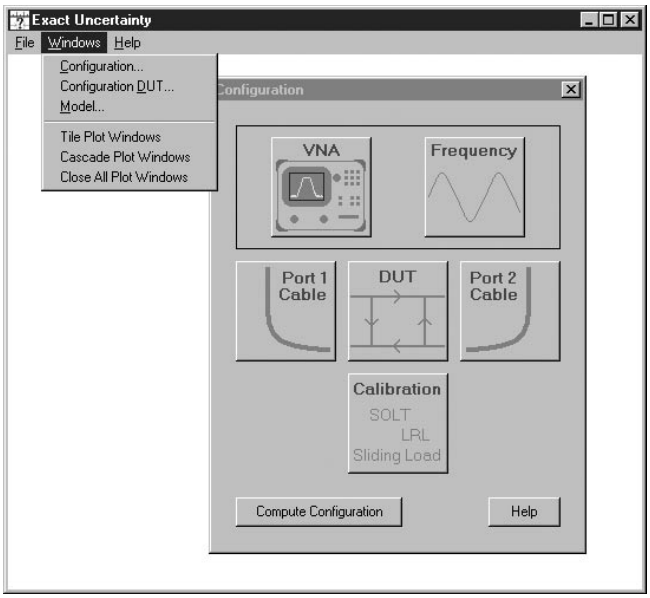



**Figure 5.** Configuration window

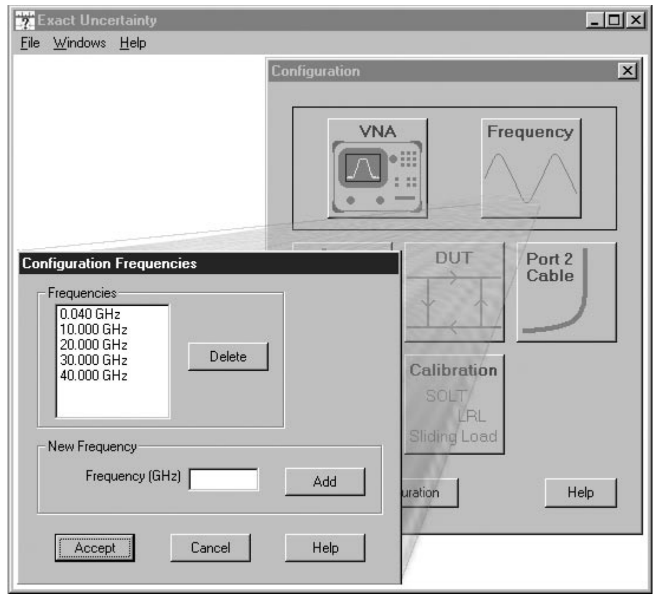



**Figure 7.** VNA configuration frequency menu.

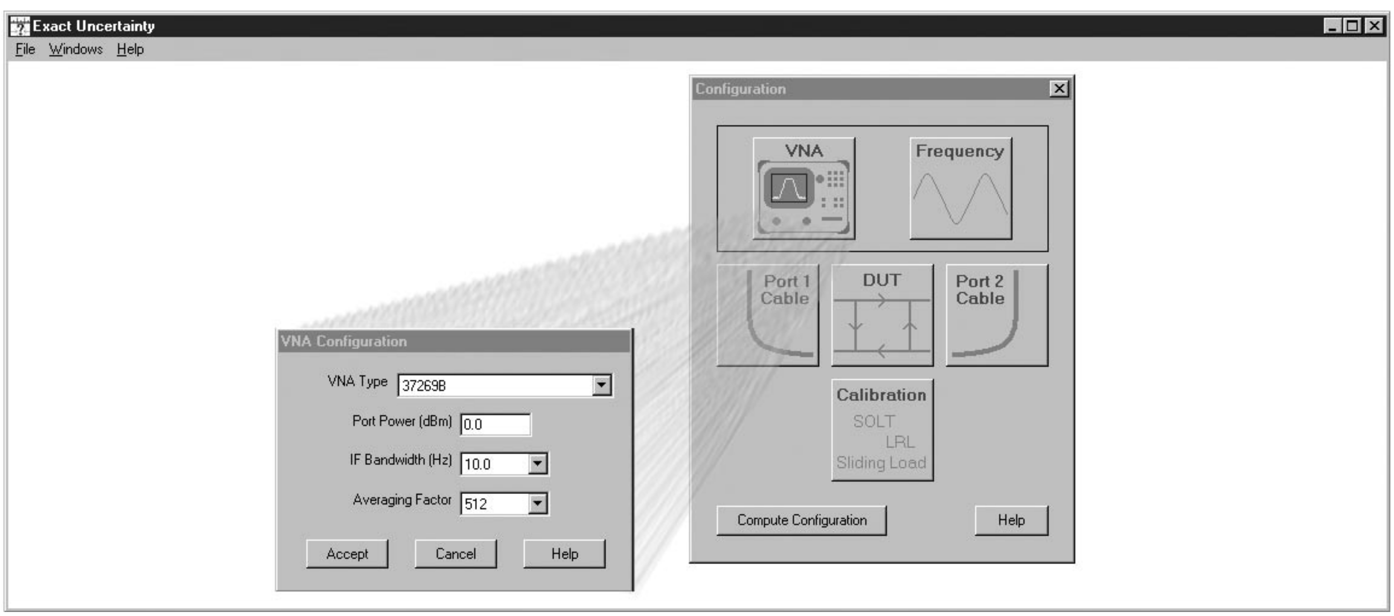



**Figure 6.** VNA configuration pop up menu.

The MODEL gives the user complete freedom to enter parameters associated with a given measurement environment leading to uncertainty curves for that specific situation. The MODEL was shown in figure 4. The user can select any parameter such as Port 1 directivity - CDr, and a window will appear as shown in figure 8. This enables the user to enter parameters appropriate for the calibration. The NRc was discussed above. It is recommended that this figure be obtained for an IFBW of 1kHz and an averaging factor of 10. Once these parameters are entered into the model and in the lower section of figure 9 the user can change them in the upper section and the program will automatically adjust NRc for uncertainty computation. When all parameters are defined Compute Model will provide the uncertainty for the application.

A good example of program use is the measurement of a microstrip device in a fixture. The Anritsu Universal Test Fixture (UTF) Model 3680 will be used. Calibration standards are available for in fixture calibration, such as the 36804-15M, which is appropriate for 15 mil Alumina microstrip. In fixture calibration standards are desirable as they eliminate the problems associated with deembedding adapters or launchers required, to get from the coax port of the VNA to the fixture. However, in this situation the important effective calibration parameters - directivity and port match must be estimated. The 36804-15M does include a long line and an offset termination. These can be measured and the data analyzed using ripple techniques to determine the desired parameters. Figures 10 and 11 show the data and include the directivity and port match appropriate for this application. The system noise floor can be determined for the application, which requires specifying Averaging and IF bandwidth for the test. In this case the noise floor was -75dBm. Entering these parameters into the program provides the uncertainty curves shown in figures 12 and 13.

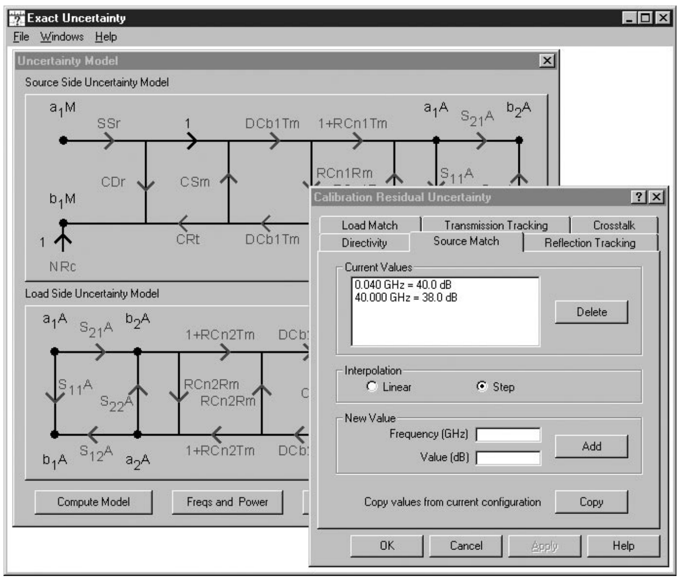



**Figure 8.** Model directivity panel.

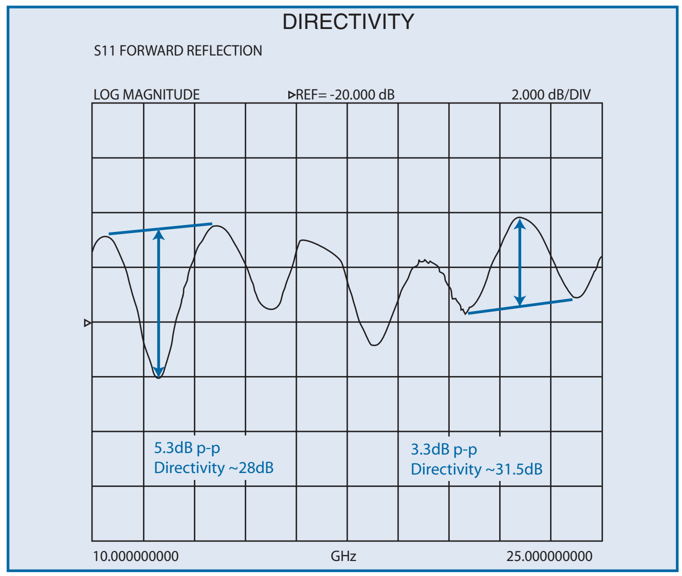



**Figure 10.** Ripple pattern - Directivity.

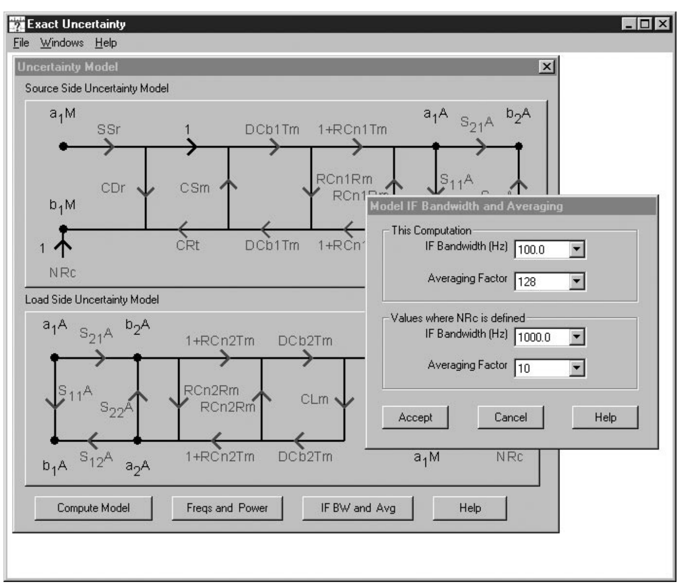



**Figure 9.** Model IFBW and averaging panel.

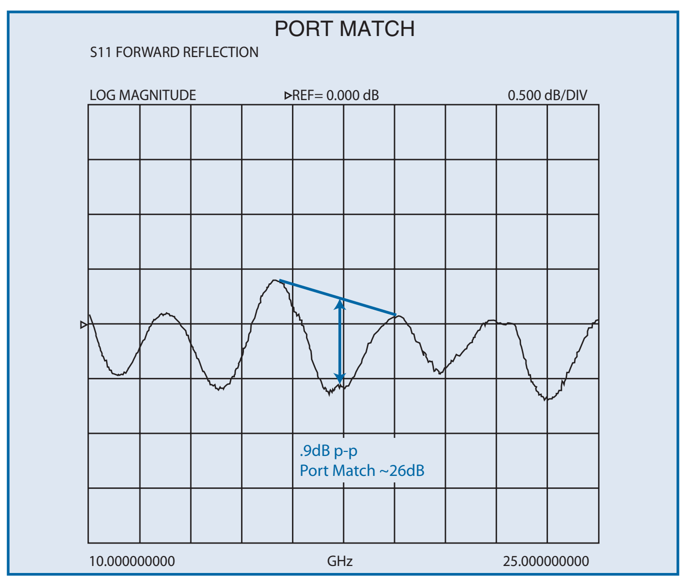



**Figure 11.** Ripple pattern - Port Match.

To this point the curves generated are for an ideal DUT, S11 and S22 = 0 and S21 and S12 = 1. The S-parameter characteristics of the DUT can be included in the computation by selecting User Defined in the DUT menu as shown in figure 14. Compute model then results in a table as shown in figure 15 which presents the uncertainties at specified frequencies for the measurements being made.

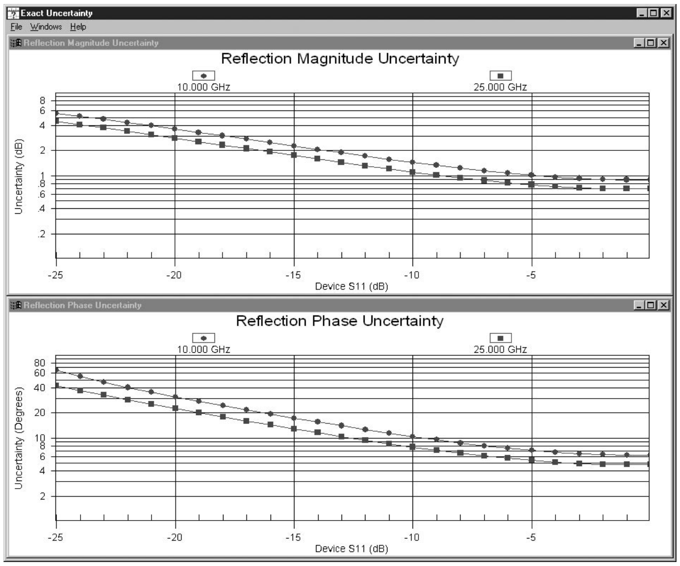



**Figure 12.** Reflection ($S_{11}$) uncertainty curves.

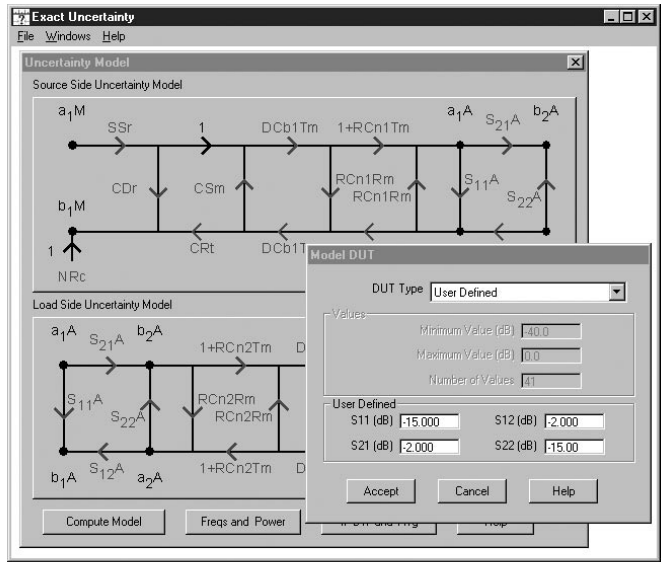



**Figure 14.** DUT parameter panel.

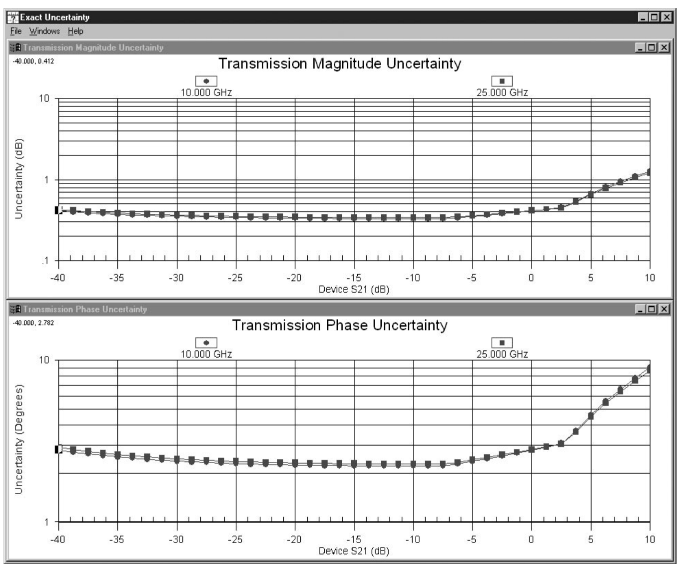



**Figure 13.** Transmission ($S_{21}$) uncertainty curves.

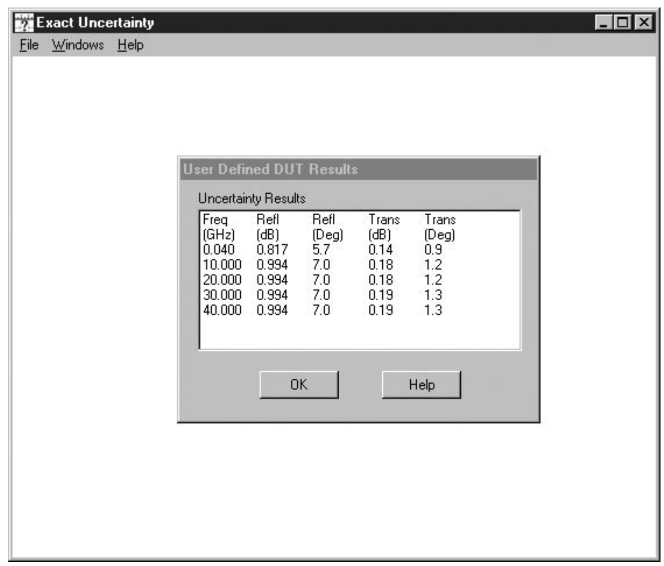



**Figure 15.** Uncertainty, considering DUT parameters.

## Conclusion

An easy to use program has been developed that enables the VNA user to estimate the uncertainty appropriate for conditions associated with a specific measurement. This will enable users to meet the uncertainty analysis requirements of the ISO standards. A practical measurement example was examined that demonstrates the utility of the program.

The model and program was developed by Don Metzger of Modulation Instruments, Colorado Springs, CO.

## *Appendix A*

### Computation of Uncertainty

The uncertainty model used by Exact Uncertainty is shown in figures A-1 and A-2. Because of the large size of the model in two halves, the source side and the load side. The location of the DUT is repeated to show the connection between the two halves of the model.

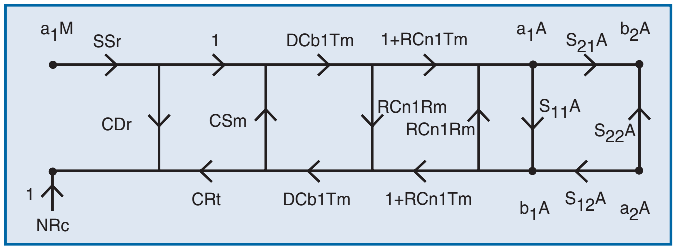



**Figure A-1.** Source side uncertainty model.

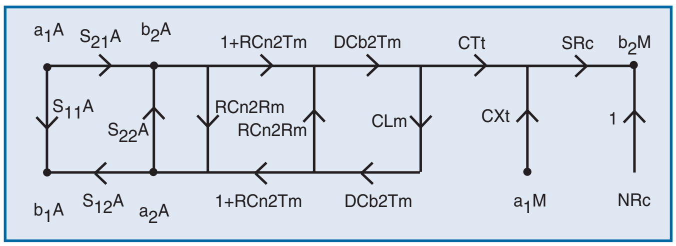



**Figure A-2.** Load side uncertainty model.

When computing the uncertainty, the model is first combined using signal flow graph mathematics, to the condensed model shown in figure A-3. Much of the model has been combined into the M two-port.

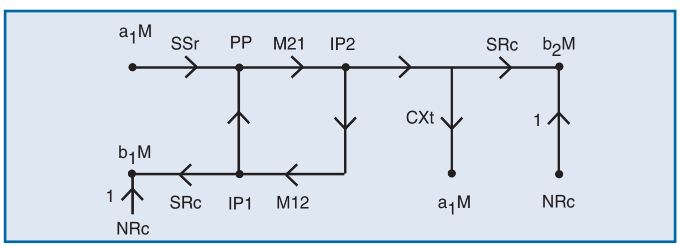



**Figure A-3.** Condensed uncertainty model.

The next steps in computing the uncertainty involve the computation of the received powers, leading to the determination of the compression and noise effects.

The input power at the VNA ports (IP1 and IP2 in figure 3) are found from the user selected port power (PP in figure 3) and the DUT values as:

$$IP1 = PP + S_{11}A$$

and

$$IP1 = PP + S_{21}A$$

where the powers are in dBm and S11A and S21A are in dBs.

The received powers (RP1 and PR2) are computed as

$$RP1 = IP1\text{-}CL$$

and

$$RP2 = IP2\text{-}CL$$

where the powers are in dBm and CL is the coupler loss in dB.

The receiver compression term SRc is computed for each port of the VNA based on the received power. Thus, SRc1 is the compression uncertainty term for port 1 of the VNA and is computed bsed on the value of RP1. Likewise, SRc2 is the compression uncertainty term for port 2 of the VNA and is computed based on the value of RP2. The computation is an interpolation of the user entered values for the SRc term.

The effects of the receiver noise on uncertainty, NRc1 and NRc2, are computed from the noise of the receiver (NRc) and the received powers (RP1 and PR2) as

$$NRc1 = \sqrt{\frac{NRc}{RP1}}\, M_{11}$$

and

$$NRc2 = \sqrt{\frac{NRc}{RP2}}\, M_{21}$$

where the powers are in Watts and the M's are linear (not dB).

Based on the previous computations, the uncertainties for S11 and S21 (U11 and U21) are now computed as

$$U_{11} = SSrxM_{11} \text{ x } SRc1 + NRc1$$

and

$$U_{21} = (SSr \text{ x } M_{21} + CXt) \text{ x } SRc2 + NRc2$$

where all of the terms are linear (not dB).

The phase uncertainty is computed as

$$PU_{11} = \sin^{-1}\left(\frac{U_{11} - S_{11}A}{S_{11}A}\right) + DCb1Tp \text{ x } 2$$

and

$$PU_{21} = \sin^{-1}\left(\frac{U_{21} - S_{21}A}{S_{21}A}\right) + DCb1Tp + DCb2Tp$$

where all terms on the right sides of the equations are linear (not dB). This is the phase uncertainty which is displayed in the plots.

The magnitude uncertainty which is displayed in the plots is

$$MU_{11} = U_{11} - S_{11}A$$

and

$$MU_{21} = U_{21} - S_{21}A$$

where all values are in dB.

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