



# Primary Standards Laboratory Microwave Project

## Fact Sheet

Primary Standards Laboratory (PSL) microwave standards capabilities include power (both CW and pulse), group delay, and scattering parameters (which include attenuation and reflection coefficients or Voltage Standing-Wave Ratio [VSWR]). All the primary microwave standards are directly traceable to the Systeme International through the National Institute of Standards and Technology (NIST). The primary standards include 50 ohm terminations, various coaxial air lines, and coaxial and waveguide thermistor mounts. These standards support a variety of measurement systems, including four Vector Network Analyzers (VNAs), a power standard calibration system, and a power meter calibration system.

### Capabilities

Below is a representative sample of the Microwave Laboratory's uncertainties. The PSL is accredited under Lab Code 105002-0 by the NIST/National Voluntary Laboratory Accreditation Program (NIST/NVLAP). For details, see <http://ts.nist.gov/Standards/scopes/105020.pdf>



**Low-Band Vector Network Analyzer**

| Quantity                                | Uncertainty (k=2) |
|---|-------------------|
| <b>S-Parameters [0.3 MHz TO 18 GHz]</b> |                   |
| Magnitude $ S_{ij} , i \neq j$          |                   |
| 0 to 60 dB                              | 0.018 dB/10 dB    |
| Phase - Arg ( $S_{ij}$ ), $i \neq j$    |                   |
| 0° to 360°                              | 0.2° to 4°        |
| Magnitude $ S_{ii} $                    |                   |
| 0 to 1                                  | 0.001 to 0.05     |
| Phase - Arg ( $S_{ii}$ )                |                   |
| 0° to 360°                              | 0.01° to 180°     |
| <b>CW Power</b>                         |                   |
| 0.1 nW to 200W                          |                   |
| 10 MHz to 18 GHz                        | 1.7% to 10%       |
| <b>Thermistor Mounts</b>                |                   |
| 1 mW to 10 mW                           |                   |
| 1 MHz to 18 GHz                         | 0.3% to 1.1 %     |
| <b>Pulse Power</b>                      |                   |
| 10 mW to 100 mW                         |                   |
| Pulse Width 0.2 to 0.5 $\mu$ s          |                   |
| 2 GHz to 18 GHz                         | 7% to 10%         |

| Group Delay                |                       |
|----------------------------|-----------------------|
| 5 to 500 ns                |                       |
| for $ S_{ij} , \leq 10$ dB |                       |
| 50 MHz to 50 GHz           | $\pm 0.02$ ns to 1 ns |

### Major Resources

- Scattering (S) parameters of an n-port device (for n up to 4) characterize how the device interacts with signals presented to its various ports. Since the S parameters are dimensionless ratios (i.e. reflection and attenuation coefficients), a reference impedance must be specified. A 50 $\Omega$  impedance level is used for virtually all microwave devices calibrated. Four VNAs are used to make low-uncertainty S-parameter measurements very rapidly at many frequencies.



- Thermistor mounts provide the basis for all microwave power measurements. The effective efficiency and/or calibration factor of an unknown thermistor mount is determined by comparison with a NIST-calibrated coaxial or waveguide thermistor mount. Calibrations are performed on a system that combines power-ratio and reflection measurements to eliminate all mismatch uncertainties.
- All power meter calibrations are performed on the system shown in the figure above. Every calibration is based on the Brammell technique, or a variation thereof, wherein each calibration power level is referenced to a NIST-calibrated thermistor mount by means of power ratio measurements. Pulse power meter calibrations also employ notch-wattmeter techniques.
- Group Delay is the ratio of the change in transmission phase shift through a two-port device to the change in its radian frequency of excitation that caused the change in phase shift. The measurement of the transmission phase shift is referenced to the electrical length of a NIST-calibrated air line, whereas the change in the frequency of excitation is measured relative to NIST-traceable GPS-derived frequencies.

## **Special Capabilities**

### **Dielectric Material Properties Measurements**

Dielectric material properties can be measured on the VNAs at frequencies in the 0.03 to 18 GHz band using resonant cavity and/or transmission-line techniques. Cavity techniques provide high accuracy at the relatively few frequencies where resonant cavities are available, while transmission techniques cover many frequencies but at lower accuracies. Parameter range capabilities are 1 to 10 for real part of dielectric

constant and 0.0001 to 0.1 for loss tangent.

### **Certification of HP Network Analyzer Uncertainties**

Tables of uncertainties for scattering parameter measurements made by HP/Agilent Models 8510 and 8753 VNAs are readily generated using the CERTVANA certification procedures. Typically the uncertainties for a given scattering parameter measurement are tabulated as a function of frequency and measurand magnitude. The uncertainties are deduced from network error models for the particular VNA system and scattering parameter. For reflection scattering parameters, the Thru-Reflect-Line (TRL) and Thru-Match-Short techniques are used to deduce the parameters of the error model. A standard attenuator and a bootstrap technique are used to establish  $|S_{ij}|$  uncertainties. Finally,  $\text{Arg}(S_{ij})$  uncertainties are determined from measurements on air lines of certified electrical length.

### **Certification of Passive Three or Four-Port Networks**

Accurate calibrations of multiport devices (like directional couplers, hybrid junctions, reflectometers, power splitters, and power dividers) can be performed using a VNA. Virtually any combination of popular microwave connector types may appear at the device ports. During calibration measurements between each 2-port pair on the device, the effects of the terminations on the remaining ports are rigorously accounted for. The device may be unilateral or bilateral. One can certify either scalar or vector values of the S-parameters of the device. Additionally, the effective source reflection coefficient of a three-port network may be certified. Finally, a certificate can tabulate the worst-case uncertainties of a four-port network when used as a scalar reflectometer.



**Microwave Power Calibration**

### **Check Standard Software**

Verification of the proper operation of a measurement system is critical to providing accurate measurements of customer's devices. The Microwave Laboratory developed a check standard measurement and database program to provide assurance to the user of the accurate operation of the measurement system. Current check standard measurements are plotted along with the means and standard deviations of prior measurements to indicate the measurement system's present state of statistical control.

Two versions of the software are available. One version can automatically acquire data from either an HP/Agilent 8510 or 8753 VNA; the second version is more general and allows data entry by keyboard, file input, or directly from instruments via user-prepared data-acquisition subprograms. The software can present either parameter-dependent (e.g. frequency-dependent) and/or the familiar time/event-dependent displays. Both versions run under HP Basic or HT Basic.



This capability provides the user with a quick and accurate means to verify that the measurement system is operating within control. Problems are quickly identified before any measurements are made, thus saving time and assuring high-quality measurements.

---

## Contacts

### **Ricky Sandoval** **Project Lead**

Sandia National Laboratories  
P. O. Box 5800; M/S 0665  
Albuquerque, NM 87185-0665  
Phone: (505) 845-3683  
FAX: (505) 844-4372  
Email: rlsando@sandia.gov

### **Roger Burton, P.E.** **Manager**

Sandia National Laboratories  
P. O. Box 5800; M/S 0665  
Albuquerque, NM 87185-0665  
Phone: (505) 284-9901  
FAX: (505) 844-4372  
Email: rburto@sandia.gov

