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Reflection/Transmission Measurements Using USB Power Detectors

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This product application article shows how economical, easy-to-use USB power sensors can be combined with standard lab accessories to create a scalar network analysis system

A scalar network analyzer is a low cost solution for making reflection and transmission measurements. This paper discusses how to configure the hardware, combining appropriate reflection/transmission test components into a scalar analyzer system, and presents methods for making quality reflection and transmission measurements, including calibration.

Reflection Measurement Solution

The reflection scalar network analyzer solution is used for making reflection measurements on a port of a DUT (Device Under Test). In the solution shown in Figure 1, the RF source is connected to a Forward and a Reflected signal separation device (reflectometer or directional coupler). The DUT is connected to the output of the reflected signal separation device. The signal separation devices are oriented to couple the forward and reflected signals as shown. For each signal separation device, the coupled arm is connected to an LB4XXA PowerSensor+™ used as the signal level detector.

The Ladybug Technologies LB4XXA PowerSensor+ products are ideal for this application because they offer:

- Easy to integrate ATE software components
- Fast 2000 settled points/second enabling real time measurements
- Wide dynamic range of –60 dBm to +20 dBm

Signal Separation Device Selection

The signal separation device is often a coupler. Consideration should be given to the coupler's directivity and match. Usually, directivity dominates measurement error; however, as the DUT's return loss becomes smaller, the poorer impedance match becomes a more significant contributor to the total error. Table 1 shows the required coupler directivity and match performance for a range of DUT return loss and worst case error values. Worst case error assumes that an open-short tracking calibration has been done.

Example 1: Determine coupler specifica-

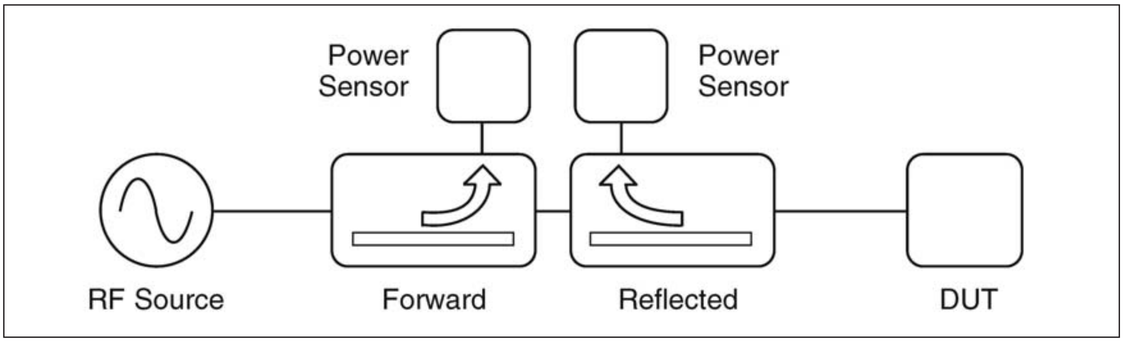

Figure 1 · Block diagram of a scalar analyzer.

tions for a DUT with a (expected) return loss of 15 dB and a total worst case error of 40%.

Solution 1: Use coupler specifications for 40% and 16 dB worst case error. In this case, coupler directivity = 26 dB and coupler match = 19 dB. Further, measurement dynamic range can be maximized by selecting a coupler with 10 dB coupling factor.

If avoiding calibration is desired, use well-matched forward and reflected couplers to minimize their insertion loss. Also minimize adapters and cabling between the couplers and the DUT. Unless DUT return loss is less than 10 dB, a dual directional coupler is not recommended because of poor resulting directivity (even if the coupler is specified as having reasonably good directivity). The tracking error is approximately twice the insertion loss of the coupler and cabling between the reflected coupler and the DUT. Approximate worst case error is found by adding this tracking error to the error shown in the table.

Worst Case Error ⇒	**10% +.8 dB/–.9 dB**	**20% +1.6 dB/–2 dB**	**30% +2.3 dB/–3.1 dB**	**40% +2.9 dB/–4.4 dB**
DUT Return Loss ⇓				
4 dB	32 dB Directivity 25 dB Match	26 dB Directivity 19 dB Match	22 dB Directivity 19 dB Match	18 dB Directivity 19 dB Match
7 dB	33 dB Directivity 25 dB Match	27 dB Directivity 19 dB Match	23 dB Directivity 19 dB Match	20 dB Directivity 19 dB Match
10 dB	34 dB Directivity 25 dB Match	28 dB Directivity 19 dB Match	24 dB Directivity 19 dB Match	22 dB Directivity 19 dB Match
13 dB	36 dB Directivity 25 dB Match	30 dB Directivity 19 dB Match	26 dB Directivity 19 dB Match	24 dB Directivity 19 dB Match
16 dB	38 dB Directivity 25 dB Match	32 dB Directivity 19 dB Match	29 dB Directivity 19 dB Match	26 dB Directivity 19 dB Match
20 dB		36 dB Directivity 19 dB Match	32 dB Directivity 19 dB Match	29 dB Directivity 19 dB Match
23 dB		38 dB Directivity 19 dB Match	35 dB Directivity 19 dB Match	32 dB Directivity 19 dB Match
26 dB			38 dB Directivity 19 dB Match	35 dB Directivity 19 dB Match
30 dB				39 dB Directivity 19 dB Match

Table 1 · Determine required coupler directivity and match.

Example 2: Determine the additional error in Example 1 if a tracking calibration is not done.

Solution 2: Typical insertion loss for a 10 dB coupling factor coupler is 0.5 dB. Assume cable loss between the coupler and DUT is 0.1 dB. This additional error or tracking error is 1.2 dB (0.5 dB × 2 + 0.1 dB × 2).

Alternatively, the tracking error can be estimated (or measured by calibration) and removed from the result. Because tracking error is a loss, the resulting match measurement is simply offset by the estimated tracking error. Add the tracking error to the match measurement.

Example 3: Assume a 17.1 dB measurement result and Example 2 configuration. Determine the match result given the tracking error offset.

Solution 3: 15.9 dB is the result, after adding the 1.2 dB tracking error to the 17.1 dB match measurement.

The forward signal separation device may be replaced with a two resistor power splitter, such as a Picosecond Pulse Labs 5336 or an Agilent 11667A. A resistive splitter offers good broadband performance; however, it has a limited power level and cannot be used for high power meaurements.

Maximizing Dynamic Range

As noted in Example 1 the necessary dynamic range should be considered. In general dynamic range is maximized by:

1. Using low coupling factor couplers. In general, default to using a 10 dB (coupling factor) coupler.
2. Maximize RF source power, keeping it within the range of the power sensors being used. As source power begins to exceed 1/2 watt, increase the coupler coupling factor to sensor received power.
3. Select power sensors with maximum measurement speed throughout its dynamic range. For exampe, the LadyBug Technologies LB4XXA PowerSensor+ can measure 2000 settled points per second at –60 dBm.

Reflection/Transmission Solution:

By adding a third LB4XXA PowerSensor+, transmission measurements (S_{21} or S_{12}) can be made, as shown in Figure 2. Port matching of the power sensor and of the reflectomer, in combination with DUT's S-parameters, determine errors in measuring the DUT's S_{21} or S_{12}. Measurement error for a DUT with $S_{21} = S_{12} = 0$ dB is typically 0.27 dB (DUT return loss = 15 dB; power sensor return loss = 27 dB; reflectometer return loss = 19 dB). Increased DUT S_{21} and S_{12} can reduce this error to 0.22 dB; the error would begin to rise when considerations for dynamic range are included.

Correction

Mathematics of the correction is considered in this section. It is assumed the user has the expertise to apply the programming examples provided in the LadyBug product lit-

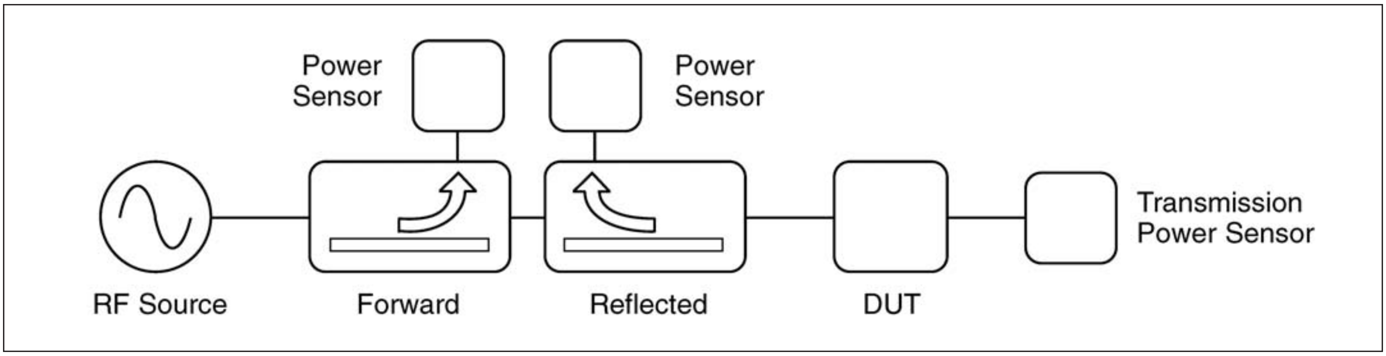

Figure 2 · Block diagram of a transmission/reflection scalar analyzer .

erature to set up and read power measurements from the LB4XXA PowerSensor+ and apply those measurements to the equations below.

Reflection Measurement and Correction

The basic measurement equations can be done in either linear or dB form. Both are presented below. In dB form, power measurements in dBm can be used directly. In linear form the square root of linear power must be taken.

Linear form of the solution—

Reflected match is:

$\rho = \tau\,(b/a)$.

where:

ρ is the linear reflection coefficient of the DUT;

τ is the linear tracking correction between the forward and reflected signals;

b is the linear measured reflected square root of power;

a is the linear measured forward square root of power.

All that remains is to determine the correct value of τ.

Reflection Calibration

The objective of the calibration is to measure τ. τ is computed from the measurement of two calibration standards, an open and a short. Removal of the source match error from τ is accomplished by ensuring the open and short are balanced, and their reflection coefficients are 180 degrees apart. Measurement of the open is:

$\rho_O = |1| = \tau_O\,(b_O/a_O)$, or
$\tau_O = (a_O/b_O)$.

where:

$\rho_O = |1|$ is the linear magnitude reflection coefficient for an ideal open;

τ_O is the linear tracking measurement for the open calibration;

b_O is the linear measured reflected square root of power for the open calibration;

a_O is the linear measured forward square root of power for the open calibration.

Measurement of the short is:

$\rho_S = |-1| = \tau_S\,(b_S/a_S)$, or
$\tau_S = (a_S/b_S)$

where:

$\rho_S = |-1|$ is the linear magnitude reflection coefficient for an ideal short;

τ_S is the linear tracking measurement for the short calibration;

b_S is the linear measured reflected square root of power for the short calibration;

a_S is the linear measured forward square root of power for the short calibration.

τ is determined by averaging τ_O and τ_S:

$\tau = (\tau_O + \tau_S)/2$.

It should be noted that a single calibration with either τ_O or τ_S may be used for τ; however, the error associated with source match for the final result will increase. This additional error may be as high as 0.4 to 0.5 dB. If this tradeoff is acceptable, the use of 20 dB couplers should be considered, to minimize the error and avoid a calibration altogether.

Example 4: Same as in Example 2, but using 20 dB couplers. Determine the approximate tracking error.

Solution 4: Typical insertion loss for a 20 dB coupler is 0.12 dB. The resulting tracking error offset would be 0.44 dB (0.12 dB × 2 + 0.1 dB × 2).

dB form of the solution—

Return Loss is:

$\mathrm{RL} = \rho_{dB} = \tau_{dB} + b_{dB} - a_{dB}$

where:

$\mathrm{RL} = \rho_{dB}$ is the return loss of the DUT;

τ_{dB} is the tracking correction in dB;

b_{dB} is the reflected power measurement in dBm;

a_{dB} is the forward power measurement in dBm.

Reflection Tracking Calibration

Measurement of the open in dB is:

$$RL_O = \rho_{dBO} = T_{dBO} + b_{dBO} - a_{dBO}$$

or, $T_{dBO} = a_{dBO} - b_{dBO}$

where:

$\rho_{dBO} = 0$, the return loss for an ideal open;

T_{dBO} is the tracking measurement in dB for the open calibration;

b_{dBO} is the reflected power measurement in dBm for the open calibration;

a_{dBO} is the forward power measurement in dBm for the open calibration.

Measurement of the short in dB:

$$RL_S = \rho_{dBS} = T_{dBS} + b_{dBS} - a_{dBS}$$

or, $T_{dBS} = a_{dBS} - b_{dBS}$

where:

$\rho_{dBS} = 0$, the return loss for an ideal short;

T_{dBS} is the tracking measurement in dB for the short calibration;

b_{dBS} is the reflected power measurement in dBm for the short calibration;

a_{dBS} is the forward power measurement in dBm for the short calibration.

Determine T by taking the linear average of T_O and T_S:

$$T = 20\mathrm{Log}_{10}[10^{(-\mathrm{T_O}/20)}+10^{(-\mathrm{T_S}/20)}]/2$$

Transmission Measurement and Correction

Both the linear and dB form of the measurement equation is presented below. In dB form, power measurements in dBm can be used directly. In linear form, the square root must be taken for conversion to linear power before application of the equations.

Linear form of the solution—
Transmission gain or loss is:

$$L = T_T\ (c/a)$$

where:

L is the linear transmission gain or loss of the DUT;

T_T is the linear transmission tracking correction;

c is the linear measured transmitted square root of power;

a is the linear measured forward square root of power.

Measurement of T_T—The objective of the calibration is to measure T_T. T_T is measured by connecting the transmitted LB4XXX PowerSensor+ to the reflectometer; referred to as a thru.

The thru measurement is:

$$L_1 = 1 = T_T\ (c_L/a_L)$$
$$\text{or, } T_T = (a_L/c_L)$$

where:

$L_1 = 1$ is the linear transmission gain for the thru;

T_T is the linear transmission tracking correction term;

c_L is the linear measured transmitted square root of power for the thru;

a_L is the linear measured forward square root of power for the thru.

dB form of the solution—
Transmission gain or loss is:

$$L_{dB} = T_{TdB} + c_{dB} - a_{dB}$$

where:

L_{dB} is the dB gain or loss of the DUT;

T_{TdB} is the transmission tracking correction in dB;

c_{dB} is the measured transmitted power;

adB is the measured forward power.

Measurement of T_{TdB}—The thru measurement is:

$$L_{1dB} = 0 = T_{TdB} + c_{LdB} - a_{LdB}$$

or, $T_{TdB} = a_{LdB} - c_{LdB}$

where:

$L_{1dB} = 0$ is the dB transmission gain for the thru;

T_{TdB} is the dB transmission tracking correction term;

c_{LdB} is the measured transmitted power for the thru;

a_{LdB} is the measured forward power for the thru.

Summary

Power sensors such as the Ladybug Technologies LB4XXA PowerSensor+, with high accuracy, fast settled measurement time and simple computer/ATE interface capabilities, can be used to create an effective scalar network analysis system. Engineers can combine these high performance sensors with standard laboratory signal sources and signal separation devices such as directional couplers to make calibrated forward and reflected power measurements on their active or passive RF/microwave devices.

Author Information

Richard Hawkins is President of LadyBug Technologies. As an R&D engineer, he developed hardware for vector network analyzers, microwave sources, mechanical calibration kits and large distributed monitoring systems. He also managed a number of R&D projects in RF and microwave test equipment and test systems. Richard received his BSEE from Cal Poly, San Luis Obispo, California, graduating Magna Cum Laude. He can be reached at: richard_hawkins@ladybug-tech.com

Information about the company's products can be found on their web site: www.ladybug-tech.com