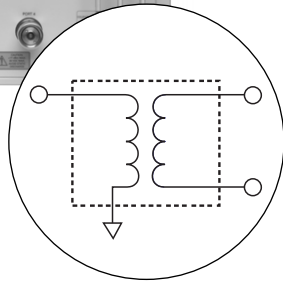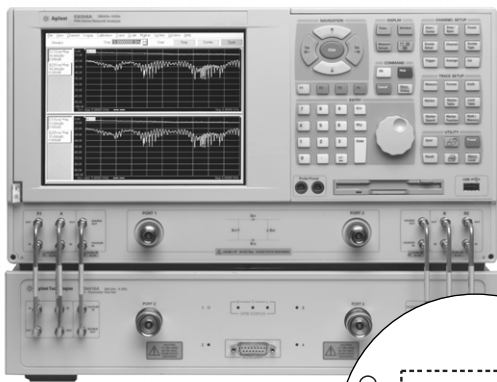# Agilent
Balanced Measurement Example: Baluns

Application Note 1373-6

Introduction

Differential circuits are becoming more widely used in RF circuits for the same reasons that they have been used for years in lower frequency analog circuits. The benefits of using differential circuits include immunity to electromagnetic interference, power supply noise and ground noise; even-order harmonic suppression; and tolerance to non-ideal RF grounds. Generally, the balanced circuit needs to interface to a single-ended circuit at some point. Baluns provide this ability. The term balun is a contraction of balanced-unbalanced and usually is implemented as a transformer (see figure 1).

Characterization techniques

Since most test equipment has two single-ended test ports, baluns are often characterized back-to-back in pairs. Each balun, in this case, essentially converts the balanced port of the other balun to a single-ended port. This method gives the user some idea of the loss, but does not provide comprehensive characterization of the balun. For example, it does not provide any way of determining how much of the insertion loss is due to impedance mismatch on the differential port, or how much results from amplitude or phase imbalance.

It is possible to characterize a balun as a three-port device by making a series of two-port measurements. In addition to being a time-consuming process, this approach does not describe the impact that imperfections in the balun will have on system level performance.

Agilent balanced-measurement systems greatly improve testing of balanced devices. Unlike a single-ended two-port system, these solutions provide accurate data with a one-time connection of the test system to the device. They offer accurate, convenient, and comprehensive characterization. Data from the systems can be viewed as both single-ended multiport S-parameters and as mixed-mode S-parameters, which provide considerable insight into the performance of balanced circuits.

Single-ended multiport data example

Consider, for example, the circuit in figure 1, and its multiport single-ended S-parameters shown in figure 2.

The Smith charts show that the impedance of each port is centered near 50Ω. The rectangular plot shows that the transmission characteristics from the single-ended port to one side of the balanced pair has an insertion loss of about 7.5 dB, and about 8.5 dB to the other side of the balanced pair. 3 dB of this is due to the power split. The isolation between the terminals of the balanced pair is about 9.5 dB.

By using the user-defined display capability of Agilent's balanced-measurement solutions, it is also possible to use the single-ended S-parameter data to look at the amplitude and phase balance. These are shown in figure 3.
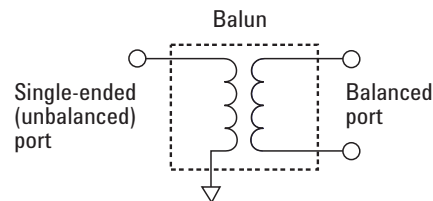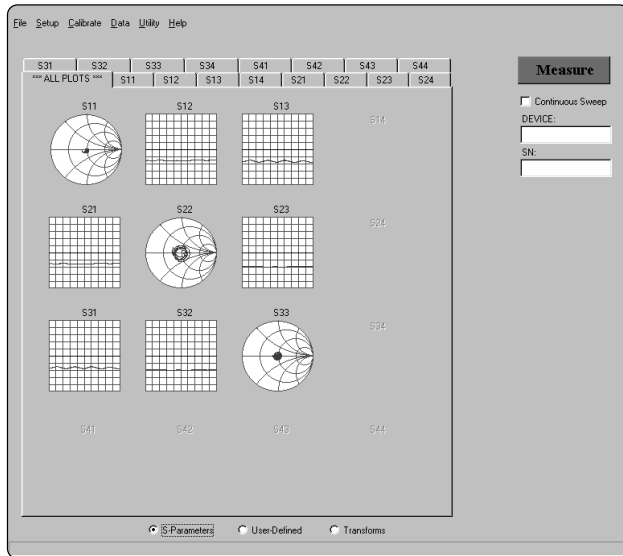

Figure 1. Sample circuit

Figure 2. Multiport single-ended S-parameters of the sample circuit
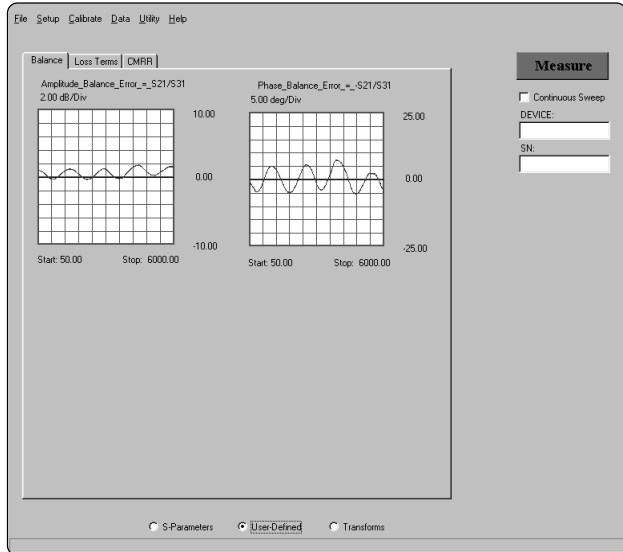

Figure 3. Amplitude and phase balance of the sample circuit

Mixed-mode data example

The single-ended data on the balun shows that its performance is not ideal. However, it does not tell what effect the imperfections will have on the system performance. For example, it does not show how much amplitude and phase balance error is acceptable.

Consider the mixed-mode S-parameter data shown in figure 4.

Along the diagonal, the reflections can be seen from the single-ended port, and from the balanced port in differential- and common-modes. The term SDS21 shows the forward transmission characteristics when only the differential output signal is considered. Since this term considers power from both sides of the balanced pair, a loss of 3 dB due to power splitting no longer needs to be considered.

When an input is applied to the single-ended port, the balun will have a differential output power that is lower than the available input power by about 5.1 dB. However, it will also have, in the worst case, a common-mode component that is lower by about 24 dB.

The parameter SDS21 includes the following loss terms:

- Reflection mismatch loss
- Ohmic loss
- Mode conversion loss (amplitude and phase balance)

The user-defined display also allows each of these components to be calculated, as shown in figure 5. In this example, the ohmic loss dominates. The reflection from the differential port can also be relatively large, but the single-ended reflection and the phase and amplitude balance (mode conversion) terms contribute very little to the insertion loss.
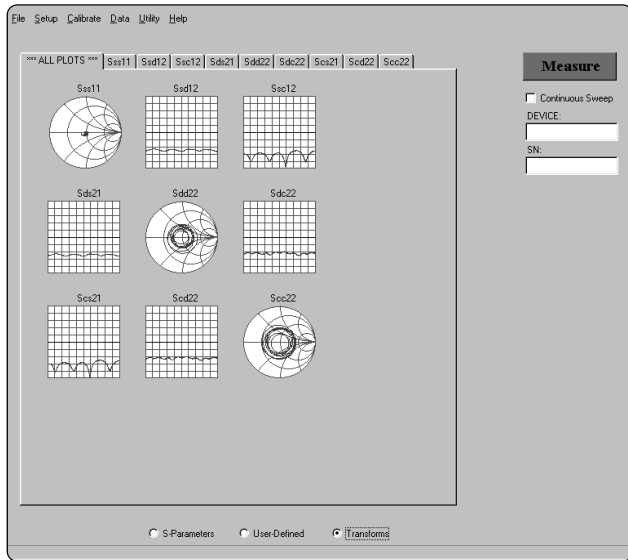
Figure 4. Mixed-mode S-parameter data

Figure 5. Loss terms

Another way of determining the quality of the balun is to calculate its common mode rejection ratio (CMRR). This is the ratio of the differential-mode gain to the common-mode gain. It is shown in figure 6.
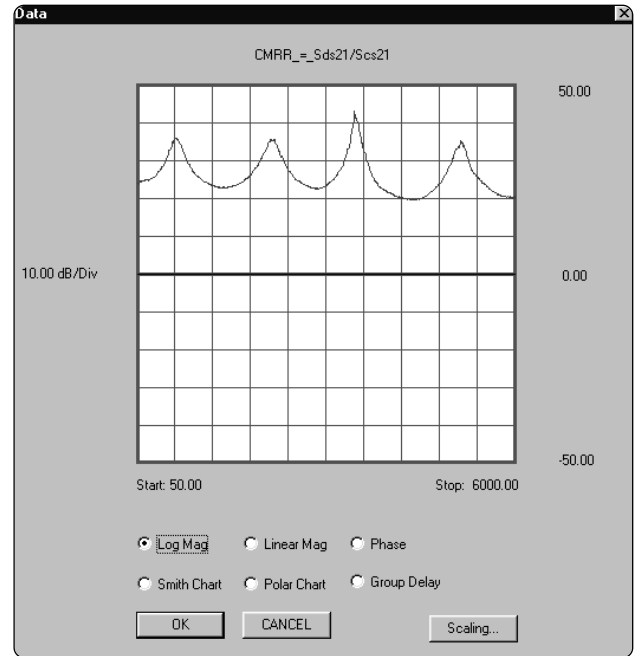

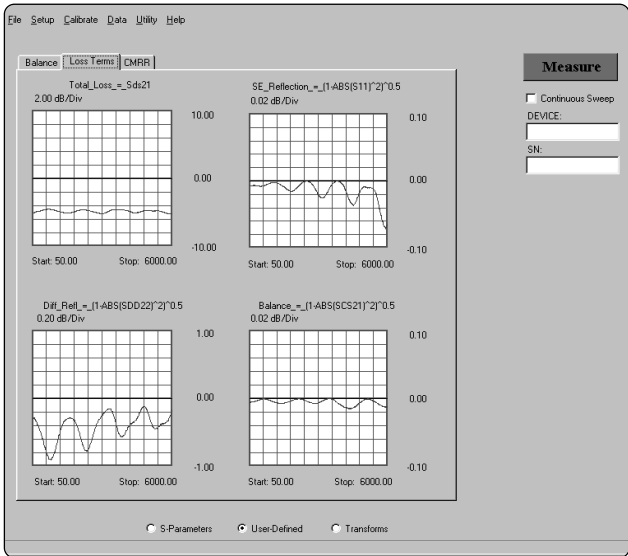**Figure 6. Common mode rejection ratio (CMRR)**

Conclusion

This application note demonstrates how the Agilent balanced-measurement solutions greatly improve testing of balanced devices such as baluns. These systems provide accurate data with a one-time connection of the test system to the device and also offer comprehensive characterization of balanced devices in a manner that provides considerable insight into the performance of the device.

Related literature

Agilent Balanced Measurement Example: SAW Filters, Application Note 1373-5, literature number 5988-2922EN

Agilent Balanced Measurement Example: Differential Amplifiers, Application Note 1373-7, literature number 5988-2923EN

Measurement Solutions for Balanced Components, Product Overview, literature number 5988-2186EN

Key web resources

For more information on Agilent's balanced solutions please visit:

www.agilent.com/find/balanced

Visit our component manufacturer industry area at:

www.agilent.com/find/component_test

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