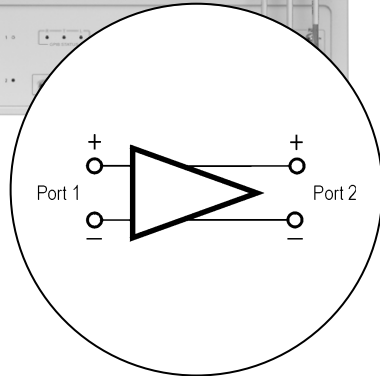
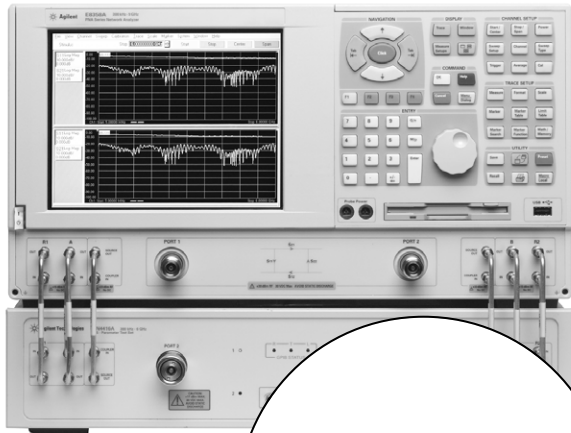


Agilent Balanced Measurement Example: Differential Amplifiers

Application Note 1373-7



Introduction

Agilent Technologies has developed a solution that allows the most accurate method available for measuring differential RF circuits. The approach uses Agilent N444x-series Balanced-Measurement Systems, which provide the ability to test multipoint (single-ended) devices to the level of accuracy of traditional two-port systems. The systems can also test differential devices and show the performance under balanced (differential- and common-mode stimulus and response) operating conditions using mixed-mode S-parameters.

Mixed-mode S-parameter analysis brings a great deal of insight to differential circuit design. The following figures provide a simple example.

The sample circuit A, illustrated in Figure 1, consists of two gain channels that are perfectly symmetrical, and completely isolated from each other. Its multiport single-ended S-parameters are shown in Figure 2. The amplifier is perfectly matched on all ports, and the gain in each channel (S21 and S43) is about 8 dB.

Since this is a differential amplifier, it is also interesting to consider how the circuit behaves with differential and common-mode stimuli. This can be determined from the mixed-mode S-parameters shown in Figure 3. Again, both the input and output ports are matched for both differential and common-mode signals. The differential and common mode gains are also the same, about 8 dB of gain.

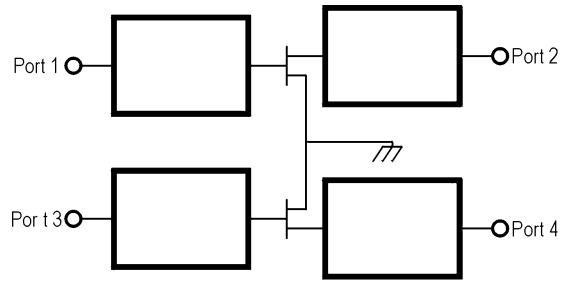


Figure 1: Sample circuit A

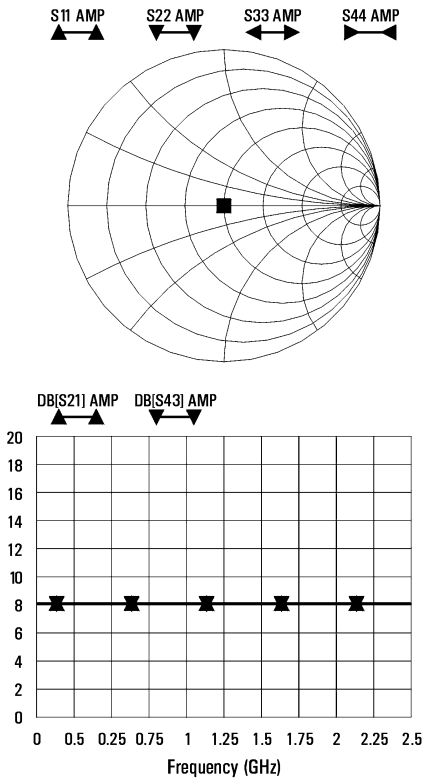


Figure 2: Single-ended S-parameters of sample circuit A

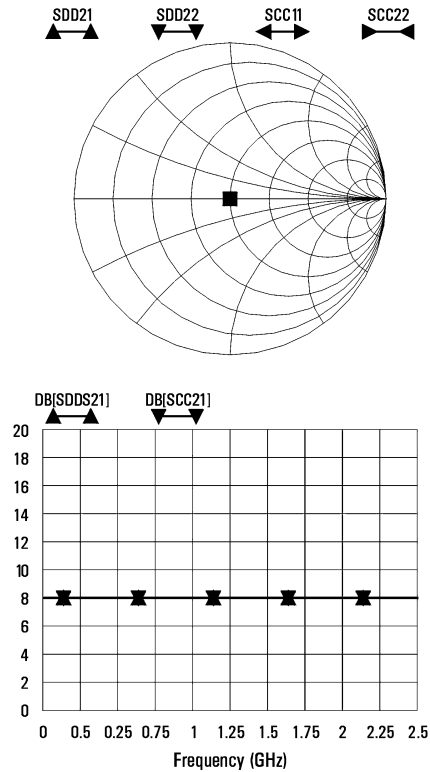


Figure 3: Mixed-mode S-parameters of sample circuit A

If the ideal ground is removed, the two channels will no longer be isolated. Figure 4 illustrates the new sample circuit B, schematically. In this example, each port is coupled to each other port when the circuit is viewed as a single-ended device.

The impedance seen at each port is now 150 ohms, and the single-ended gain is only about 2 dB, as shown in Figure 5. By looking only at the single-ended S-parameters, it is natural to assume that this circuit is not as good as the previous one. This conclusion would be misleading, as the mixed-mode S-parameters show in Figure 6.

Because of the virtual ground that is present with a differential stimulus, the ports are matched, and the gain is again 8 dB. With a common-mode stimulus, the ports are open circuited and the device has no gain. Therefore, the single-ended performance is reflecting a composite of the differential-mode and the common-mode performance. This underscores the importance of representing the data in the mode of operation in which the device will be used.

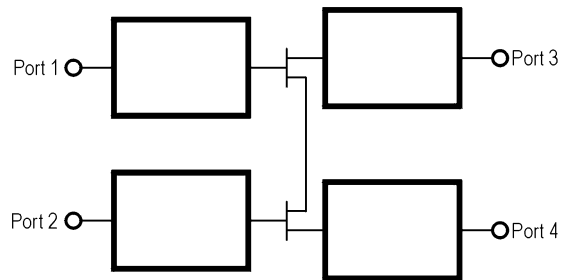


Figure 4: Sample circuit B, device without channel isolation

Contrary to the indications of the single-ended data, this is actually a much better device than the previous example because it has a very high common-mode rejection (ratio of differential-to-common mode gain).

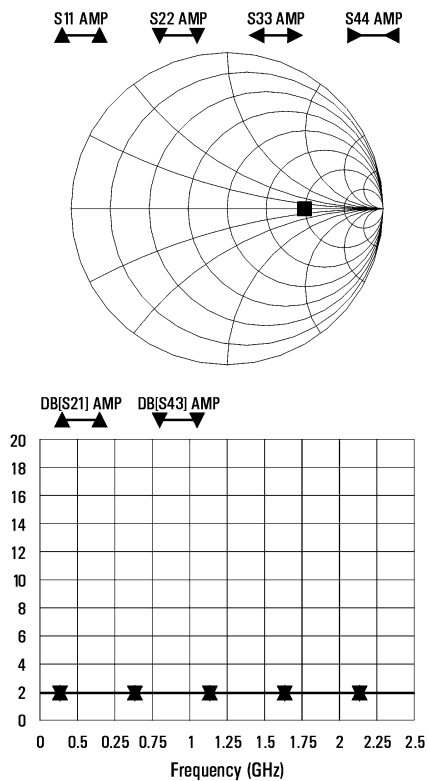


Figure 5: Single-ended S-parameters of sample circuit B

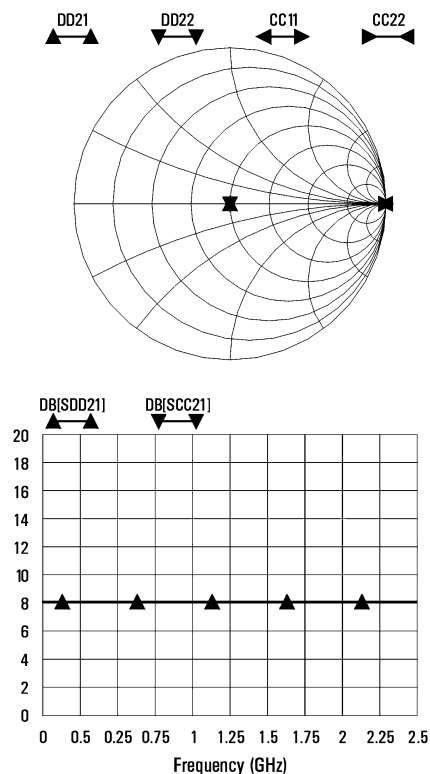


Figure 6: Mixed-mode S-parameters of sample circuit B

Differential amplifier measurement

The information available from mixed-mode S-parameter analysis can be further understood by examining data from a four-terminal device. One such device is shown in Figure 7.

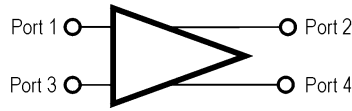


Figure 7: A four-port single-ended device

Single-ended performance

Measured on the Agilent N4444A balanced-measurement system, a sample device exhibited the performance shown in Figure 8.

Used as a single-ended circuit, this amplifier has about 14 dB of gain in each of its two channels (S21 and S43). The input impedances of the two channels (S11 and S33) are similar, as are the two output impedances (S22 and S44).

The isolation between the two input ports (S13 and S31), and between the two output ports (S24 and S42), is less than 10 dB at some frequencies, indicating a moderate amount of coupling.

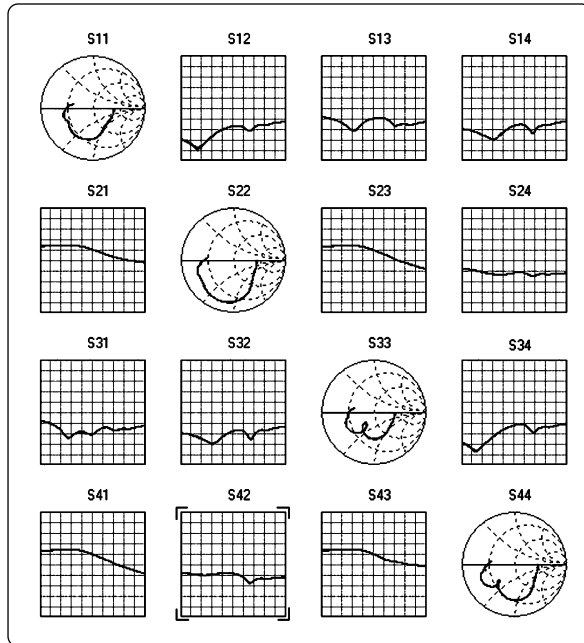


Figure 8: Single-ended parameters of the single-ended device

Mixed-mode performance

Because of the similarity in performance of the two channels and the moderate isolation between them, one would expect the differential-mode and common-mode performance to be different. The S-parameters in Figure 9 show the mixed-mode performance of this device.

As expected, the 2x2 sub-matrix in the upper left quadrant is very different than the 2x2 sub-matrix in the lower right quadrant, showing that the differential-mode performance is not the same as the common-mode performance.

The device used in this example is the Analog Devices AD8350-20, a high-performance, fully-differential amplifier for use in RF and IF circuits. For more information on this device, please see www.analogdevices.com.

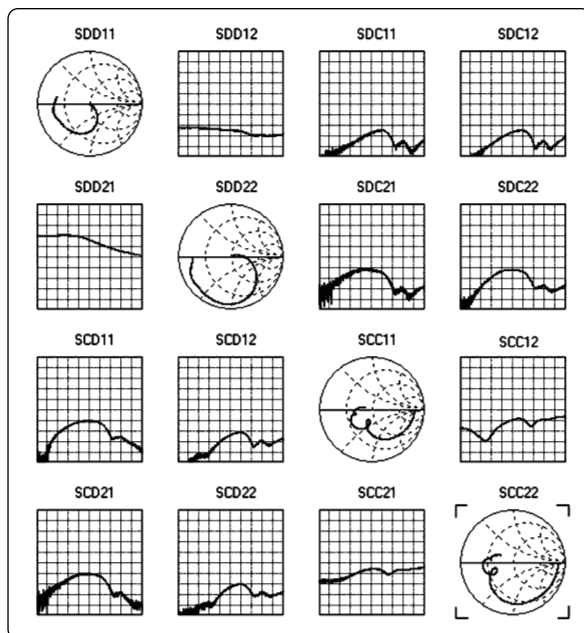


Figure 9: Mixed-mode S-parameters of the single-ended device

Common-mode rejection ratio (CMRR)

A balanced system is normally designed to operate in differential mode because of the performance attributes that this mode offers. However, although not intended, common-mode signals, are always present on the device along with the intended differential-mode signal. Ideally, a differential should respond only to the differential-mode signal. One way of quantifying how well a differential device discriminates between modes is the Common-mode rejection ratio (CMRR). This is a ratio of the differential-mode gain (S_{dd21}) to the common-mode gain (S_{cc21}). If a device has equal gain in common- and differential-modes, then $S_{dd21} = S_{cc21}$, and the $CMRR = 0$ dB.

A device will respond the same to each mode when there is high isolation between the two sides of the balanced pair.

Figure 10 shows the CMRR of the differential device described earlier. This device has a CMRR of better than 35 dB in the band of operation below 500 MHz. This says that if the input to the amplifier is a signal with equal common- and differential-mode components, the output will be almost purely differential. This is because the differential-mode component is being amplified, while the common-mode component is being attenuated.

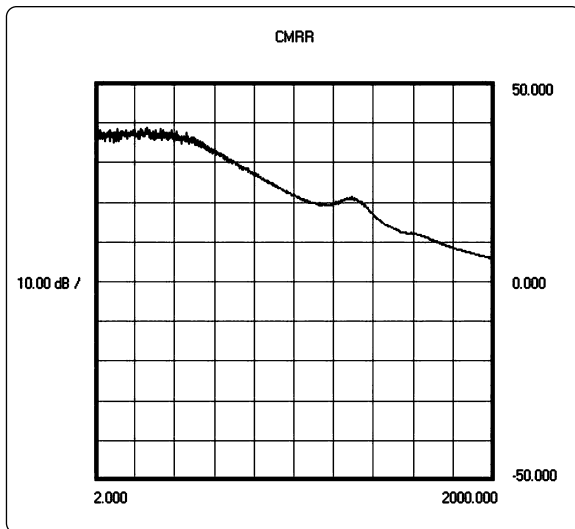


Figure 10: Common-mode-rejection-ratio (CMRR)

The significance of mode conversion in balanced devices

The degree of circuit symmetry is very important for differential applications since symmetry is the fundamental assumption needed to realize such benefits as electromagnetic interference immunity, power supply noise immunity, even-order harmonic suppression, and more. A perfectly symmetrical circuit will have no mode conversion. This means, for example, that a differential stimulus will elicit a response with a differential-mode component, but no common-mode component, and vice versa. Therefore, the mode conversion terms in the mixed-mode S-parameter matrix are all equal to zero in a perfectly symmetrical circuit. Examining these terms provides a direct measurement of the degree of symmetry of the device.

Differential- to common-mode terms

An example of a mode-conversion term is S_{cd21} , shown in the upper right quadrant of Figure 11. The data shows that if the circuit is stimulated with a pure differential-mode input signal, some of the power will be converted to a common-mode component at the output. The common-mode signal that is generated will also appear on a ground return and could potentially radiate. Therefore, differential-to-common mode conversion can potentially be a source of EMI.

The ratio S_{dd21}/S_{cd21} - shown in the lower left quadrant of Figure 11 - is more than 30 dB in the operating band, so less than 1% of the available differential input power of this device is being converted to a common-mode output.

Similar analyses can be performed on the reflection parameters.

Common-to-differential mode terms

It is also possible to analyze the behavior of the circuit with a common-mode stimulus, examining the common-mode and differential-mode responses at each port.

As described earlier (in Mixed-mode performance) because of the nature of the device used in this example, the S_{dc} parameters are approximately equal to the S_{cd} parameters. In general, this equality does not hold.

Having a common-mode signal converted to a differential-mode can have a significant impact on overall system performance, and indicates a potential susceptibility to performance degradation due to EMI. In differential circuits therefore, characterization of low-mode conversion (in relation to circuit symmetry) is critical, and until now, extremely difficult.

Conclusion

Agilent has developed a solution that provides the most accurate, commercially available method for measuring differential RF circuits. The approach uses the Agilent N444x Series of Balanced Measurement Systems. All of these solutions characterize differential devices by representing the data in terms of mixed-mode S-parameters that describe the behavior of the circuit with differential-mode and common-mode stimuli and responses.

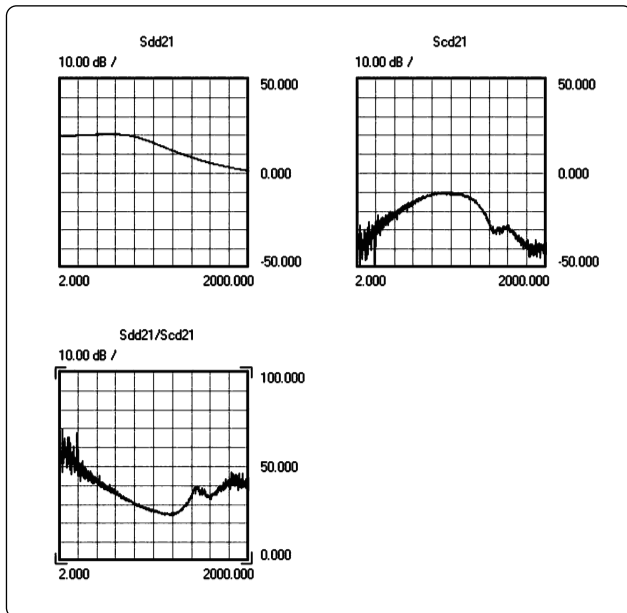


Figure 11: Mode conversion terms

Related literature

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

Agilent Balanced Measurement Example: Baluns,
Application Note 1373-6, publication # 5988-2924EN

Measurement Solutions for Balanced Components,
Product Overview, publication # 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

By internet, phone, or fax, get assistance with all your test & measurement needs

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