Agilent Webcast Template 2.0 Instructions

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RF Balanced Device Characterization

Part 1 – January 14, 2003

Archive available at: www.agilent.com/find/RFBalance

Part 2 – January 23, 2003

Presented By:

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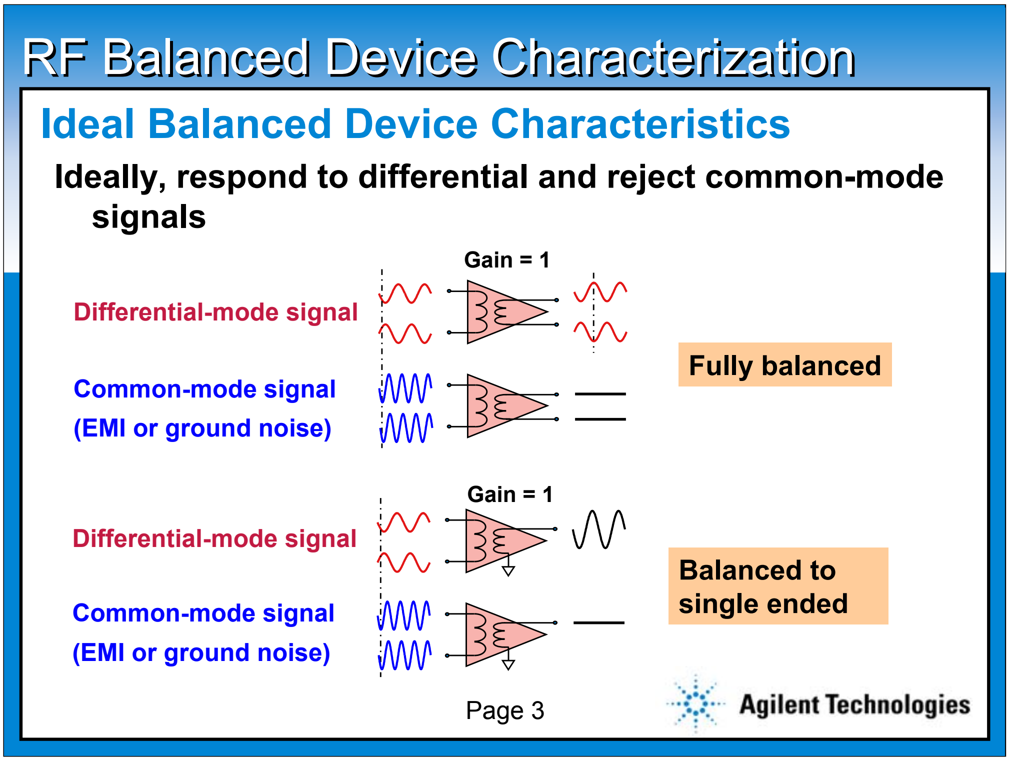
RF Balanced Device Characterization

Agenda

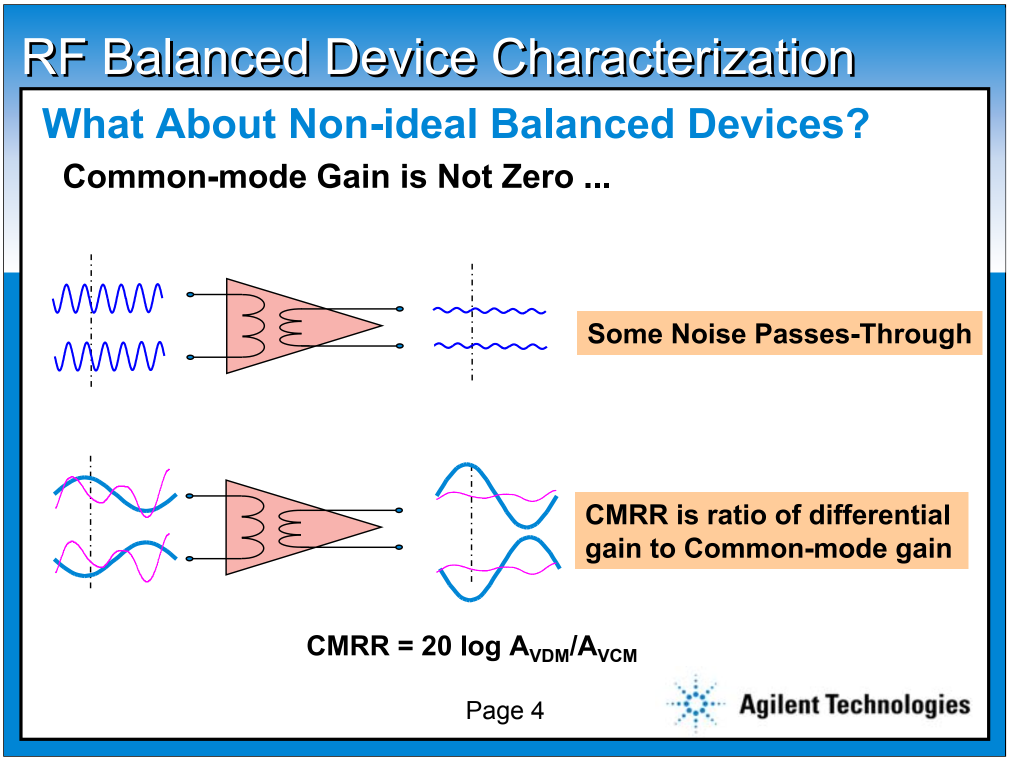
- Part I review
  (Archive available: www.agilent.com/find/RFBalance)
- Detailed comparison of measurement alternatives
- Fixturing for balanced device measurements
- Introduction to using mixed-mode S-parameters for component and circuit design
- Conclusion



Differential signals are 180 deg. out of phase

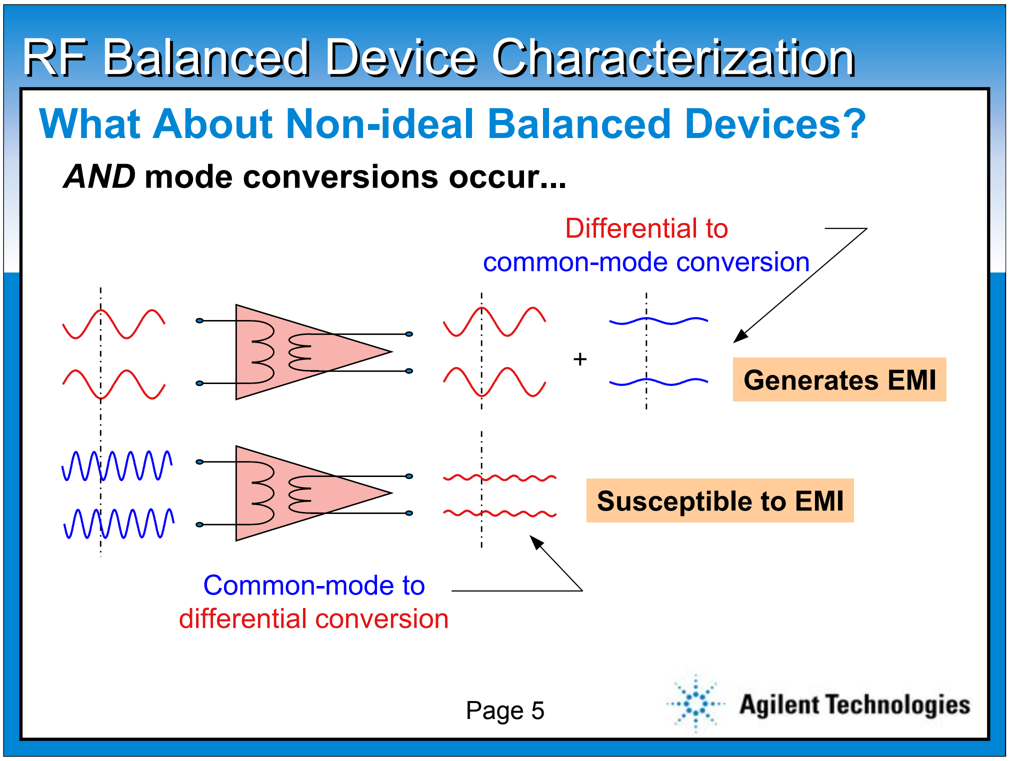
Common mode signals are in phase

Differential input is desired mode of operation



The previous slide showed the operation of an ideal balanced device. But designing high performance balanced components/devices and circuits is difficult and all devices will have some non-ideal behavior.

One of the key issues is the degree of balance of the device and how our DUT may affect the whole circuits degree of balance. As the degree of balance becomes worse, the device will perform what is called “mode conversion”. If a device converts some of its incoming differential signal to common mode on its output, then the system (whole circuit) will generate EMI radiation. If a device converts some of its incoming common mode signal (typically noise) to differential on its output, that reduces the systems noise immunity.



The previous slide showed the operation of an ideal balanced device. But designing high performance balanced components/devices and circuits is difficult and all devices will have some non-ideal behavior.

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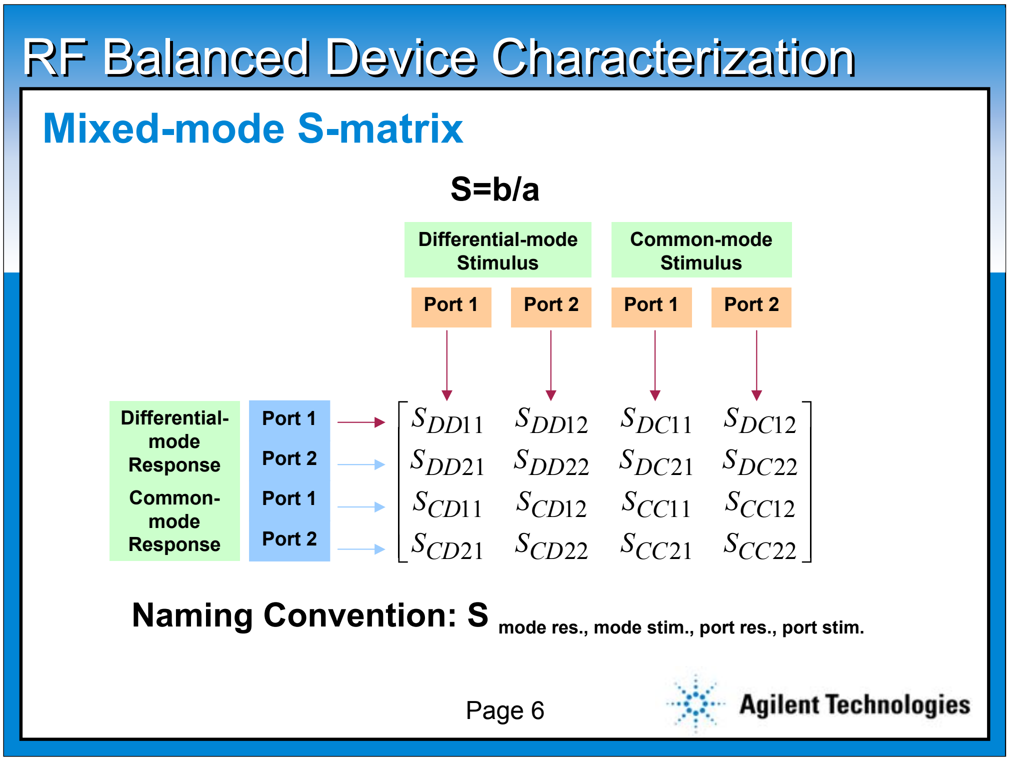


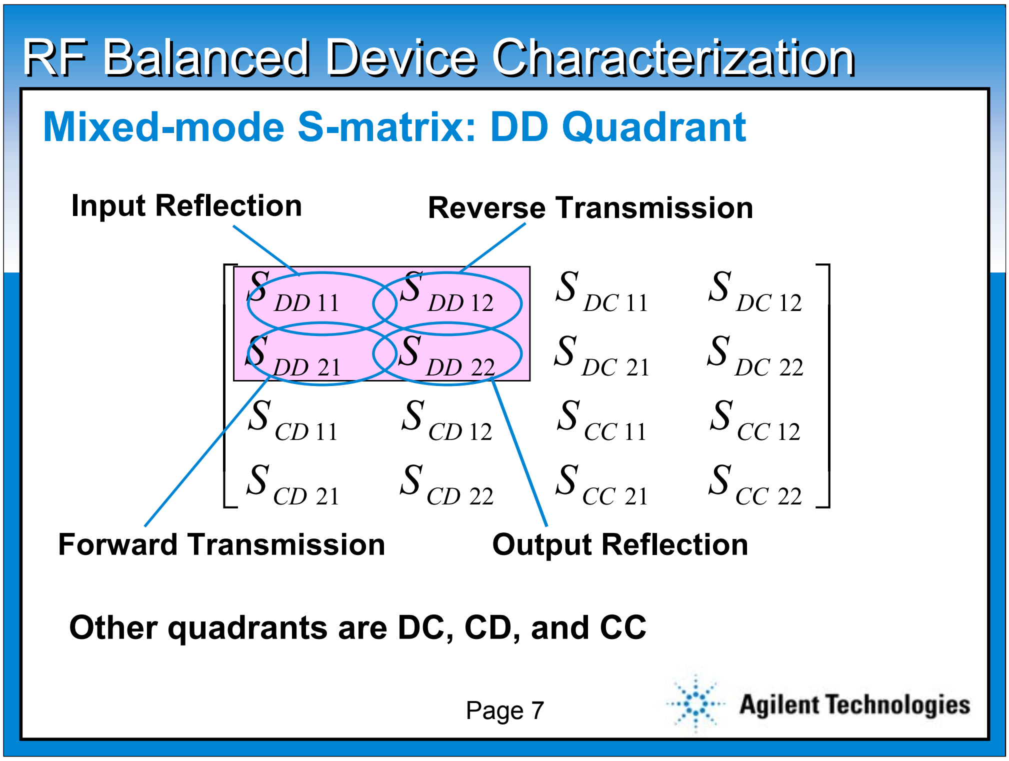
Again we can take a ratio of all of the possible combinations of response over stimulus for the differential and common-mode normalized power waves to calculate the mixed-mode s-parameters.

A mixed-mode s-matrix can be organized in a similar way to the single-ended s-matrix, where each column represents a different stimulus condition, and each row represents a different response condition.

Unlike the single-ended example, though, in the mixed-mode s-matrix we are not only considering the port, we are also considering the mode of the signal at each port.

The naming convention for the mixed-mode s-parameters must include mode information as well as port information. Therefore, the first two subscripts describe the mode of the response and stimulus, respectively, and the next two subscripts describe the ports of the response and stimulus.

The mixed-mode matrix fully describes the linear performance of a balanced two-port network. To understand the information contained in the mixed-mode s-matrix, it is helpful to examine each of its four modes of operation independently by dividing this matrix into four quadrants.



For a device with two balanced ports, the quadrant in the upper left corner of the mixed-mode s-matrix describes the performance with a differential stimulus and differential response. When the performance of the device is isolated to this specific mode, these four parameters describe the input and output reflections, and the forward and reverse transmissions much in the same way a 2-port s-matrix describes the performance of a single-ended device.

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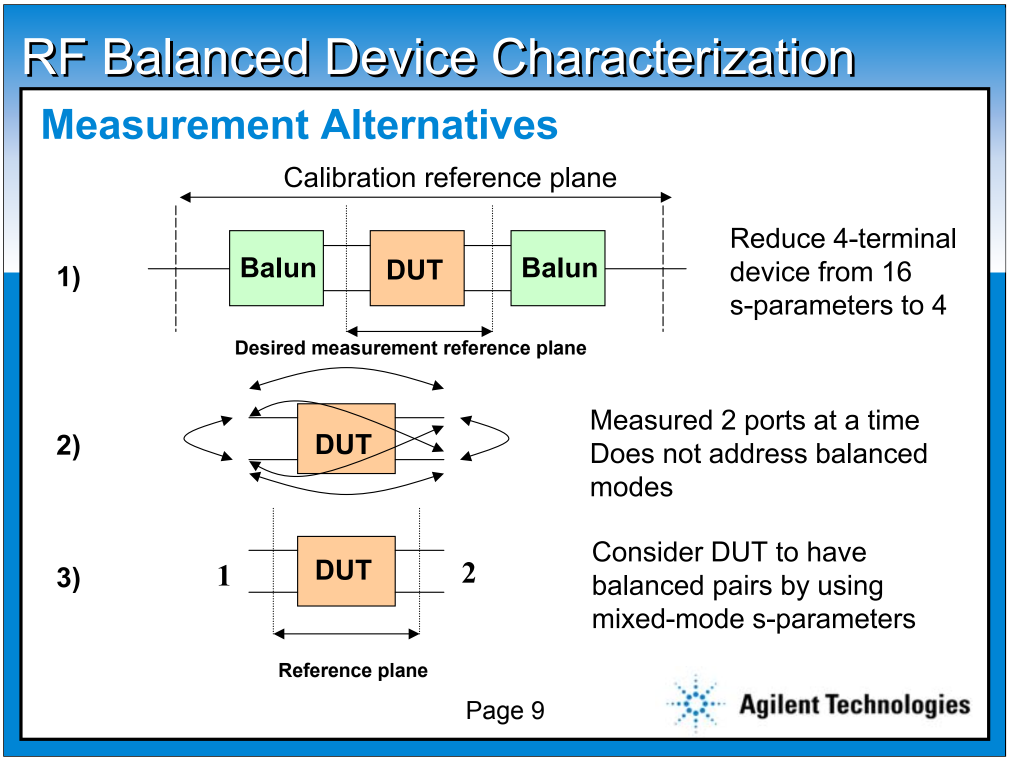
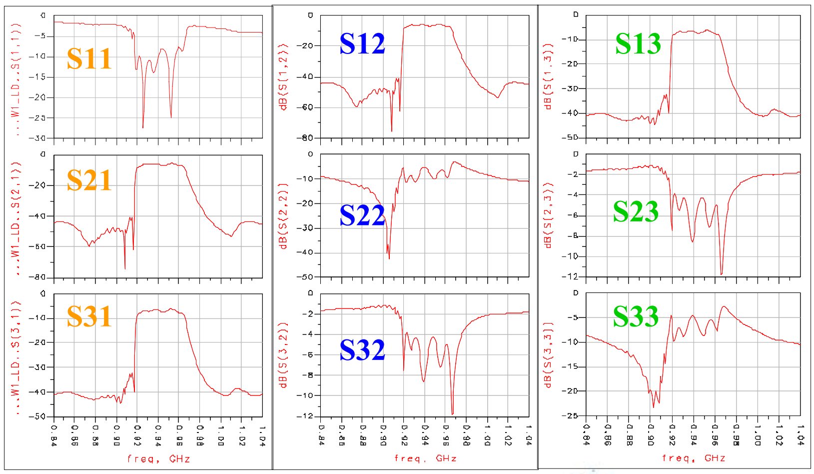


The third method that is preferred for its accuracy, completeness, and ease of interpretation is to characterize the DUT using mixed-mode s-parameters such as measured on the Agilent Differential & Multiport Measurement Systems. In this example we treat the 4-terminal device as having only 2 ports but each of those ports are balanced ports (potentially carrying both common mode and differential mode signals). When we use this approach we can define the behavior of our device using "mixed-mode s-parameters".

RF Balanced Device Characterization

Single-ended 50 Ohm S-parameters for a 3-port Device



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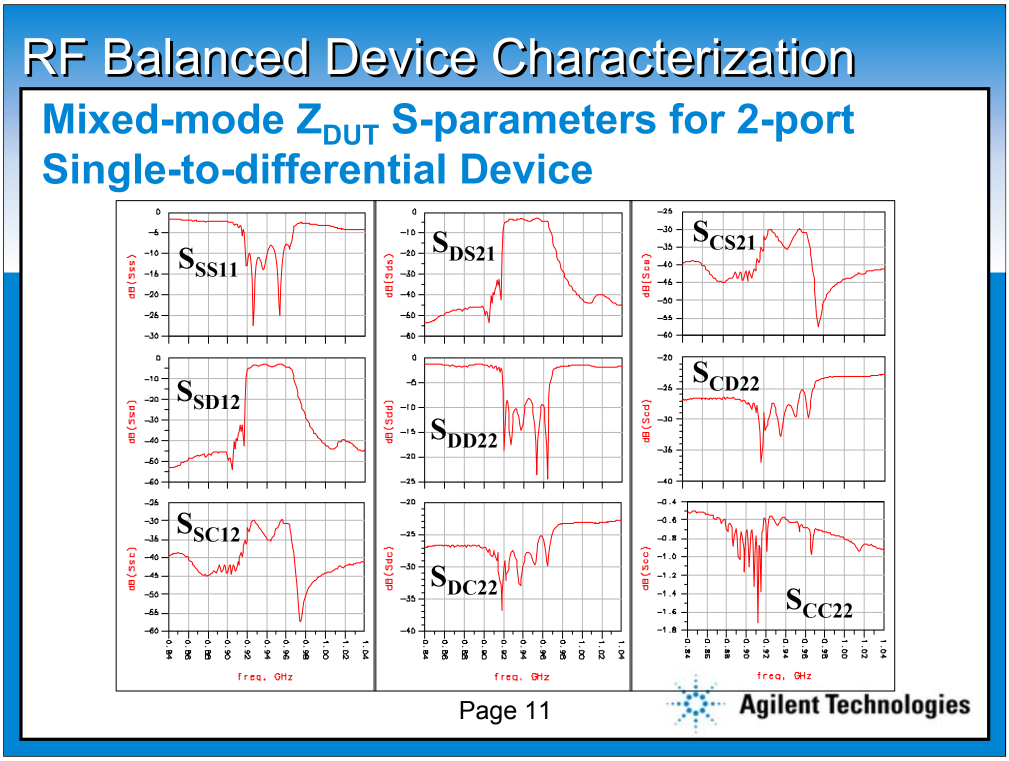
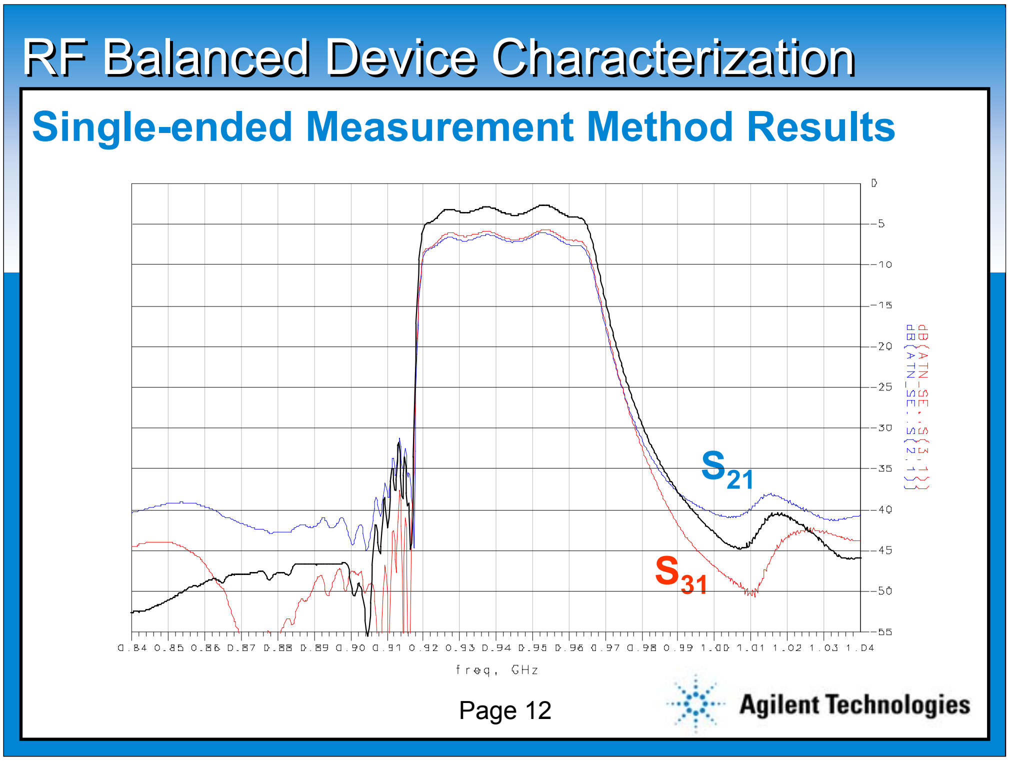
These are the single ended 3 port s-parameters from the SAW filter. Notice the values of the insertion loss parameters. The S21, S31 parameters are similar in shape but do not accurately represent the single ended to differential insertion loss. The S22 and S33 parameters are the match of the balanced terminals in single-ended mode. How do we interpret this match since it is not the differential match? In fact the match at those terminals does not look that good. We need to measure the differential match to get an accurate result.



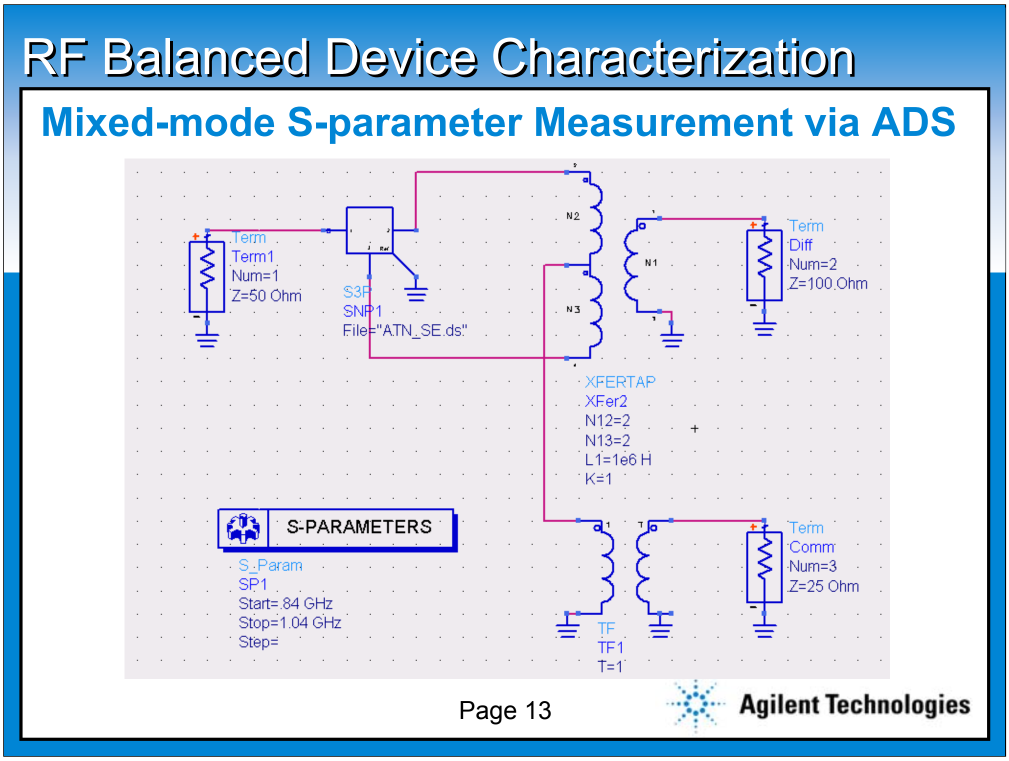
These are the single ended 3 port mixed mode s-parameters from the SAW filter. Notice the values of the insertion loss parameters compared to the previous single-ended s-parameter insertion loss.

Also compare S_{DD22} and S_{CC22} with S_{22} and S_{33} on the previous slide. As we might expect, the differential match is quite good and the common match is quite poor. S_{22} and S_{33} look bad because they are a combination of the differential- and common-mode responses.

This particular device has a 50 ohm input impedance and a 100 ohm output impedance so the impedance transformation step was unnecessary.



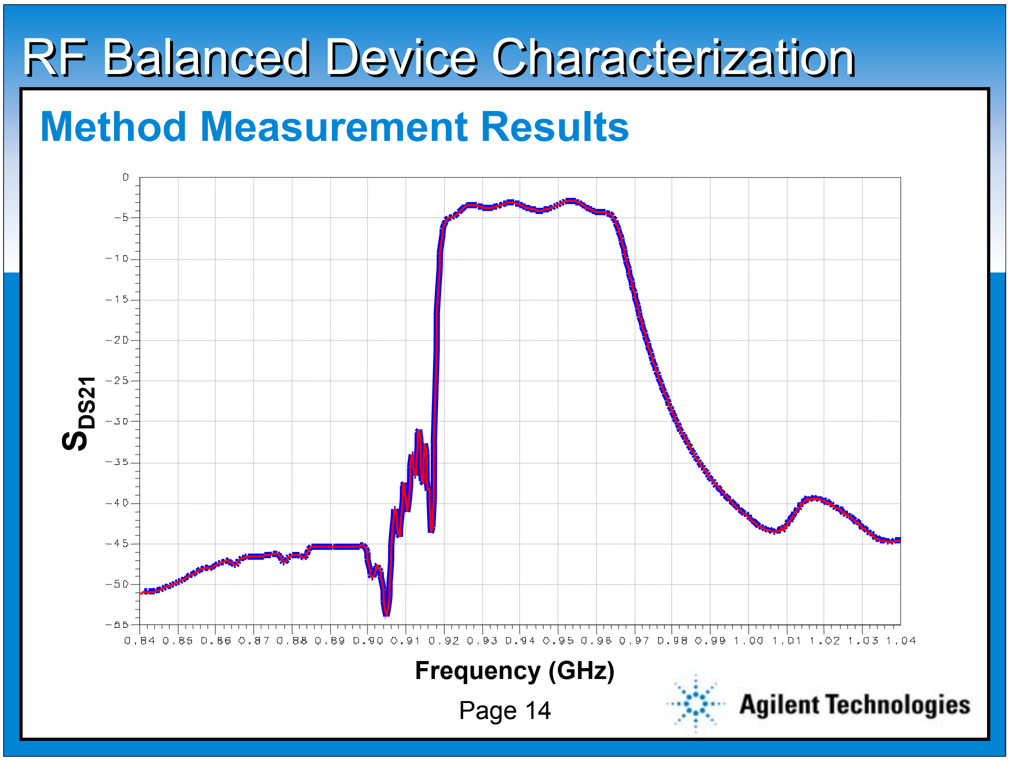
Here single-ended measurments of S_{31} and S_{21} on our three-port device are compared with S_{DD21}. While the single-ended results agree superficially with the differential performance, the error would not be tolerated in many applications.



•The following is an interesting digression that reinforces two conclusions presented earlier: First, that 3-port single-ended S-parameters contain all of the information required to interprete mixed mode operation, and 2) that the differential termination should be 4x larger than the common-mode termination.

• A circuit simulator can also be used to measure mixed-mode parameters of the differential device. The device is modeled with 3-port single-ended S-parameters in the simulation. (I.e., the single-ended parameter set was not converted to a mixed mode parameter set).

•A center-tapped balun is used to perform the differential mode conversion and also provides the mechanism for the common-mode terms (Note the balun is ideal). The common-mode conversion occurs at the center tap of the balun where only common-mode signals will appear because of the ideal characteristics of the balun. These common-mode signals are then terminated through a balun into a 25-ohm termination, which is the common-mode impedance of the SAW device. This configuration will allow all the mixed-mode characteristics of the device to be measured.



The simulated and calculated mixed-mode measurements are virtually identical--so identical that the response of the mixed mode is exaggerated to show that two curves are being presented.

The calculated mixed-mode method is considered superior; however, because it does not require a circuit simulator to perform the conversion.

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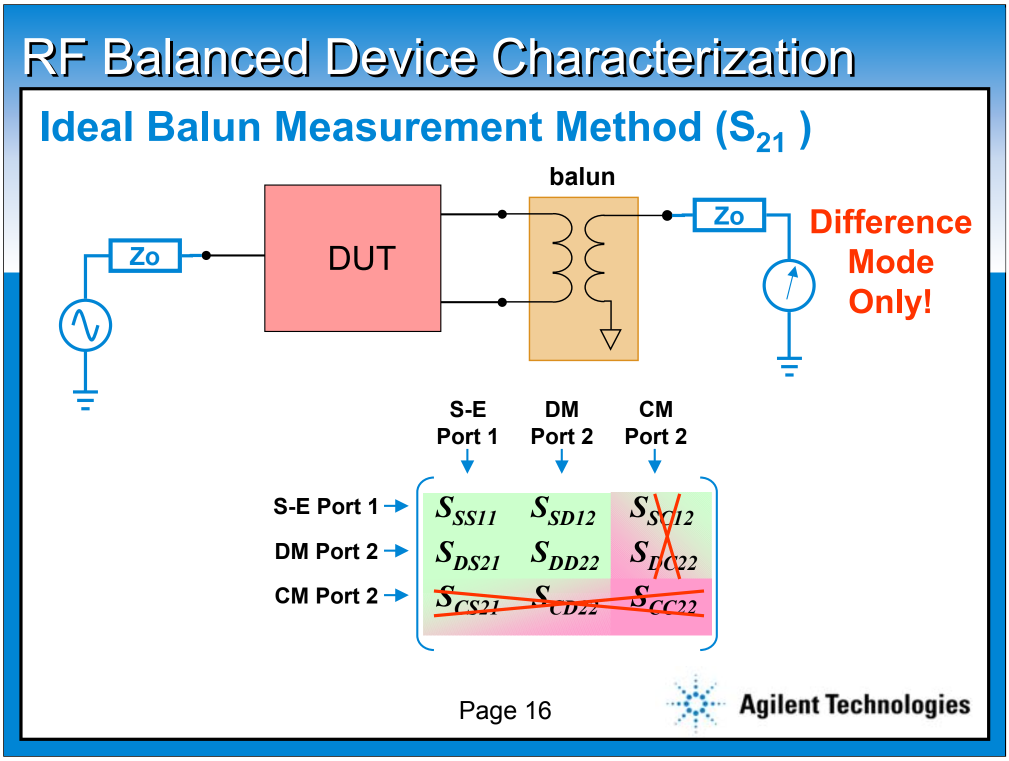
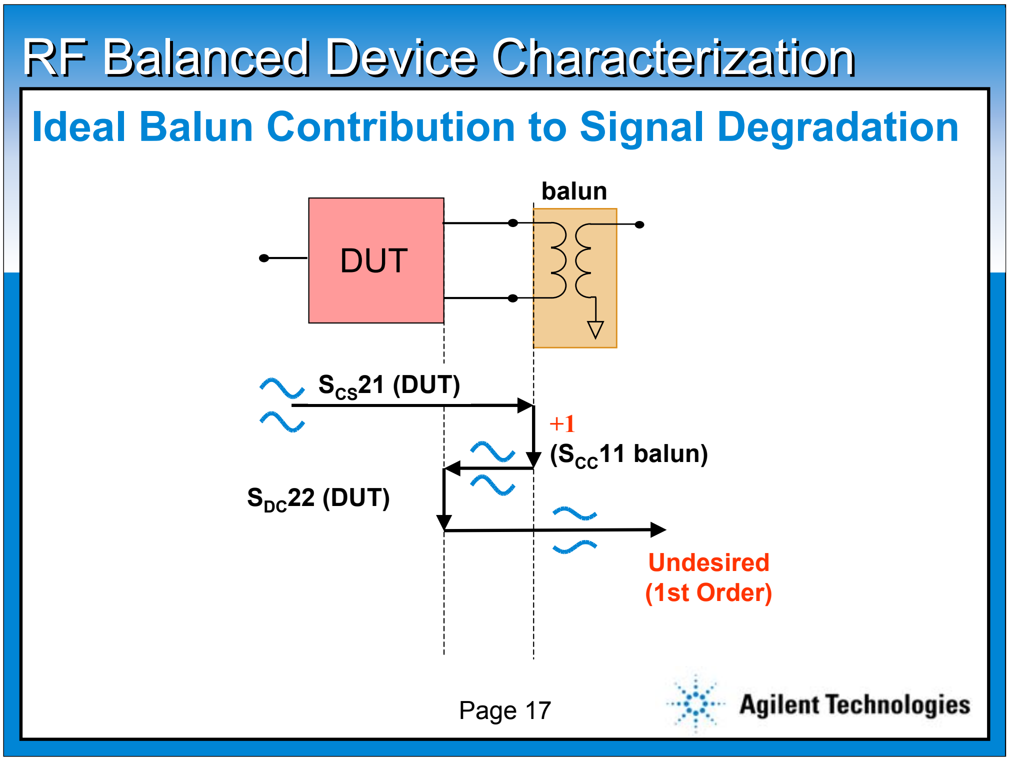
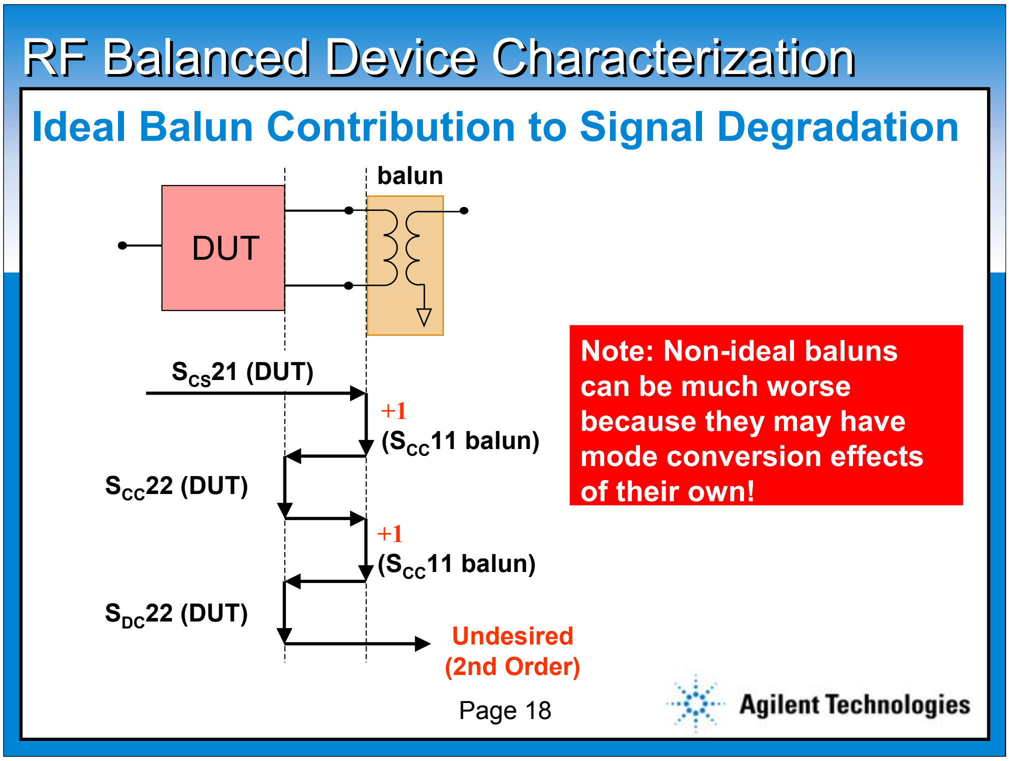


•Historically, baluns have been used to solve the problem of interfacing single-ended 50 ohm input test equipment with balanced devices. Because this practice is so ubiquitous, we will examine this approach in considerable detail.

• The balun-based technique requires that the balun be placed between the differential port of the device and the single-ended port of the analyzer. In our example, the balun transforms the output of the differential device to single-ended signal that can be input to the analyzer. There are a number of problems with this approach, but the most obvious limitation is that we have no way of measuring common-mode signals. We lose insight into the common-mode performance and both conversion modes. Only the single-ended to differential performance can be characterized, and if this were a fully balanced device, only the differential to differential performance could be characterized.

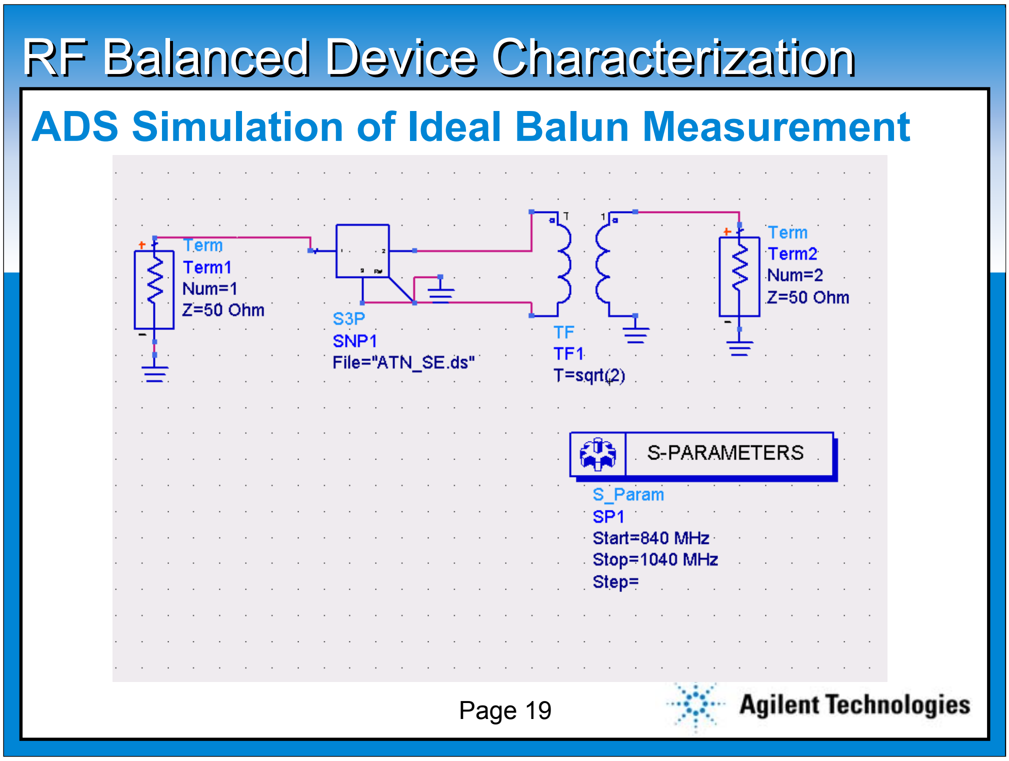


•Even if the balun is assumed to be ideal, the accuracy of the single-ended to differential cannot be guaranteed. In the example to the left, a common-mode signal is output from the DUT as a result of the single-ended to common forward transfer mode. 100% of this signal is reflected back to the DUT by the balun. (As shown the balun has an S11 of +1, and if the balun center tap is grounded, it has a reflection coefficient of -1.) Some of this energy is reflected back to the balun as a difference-mode signal due to the common to differential-mode reflection coefficient. This signal is indistinguishable from the normal differential output signal and would affect the accuracy of single to differential mode measurements.

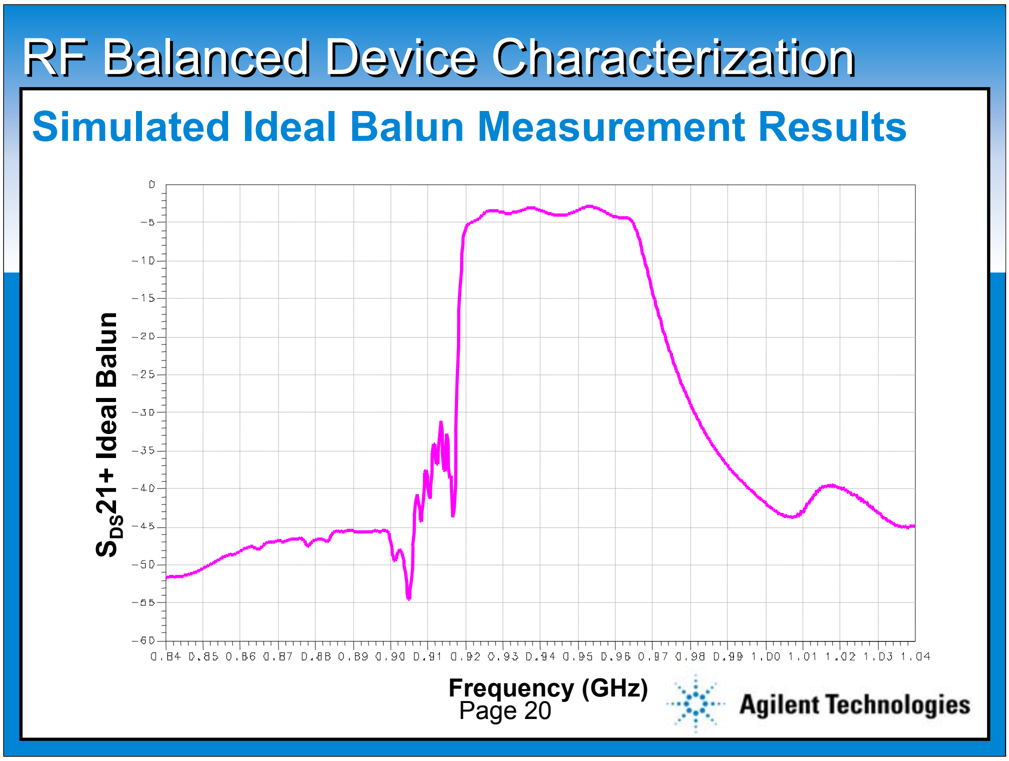


•Similarly, a second order effect occurs when energy from the common- to common-mode output reflection coefficient is converted to a differential signal. Again, this signal adds directly to the output when measuring S_{DS21}.

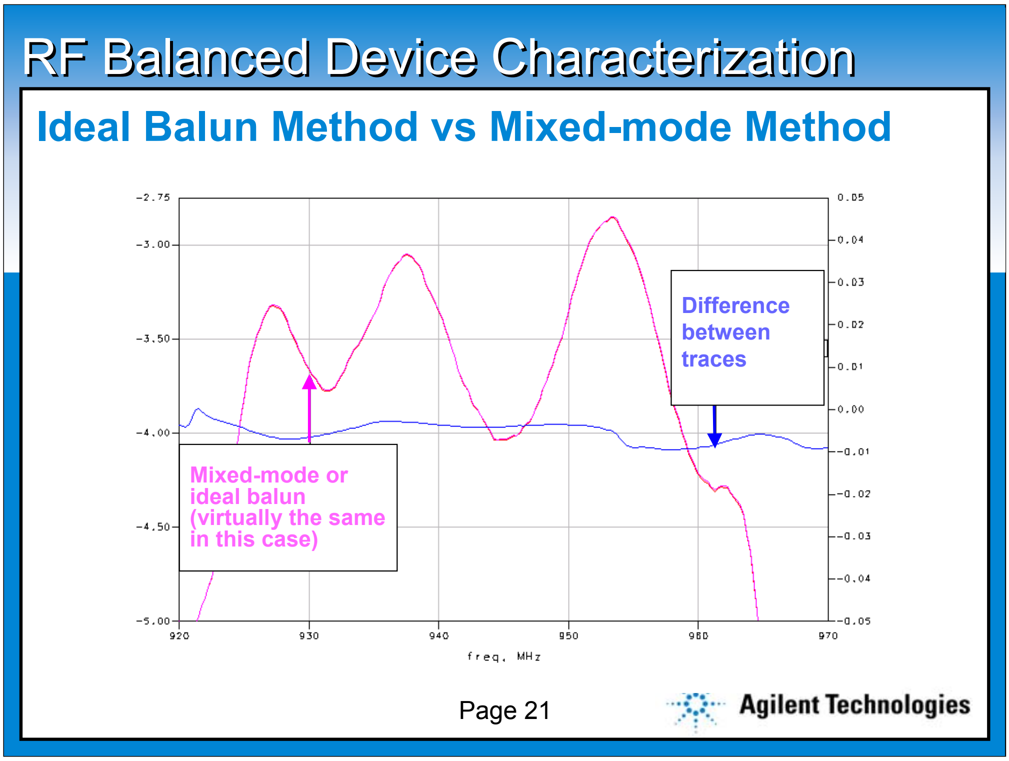
• Since we have no way of measuring the common-mode and conversion-mode parameters, we cannot know their impact on S_{DS21}.



While the ideal balun does not exist, it can be realized in simulation. In this simulation the complete set of single-ended S-parameters are used to simulate the DUT, and an ideal balun is used to convert the differential signal to a single ended signal.

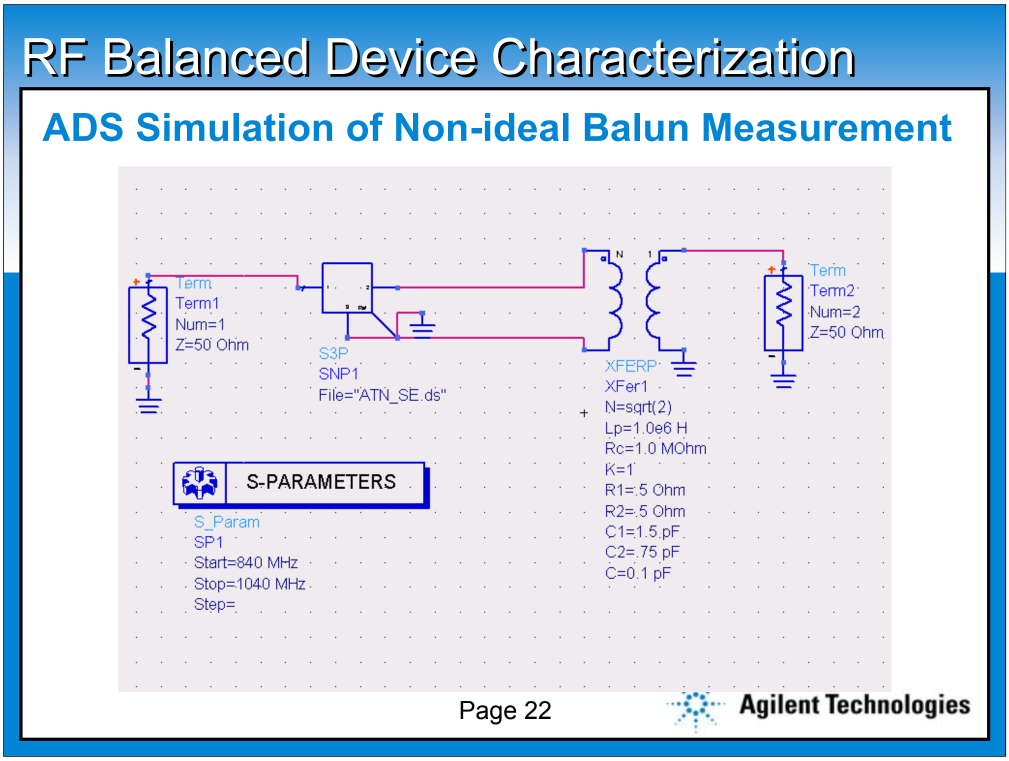


This is the SDS21 simulation results obtained using an ideal balun. Superficially, it looks perfect.

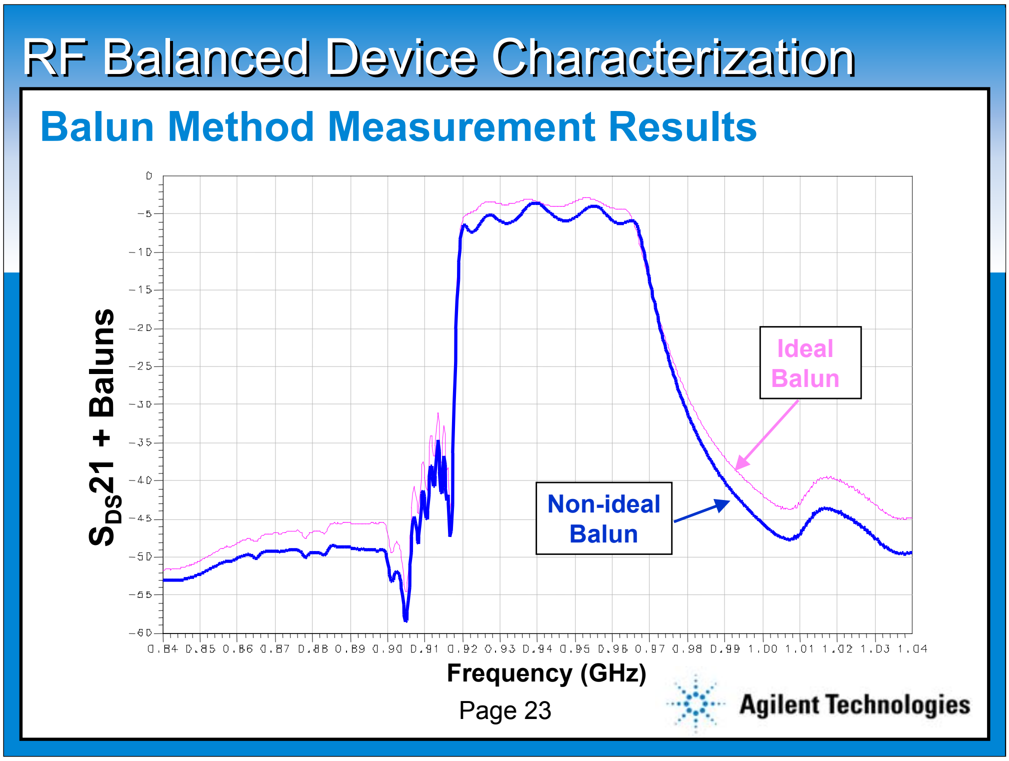


In fact, it is very close to perfect. However, if we compare it carefully with the results of our mixed-mode method, we find small differences. These differences are the result of common-mode signal being reflected off the balun and the conversion-mode effects of the DUT.

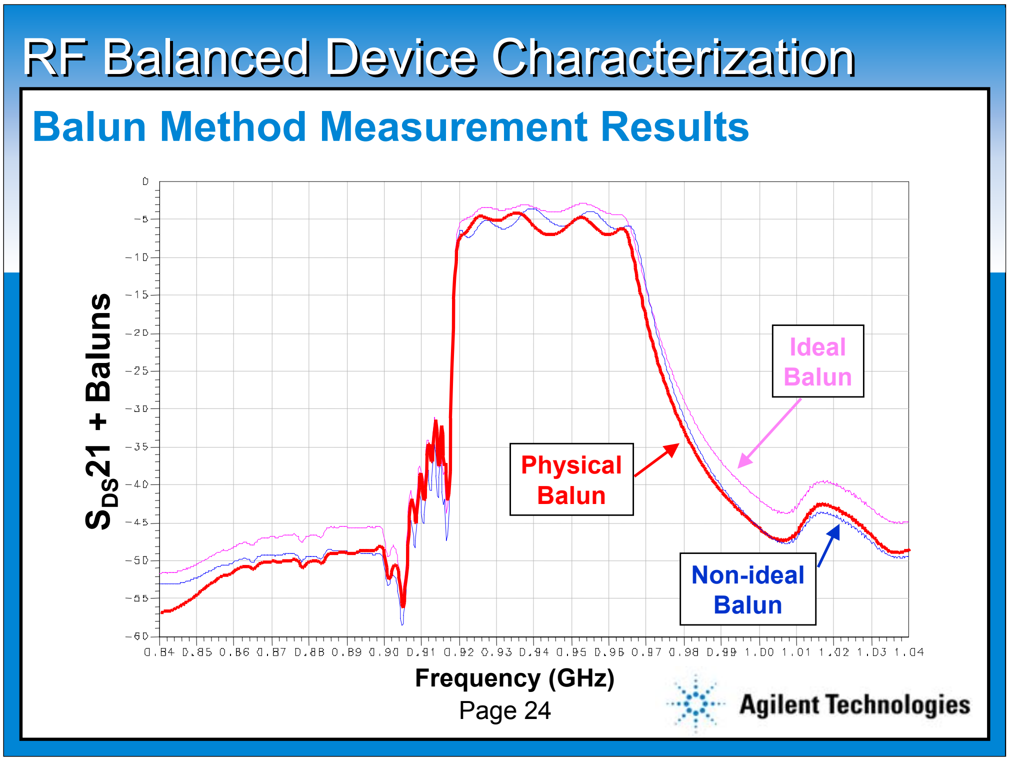
While 0.01 dB is probably not of much consequence, the point is that, using baluns, we have no way of knowing the magnitude of this error and whether or not its consequential.



We will now consider the effects of using a simulated non-ideal balun measurement and compare this to a measurement using a physical balun. Component values for the balun where chosen from a typical manufacture's data sheet. The figure above shows the simulation setup for the non-ideal balun. A calibration was performed at the terminals of the analyzer since there are no standard calibration standards for differential mode.



Here the results of our simulation with a non-ideal balun are compared with the results obtained using an ideal balun. Errors in the bandpass are in the order of 2 to 3 dB. Clearly unacceptable in many applications.



•Finally, the SDS21 of our DUT is measured using a physical balun and compared with both the simulated results using both an ideal and non-ideal balun obtained earlier.

• The results obtained using a physical balun are substantially like the results obtained by simulating the non-ideal balun. They differ because the parameters used for the simulation of the non-ideal balun were taken from a data sheet--not measured for the individual device.

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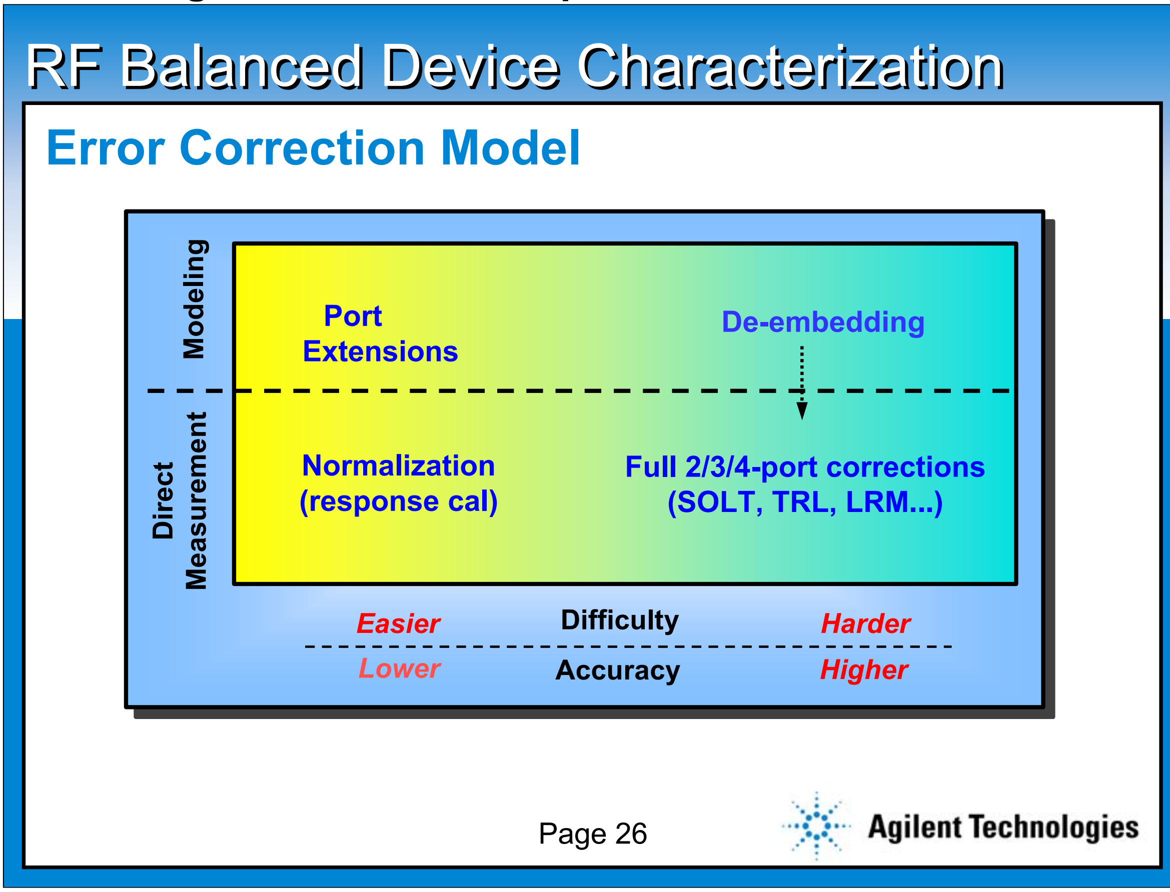


Before we get to the specifics of fixture design, we need to review the calibration choices available to decide what type of calibration standards (if any) we may need. The relative performance of our fixture compared to the specifications of the DUT that we are trying to measure will determine what level of calibration is required to meet the necessary measurement accuracy.

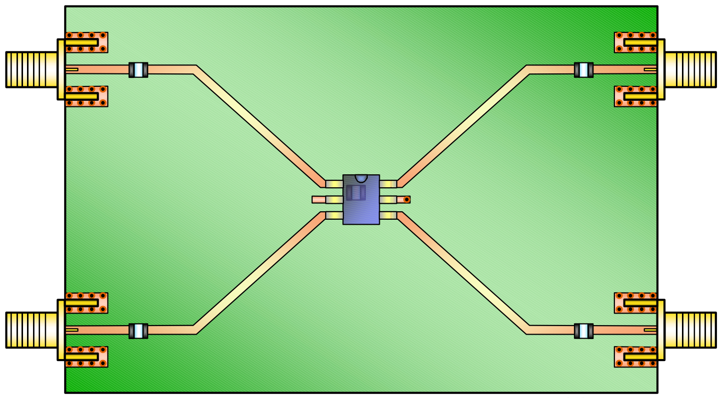
There are two fundamental error-correction techniques: modeling and direct measurement. Each has relatively simple versions and more complicated versions that require greater work, but yield more accurate measurements. Calibration based on modeling uses mathematical corrections derived from a model of the fixture. Often, the fixture is measured as part of the process of deriving an accurate model.

Direct measurement usually involves measuring physical calibration standards and calculating error terms. This method provides accuracy that is based on how precisely we know the characteristics of our calibration standards. The number of error terms that can be corrected varies considerably depending on the type of calibration used. Normalization only removes one error term, while full two-port error correction accounts for twelve error terms. Since standard cal-kit definitions used in the VNA are based on coaxial standards, modifying these definitions for in-fixture calibration is very important for accurate measurements. We will cover this in more detail later in the paper.

RF Balanced Device Characterization

Measuring Differential Devices

- Make all traces 50 ohms
- Keep traces uncoupled all the way to DUT



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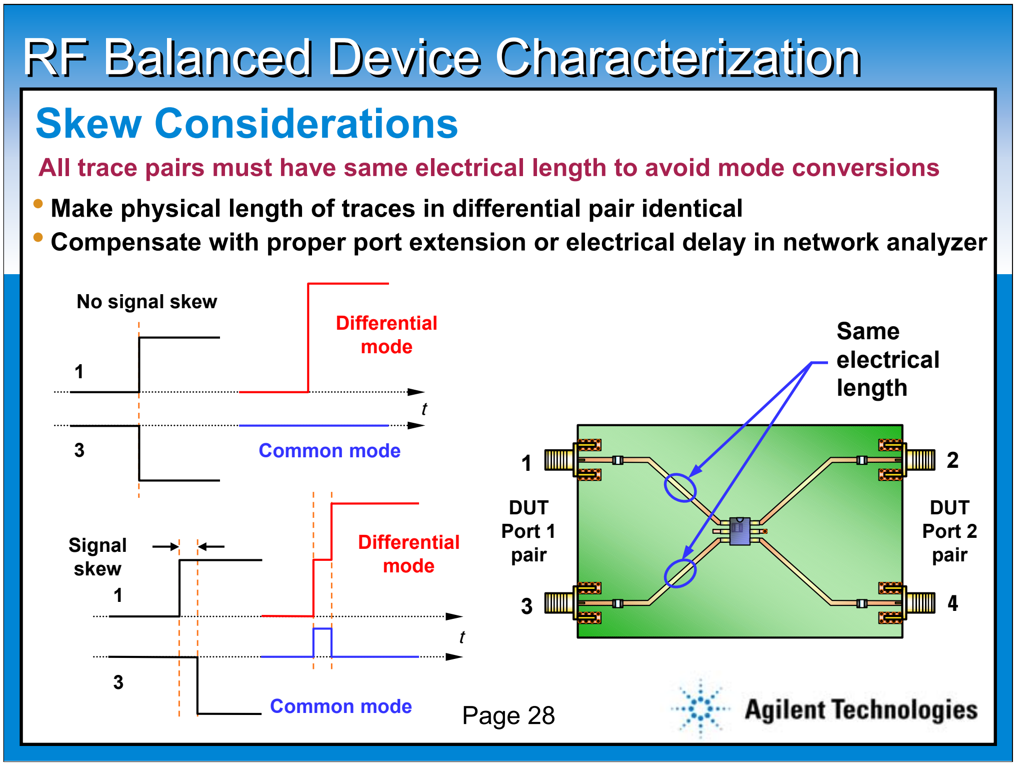
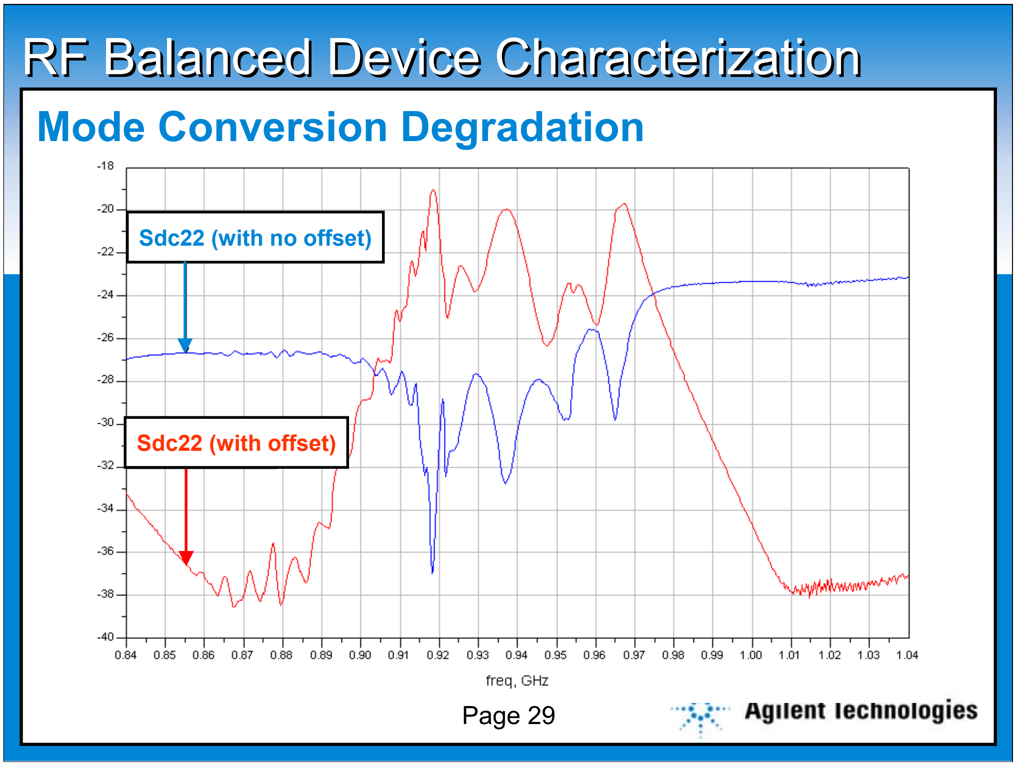
When measuring differential devices on PCB fixtures, it is best to use 50 ohm traces that are uncoupled. You can think of these traces as extensions of the coaxial test cables between the VNA and the fixture. By using uncoupled 50 ohm lines, we can use the following order of mathematical transformations:

1. Extend the coaxial test ports so that our reference plane is right at the terminals of the DUT (port extensions).
2. Transform the S-parameter measurements to the reference impedance that the DUT wants to see.
3. Transform from single-ended to mixed-mode S-parameters.

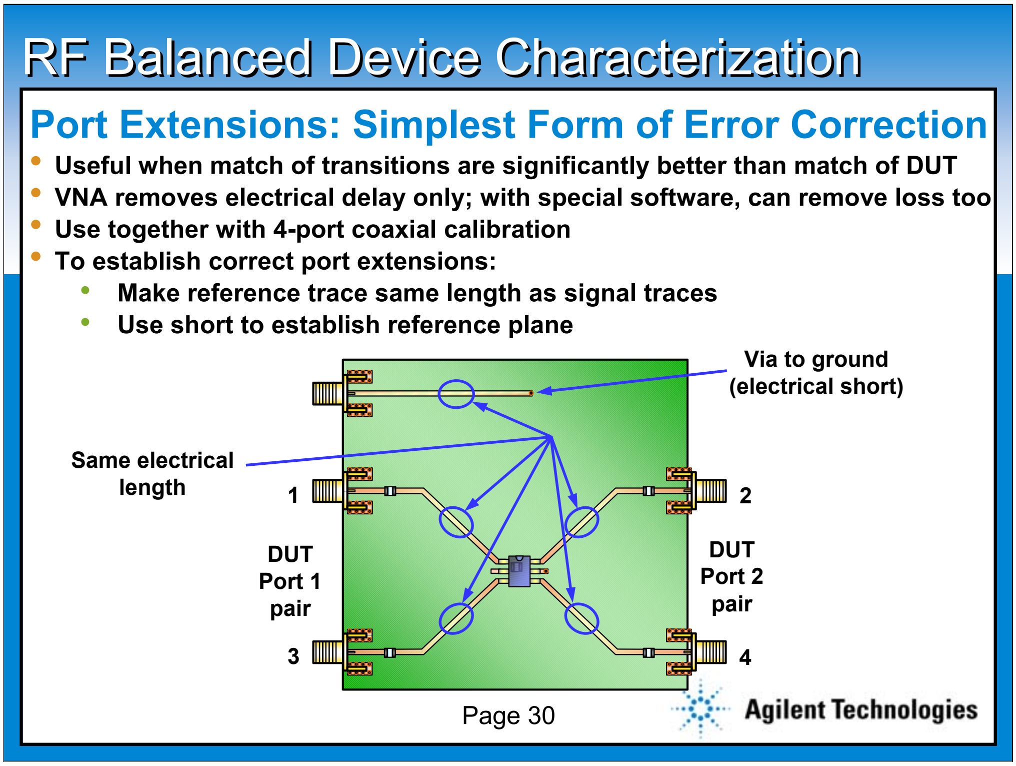


It is very important that any pair of traces that make up a differential transmission line be the same electrical length. If one trace is electrically longer than the other, then signal skew will occur, causing one signal to arrive at the destination before the other. This phenomenon causes mode conversions to occur. The slide illustrates differential-to-common-mode conversion.

We can ensure that no skew occurs by making the physical length of each trace of a differential pair identical, or by using the port extension or electrical delay feature of the VNA to mathematically equalize the electrical lengths.



Here S_{DC22} with an offset in the fixture is compared to the S_{DC22} obtained without an offset in the fixture. Recall from our discussion of basic differential device operation that mode conversion is caused by a lack of symmetry. This degradation of the SDC22 term is hardly a surprise.



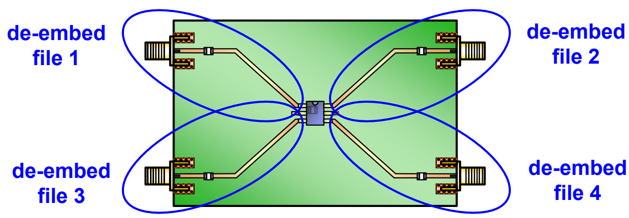
Port extensions are a very useful technique when the quality of the fixture is good compared to the performance of the DUT. Since fixture loss is usually negligible, the dominating performance factor is the match of the coaxial transitions. With proper connectors and geometries, matches of 30 dB can be achieved. This might mean that it is possible to verify a DUT match of 15 dB without excessive measurement uncertainty. The better the match of the DUT or the lower uncertainty we desire, the less likely that port extensions alone will be sufficient for our measurements.

One way to find out how much port extension is needed is to provide a reference trace on the PCB that is the same electrical length as the traces used to connect to the DUT. The end of the trace is shorted, and port extension is applied until the phase response of a reflection measurement is flat. It is often helpful to add 180° of phase offset to the measurement so that it is centered around 0° instead of +/- 180°, where phase wrapping occurs.

RF Balanced Device Characterization

De-embedding

- Requires S-parameter data for each section of fixture (a fixture for a fully balanced device would need four de-embedding files)
- Effects of fixture are removed by subtracting de-embedding files from DUT measurements
- Can use measurements or modeling (or both) to obtain fixture S-parameters
- Allows user to characterize fixture once, and then use periodic coaxial calibrations to remove network analyzer errors
- No need to re-characterize fixture until wear causes significant errors



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De-embedding is conceptually a simple technique. If we have the S-parameter performance of each section of our fixture, we can mathematically remove the effects of each of these sections from the measured S-parameters of our fixtured DUT. The resulting de-embedded S-parameters would be due to the DUT alone, without the degradation of the fixture. This approach works well if the fixture performance does not change over some period. During this period, we only need to perform coaxial calibrations of the VNA itself, which is relatively easy with coaxial calibration standards. There is no need to re-characterize the fixture until wear has caused significant changes to the RF performance of the fixture.

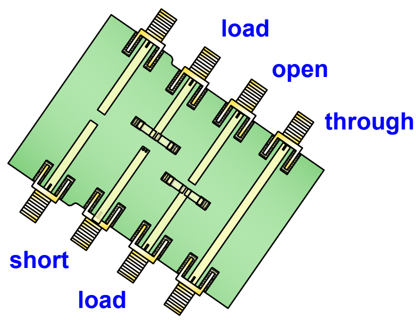
The difficulty with de-embedding is that it is not necessarily easy to obtain the S-parameters of the fixture. Traditionally, de-embedding was done for microwave fixtures built with thin-film processes on sapphire substrates. The quality of these fixtures was very good, and S-parameter performance could be modeled to a high level of accuracy. With PCB-based fixtures, it is harder to obtain an accurate model of the fixture. A combination of measurements and modeling is often used to derive the fixture's S-parameters. For many cases, it is probably easier to build in-fixture calibration standards than it is to derive files for de-embedding.

RF Balanced Device Characterization

Short-Open-Load-Through (SOLT) Calibration

SOLT calibration is attractive for RF fixtures

- simpler and less-expensive fixtures and standards
- relatively easy to make broadband calibration standards
  - short, thru are easiest
  - open requires characterization
  - load is hardest (quality determines corrected directivity)



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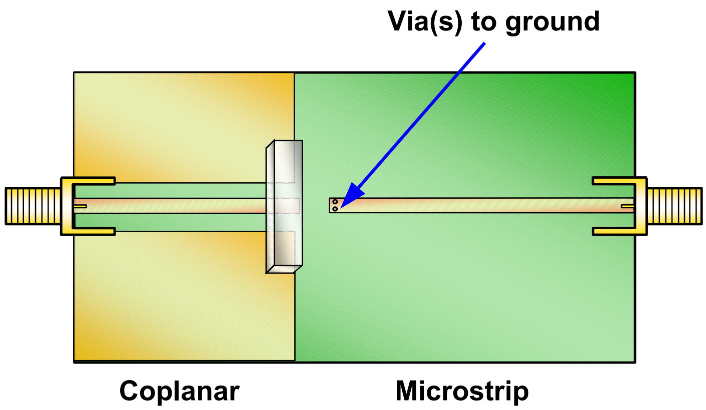
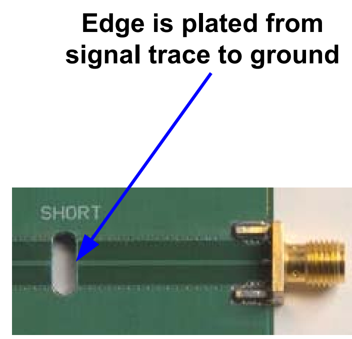
For RF applications, SOLT-based error correction for calibrating fixtures is very attractive because the standards and fixtures can be simple and inexpensive, and the standards generally work over a very broad bandwidth - calibration from DC to 3 GHz is easy to achieve.

The short is the simplest standard to make, giving ideal reflection. The open, while not difficult to "make" (it is usually the fixture containing no part or a dummy part), is harder to characterize for our cal-kit definition because we have to account for fringing capacitance. The load is the hardest standard to make well. The quality of the load will determine our corrected system directivity which in turn determines how much uncertainty we will have for reflection measurements. For the thru standard, we need to accurately know the impedance and length of the transmission line. These values must then be incorporated into the cal-kit definition of the through.

RF Balanced Device Characterization

Short Standard





Real-life example

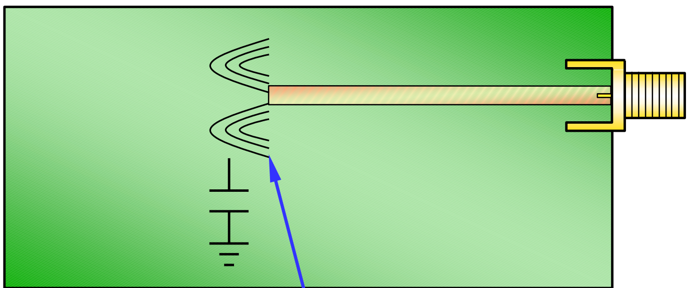
- Ideal: unity reflection with 180° phase shift
- Simply short signal conductor to ground (e.g. with vias or metal bar)
- If using coplanar lines, short to both ground planes
- Avoid excess inductance by keeping length as short as possible

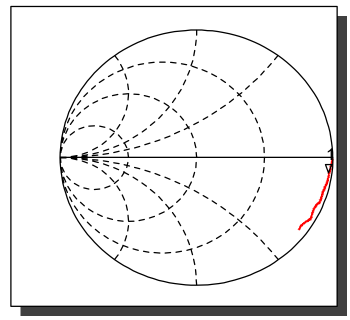
The electrical definition of an ideal short is unity reflection with 180 degrees of phase shift. This means all of the incident energy is reflected back to the source, perfectly out of phase with the reference. A simple short-circuit from signal conductor to ground makes a good short standard. For example, the short can be a few vias to ground at the end of a microstrip transmission line. If coplanar transmission lines are used, the short should go to both ground planes.

To reduce the inductance of the short, avoid excess length. A good RF ground should be nearby the signal trace to accomplish this. If the short is not exactly at the contact plane of the DUT, an offset length can be entered (in terms of electrical delay) as part of the user cal kit definition.

RF Balanced Device Characterization

Open Standard

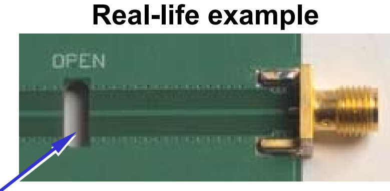




Electromagnetic fringing (looks capacitive)

- Ideal: unity reflection with no phase shift
- Can be unterminated transmission line
- Actual model accounts for fringing capacitance (a concern around 300 MHz and above)

Real-life example



Hole minimizes stray capacitance

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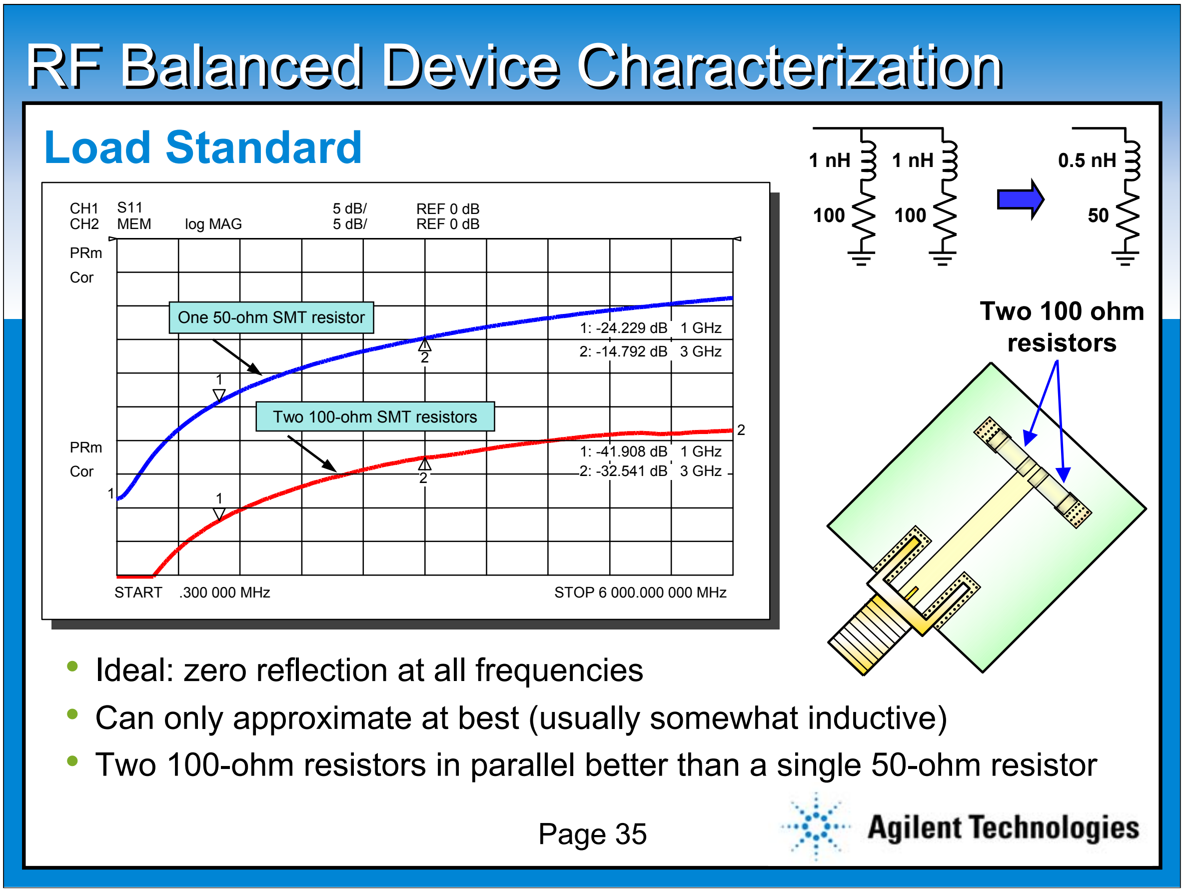
The open standard is typically realized as an unterminated transmission line. The electrical definition of an ideal open is unity reflection with no phase shift. The actual model for the open, however, does have some phase shift due to fringing capacitance.

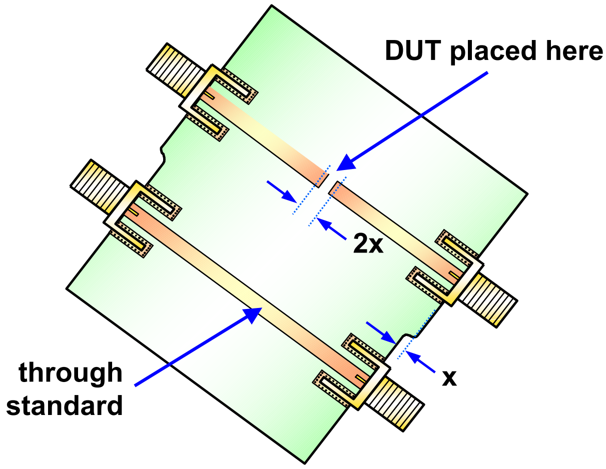


An ideal load reflects none of the incident signal, thereby providing a perfect termination over a broad frequency range. We can only approximate an ideal load with a real termination because some reflection always occurs at some frequency, especially with noncoaxial standards.

At RF, we can build a good load using standard surface mount resistors. Thin-film resistors provide even better performance. Usually, it is better to use two 100-ohm resistors in parallel instead of a single 50-ohm resistor, as the parasitic inductance is cut in half. For example, 0805 size SMT resistors have about 1.2 nH series inductance and 0.2 pF parallel capacitance. Two parallel 100-ohm 0805 resistors have nearly a 20 dB better match than a single 50-ohm resistor.

RF Balanced Device Characterization

Through Standard



- Thru is a simple transmission line
- Desire constant impedance and minimal mismatch at ends

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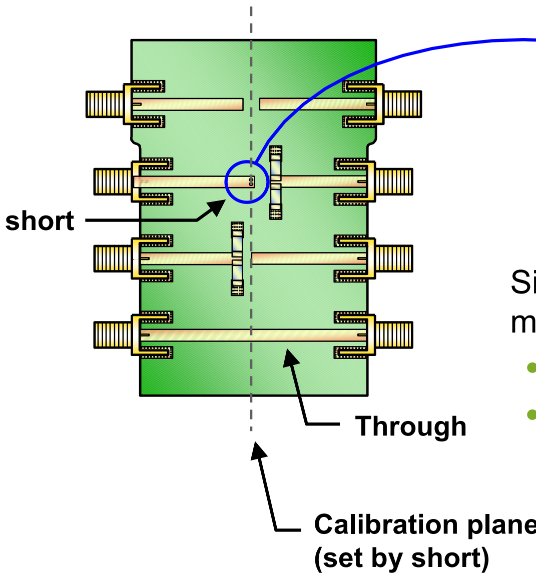
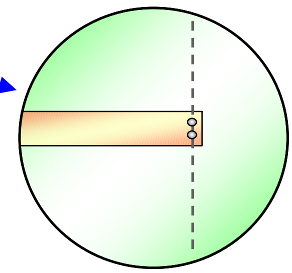
The through standard is usually a simple transmission line between two coaxial connectors on the fixture. A good through should have minimal mismatch at the connector launches, and maintain a constant impedance over its length (which is generally the case for PCB throughs). The impedance of the through should match the impedance of the transmission lines used with the other standards (all of which should be 50 ohms).

Notice in the above drawing that the PCB is wider for the transmission line where the DUT will be soldered. Since we want the two halves of this line to be equal in electrical length to the through line, the PCB must be widened by the length of the gap between the two lines. We may wish to provide a little bit extra length of transmission line on either trace that will be used to measure the DUT, so that the reference plane is at the point that we will actually solder the device. If the reference plane is exactly at the end of the trace, it would be difficult to solder the terminals of the DUT to the traces of the fixture.

RF Balanced Device Characterization

Characterizing Through Standard





Since the calibration plane is in the middle of the fixture:

- The length of the thru standard is zero
- We don't need to measure thru loss

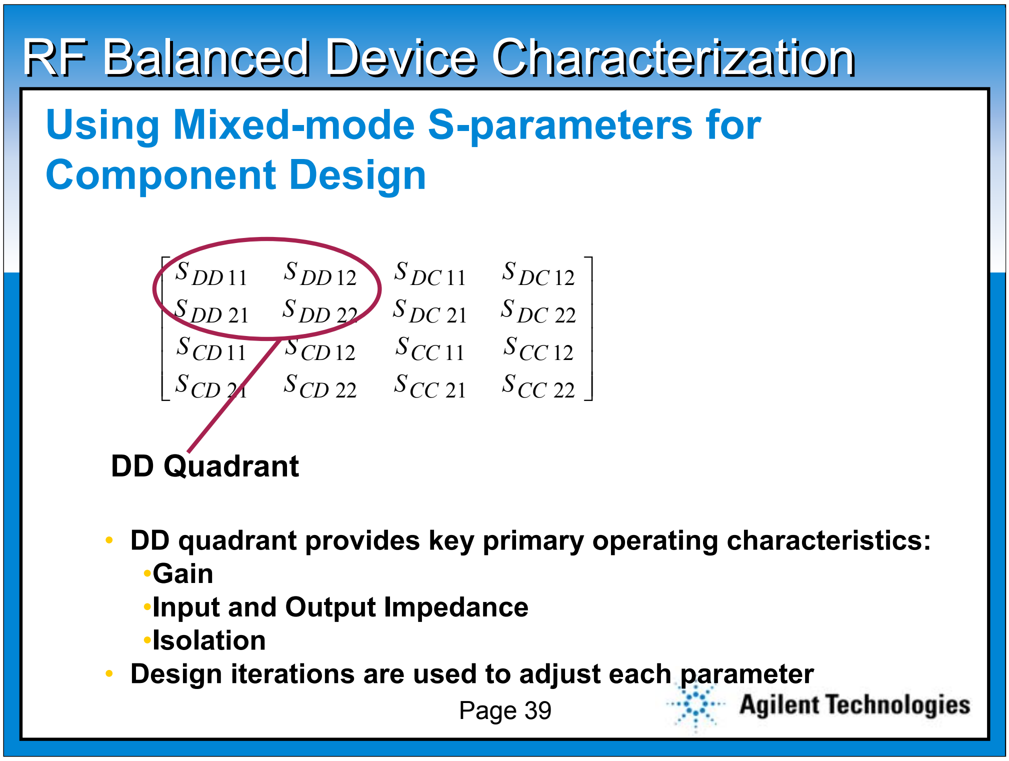
Agilent Technologies

With a properly designed PCB fixture, the short (or open) defines the calibration plane to be in the center of the fixture. This means that the through will have a length of zero (which is usually not the case for fixtures used in manufacturing applications, where a set of calibration standards are inserted into a single fixture). Since the length is zero, we don't have to worry about characterizing the loss of the through standard.

RF Balanced Device Characterization

Agenda

- Part I review
- Detailed comparison of measurement alternatives
- Fixturing for balanced device measurements
- Introduction to using mixed-mode S-parameters for component and circuit design
- Conclusion



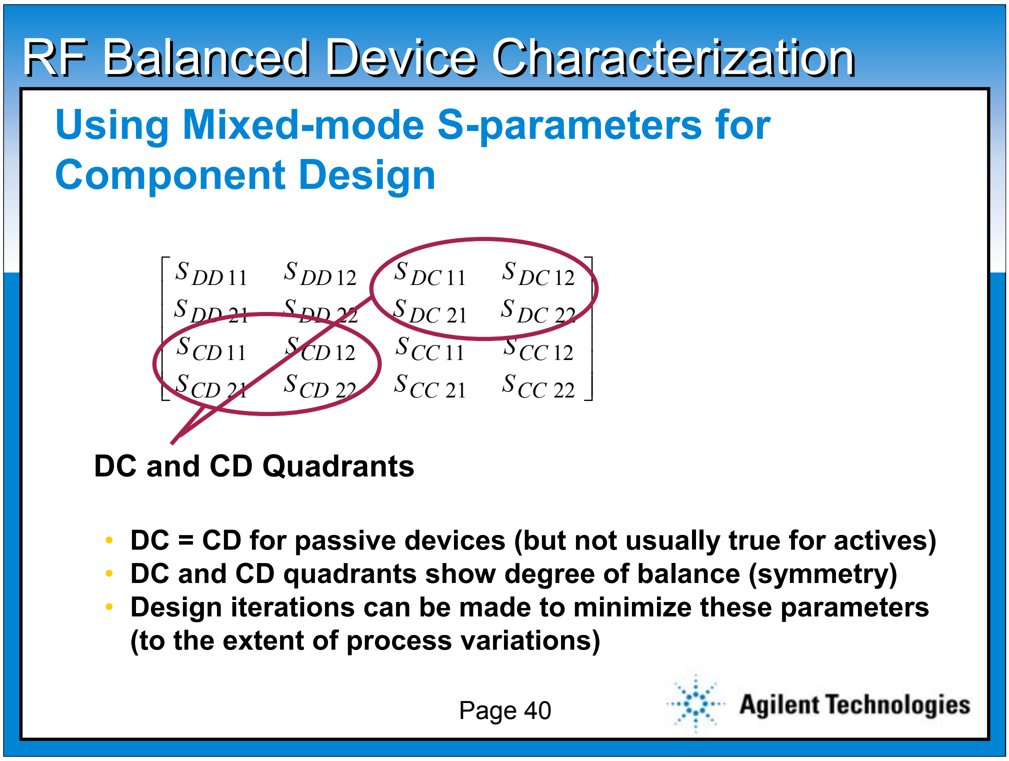
Finally, the parameters in the upper right corner describe the differential response of a device to a common-mode stimulus. Again, there are reflection parameters on each port, and transmission parameters in each direction.

In an ideal balanced device that is perfectly symmetrical, there will be no conversion from common mode to differential mode. In that case, all of these terms will be equal to zero. As the device becomes asymmetrical, these terms become larger. Therefore, the mode conversion terms provide a measure of device symmetry.

Why is mode conversion important?

All of the performance benefits of differential circuits assume that the device is symmetrical. The benefits become diminished as the device becomes more asymmetrical.

Where differential to common mode conversion is related to the generation of EMI in a balanced device, the common to differential terms are related to the susceptibility of a device to EMI. Common-mode noise, for example, can become converted to differential mode and degrade the signal-to-noise ratio of the system.



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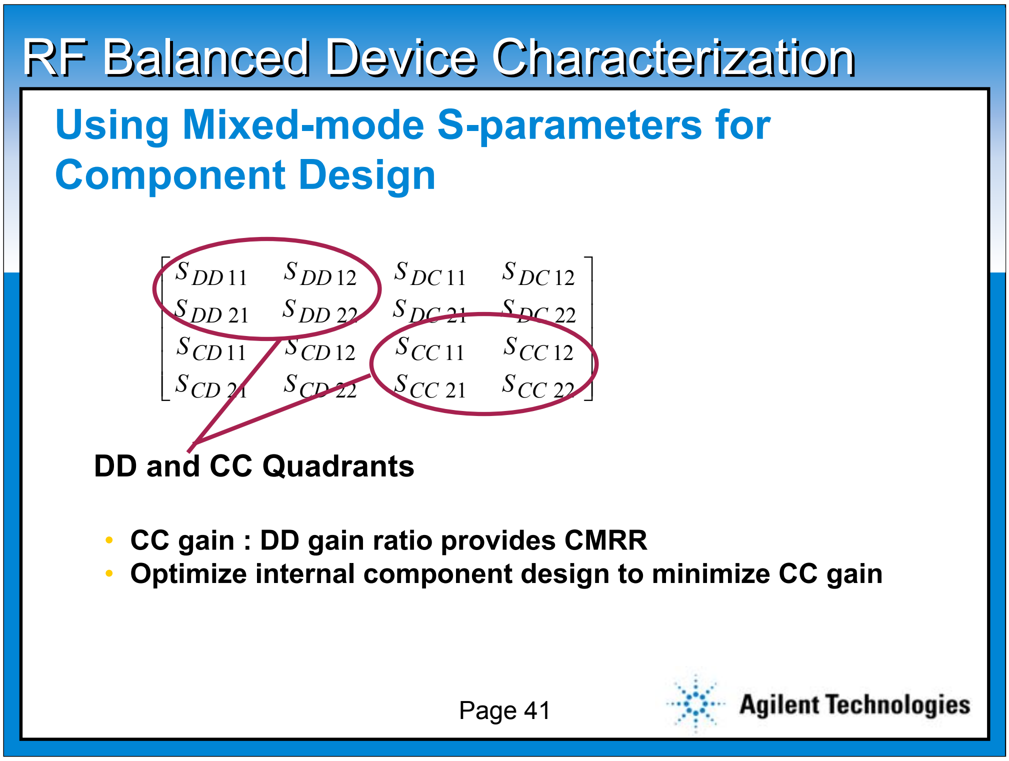

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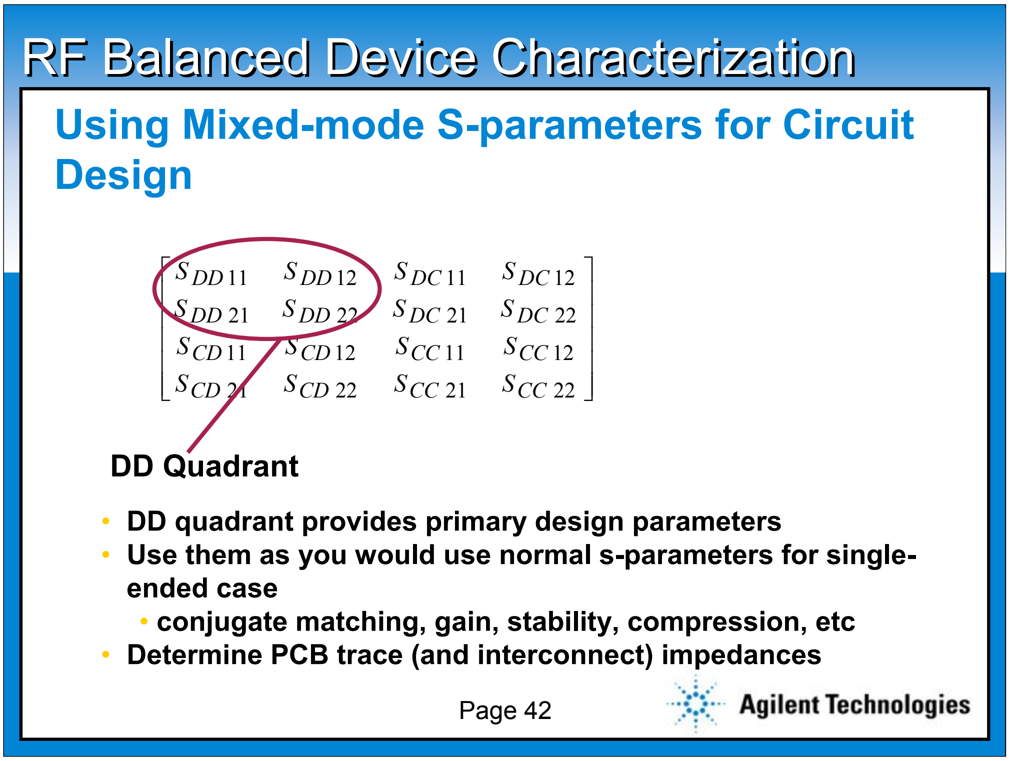

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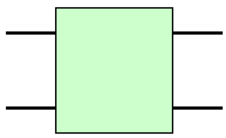
RF Balanced Device Characterization

DD Quadrant Design Example: Mixed-mode

What are the simultaneous conjugate input and output matching impedances of the following circuit?



Differential 2-port

Reduce performance of differential circuit to a single mode of operation using mixed-mode s-parameters, and follow same procedure as single-ended 2-port.

$$\Gamma_I = \frac{C_1^*}{|C_1|} \cdot \left[\frac{B_1}{2 \cdot |C_1|} - \sqrt{\frac{B_1^2}{|2 \cdot C_1|^2} - 1} \right]$$

$$\Gamma_O = \frac{C_2^*}{|C_2|} \cdot \left[\frac{B_2}{2 \cdot |C_2|} - \sqrt{\frac{B_2^2}{|2 \cdot C_2|^2} - 1} \right]$$

where:

$$B_1 = 1 - |S_{DD22}|^2 + |S_{DD11}|^2 - |D|^2$$

$$B_2 = 1 - |S_{DD11}|^2 + |S_{DD22}|^2 - |D|^2$$

$$C_1 = S_{DD11} - D \cdot S_{DD22}^*$$

$$C_2 = S_{DD22} - D \cdot S_{DD11}^*$$

$$D = S_{DD11} \cdot S_{DD22} - S_{DD12} \cdot S_{DD21}$$

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This a place where many designers get stumped today because they look at this device as a four-port and know that the concept of simultaneous conjugate match does not exist for a device with more than two ports.

Earlier we showed how the mixed-mode s-parameters are defined mathematically, and how similar they are to single-ended s-parameters. A very powerful property of the mixed-mode s-parameters is that if a balanced device is isolated to a specific mode, the resulting two port parameters can be used exactly the way single-ended two-port s-parameters are used.

Even though our device has four *terminals*, it has only two *ports*, and we have defined it to be operating in a differential mode.

Therefore, if we isolate its operation to a differential mode, we know its performance from the upper-left quadrant of the mixed-mode s-matrix. This 2-by-2 sub-matrix can, therefore, be used the same way a 2-by-2 s-matrix is used for single-ended devices. The formulas are exactly the same, we simply substitute parameters.

RF Balanced Device Characterization

Simultaneous Conjugate Match: Single-ended vs. Differential

Single-Ended 2-port

$$\Gamma_I = \frac{C_1^*}{|C_1|}\cdot\left[\frac{B_1}{2\cdot|C_1|} - \sqrt{\frac{B_1^2}{|2\cdot C_1|^2} - 1}\right]$$

$$\Gamma_O = \frac{C_2^*}{|C_2|}\cdot\left[\frac{B_2}{2\cdot|C_2|} - \sqrt{\frac{B_2^2}{|2\cdot C_2|^2} - 1}\right]$$

where:

$$B_1 = 1 - |S_{22}|^2 + |S_{11}|^2 - |D|^2$$

$$B_2 = 1 - |S_{11}|^2 + |S_{22}|^2 - |D|^2$$

$$C_1 = S_{11} - D\cdot S_{22}^*$$

$$C_2 = S_{22} - D\cdot S_{11}^*$$

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Differential 2-port

$$\Gamma_I = \frac{C_1^*}{|C_1|}\cdot\left[\frac{B_1}{2\cdot|C_1|} - \sqrt{\frac{B_1^2}{|2\cdot C_1|^2} - 1}\right]$$

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where:

$$B_1 = 1 - |S_{DD22}|^2 + |S_{DD11}|^2 - |D|^2$$

$$B_2 = 1 - |S_{DD11}|^2 + |S_{DD22}|^2 - |D|^2$$

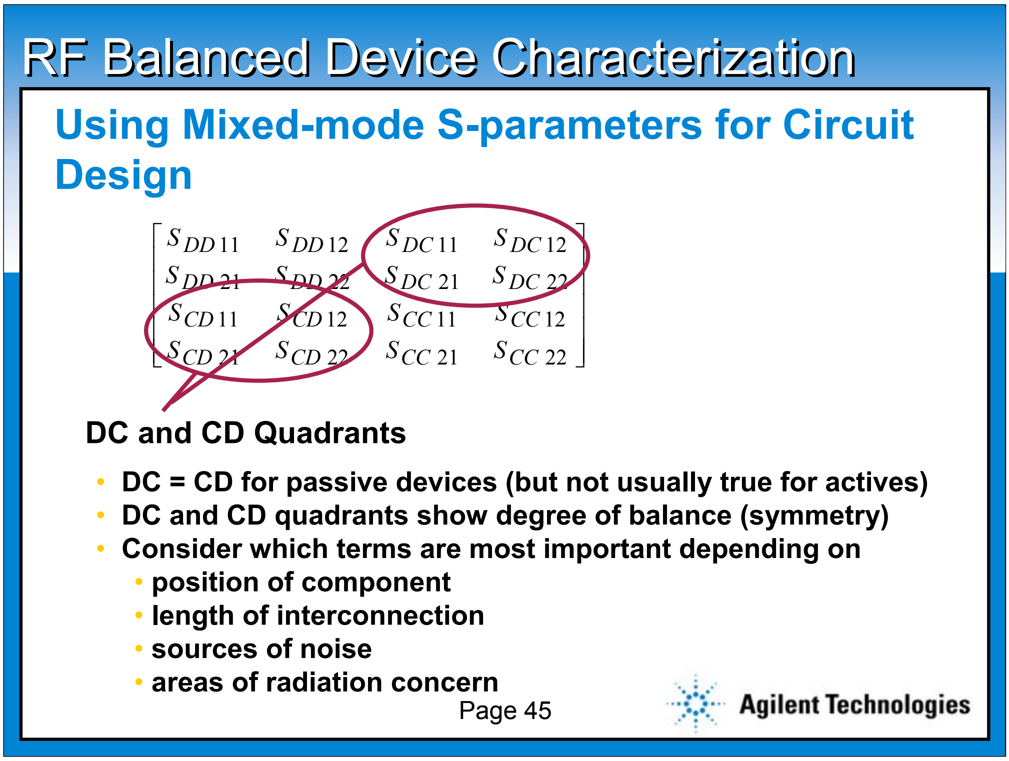
$$C_1 = S_{DD11} - D\cdot S_{DD22}^*$$

$$C_2 = S_{DD22} - D\cdot S_{DD11}^*$$

$$D = S_{DD11}\cdot S_{DD22} - S_{DD12}\cdot S_{DD21}$$

Comparing these calculations one more time shows the similarities. They are identical except for a parameter substitution.

Using this technique, designing a differential device becomes as straightforward as designing a single-ended device.



Finally, the parameters in the upper right corner describe the differential response of a device to a common-mode stimulus. Again, there are reflection parameters on each port, and transmission parameters in each direction.

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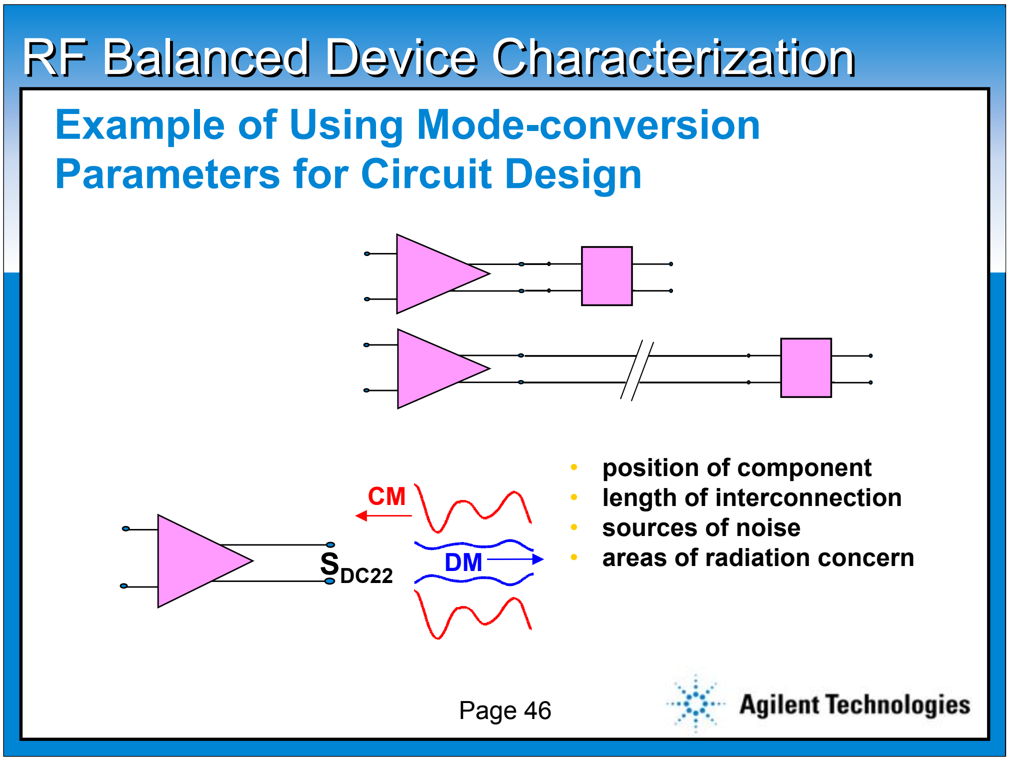
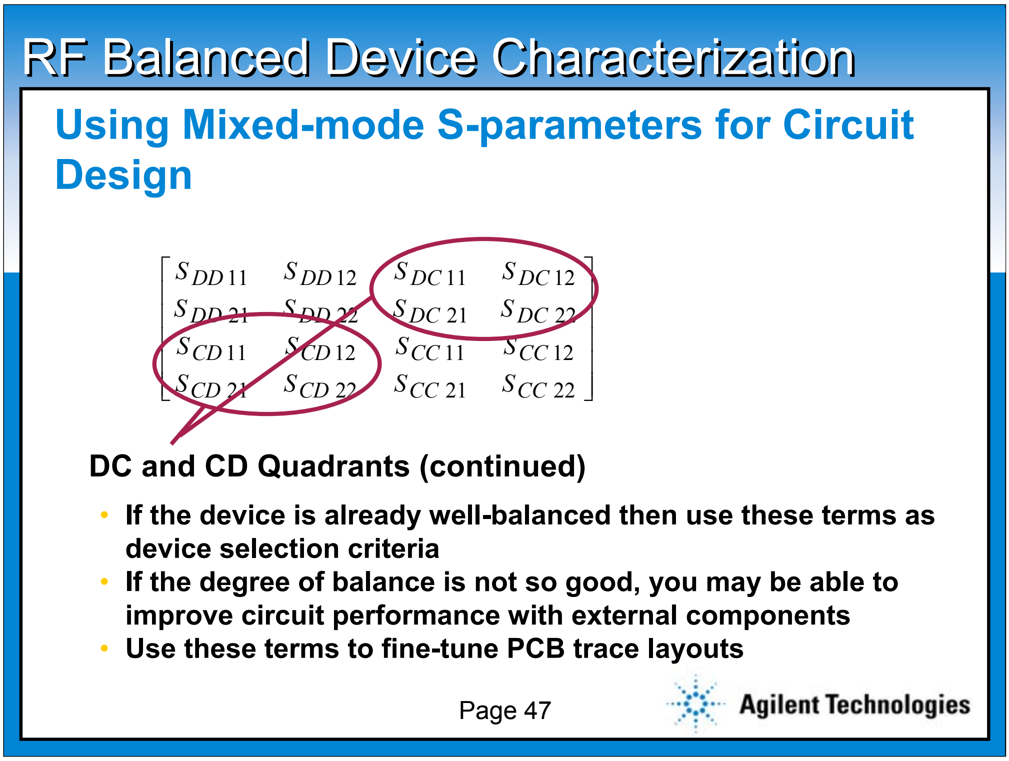


The previous slide showed the operation of an ideal balanced device. But designing high performance balanced components/devices and circuits is difficult and all devices will have some non-ideal behavior.

One of the key issues is the degree of balance of the device and how our DUT may affect the whole circuits degree of balance. As the degree of balance becomes worse, the device will perform what is called "mode conversion". If a device converts some of its incoming differential signal to common mode on its output, then the system (whole circuit) will generate EMI radiation. If a device converts some of its incoming common mode signal (typically noise) to differential on its output, that reduces the systems noise immunity.



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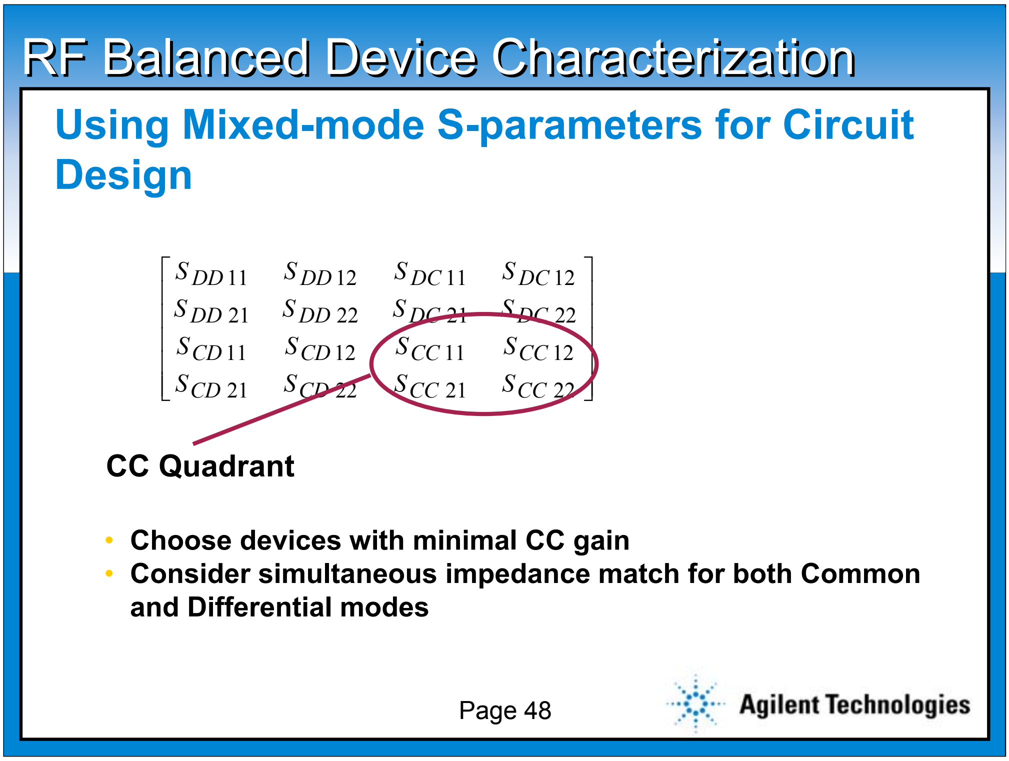

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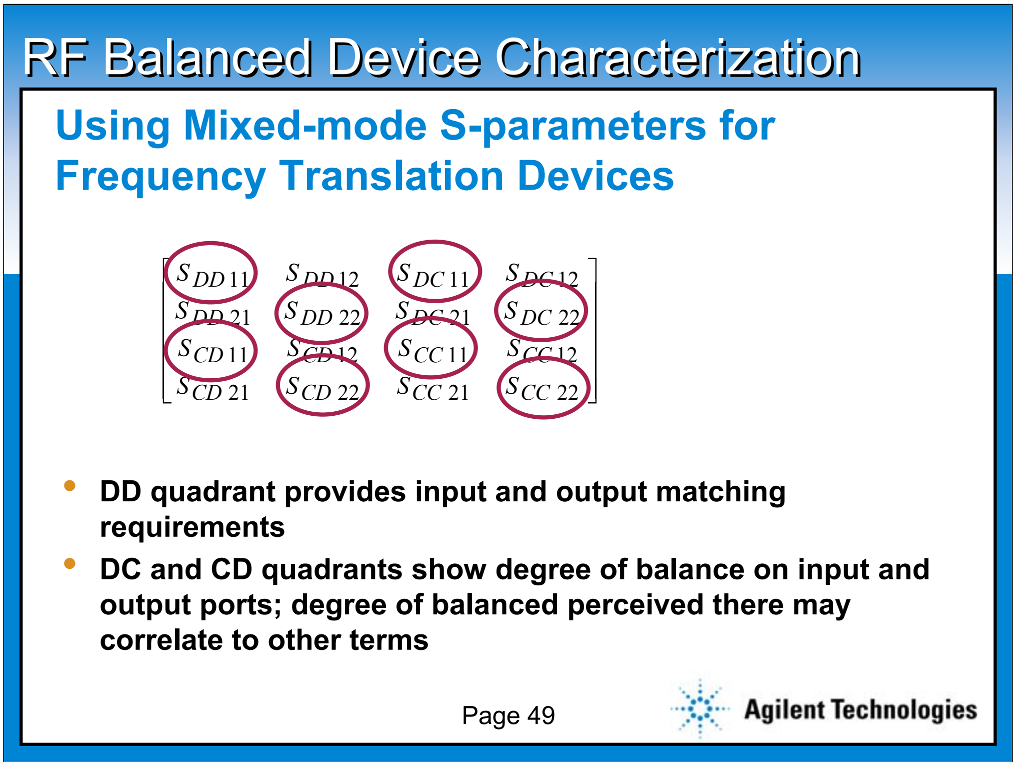
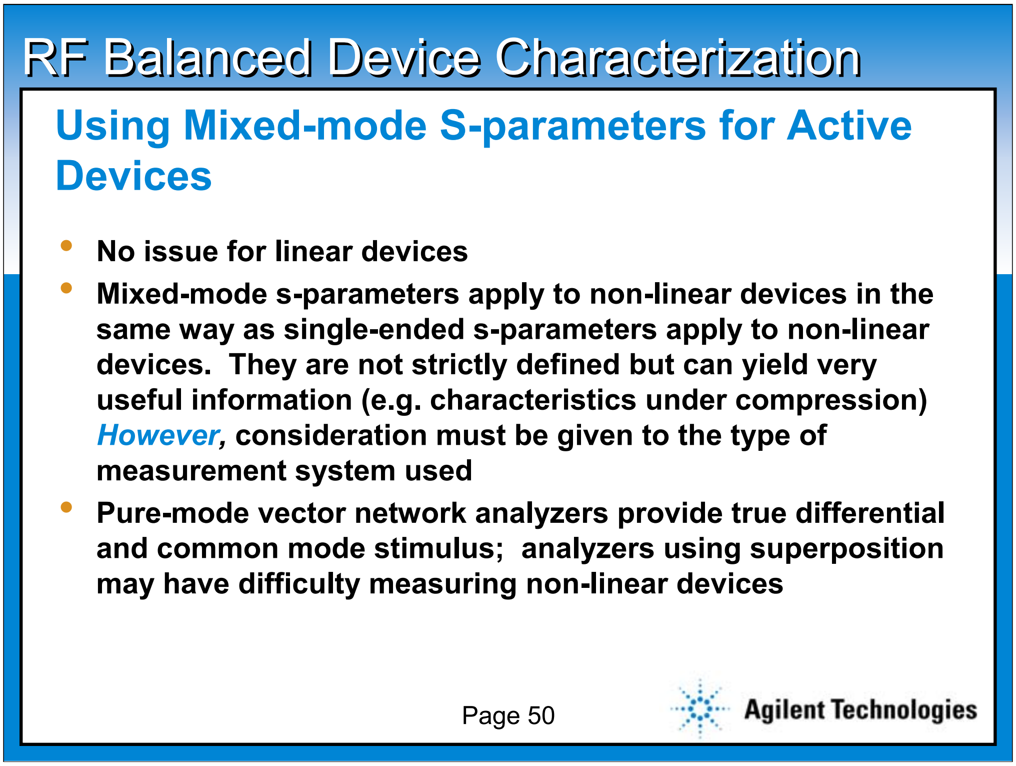


A higher level of integration is often the path to better performance, smaller size devices and lower cost. Balanced devices are an enabling technology for RFICs.

Improved simulation and measurement tools for balanced devices have been created in response to the demand from designers--principally handset RFIC designers. While there is still room for improvement in these tools, you will see today that it is possible to fully and accurately characterize the linear performance of a balanced device.



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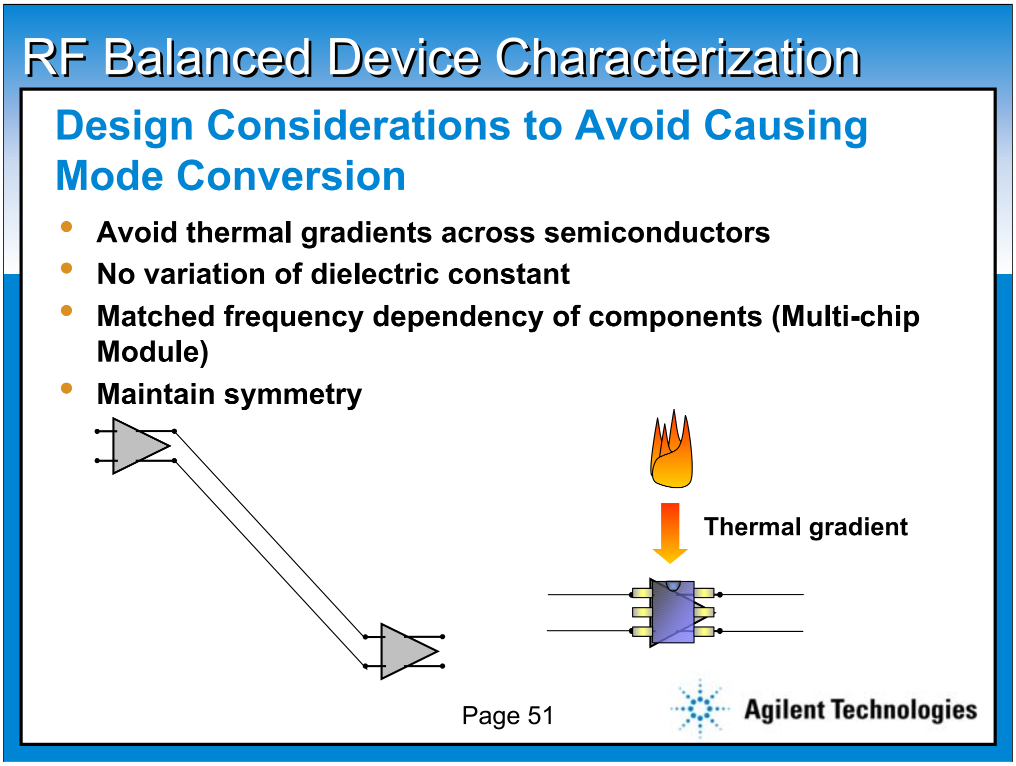


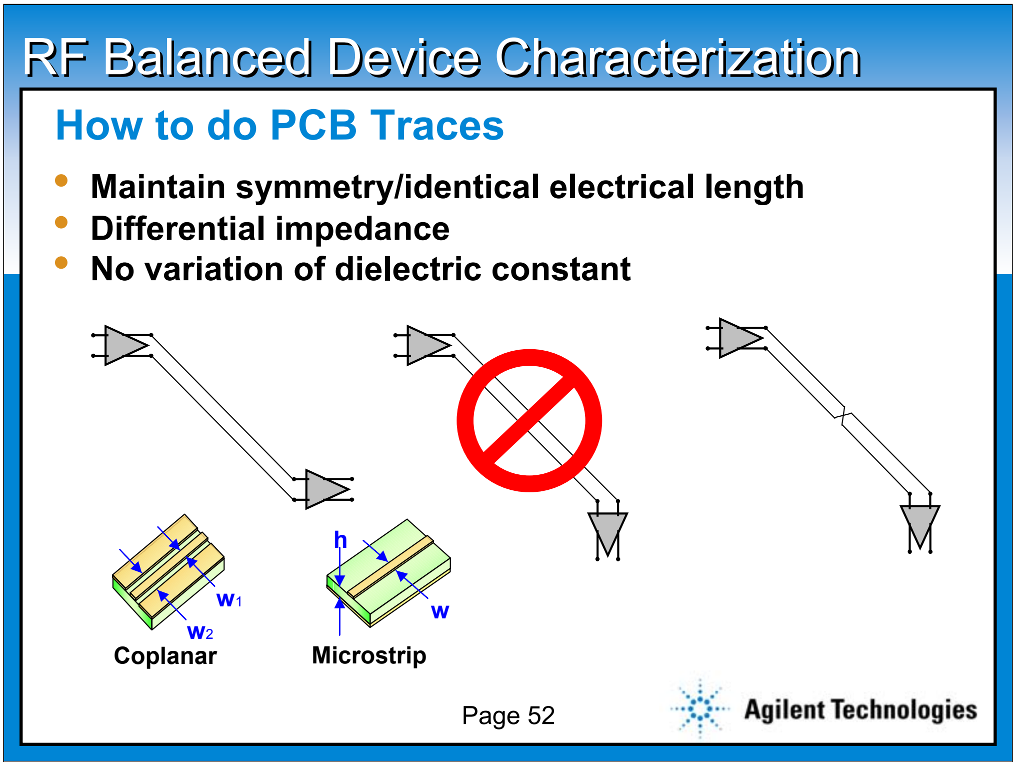
•Now a common mode signal is applied to the input. It is illustrated with a noise-like signal because common mode signals virtually always consist of EMI (conducted or radiated) from some external source. (Note that thermal noise is not a common-mode signal.) Usually, the output signal is a greatly attenuated version of the input signal. It may be inverted by 180 degrees, but the important attributes are having the same amplitude and waveshape on both terminals of the port with 0 degrees separation.

•In this case the common mode voltage equals 0.01 V + 0.01 V divided by 2 or 0.01 V peak-to-peak. Note the common mode current equals the difference in the currents flowing in the terminal of the port.

•The difference mode output signal is obviously 0 volts.

•Looking back on the last side and incorporating this example, it is obvious that the signal is getting better! Common mode signals don’t seem like much of a problem if they get smaller and smaller with more stages of amplification. Unfortunately, there are two major issues with which designers must contend, 1) large common mode signals on the input of a device can eat up the headroom and cause non-linear operation, and 2) mode conversion.

•Lets take a look at mode conversion.



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RF Balanced Device Characterization

Using Mixed-mode S-parameters in an Electronic Design Automation Software Environment

- **Mixed-mode matrix provides insight into component or circuit behavior; enables device selection**
- **Single-ended matrix data is entered into EDA software**

$$\begin{bmatrix} S_{DD11} & S_{DD12} & S_{DC11} & S_{DC12} \\ S_{DD21} & S_{DD22} & S_{DC21} & S_{DC22} \\ S_{CD11} & S_{CD12} & S_{CC11} & S_{CC12} \\ S_{CD21} & S_{CD22} & S_{CC21} & S_{CC22} \end{bmatrix} \quad \begin{bmatrix} S11 & S12 & S13 & S14 \\ S21 & S22 & S23 & S24 \\ S31 & S32 & S33 & S34 \\ S41 & S42 & S43 & S44 \end{bmatrix}$$

Agilent Technologies

Again we can take a ratio of all of the possible combinations of response over stimulus for the differential and common-mode normalized power waves to calculate the mixed-mode s-parameters.

A mixed-mode s-matrix can be organized in a similar way to the single-ended s-matrix, where each column represents a different stimulus condition, and each row represents a different response condition.

Unlike the single-ended example, though, in the mixed-mode s-matrix we are not only considering the port, we are also considering the mode of the signal at each port.

The naming convention for the mixed-mode s-parameters must include mode information as well as port information. Therefore, the first two subscripts describe the mode of the response and stimulus, respectively, and the next two subscripts describe the ports of the response and stimulus.

The mixed-mode matrix fully describes the linear performance of a balanced two-port network. To understand the information contained in the mixed-mode s-matrix, it is helpful to examine each of its four modes of operation independently by dividing this matrix into four quadrants.

RF Balanced Device Characterization

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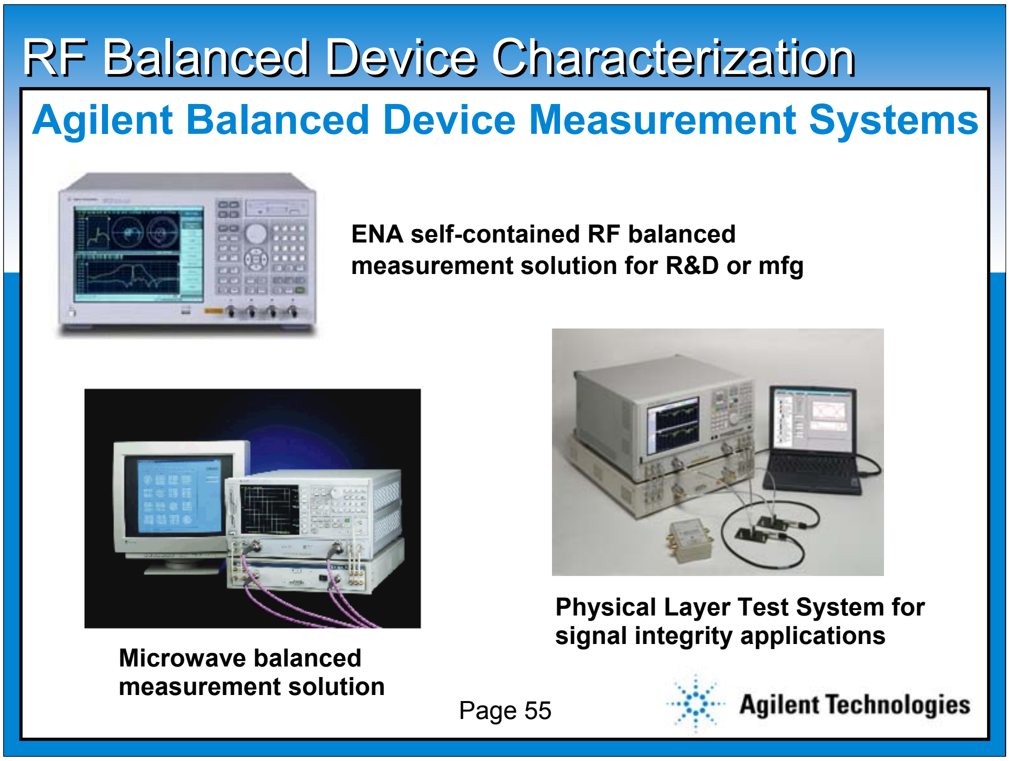

Agilent has also developed a new high speed series of multiport network analyzers. This is called the ENA series. This is an integrated multiport and balanced measurement solution (I.e. the instrument directly displays mixed-mode s-parameters). These network analyzers use a receiver per channel architecture resulting in very high speed high accuracy measurements.

RF Balanced Device Characterization

Conclusion

- **Mixed-mode s-parameters provide more information and higher accuracy than balun-based test setups**
- **Fixtures for balanced devices should comply with good RF fixture design standards and must consider other factors to ensure accurate device evaluation**
- **Balanced component and circuit design can be improved through the proper measurement, understanding, and application of mixed-mode s-parameters**
- **New solutions are available to meet many of the key test requirements for balanced RF, Microwave, and high-speed digital communications applications**

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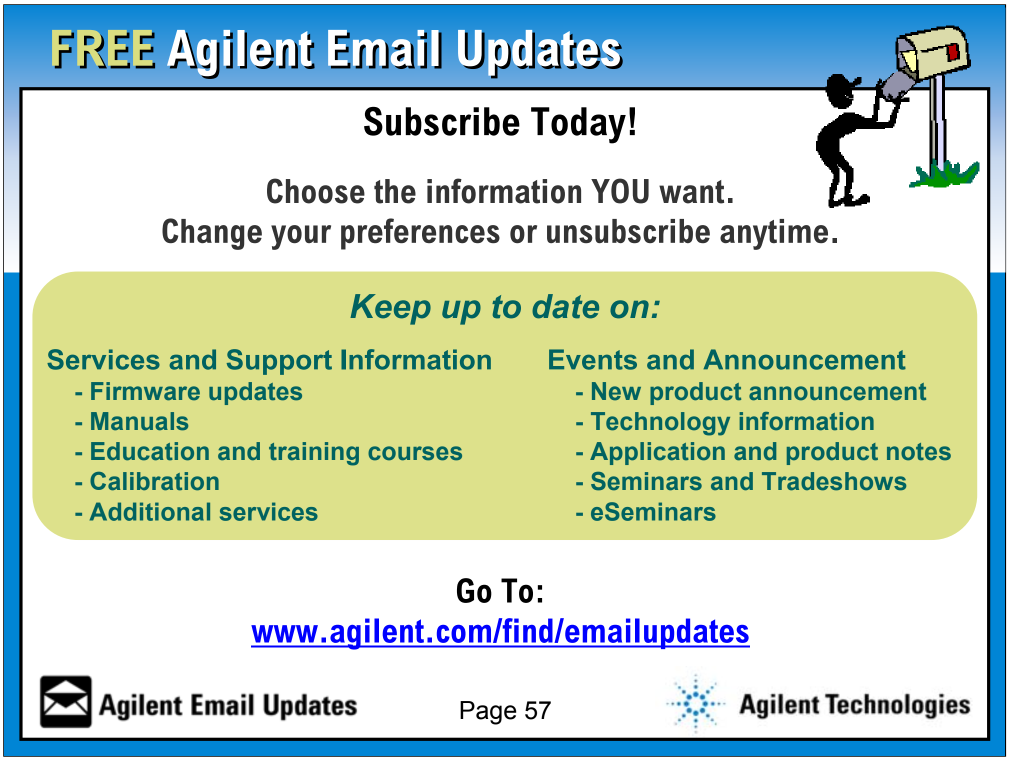
In conclusion, balanced devices are being increasingly used because of the many performance benefits they offer. The representation described here shows how the performance of balanced devices can be represented.

This technique provides much better accuracy than other commonly used alternate techniques, and does to require a new infrastructure of balanced calibration standards or balanced interconnect components.

The mixed-mode s-parameters comprehensively describe the performance of a DUT as a balanced device, and are not misleading like examining the single-ended s-parameters of a balanced device can be.

Measuring each operating mode of a balanced device provides very good insight into the impact that that device will have on the performance of the system.

Agilent Webcast Template 2.0 Instructions



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