Balanced Cable Measurement using the 4-port ENA - FAQs

How does the ENA measure balanced cables?

The ENA's fixture simulator function offers a new approach to measuring balanced devices without using actual balun transformers, which is called the mixed–mode S-parameter measurement method or the modal decomposition method.

The ENA measures full 4-port single-ended S-parameters by considering a balanced DUT as a 4-port device. The ENA stimulates the DUT's 1, 2, 3 and 4 ports with a single-ended test signal. Applying the single-ended signal to each port is mathematically equivalent to applying superposed differential and common mode signals to the paired ports as shown in Figure 1.

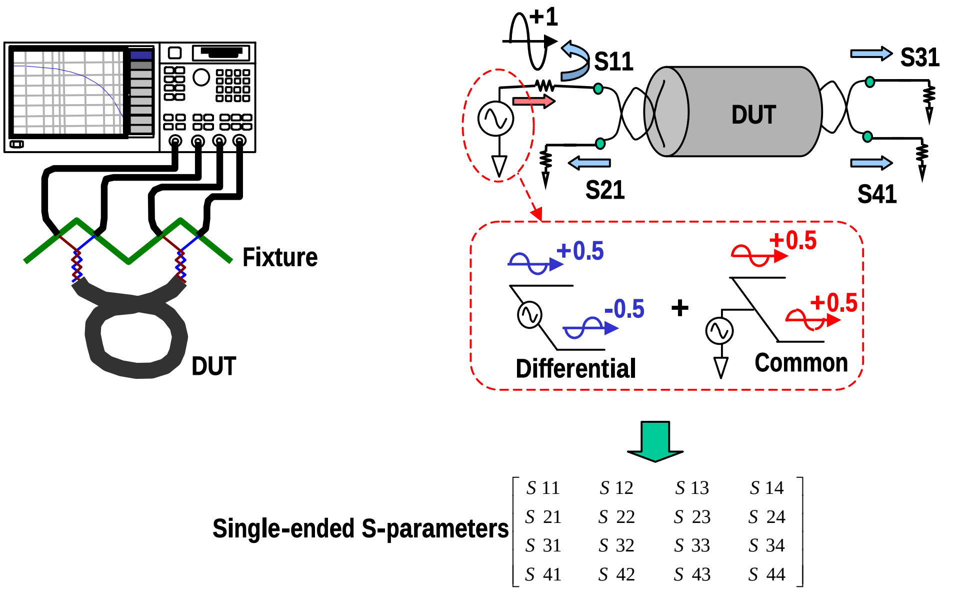

Figure 1. Measure single-ended 4 x 4 S-parameters.

Then the ENA mathematically decomposes single-ended measurement data into differential and common mode elements by simulating the operation of ideal hybrid baluns. This simulation provides a mixed mode S-parameter matrix, which shows the characteristics of the balanced DUT as shown in Figure 2.

(For more detailed information on the mixed-mode S-parameters, refer to the ENA product note E5070/71-1 "Introduction to the Fixture Simulator Function of the ENA", PN 5988-4923EN.)

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The mixed-mode S-parameter method has the following advantages over traditional balanced cable measurement methods using physical balun transformers.

- Mathematical baluns provide ideal unbalanced-to-balanced conversion over wide frequency ranges.
- You can measure both differential and common mode S-parameters very easily.
- The measurement system can be accurately calibrated with NIST traceable coaxial calibration kits.

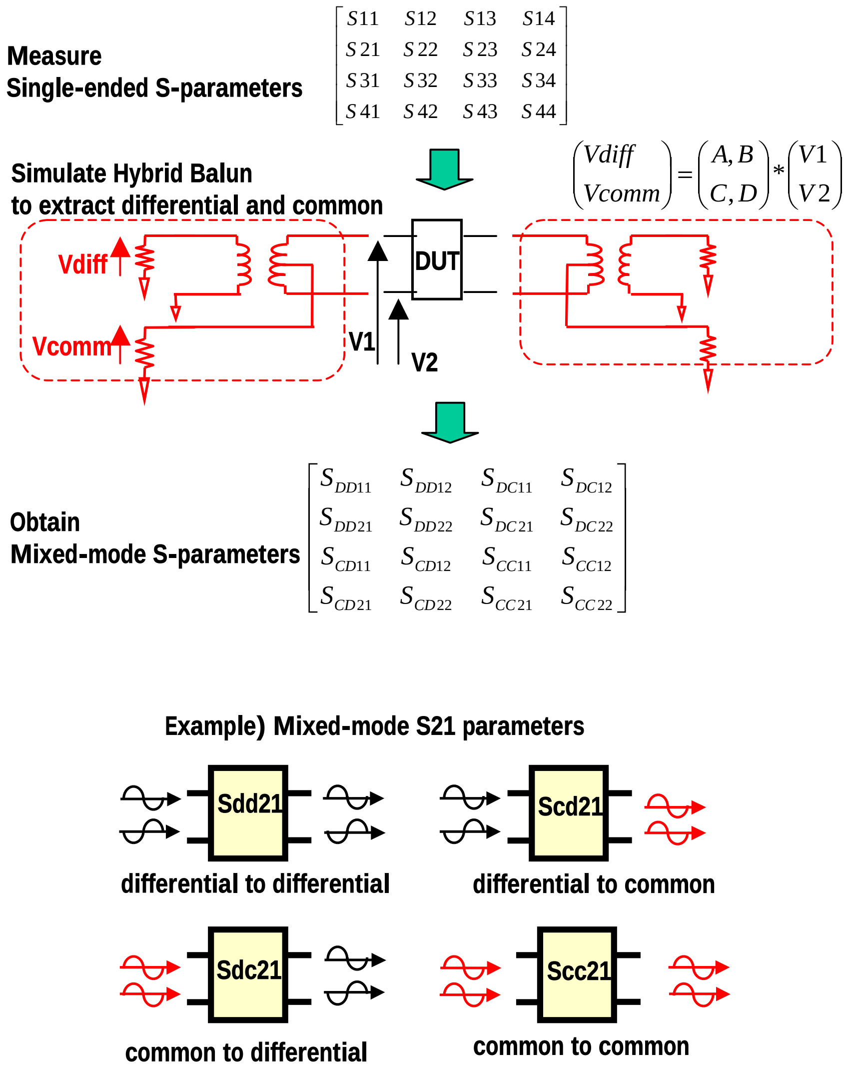
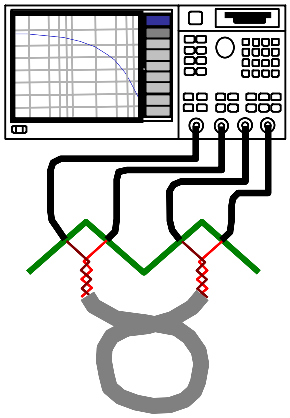


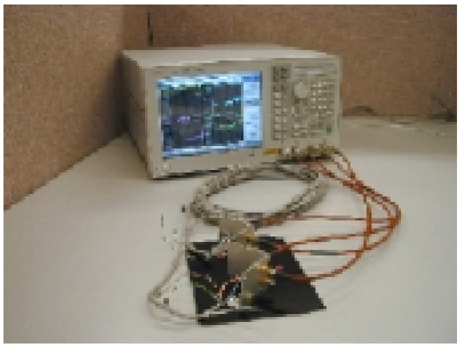
Figure 2.Converting single-ended S-parameters to mixed-mode S-parameters

What parameters can be measured with the ENA?

The following parameters can be measured directly with the ENA by connecting both ends of the measured pairs to the test ports.

- Insertion loss: Sdd21
- Return loss: Sdd11
- Input impedance Zin: Turn on ZREF Z Conversion for Sdd11.
- LCL (Longitudinal Conversion Loss): Sdc11
- Delay: Sdd21 in Delay format
- Time-domain analysis: Turn on Time-domain Conversion for Sdd21.





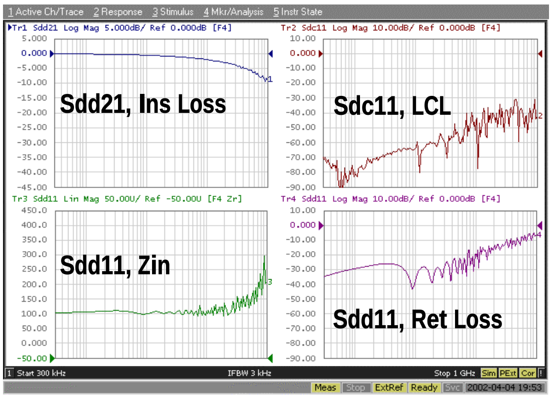


Figure 3. Measurement example of ins.loss, ret.loss, Zin, and LCL (LAN cable)

The following parameters can be measured by doing some calculations while making test cable connections and removals.

- Characteristic impedance Zc
- Crosstalk (NEXT, FEXT) and power sum of multipair cables

How to measure characteristic impedance Zc

The characteristic impedance Zc can be calculated from Sdd11, Sdd21, Sdd12, and Sdd22 measurement results by using the following equation. Z0 is the analyzer's system impedance in differential mode.
Figure 3 shows a Zc measurement example of a LAN cable using the ENA and the VBA sample program for Zc calculation. The program calculates Zc and plots it on the ENA's screen.
(You can download this program from the ENA VBA Library.)

$$Zc = Z_0 \times \sqrt{\frac{\{(1+S_{dd11})(1+S_{dd22}) - S_{dd12}S_{dd21}\}\{(1+S_{dd11})(1-S_{dd22}) + S_{dd12}S_{dd21}\}}{\{(1-S_{dd11})(1-S_{dd22}) - S_{dd12}S_{dd21}\}\{(1-S_{dd11})(1+S_{dd22}) + S_{dd12}S_{dd21}\}}}$$

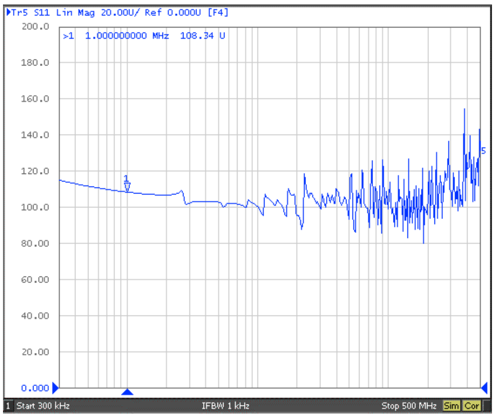


Figure 4. Measurement example of Zc (LAN cable)

DUT length for accurate Zc measurement

To accurately measure Zc with the mixed-mode method, all four differential S-parameters (Sdd11, Sdd21, Sdd12, and Sdd22) must be accurately measured. If the DUT length is too long, the DUT's loss may be greater than the analyzer's dynamic range, or the leakage signal due to mutual coupling at the DUT ends may be greater than the test signal flowing through the DUT. In such cases, the calculated Zc values may have errors.

On the other hand, if the DUT length is too short, the effects of the DUT's unbraided wire parts at both ends are not negligible, and they may cause Zc measurement errors.

Roughly speaking, appropriate DUT lengths are several tens or several hundreds of meters. It is not recommended to measure Zc of several thousands of meters or several 10-centimeter DUTs with the mixed-mode method.

Correlation of Zc measurement with open / short method

The open / short method is one of the conventional Zc measurement methods using physical baluns. The Zc calculation of the mixed-mode method is theoretically equivalent to the open / short method. Therefore, both methods should give very similar Zc measurement results.

However, you may sometimes see different Zc measurement results between these two methods. A typical symptom is:

"The mixed-mode method gives an increasing Zc trace at high frequencies, while the open / short method gives a flat Zc trace."

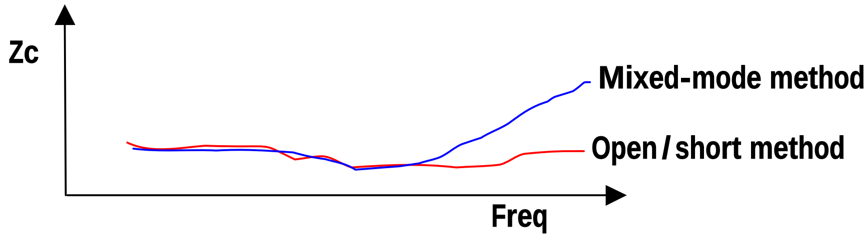


Figure 5. Typical Zc measurement problem

If you have such a problem, check the following points:

- In the open / short method using baluns, if you are not properly setting the inductance value of your load calibration device (e.g. leaded 50-ohm resistor) to the network analyzer's calibration kit definition menu, it may incorrectly flatten the Zc trace at high frequencies. We recommend that you check the inductance of your load device by measuring it with impedance analyzers / LCR meters, and set it to the network analyzer for more accurate calibration.

- In the mixed-mode method, it is necessary to properly extend the calibration plane with port extension (or fixture de-embedding) as shown in Figure 6. Otherwise the Zc trace may incorrectly increase at high frequencies.

- In each method, the distance and length of unbraided wires must be the same as those of the other method, as shown in Figure 6.

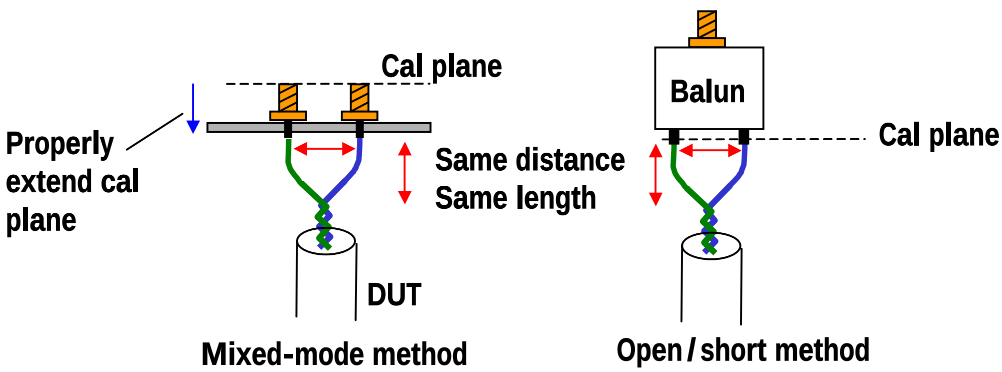
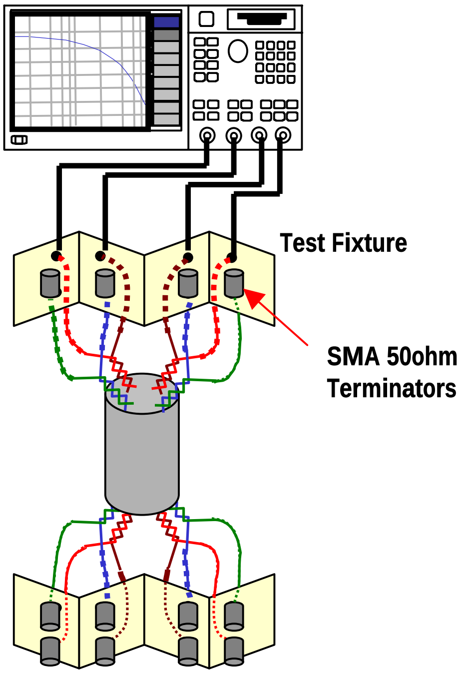


Figure 6. Tips for correlating Zc measurement data

How to measure crosstalk

The crosstalk of multi-pair cables (NEXT: Near End Crosstalk, FEXT: Far End Crosstalk) can be measured by terminating the DUT's pairs that are not connected to the analyzer. The following figure shows a configuration for efficiently measuring the NEXT by using two fixtures and 50-ohm coaxial terminators. You can measure the NEXT of all pairs by changing the connections of the test cables and the coaxial terminators.



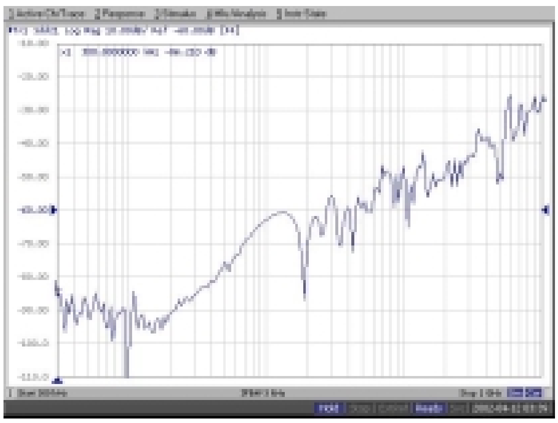


Figure 7. Measurement example of NEXT (LAN cable)

How to measure power sum

The power sum is calculated as the sum of the crosstalk values from all of the adjacent pairs. In Figure 8, the power sum NEXT is calculated as NEXT-1 + NEXT-2 + NEXT-3 + NEXT-4. Note that the power sum calculation must be done for linear magnitude values.
The ENA's built-in VBA programming capability is useful for making this calculation.

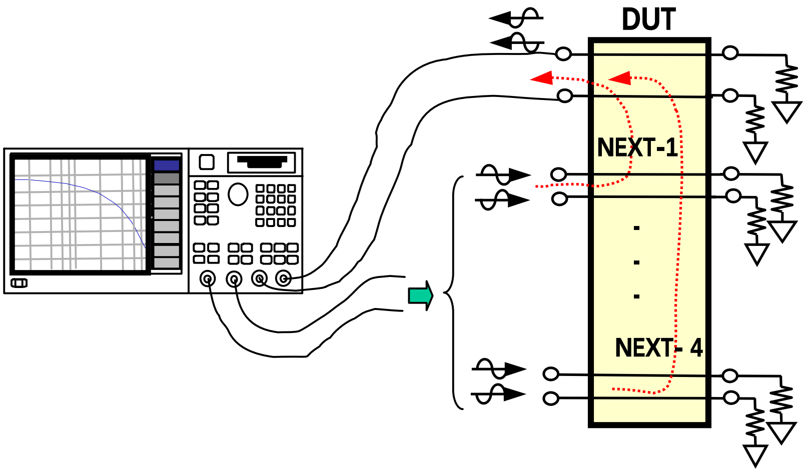


Figure 8. Power sum NEXT

Terminations for crosstalk measurement

All of the pairs that are not connected to the error-corrected analyzer test ports must be terminated with resisters equal to the DUT's characteristic impedance. If the DUT's differential characteristic impedance is 100 ohms, each wire must be terminated with 50 ohms. Inaccurate terminations may cause crosstalk measurement errors. In particular, if a pair is terminated with imbalanced impedances, as shown in Figure 9, it may significantly affect the crosstalk measurement accuracy.

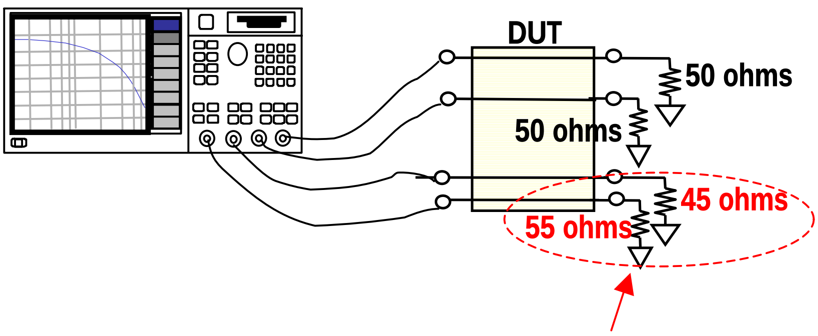


Figure 9. Unbalanced termination impedance causes crosstalk measurement errors

Tips for fixturing

Here are some hints for better fixturing.

1) Make the extension from the calibration plane to the DUT as short as possible, and maintain a 50-ohm transmission line to the DUT. This will allow you to use the port extension technique to compensate for measurement errors between the calibration plane and the DUT. The easiest way to do this is by directly soldering SMA connectors to the DUT.

2) Make a good ground on the fixture.

3) Make the unbraided part of the DUT as short as possible. If this part is long, the measurement result will be affected, especially if the DUT's length is not so long.

4) To minimize crosstalk measurement errors at the unbraided part of the DUT, make a shield plate between two pairs. This will prevent mutual coupling between two pairs.

5) Make a shield plate between both ends of the DUT. This will prevent coupling at the ends of the DUT.

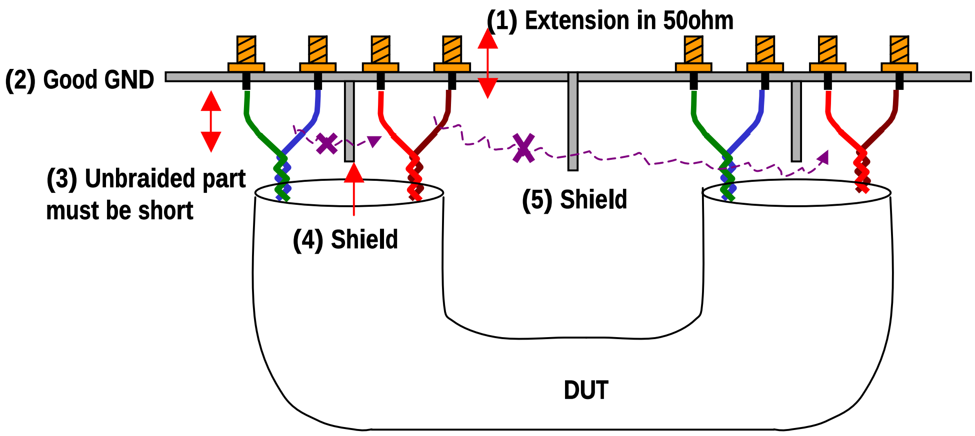


Figure 10. Tips for fixtuing

Test fixture example

Here is an example of a test fixture for balanced cables that does not have connectors.

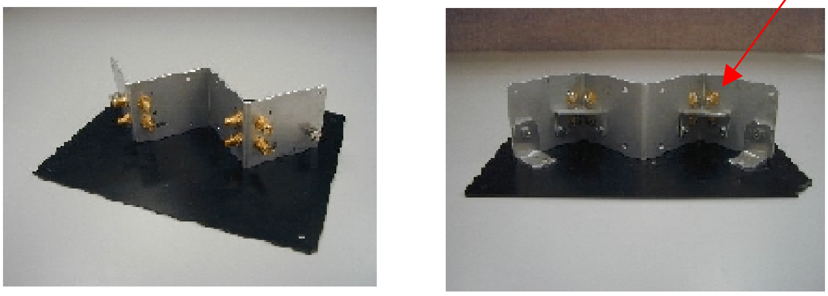


Figure 11. Test fixture example