White Paper

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Superposition vs. True-Balanced: What’s Required for Your Signal Integrity Application

By Jon Martens

Introduction

Signal integrity applications commonly utilize balanced/differential transmission lines that are typically characterized using vector network analyzers (VNAs). There are two approaches to performing these measurements and the selection of the best method depends on what you need to measure.

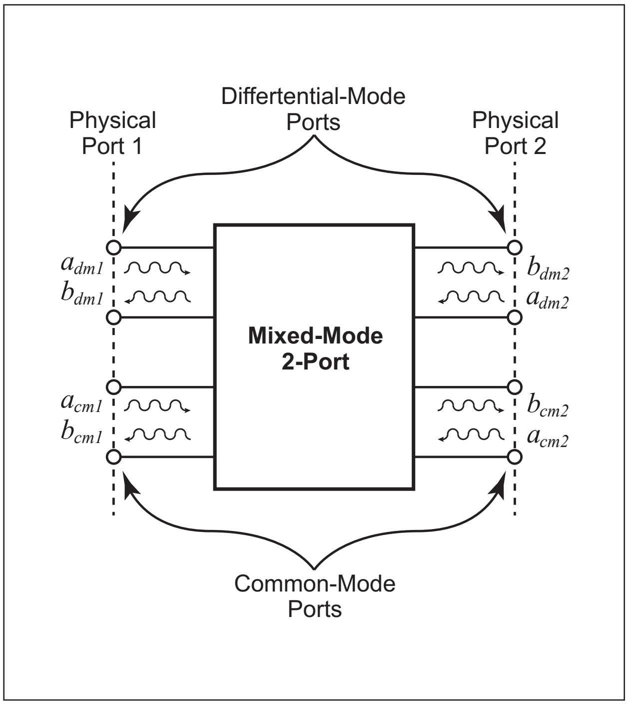
The superposition technique relies on the inherent linear nature of a transmission line, and mathematically derives the differential and common-mode transmission line characteristics through superposition while stimulating just one side of the balanced transmission line at a time. The true-balanced/differential technique, also known as True-Mode Stimulus, uses two sources to create actual differential and common-mode stimuli. This white paper offers guidance to signal integrity designers on the differences between these approaches and which one may best fit their need.

Measurement Theory

The most complete description for balanced devices are the mixed-mode S-parameters (Figure 1). Mixed-mode S-parameters are comprised of four blocks of four parameters: differential, common-to differential-mode, differential-to common-mode, and common-mode parameters. These 16 parameters are one way of providing a complete description of a 4-port device. The balanced transmission line does not need to have a ground plane or common terminal. When no ground is physically present, a “virtual” ground is assumed. Measurement Technique Overview

Measurement Technique Overview

While both the superposition and true-balanced techniques use VNAs, the difference between them lies with the configured options, calibration stability, and complexity of the instrument.



$$\begin{bmatrix} b_{d1} \\ b_{d2} \\ b_{c1} \\ b_{c2} \end{bmatrix} = \begin{bmatrix} \begin{bmatrix} S_{d1d1} & S_{d1d2} \\ S_{d2d1} & S_{d2d2} \end{bmatrix} & \begin{bmatrix} S_{d1c1} & S_{d1c2} \\ S_{d2c1} & S_{d2c2} \end{bmatrix} \\ \begin{bmatrix} S_{c1d1} & S_{c1d2} \\ S_{c2d1} & S_{c2d2} \end{bmatrix} & \begin{bmatrix} S_{c1c1} & S_{c1c2} \\ S_{c2c1} & S_{c2c2} \end{bmatrix} \end{bmatrix} \begin{bmatrix} a_{d1} \\ a_{d2} \\ a_{c1} \\ a_{c2} \end{bmatrix}$$

(a) Mixed-mode two-port conceptual diagram.

(b) Mixed-mode S-parameter matrix.

Figure 1. Mixed-mode parameters include important mode conversion parameters for determining both the differential and common-mode characteristics.

For the superposition technique, the mixed-mode parameters are mathematically derived from the standard 4-port S-parameters of the device. This is achieved by measurement of the 4-port S-parameters as a group of single-ended parameters and the use of superposition and relevant impedance transformations to calculate the end result (Figure 2). Superposition requires that the network is linear and time invariant. Due to this principle, the parameters resulting from the first port being stimulated can be combined with the result from the second port (of the differential/common-mode pair) being stimulated, resulting in the equivalent response from a true-balanced or a true common-mode stimulus signal. The execution advantage is that only a single source is required.

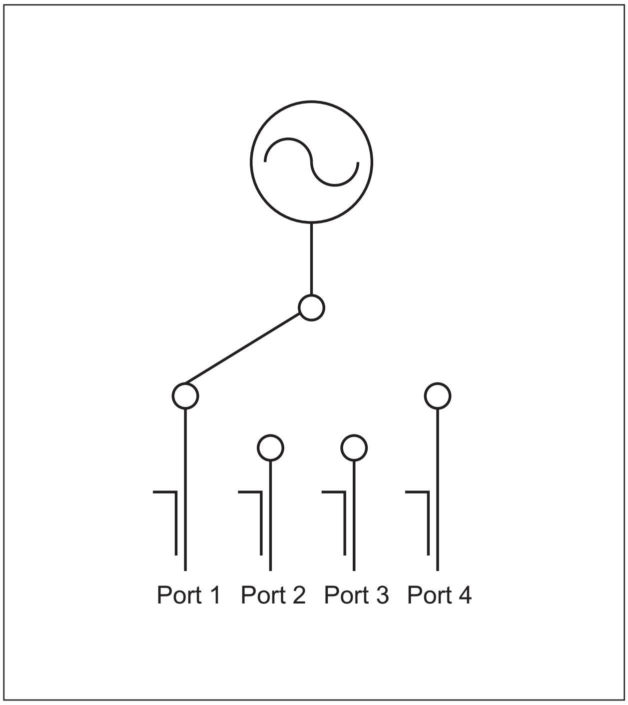


Figure 2. The superposition technique uses a standard single-source, two-port VNA with a switch matrix to measure single-ended S-parameters for deriving differential and mixed-mode parameters.

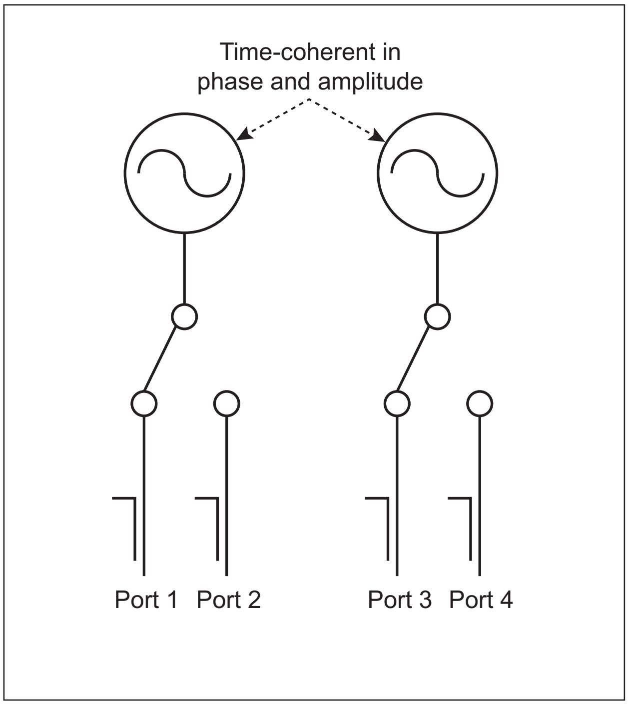


Figure 3. The true-balanced technique uses a dual-source VNA with the sources synchronized with a 180° phase difference to directly measure the common, differential, and mixed-mode parameters.

The true-balanced technique directly measures the differential and common-mode parameters. It requires the use of two sources that are phase coherent, and use active phase and amplitude control of each of the two input sources. An example is shown in Figure 3. In addition, the VNA may have special features, such as multipliers, amplifiers, and ALC circuitry for precisely controlling each source output. Controlling multiple sources with very precise magnitude and phase alignment also requires a more extensive calibration and can potentially limit the stability of the calibration over time. Further complicating this, the exact phase and amplitude relationship of the signals delivered to the DUT can be a strong function of the DUT reflection characteristics, so the phase and amplitudes must be adjusted to take this into account. Due to these issues, this technique is usually only employed when required by the DUT.

What Do You Need to Measure?

Most signal integrity measurements are of passive components, such as transmission lines, PCBs, cables, and connectors. For passive devices, the superposition technique is widely accepted to generate the required differential and common-mode responses from a balanced device. Even active devices, if kept in their linear region, can be accurately tested using the superposition technique. For active devices that are driven into compression or saturation, the true-balanced technique is required. Table 1 provides a list of components and applicable measurement techniques. Where both techniques are highlighted, they will give identical results.

Device to be measured	**Superposition Technique**	**True-Balanced Technique**
Passive Balanced / Differential DUT		
Transmission Lines	X	X
PCB	X	X
Lumped Components	X	X
Passive Filters	X	X
Unshielded and Shielded Twisted Pair, Quad Cables	X	X
Connectors / Interfaces	X	X
Linear Active Balanced / Differential DUT		
Linear Amplifiers, Differential Amplifiers	X	X
Linear Active Filters	X	X
Input / Output Match ADC / DAC	X	X
Non-Linear Active Balanced / Differential DUT		
Devices in Compression / Saturation		X
Log Amplifiers		X

Table 1. Superposition offers identical results in most signal integrity applications.

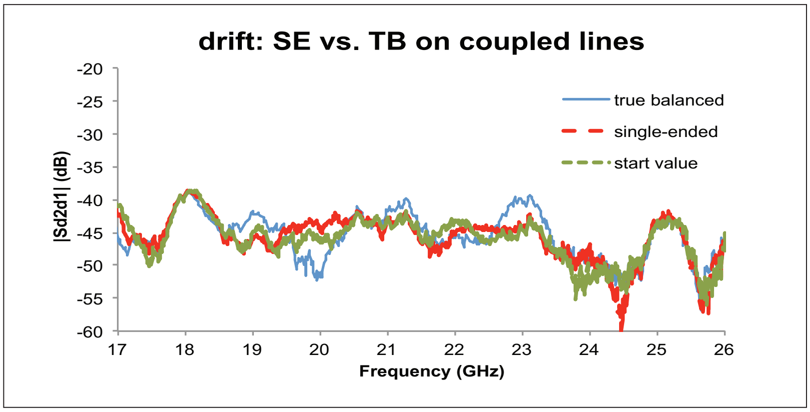
Understanding the Tradeoffs

Table 2 highlights the tradeoffs between these two measurement solutions. Most of the tradeoffs are due to the added complexity of the true-balanced measurement technique. The true-balanced technique requires a VNA with several additional options that add to the overall cost of the test solution. In addition, true-balanced measurements are dependent upon how short-and long-term phase stability impacts the ability to deliver the desired phase relationship at the input of the DUT.

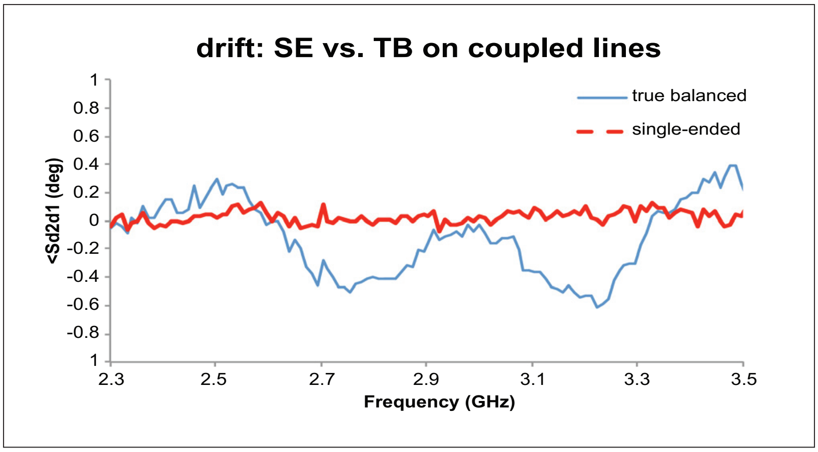
	Superposition	**True Balanced**
Type of VNA	Single-source VNA	Dual-source VNA
Method of Obtaining Differential and Mixed-Mode Parameters	Calculated	Measured directly
Type of DUTs	Passive and active linear	Passive, active linear and non-linear
Available Frequency Range	70 kHz to 110 GHz	70 MHz -110 GHz
Calibration Complexity	Typical 4-port	Typical 4-port plus calibration of dual sources
Average Calibration Time	T (Time depends on number of points, IF BW, skill of operator)	Approx. 2T
Calibration Stability Considerations	Normal measurement calibration intervals	Calibrate more frequently if VNA does not have adequate stability or calibration algorithms
Overall Solution Cost	5	55

Table 2. Comparison of measurement techniques.

Figure 4 highlights the fact that true-balance measurements are not required when measuring passive or active devices operat Conclusion



(a) Amplifier in Linear Region



(b) Amplifier in Non-Linear Region

Figure 4. In both 4a and 4b, the two traces represent measurements using superposition and true-balanced methods. 4a shows no difference between the two methods, whereas, in 4b, when measuring an amplifier in its non-linear region, the two methods produce different results. This latter situation is when true-balance mode should be used.

Conclusion

Determining which measurement technique is best for you is fairly straightforward. If you are measuring passive or active devices that stay in their linear range, then the superposition technique offers the simplest, most stable, and lowest cost solution. Assuming the VNA has adequate stability and calibration algorithms, the added cost is only worth it if you are testing active devices in their non-linear range.

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