

Differential Measurements with Copper Mountain Technologies VNAs



Measurement of Balanced Devices

Many electrical circuits are designed to be balanced, and engineers need to characterize the electrical properties, such as insertion loss and return loss, of these devices. However, unlike unbalanced devices, balanced circuits have at least 3 ports, as in the case of a balun, or more commonly 4 ports, as is standard for a simple differential transmission line. Additionally, these multiport devices have mixed mode S-parameters that characterize the transmission and reflection of single-ended, common-mode, and differential-mode signals.

Although it is possible to extract differential measurements from a 2-port VNA, the process does not lend itself to either large-scale testing or flexible development efforts. An engineer can take S-parameter measurements of multiple ports with a 2-port VNA, hook the DUT up to the VNA multiple times, extract and save S-parameter measurements, mathematically convert the data to differential S-parameters, and plot the data in an external program which will likely not provide the full functionality of Copper Mountain Technologies' VNA software to manipulate the data.

For instance, adding markers, switching individual traces between plots to study symmetries or other relations, quickly changing characteristics of the trace like IFBW, power, or number of points, or easily modulating the scale, reference level, or trace format can all be performed natively within the VNA software.



Figure 1 - Planar 808/1 4-port VNA

304/1 VNA and the 8 GHz Planar 804/1 VNA, and the process may be semi-automated due to the devices' high programmability.

For these reasons, many engineers prefer to perform differential measurements with 4-port instruments, such as Copper Mountain Technologies' 8 GHz Planar 808/1 VNA, which can display each differential parameter in a separate measurement window with ease. For information on how to perform differential measurements on the Planar 808/1 VNA, please visit www.coppermountaintech.com and download the operating manual for the Planar 808/1.

Again, differential measurements can be extracted from CMT's 2-port devices, such as the 3.2 GHz Planar

If you need any assistance on getting started or are interested in how this can be done, please feel free to contact our applications engineers via support@coppermountaintech.com. This app note gives a brief introduction to balanced and differential circuits and provides a demonstration of such measurements on a common-mode filter using split-ring resonators.

Background

In unbalanced circuits, signals are sent down a single line as a voltage with respect to ground. Some circuits, however, transmit electrical signals over two lines with a common ground, a technique using balanced lines. Balanced lines provide enhanced noise reduction by using two conductors with equal impedances along their lengths, to ground, and to other circuits, so external interference manifests as nearly identical voltage on each line. Since both lines pick up the same noise waveforms, interference on balanced lines can be considered a common (even) mode signal. Balanced lines typically feed to a differential amplifier, or subtractor, to enhance the differences between the two signals, effectively increasing resistance to electromagnetic interference.

Balanced signals can be carried with either single-ended or a differential signaling. In single-ended signaling, only one line carries information; the second line carries a reference voltage. In differential signaling, one line transmits a positive voltage signal while the other sends an identical, but negative waveform.

Since the information is carried only in the difference between the two waveforms, differential signaling is naturally compatible with balanced circuits, and they are commonly used together.

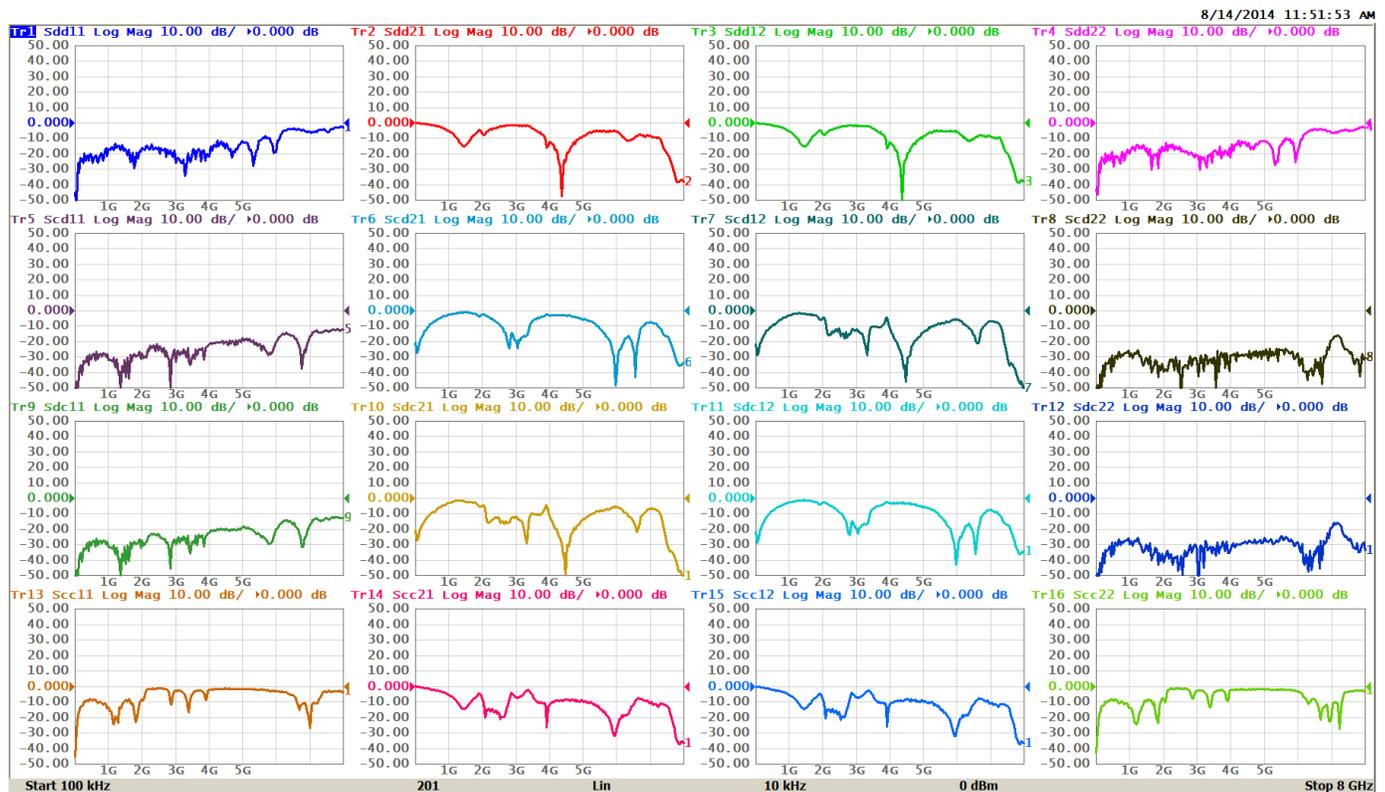


Figure 2 - 16 traces for differential measurements on a balanced common-mode filter. With a modern laptop or PC monitor, the individual traces are easy to observe, but the user can always zoom in on a particular frame of interest by double-clicking.

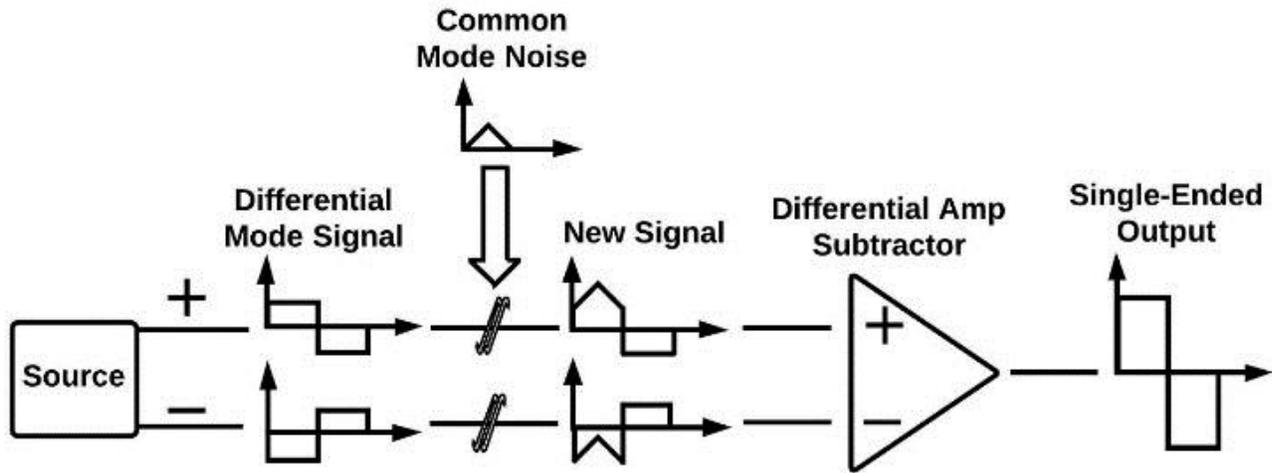


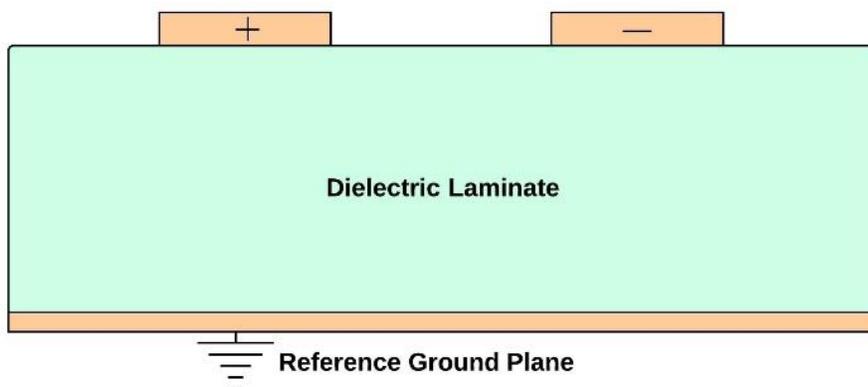
Figure 3 - When external electromagnetic interference induces noise in balanced circuitry, a subtractor is later able to remove induced noise from the differential signal.

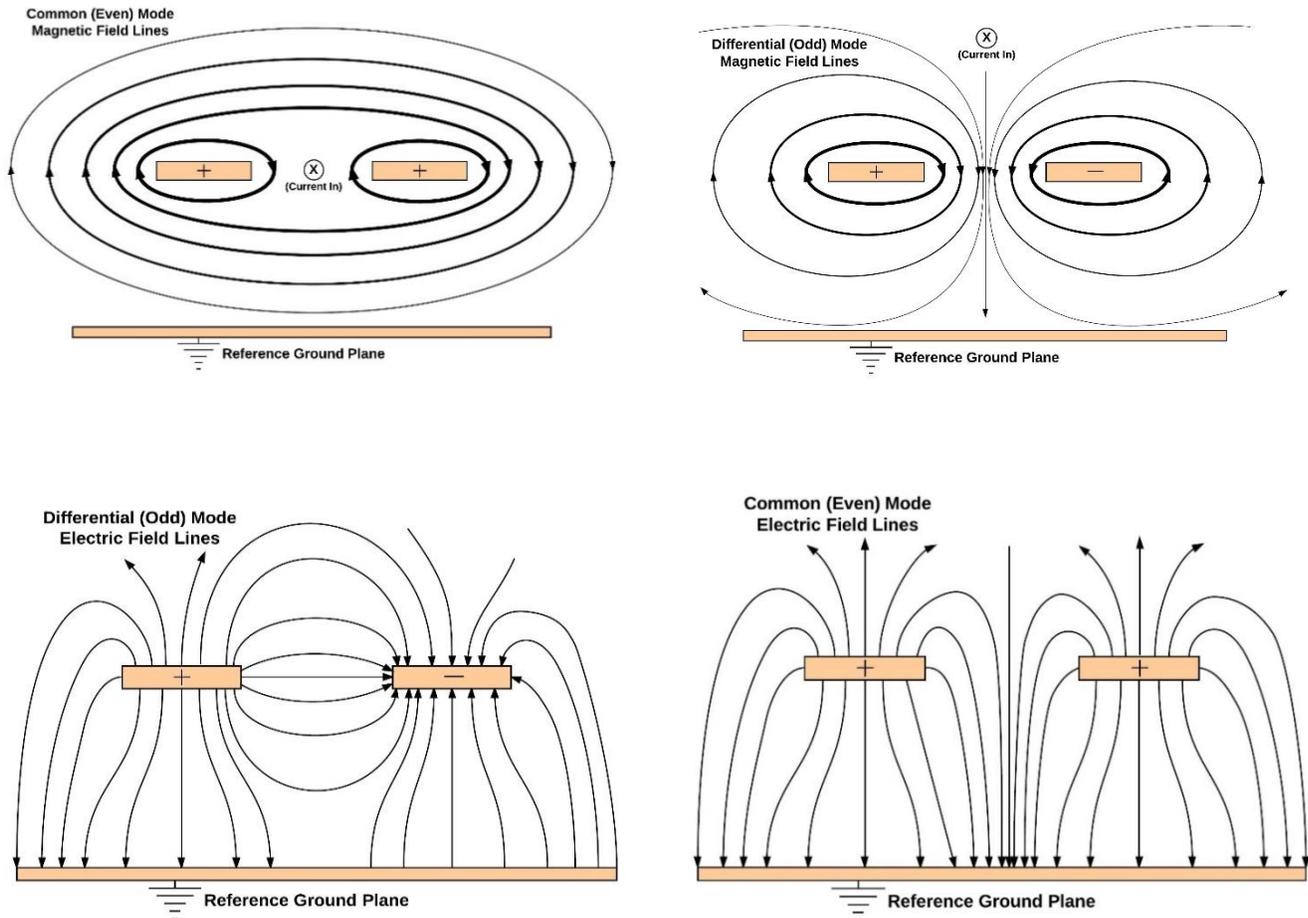
Theoretical Underpinnings

The diagrams that follow provide an idea of how the electric and magnetic fields interact on balanced differential circuitry.

First, consider the figure below including a dielectric laminate. Such a dielectric which will typically be present in most PCB applications. The subsequent figures replace the laminate with air so variations in permittivity do not need to be considered. These are only rough sketches meant to be used as a general reference.

**Typical Differential Circuit
On Printed Circuit Board (PCB)**





In common (even) mode, the voltage carried by both lines has the same sign; in differential (odd) mode, the voltages have opposite sign. When a signal is propagating along a circuit, it may contain both even and odd modes. To illustrate the magnetic fields, we can replace the positive voltages with positive charges headed into the board and negative voltages with negative charges headed into the board.

By the right-hand and left-hand rules, we can demonstrate that for even mode, the magnetic field lines will point in the same direction, leading to inductive coupling between the traces. In odd mode, however, the magnetic lines effectively reduce the net inductance. Similarly, the electric field lines in common mode weaken the net capacitance of the wires. However, in differential mode, the electric field lines will point from the positive voltage line to the negative one, creating a virtual ground between the traces and increasing the net capacitance.

Effectively, in even mode, the mutual inductance is maximized while in odd mode, the mutual capacitance is maximized. Since even and odd modes vary the characteristic capacitance and inductance present due to trace geometry and material properties, they result in different impedances inherent to differential transmission lines. Since the impedances are different from the characteristic, modified mixed-mode S-

parameter representation is required to understand the circuits' electrical responses. Additionally, impedance may be calculated as:

$$Z = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

Where Z is the impedance, R is the resistance, ω is the angular frequency, L is the inductance, C is the capacitance, and j is the imaginary number $\sqrt{-1}$. This equation thus specifies that common mode signals will have higher impedance while the differential mode signals will have lower impedance, both with respect to the characteristic impedance.

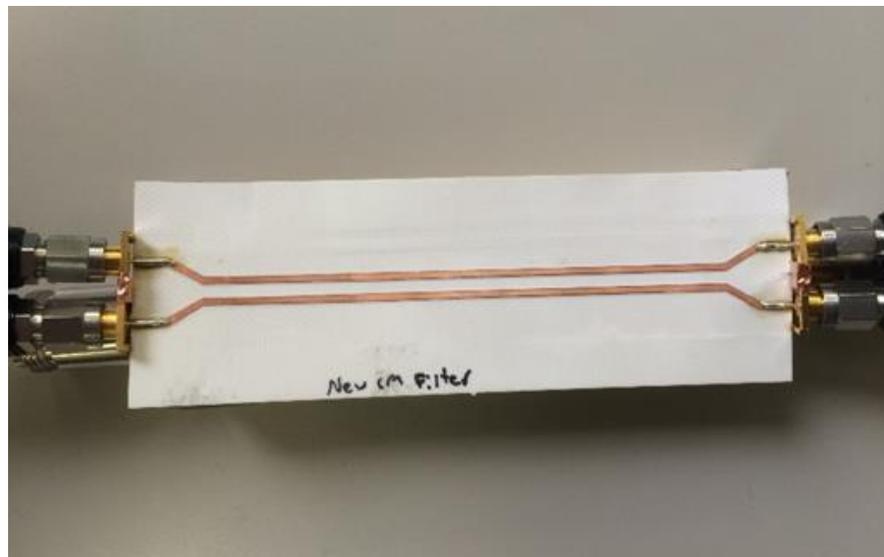


Figure 4 - Experimental common-mode Filter using split ring resonators designed by student Sang Goo under Dr. Ed Wheeler at Rose-Hulman Institute of Technology.

Illustrative Measurement Exercise

After performing 4-port calibration with Copper Mountain Technologies' 2-port, 8 GHz Automatic Calibration Module ACM8400T, only a few clicks are required to quickly set up the Planar 808/1 VNA to perform differential measurements of the experimental common-mode filter pictured above.

On the Analysis>Fixture Simulator menu, enable Fixture Simulation, choose Balanced-Balanced Topology, and click BalUn ON All Traces to view differential measurements. The Measurement softkey allows for selecting the differential parameter to be plotted on the active Trace.

The results of the differential measurements are shown on the following page. Symmetric parameters were plotted in the same window to save space, but it is possible to include up to 16 windows on Copper Mountain Technologies' VNAs.

Conclusion

As can be seen, measurement of differential circuits and devices is most readily accomplished with a 4-port VNA such as Planar 808/1. Once calibration of the instrument is accomplished, either using a conventional mechanical kit or the advantageous 4-port Automatic Calibration Module ACM8400T, determining the differential parameters of the device under test is a very straightforward process.

For more information, please contact us at support@coppermountaintech.com



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