BALANCED MEASUREMENT WITH A VNA

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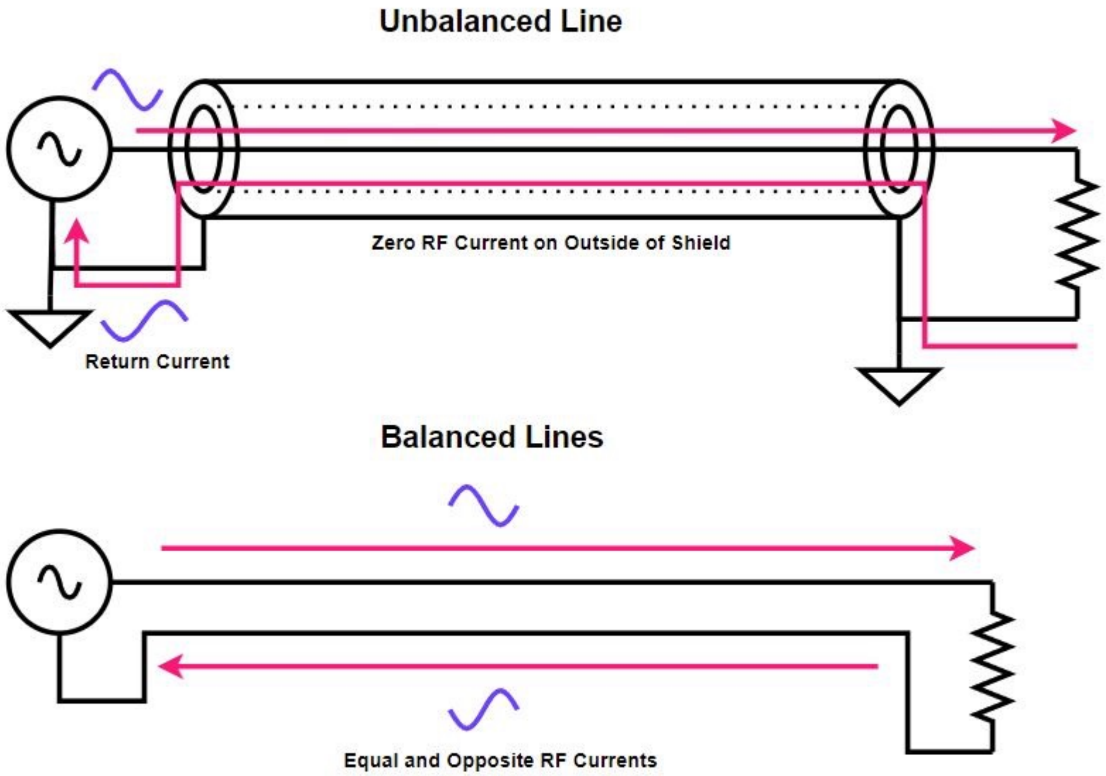
AGENDA

- Balanced and Unbalanced Media
- Differential and Common Modes
- Differential Mixed Mode Parameters
- Using a Balun
- Mixed Mode Balun Parameters
- De-Embedding a Balun Measurement

BALANCED AND UNBALANCED TRANSMISSION LINES

- *Unbalanced* (Coaxial) transmission lines pass RF signals from source to load with RF return current on the INSIDE of the shield
- The voltage on the return current side of the source may be zero, ground referenced, but the total current is balanced
- A *Balanced* transmission line will have equal and opposite RF currents and voltages on each line and may not be referenced to a system ground at all



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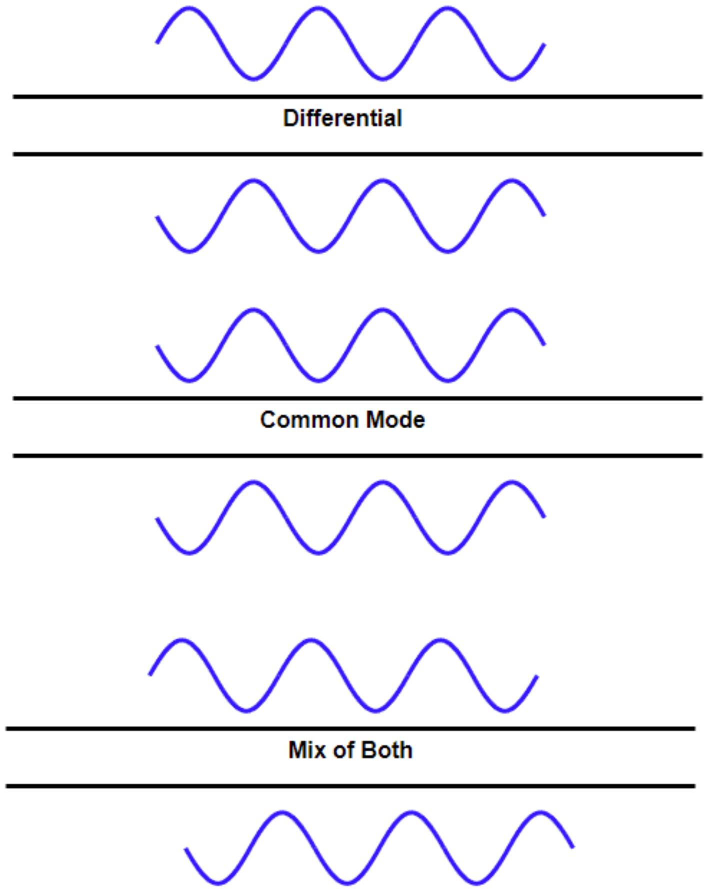
DIFFERENTIAL AND COMMON MODES

- A perfect Differential Mode signal on a balanced transmission line will contain two signals which are exactly 180 degrees out of phase with each other
- A completely Common Mode signal on a balanced transmission line will contain two signal which are exactly in phase
- In practice, a signal on a balanced transmission line will be a weighted sum of both modes where the common mode component is fairly small



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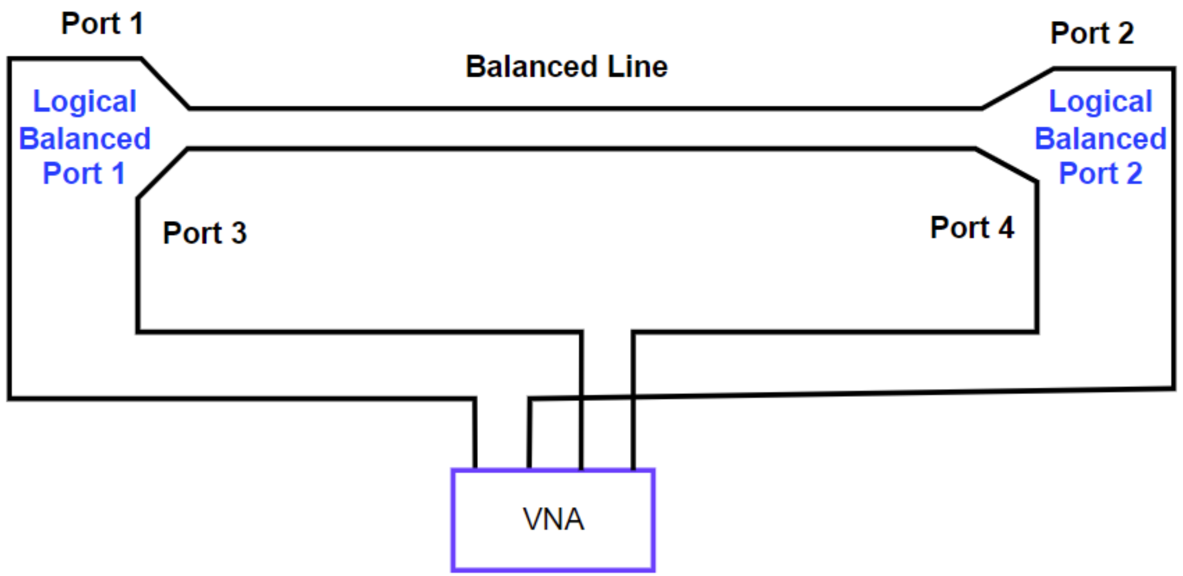
BALANCED AND UNBALANCED TRANSMISSION LINES

- A passive linear balanced system (without ferrites) may be characterized by making a series of single ended, unbalanced, measurements on each line and calculating the effective balanced response
- This will not work well for an active balanced amplifier since the output may not be a linear combination of its inputs if one input is undriven
- A four port VNA can do this easily and display the *Mixed Mode* Balanced parameters



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MIXED MODE BALANCED PARAMETERS

- The following 16 Mixed Mode balanced parameters are defined
- Port numbers here refer to *Logical Ports*

- SDD_{11}, Port 1 Differential return loss
- SDD_{21}, Forward Differential Insertion Loss
- SDD_{12}, Reverse Differential Insertion Loss
- SDD_{22}, Port 2 Differential return loss

- SDC_{11}, Differential reflection from Port 1 caused by incident common mode on Port 1
- SDC_{21}, Differential Signal on Port 2 caused by common mode on Port 1
- SDC_{12}, Differential Signal on Port 1 caused by common mode on Port 2
- SDC_{22}, Differential Reflection from Port 2 caused by incident common mode on Port 2

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MIXED MODE BALANCED PARAMETERS

- SCD_{11}, Common Mode Reflection on Port 1caused by incident differential mode on Port 1
- SCD_{21}, Common Mode Signal on Port 2 caused by Differential signal on Port 1
- SCD_{12}, Common Mode Signal on Port 1 caused by Differential signal on Port 2
- SCD_{22}, Common Mode reflection on Port 2 caused by Differential signal on Port 2
- SCC_{11}, Common Mode reflection on Port 1 caused by incident common mode signal on Port 1
- SCC_{21}, Common Mode signal on Port 2 caused by common mode signal on Port 1
- SCC_{12}, Common Mode signal on Port 1 caused by common mode signal on Port 2
- SCC_{22}, Common Mode reflection on Port 2 caused by incident common mode signal on Port 2

CALCULATION OF MIXED MODE PARAMETERS

- The 16 mixed mode parameters may be calculated from a 4-port measurement connected as shown in the earlier slide, 1 to 2 and 3 to 4.

SDD_{11}	SDD_{12}	SDC_{11}	SDC_{12}
SDD_{21}	SDD_{22}	SDC_{21}	SDC_{22}
SCD_{11}	SCD_{12}	SCC_{11}	SCC_{12}
SCD_{21}	SCD_{22}	SCC_{21}	SCC_{22}

$\frac{S_{11}-S_{13}-S_{31}+S_{33}}{2}$	$\frac{S_{12}-S_{14}-S_{32}+S_{34}}{2}$	$\frac{S_{11}+S_{13}-S_{31}-S_{33}}{2}$	$\frac{S_{12}+S_{14}-S_{32}-S_{34}}{2}$
$\frac{S_{21}-S_{23}-S_{41}+S_{43}}{2}$	$\frac{S_{22}-S_{24}-S_{42}+S_{44}}{2}$	$\frac{S_{21}+S_{23}-S_{41}-S_{43}}{2}$	$\frac{S_{22}+S_{24}-S_{42}-S_{44}}{2}$
$\frac{S_{11}-S_{13}+S_{31}-S_{33}}{2}$	$\frac{S_{12}-S_{14}+S_{32}-S_{34}}{2}$	$\frac{S_{11}+S_{13}+S_{31}+S_{33}}{2}$	$\frac{S_{12}+S_{14}+S_{32}+S_{34}}{2}$
$\frac{S_{21}-S_{23}+S_{41}-S_{43}}{2}$	$\frac{S_{22}-S_{24}+S_{42}-S_{44}}{2}$	$\frac{S_{21}+S_{23}+S_{41}+S_{42}}{2}$	$\frac{S_{22}+S_{24}+S_{42}+S_{44}}{2}$

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CALCULATION OF MIXED MODE PARAMETERS

- A 2-Port VNA can make all these measurements, 2-ports at a time while terminating the unused ports with a 50 Ω load
- Note that the two differential return loss measurements SDD_{11} and SDD_{22} are measured from only one end or the other. With a simple script to post-process the four measurements one could easily make these differential measurements with a 2-Port VNA

DEMONSTRATE THE 4-PORT MEASUREMENT

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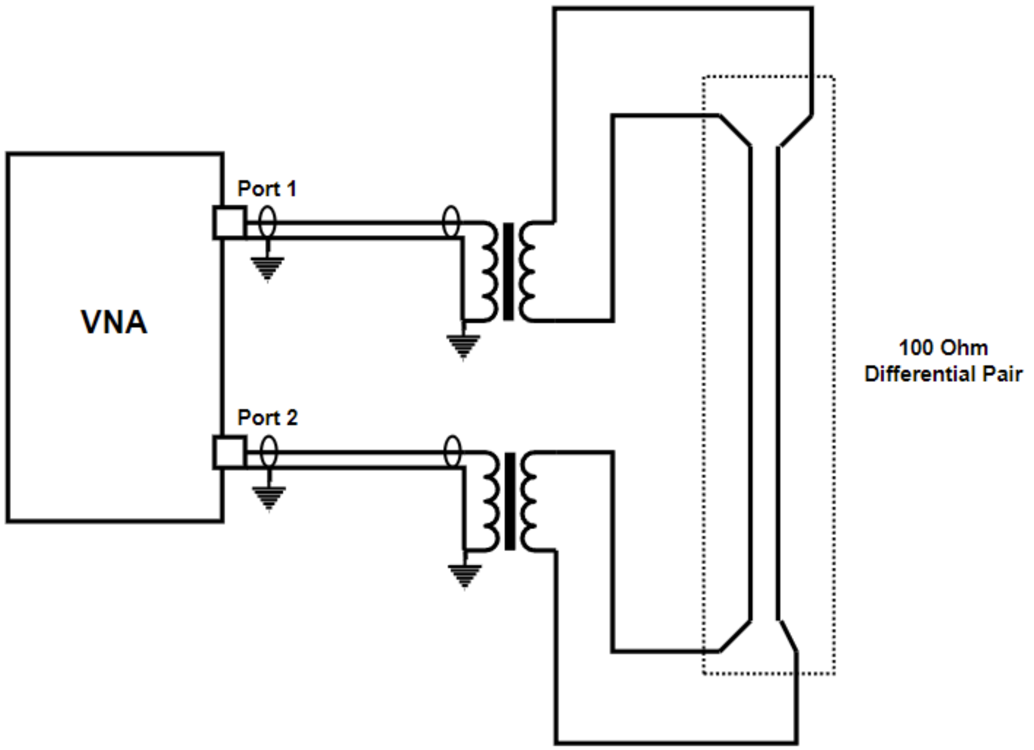
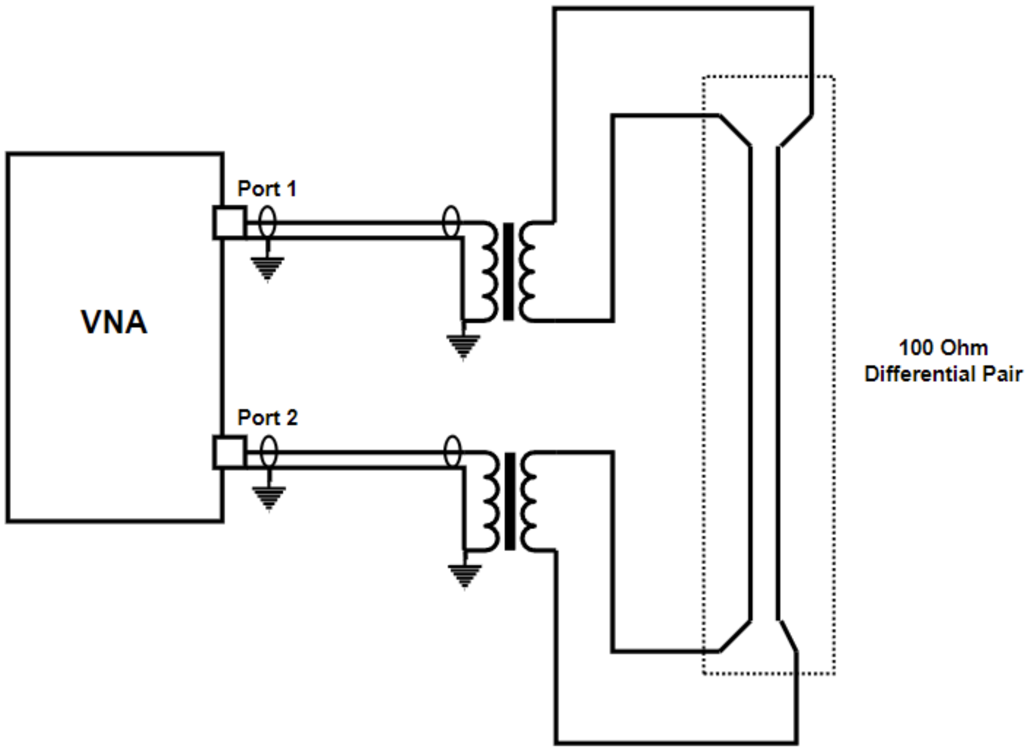
USING A BALUN

- Fully balanced measurements may be made with a 2-Port VNA and a pair of *Baluns*
- A balun converts the unbalanced signal from the VNA into a pair of balanced signals and visa versa
- A balun *CAN* be used to measure a differential amplifier since the incident signal consists of two signals in phase and anti-phase



USING A BALUN

- This is not a perfect solution!
- The 4-port measurement derives all performance criteria of a balanced DUT
- A balun measurement cannot be used to measure the mixed terms such as SDC_{21}
- It can only measure SDD_{11}, SDD_{21}, SDD_{12} and SDD_{22} and only if the balun is de-embedded from the DUT measurement
- The imperfect balun also generates some mixed terms which may affect the measurement



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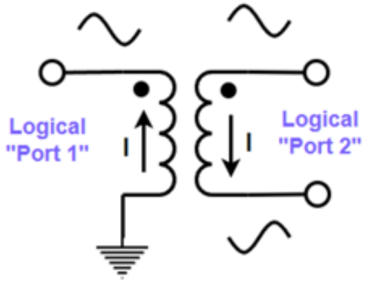
MIXED MODE BALUN PARAMETERS

- The chart at right shows the various Balun parameters
- Logical Port 1 is the unbalanced port and Logical Port 2 is the balanced port

Logical port mode	Stimulus	Single-ended	Differential	Common
Receiver	**Logical port number**	**1**	**2**	**2**
Single-ended	**1**	Sss11	Ssd12	Ssc12
Differential	**2**	Sds21	Sdd22	Sdc22
Common	**2**	Scs21	Scd22	Scc22



Voltage Balun

MIXED MODE BALUN PARAMETERS

- Differential Balun parameters are defined as follows:
  - SSS_{11} is the Return loss looking into the Single-ended Port 1
  - SSD_{12} is the Single-ended signal developed on Port 1 from the balanced signal on Port 2
  - SSC_{12} is the Single-ended signal developed on Port 1 by the Common mode signal on Port 2. This should be a very small number for a good balun
  - SDS_{21} is the Differential “thru” response of the balun
  - SDD_{22} is the Differential Port 2 return loss
  - SDC_{22} is the Differential mode reflection from Port 2 due to a Common mode signal exciting it

MIXED MODE BALUN PARAMETERS

  - SCS_{21} is the Common mode signal generated on Port 2 by the Single-ended Port 1 input. This should be very small for a good balun
  - SCD_{22} is the Common mode reflection from Port 2 due to a Differential excitation to it
  - SCC_{22} is the Common mode reflection from Port 2 due to a Common mode excitation to it
- An additional figure of merit for a balun is its Common mode rejection ratios in each direction
  - CMRR1 = Sds_{21}/Scs_{21}, the ratio of the Differential to Common mode signal generated on Port 2 by a signal on Port 1
  - CMRR2 = Ssd_{12}/Ssc_{12}, the ratio of the Single-ended signal generated on Port 1 by a Differential signal on Port 2 to the one created by a Single-ended signal on Port 2

MIXED MODE BALUN PARAMETERS

- All balun parameters may be determined by a 3-port measurement of the balun
  - Or a series of 2-port measurements
- The parameters (defined earlier) which we will use for de-embedding may be calculated as follows:

$$SSS_{11} = S_{11}$$

$$SDS_{21} = \frac{S_{21} - S_{31}}{\sqrt{2}}$$

$$SSD_{12} = \frac{S_{12} - S_{13}}{\sqrt{2}}$$

$$SDD_{22} = \frac{S_{22} - S_{23} - S_{32} + S_{33}}{2}$$

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DE-EMBEDDING THE BALUN

- If we ignore all the mixed modes of the balun and assume it is a perfect device (Huge assumption!) we can create a simple 2-port Touchstone file, filling it with the fully differential parameters only
- The S_{11}, S_{12}, S_{21} and S_{22} are replaced by the balun's differential terms and this matrix is used as a de-embedding file by the VNA

$$\begin{vmatrix} SSS_{11} & SSD_{12} \\ SDS_{21} & SDD_{22} \end{vmatrix}$$

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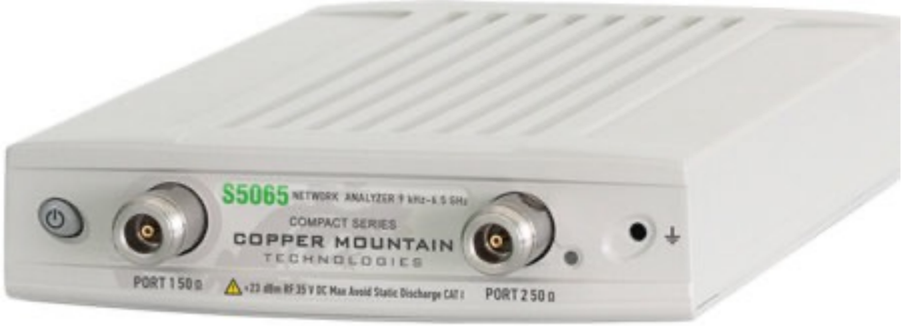
DEMONSTRATE THE 2-PORT MEASUREMENT



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QUESTIONS

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