SAS-2 Transmitter/Receiver
S-Parameter Measurement (07-012r1)

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(1/16/2007)
S-Parameter Measurement

Four Port S-Parameter Table

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>S11</td>
<td>S12</td>
<td>S13</td>
<td>S14</td>
</tr>
<tr>
<td>S21</td>
<td>S22</td>
<td>S23</td>
<td>S24</td>
</tr>
<tr>
<td>S31</td>
<td>S32</td>
<td>S33</td>
<td>S34</td>
</tr>
<tr>
<td>S41</td>
<td>S42</td>
<td>S43</td>
<td>S44</td>
</tr>
</tbody>
</table>
Balanced S-Parameter Measurement

Two Port Balanced (differential) S-Parameter Table

<table>
<thead>
<tr>
<th>Sdd11</th>
<th>Sdd12</th>
<th>Sdc11</th>
<th>Sdc12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sdd21</td>
<td>Sdd22</td>
<td>Sdc21</td>
<td>Sdc22</td>
</tr>
<tr>
<td>Scd11</td>
<td>Scd12</td>
<td>Scc11</td>
<td>Scc12</td>
</tr>
<tr>
<td>Scd21</td>
<td>Scd22</td>
<td>Scc21</td>
<td>Scc22</td>
</tr>
</tbody>
</table>

BALANCED PORT 1
BALANCED PORT 2
S-Parameter Terminology

• For unbalanced terms the form is,
  – $S_{<\text{measured port}><\text{injected port>}}$
  – For example, $S_{32}$ is the response measured at port 3 from the signal injected into port 2

• For balanced terms the form is,
  – $S_{<\text{mode of measured port}><\text{mode of injected port>}<\text{measured port}><\text{injected port>}}$
  – For example, $S_{d_{c12}}$ is the differential response measured at ports 1/3 from a common mode signal injected on both ports 2 and 4 (see balanced measurement diagram)

• Correctly interpreting the common mode to differential conversion measurement is difficult. More on that topic later.

• This presentation will focus on the various $S_{11}$ terms
# Balanced Port Values

<table>
<thead>
<tr>
<th></th>
<th>Differential Mode</th>
<th>Common Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Voltage</strong></td>
<td>$V_A - V_B$</td>
<td>$V_A + V_B$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\frac{V_A + V_B}{2}$</td>
</tr>
<tr>
<td><strong>Current</strong></td>
<td>$\frac{I_A - I_B}{2}$</td>
<td>$I_A + I_B$</td>
</tr>
<tr>
<td><strong>Impedance</strong></td>
<td>$Z_{DM} = \frac{V_{DM}}{I_{DM}}$</td>
<td>$Z_{CM} = \frac{V_{CM}}{I_{CM}}$</td>
</tr>
</tbody>
</table>

![Balanced 1-port diagram](image)
Reflection Coefficient ($\Gamma$) and $S_{11}$

- How do the $S_{11}$ terms correlate to the reflection coefficient?
- The reflection coefficient ($\Gamma$) is the ratio of the amplitudes of the reflected wave to the incident wave.
- It can be computed from the impedances of the incident media and termination.
- The magnitude of $\Gamma$ is $\rho$ and the $S_{11}$ magnitude is then

$$S_{11} = 20 \log(\rho)$$
Comparison of $\rho$ and $S_{11}$ Results

- To verify the interpretation of the $S_{11}$ terms is correct, the following circuit was constructed with various termination values
- Both $S_{11}$ and $\rho$ where measured. $S_{11}$ was then verified using the equations presented earlier
Comparison of $\rho$ and $S_{11}$ Results

- In the following case the differential impedance matches the transmission line at $100\,\Omega$ but the common mode impedance is $22.2\,\Omega$. Since the legs are mismatched a conversion is also introduced. We will introduce a common mode signal and analyze the conversion.
Comparison of $\rho$ and $S_{11}$ Results

- Calculating the reflection coefficient $\rho$ for the first leg we obtain is 0.143 and -0.200 for the second.
- Also note that the results match very closely to the measured values.
- For the reflected wave the first leg experiences a positive transitioning signal and the second leg a negative transitioning one.

$$\rho = \frac{66.7 - 50}{66.7 + 50} = 0.143 \quad \rho = \frac{33.3 - 50}{33.3 + 50} = -0.200$$
Comparison of $\rho$ and $S_{11}$ Results

- The reflected waves can be thought of as a signal injected into the instrumentation by the DUT. The same balanced port equations apply but in the opposite direction.
- The reflected waves can be expressed as a ratio of the original signal injected into the termination network.
- To determine $S_{DC11}$ for the DUT, we merely need to interpret the reflected currents as differential mode signals.

Balanced 1-port

\[
\begin{align*}
I_A &= 0.143 \times I_A \\
I_B &= -0.200 \times I_B
\end{align*}
\]
Comparison of $\rho$ and $S_{11}$ Results

- The equation for differential mode currents presented earlier is $(I_A - I_B)/2$. Using the calculated values we obtain:

$$\frac{0.143 - (-0.200)}{2} = 0.172$$

$$S_{DC11} = 20 \log(0.172) = -15.3$$

- Below 1 GHz, this value compares well with the actual measurement shown to the right.
Full $S_{DC11}$ Equation

- The equation used in the above comparison is:

$$20 \times \log \left( \frac{\rho_{pos\_leg} - \rho_{neg\_leg}}{2} \right)$$

- Assuming identical impedance for both legs of the testing fixture we obtain:

$$20 \times \log \left( \frac{R_{pos\_term} - Z_{fixture}}{2} \right)$$
What do $S_{11}$ values mean?

- The fixture shown below can be used to demonstrate the relationship between $S_{11}$ and $S_{21}$.

- The $S_{11}$ and $S_{21}$ are the relative amplitude and not power.
What do $S_{11}$ values mean?

- For interfaces with impedance discontinuities, power is conserved. The sum of the reflected and transferred power is equal to the injected power – minus the power dissipated across the span of the discontinuity.

- Signal amplitude is determined by the reflection coefficient.

- $S_{11}$ is not a direct indicator of what $S_{21}$ is.
Vendor Samples

- To the right are $S_{DD11}$ measurements of two test boards provided by two different PHY suppliers.
- The measurements are made with power on and off.
- Test board effects were not de-embedded from the measurements.
Reference Material

• Agilent has two application notes with materials used in this presentation. Both are good for further reading on this topic.
  1. Characterization of balanced digital components and communication paths
  2. Advanced measurements and modeling of differential devices