SLED-II RF Components and Systems

S. Tantawi, C. Nantista, and V. Dolgashev

SLAC
Outline

• Component summary
• Modifications to RF components
  1. to avoid pulsed heating
  2. to Improve efficiency
  3. to correct errors after cold testing
• Dual Modeled Delay Line Tests
• The next generation of RF comports and systems
Pulsed Heating
The Dual-Moded SLED-II Head

- Dual-Moded Combiner
- Height Taper
- Dual-Moded Flange
- Dual-Moded Super-Hybrid
- Jog Converter
- Circular to Rectangular Taper
Redesigned Magic H Hybrid

\[
\begin{array}{cccc}
(P1 \ M1) & (P2 \ M1) & (P3 \ M1) & (P4 \ M1) \\
0.0028 & 0.7071 & 0.7071 & 0.0028 \\
0.7071 & 0.0028 & 0.0028 & 0.7071 \\
0.7071 & 0.0028 & 0.0028 & 0.7071 \\
0.0028 & 0.7071 & 0.7071 & 0.0028 \\
\end{array}
\]

@ 600 MW, 1.435” height:
\[|E_{\text{max}}| = \sim 45.6 \text{ MV/m} \]
\[|H_{\text{max}}| = \sim 168 \text{ kA/m} \]

C. Nantista ‘02
Width Taper (0.900” → 1.442”)

@ 600 MW  \[ |E_{\text{max}}^s| = \sim 36.8 \text{ MV/m} \]

\[ |H_{\text{max}}^s| = \sim 106 \text{ kA/m} \]

@ 600 MW  \[ |E_{\text{max}}^s| = \sim 37.1 \text{ MV/m} \]

\[ |H_{\text{max}}^s| = \sim 116 \text{ kA/m} \]
Jog Mixer

@ 600 MW

$|E_s^{\text{max}}| = \sim 36.6 \text{ MV/m}$

$|H_s^{\text{max}}| = \sim 78.9 \text{ kA/m}$

@ 600 MW

$|E_s^{\text{max}}| = \sim 40.3 \text{ MV/m}$

$|H_s^{\text{max}}| = \sim 81.3 \text{ kA/m}$

S. Tantawi ‘02
This configuration allows SLEDed (TE$_{01}$°) and unSLEDed (TE$_{11}$°) operation and (with an additional mode mixer and SLED-II irises removed) BPC operation.

will improve with mode mixer refinement.

@ 150 MW SLEDed to 600MW

|E$_{\text{max}}$| = ~48.5 MV/m

|H$_{\text{max}}$| = ~256 kA/m

(depending on phase of reflected wave)
8-Pack Cross Potent Substitute

Through MSLED-II

@ 516 MW,

|E_s|_{max} = ~45.8 MV/m

|H_s|_{max} = ~156 kA/m

With copper losses:

\[
\begin{array}{cccc}
\text{(P 1 M 1)} & 0.0020 & 0.0118 & 0.9999 & 0.0006 \\
\text{(P 1 M 2)} & 0.0118 & 0.0077 & 0.0008 & 0.9999 \\
\text{(P 2 M 1)} & 0.9999 & 0.0008 & 0.0020 & 0.0118 \\
\text{(P 2 M 2)} & 0.0008 & 0.9999 & 0.0118 & 0.0077 \\
\end{array}
\]
# Simulation Comparison of C.P. Options

## 8-Pack Cross Potent w/ Corners Rounded

<table>
<thead>
<tr>
<th></th>
<th>(P 1 M 1)</th>
<th>(P 1 M 2)</th>
<th>(P 2 M 1)</th>
<th>(P 2 M 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(P 1 M 1)</td>
<td>0.0375</td>
<td>0.0282</td>
<td>0.9988</td>
<td>0.0109</td>
</tr>
<tr>
<td>(P 1 M 2)</td>
<td>0.0282</td>
<td>0.0206</td>
<td>0.0109</td>
<td>0.9993</td>
</tr>
<tr>
<td>(P 2 M 1)</td>
<td>0.9988</td>
<td>0.0109</td>
<td>0.0375</td>
<td>0.0282</td>
</tr>
<tr>
<td>(P 2 M 2)</td>
<td>0.0109</td>
<td>0.9993</td>
<td>0.0282</td>
<td>0.0206</td>
</tr>
</tbody>
</table>

Total Power Reflected from $\text{TE}_{20}$ ($\text{TE}_{10}$) Input:

$\text{Avg.: .17106\%}$

= 0.12196\% (0.22015%)  

## Cross Potent Substitute

<table>
<thead>
<tr>
<th></th>
<th>(P 1 M 1)</th>
<th>(P 1 M 2)</th>
<th>(P 2 M 1)</th>
<th>(P 2 M 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(P 1 M 1)</td>
<td>0.0020</td>
<td>0.0118</td>
<td>0.9999</td>
<td>0.0008</td>
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<tr>
<td>(P 1 M 2)</td>
<td>0.0118</td>
<td>0.0077</td>
<td>0.0008</td>
<td>0.9999</td>
</tr>
<tr>
<td>(P 2 M 1)</td>
<td>0.9999</td>
<td>0.0008</td>
<td>0.0020</td>
<td>0.0118</td>
</tr>
<tr>
<td>(P 2 M 2)</td>
<td>0.0008</td>
<td>0.9999</td>
<td>0.0118</td>
<td>0.0077</td>
</tr>
</tbody>
</table>

Cross Potent Substitute

= 0.01985\% (0.01432%)  

Avg.: .01709%
Dual-Mode Combiner/Splitter

\[
\begin{array}{cccc}
(P_{1 M 1}) & (P_{1 M 2}) & (P_{2 M 1}) & (P_{3 M 1}) \\
(P_{1 M 1}) & 0.0043 & 4.309e-006 & 0.7071 & 0.7071 \\
(P_{1 M 2}) & 4.309e-006 & 0.0011 & 0.7071 & 0.7071 \\
(P_{2 M 1}) & 0.7071 & 0.7071 & 0.0019 & 0.0029 \\
(P_{3 M 1}) & 0.7071 & 0.7071 & 0.0029 & 0.0019 \\
\end{array}
\]
Dual-Mode Combiner/Splitter

@ 600 MW  
$|E_{\text{max}}| = \sim 45.7 \text{ MV/m}$  
$|H_{\text{max}}| = \sim 218 \text{ kA/m}$

@ 600 MW  
$|E_{\text{max}}| = \sim 31.5 \text{ MV/m}$  
$|H_{\text{max}}| = \sim 73.9 \text{ kA/m}$

C. Nantista ‘02
Instrumental components for cold testing of multimode components:

1. TE_{11} Mode launcher
2. TE_{01} Mode launcher
3. Width taper
4. Height taper
5. Small waveguide sections with different lengths at all waveguide cross sections

We followed a strict methodology of designing these instruments. They had to be simulated with at least three different codes and have a performance that is much better than any component that we have. Of course we can only do that because there is no restrictions on field levels.
Measurements of “instrumental” height taper

![Graph showing S11 in dB vs. Frequency in GHz]

- S11 [dB]
- Frequency [GHz]

Values:
- 11.324
- 11.357
- 11.391
- 11.424
- 11.457
- 11.491
- 11.524

8 October 02
Jog Converter and Bend Converter

@ 600 MW
|E_s^{max}| = ~37.5 MV/m
|H_s^{max}| = ~82.4 kA/m

@ 600 MW
|E_s^{max}| = ~37.8 MV/m
|H_s^{max}| = ~83.8 kA/m
Jog converter back to back

(instrumental width taper-instrumental height taper-Jog Converter- Jog Converter-instrumental Height taper-Instrumental width taper)
Jog converter back to back

(instrumental width taper-instrumental height taper-Jog Converter- Jog Converter-instrumental Height taper-Instrumental width taper)
# Height Taper (0.400” → 1.435”)

<table>
<thead>
<tr>
<th>(P 1 M 1)</th>
<th>(P 2 M 1)</th>
<th>(P 2 M 2)</th>
<th>(P 2 M 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0093</td>
<td>0.9998</td>
<td>0.0048</td>
<td>0.0157</td>
</tr>
<tr>
<td>0.9998</td>
<td>0.0096</td>
<td>0.0048</td>
<td>0.0155</td>
</tr>
<tr>
<td>0.0048</td>
<td>0.0048</td>
<td>0.8243</td>
<td>0.5662</td>
</tr>
<tr>
<td>0.0157</td>
<td>0.0155</td>
<td>0.5662</td>
<td>0.824</td>
</tr>
</tbody>
</table>

@ 75 MW  
$|E_{\text{max}}^s| = \sim 25.0 \text{ MV/m}$  
$|H_{\text{max}}^s| = \sim 54.8 \text{ kA/m}$

blended arc height taper  
4.000”

S. Tantawi ‘02
Two Height tapers back to back

![Graph of S11 and S12 parameters over frequency range.](image-url)
Cold Test $\text{TE}_{11}$ Launchers

$\text{TE}_{11}$ Modelaunchers Back-to-Back Transmission

$\text{TE}_{11}$ Modelauncher Back-to-Back Reflection
Vacuum Pumpout Cold Test

**WC159 Vacuum Pumpout Transmission**

- Amplitude of $S_{21}$
- Frequency (GHz)

**WC159 Vacuum Pumpout Match**

- Amplitude of $S_{11}$
- Frequency (GHz)
Dual-Mode
Rectangular-to-Circular Taper

Simulated electric fields (HFSS) of the multi-moded circular to rectangular taper

Taper Geometry
(Instrumental width taper-instrumental height taper-Circular to Rectangular taper-Instrumental TE$_{11}$-Launcher)
(Instrumental width taper-instrumental height taper-Circular to Rectangular taper-Instrumental TE_{11}-Launcher)
Wraparound mode converter, circular to rectangular taper, jog mode converter, height tapers,
An Assembly to test new components and concepts: height tapers, jog mode converter, circular to rectangular tapers

Frequency response of the assembly ($S_{12}$)  Transmitted pulse through the assembly
Reflection after an approximately 30 ns Transmission line height tapers, jog mode converter, circular to rectangular tapers.

30 ns shorted transmission line

Reflection after an approximately 30 ns Transmission line
Drift Section modified because of improved surface representation. (about 2.5 year difference between the initial design and the modification, during which our simulation capabilities improved considerably)

New Design
1-drift section modified
2-Input rectangular to rectangular taper modified
Measurements of rectangular to circular converter mode converters

![Graph showing S11 [dB] vs Frequency [GHz] for before and after modification. The graph compares two curves: one in red marked 'before modification' and one in blue dotted marked 'after modification.' The S11 values are in the range of -30 to -60 dB, and the frequency range is from 11.324 to 11.524 GHz.]
Circular to rectangular taper Modification

![Graph showing S12 frequency response before and after modification](image)

- **S12**
- **Frequency [GHz]**
  - before modification
  - after modification
Circular to rectangular taper attached to a dual moded delay line
Input Taper for a Dual-Moded System
End Taper (before the TE\textsubscript{01}-TE\textsubscript{02} Mode converter)
Input Taper

Output Taper

End Mode converter

$TE_{01}(TE_{02})$
Measured frequency response and constructed time response of the dual-moded taper assembly.
Normalized amplitude

Time [ns]
Reflective Mode Converter Mode Matching Simulation

\[ Q = 10,000 \]

Graph showing |S11| and phase versus frequency with no losses.

Frequency [GHz] range from 11.30 to 11.60.
HFSS Simulation of Reflective Mode Converter

<table>
<thead>
<tr>
<th>Code</th>
<th>TE02</th>
</tr>
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<tbody>
<tr>
<td>Agilent</td>
<td>0.99995</td>
</tr>
<tr>
<td>Ansoft</td>
<td>0.99996</td>
</tr>
<tr>
<td>Ansoft w/ Cu loss</td>
<td>0.99970</td>
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Tolerance Analysis of Reflective Mode Converter: Cup Depth

<table>
<thead>
<tr>
<th>Depth</th>
<th>TE02</th>
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</thead>
<tbody>
<tr>
<td>1.048”</td>
<td>0.99986</td>
</tr>
<tr>
<td>1.058”</td>
<td>0.9987</td>
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<tr>
<td>1.038”</td>
<td>0.9989</td>
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</table>

Mode Matching
Tolerance Analysis of Reflective Mode Converter: Cup Diameter

<table>
<thead>
<tr>
<th>Diameter</th>
<th>TE02</th>
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<tbody>
<tr>
<td>1.926”</td>
<td>0.99986</td>
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<tr>
<td>1.946”</td>
<td>0.9989075</td>
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<tr>
<td>1.906”</td>
<td>0.9995188</td>
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</table>

Mode Matching
Effect of Cup Offset

<table>
<thead>
<tr>
<th>Offset</th>
<th>TE01</th>
<th>TE02</th>
<th>TE12</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.015”</td>
<td>0.0081</td>
<td>0.9988</td>
<td>0.0382</td>
</tr>
<tr>
<td>0.029”</td>
<td>0.0063</td>
<td>0.9955</td>
<td>0.0734</td>
</tr>
</tbody>
</table>
Comparison of Design to Measured Cup Depth

Mode Matching

<table>
<thead>
<tr>
<th>Depth</th>
<th>TE(_{01})</th>
<th>TE(_{02})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.048”</td>
<td>0.01608</td>
<td>0.99987</td>
</tr>
<tr>
<td>1.052”</td>
<td>0.02653</td>
<td>0.99965</td>
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</tbody>
</table>

-35.9 dB
-31.5 dB
Tolerance Analysis of Reflective Mode Converter: Waveguide Diameter

<table>
<thead>
<tr>
<th>Dwg</th>
<th>TE01</th>
<th>TE02</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.25&quot;</td>
<td>0.01608</td>
<td>0.99987</td>
</tr>
<tr>
<td>3.24&quot;</td>
<td>0.023466</td>
<td>0.99972</td>
</tr>
<tr>
<td>3.26&quot;</td>
<td>0.009543</td>
<td>0.99995</td>
</tr>
</tbody>
</table>

![Graph showing phase and frequency]
Slightly Revised Design of Reflective Mode Converter

old design

\[ r = 0.963'' \]
\[ d = 1.048'' \]

new design

\[ r = 0.958'' \]
\[ d = 1.051'' \]

Ansoft HFSS (non-segmented)
## Design Comparison

<table>
<thead>
<tr>
<th>code</th>
<th>design1 $S_{11}$</th>
<th>design1 $S_{21}$</th>
<th>design2 $S_{11}$</th>
<th>design2 $S_{21}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ansoft</td>
<td>.00908</td>
<td>.99996</td>
<td>.00024</td>
<td>1.00000</td>
</tr>
<tr>
<td>Agilent (r-corr.)</td>
<td>.0110</td>
<td>.99994</td>
<td>.0029</td>
<td>.99999</td>
</tr>
<tr>
<td>Smatr (m.m.)</td>
<td>.01608</td>
<td>.99987</td>
<td>.00756</td>
<td>.99997</td>
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List of components:

- **Planer Components**
  1. Hybrids (Modified because of pulsed heating)
  2. H-Plane Bends
  3. E-plane bends (Modified because of pulsed heating)
  4. Combiner/Splitter (Modified to reduce pulsed heating and electric fields; waiting for parts)
  5. Jog Converters
     a) \( \text{TE}_{10} - \text{TE}_{20} \) Converter (Built and Tested)
     b) 3dB mode mixers (Design is optimized for efficiency)
     c) Bend Converters
  6. Sled-II Multimode Hybrid/Cross Potent (Modified to reduce pulsed heating and electric fields; waiting for parts)
  7. Height Taper (Built and tested)
  8. Width Taper
List of Components, Continued:

- **Circular Components**
  1. **Circular to rectangular tapers** (after cold tests the design is modified to improve mode purity and insertion losses)
  2. **Circular Pump-outs** (built and tested)
  3. **Circular directional couplers** (Waiting for parts)

- **Delay Line Components**
  1. **Up-taper** (Built and tested)
  2. **Down-taper** (Built and tested)
  3. **End mode converter** (Optimized; built and tested)
Summary

• We are almost done with fine tuning our designs.
Measurements of rectangular to circular converter mode converters

Rectangular to circular converters and horn

22 October 02
Measurements “short” rectangular to circular converter mode converter with wrap-around

![Graph showing measurements of S11 dB vs. df [MHz] for mode converter and wrap-around, along with jog-converter.](image)