Dual chip in single module solid-state power amplifier design for compact transmitter architecture

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IPAC 2013
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Introduction

• 3GeV/3.3GeV Taiwan Photon Source, in NSRRC is under construction and planned to be commissioned in 2014
• At present, two 300kW klystron transmitters are available for initial TPS operation.
• With more insertion devices or higher beam current, more RF power will be required
• Solid-state power amplifier (SSPA) transmitter is the next candidate for economic RF power upgrade.
• The experience of SSPA circuits development will be presented here.
1kW PA modules: 100kW solid-state transmitter needs 128 modules

- This topology needs quite large number of modules
- Eight 1kW-SSPA modules as a basic group for 8kW
- 16 8kW-groups for 100kW transmitter
- Each SSPA module will operate at 850W nominally
2kW PA modules: 100kW solid-state transmitter needs only 64 modules

- With 2kW SSPA modules, total number of modules can be reduced in half for the same output power
- Space, control and maintenance requirement can greatly be released.
Low profile planar balun

- With the proposed compact planar balun for 500MHz solid-state power amplifier\(^1\), dual-chip combination within in single module becomes attractive.

\(^1\)T.C. Yu, Ch. Wang, L.H. Chang etc., “A novel planar balun structure for continuous wave 1kW, 500MHz solid-state amplifier design
500MHz, 1kW SSPA using old version planar balun: the drawback

- The 1kW SSPA reported in IPAC 2012
- Reach 1kW per module
- Heat generated at output balun (>188degC@1kW)
Iteration design of the planar baluns

• The temperature decreases one by one
The latest planar balun for 1kW power

• Features:
  – Add air cooling fin on the top
  – Heat sink surround the balun at bottom
  – The cooling structure has no effects on RF performance
  – Low insertion loss: 0.1dB loss back-to-back (0.05dB/1.15% loss for one)
1kW SSPA with latest balun design

- Operation with fan cooling
Test results

- Compare with the prior version SSPA
  - Temperature decreased by about 85 degC
  - ~4% efficiency enhancement
  - ~0.5-1dB power gain improvement

![Graphs showing test results]
Dual-chip combination within single module

- Two identical SSPAs with planar two-way power divider/combiner

Two amplifiers in single module
Compact dual chip SSPA module using planar balun

- SSPA size reduction by the compact planar balun
- 50% area saving is applicable

Present: 30%

Next: 50%
Planar power splitting/combining methods

- Four methods are chosen:
  - Y-junction power divider/combiner
  - Wilkinson power divider/combiner
  - Gysel power divider/combiner
  - Balun power divider/combiner
Planar combiners (1)

- Y-junction two-way power divider/combiner
Planar combiners (2)

- Wilkinson two-way power divider/combiner
Planar combiners (3)

- Gysel power two-way divider/combiner
Planar combiners (4)

- Planar balun two-way power divider/combiner
Summary of above planar splitters/combiners

- Bandwidth of S11 and isolation

<table>
<thead>
<tr>
<th>Type</th>
<th>Y-junction</th>
<th>Wilkinson</th>
<th>Gysel</th>
<th>Planar balun</th>
</tr>
</thead>
<tbody>
<tr>
<td>S11 bandwidth [MHz]</td>
<td>178</td>
<td>160</td>
<td>107</td>
<td>155</td>
</tr>
<tr>
<td>Isolation@500MHz[dB]</td>
<td>6.33</td>
<td>25.68</td>
<td>35.84</td>
<td>5.87</td>
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</tbody>
</table>

Measured return loss

Isolation_measurement
Combining efficiency investigation (1)

- Adopting two identical 50W PA for power combination
- The setup is as below:

Combination efficiency can be found by driving power and output power.
Combining efficiency investigation (2)

- Y-junction and balance combiner need isolators
- Wilkinson and Gysel do not
- Isolators will bring additional insertion loss

No circulator for combination

Need circulator for combination
Combining efficiency investigation (3)

- Combining efficiency: $P_{\text{in}} = \? \text{ for the same } P_{\text{out}}$
- Gysel combiner reach 100W with minimum input power

![Combining efficiency graph]

- Y-junction combiner
- Wilkinson combiner
- Gysel combiner
- Balun combiner

**Best**
Performance comparison of the planar dividers/combiners

Although the bandwidth of Gysel combiner is narrow, it brings the best efficiency for power combination

<table>
<thead>
<tr>
<th>Planar power two way divider/combiner type</th>
<th>Bandwidth [MHz]</th>
<th>Additional component</th>
<th>Special cooling</th>
<th>Efficiency in actual combination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y-junction</td>
<td>178</td>
<td>Two circulators</td>
<td>Bottom cooling</td>
<td>3rd</td>
</tr>
<tr>
<td>Wilkinson</td>
<td>160</td>
<td>One 100Ohm resistor</td>
<td>Bottom cooling</td>
<td>2nd</td>
</tr>
<tr>
<td>Gysel</td>
<td>107</td>
<td>Two 50Ohm resistor</td>
<td>Bottom cooling</td>
<td>Best</td>
</tr>
<tr>
<td>Planar balun</td>
<td>155</td>
<td>Two circulators</td>
<td>Air cooling and bottom cooling</td>
<td>4th</td>
</tr>
</tbody>
</table>
Dual chip combination concept

- The cooling structure for high power test is under construction
Conclusion

• New planar balun design with better cooling
• Compact SSPA and dual chip in single module: planar balun and combiner
• Gysel power divider/splitter has best combining efficiency without circulators
Thank you for your attention