Kilowatt Level High Efficiency Solid State Power Amplifier at 100 MHz

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Outline

• Project background
• Simple theory - introduction
• Circuit simulation analysis
• Realized circuit
• Measurements & results
• Conclusion
Background: Cyclotron

- Eurostar ENEFRF project: 10 kW high efficient RF power sources for cyclotron particle accelerator at 27 and 101 MHz.
- The highest output power for LDMOS technology is about 1.8 kW.
- Combine 10-12 power amplifier modules at half the nominal power.
- Each module output 1 kW, eff>80%.
Amplifier classes of operation

Class A

Class B

\[ R_{opt} = \frac{V_{dd} - V_{knee}}{I_{max}} \]
Simple theory: ‘Continues’ Class Mode

- novelty: planar structure, kW level.
- Leave enough design space.
- Decrease knee effect on efficiency impaction.

\[ Z_{opt} = (1 - j \gamma) R_{opt} \]

\[ Z_{opt\_2h} = (0 - j a \gamma) R_{opt} \]

- The key design point is to realize reactive second harmonic impedance.
Push-pull and single ended architectures

Push-pull

Single Ended (resonant output network)
Simple output linear model

- Parasitic output capacitor of transistor: ~200 pF
- Jumping wire inductor: ~0.2 nH
- Capacitor of package: ~4 pF
Simple output linear model

Connected directly for Single-ended application
Final layout with EM Simulation

Finalized layout with mesh
Harmonic Simulation

Waveform at transistor’s I-gen plane

Load-line Curve
Work Prototype for Measurement

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Frequency Sweep

**Vdd = 45V, Idq= 200mA**

<table>
<thead>
<tr>
<th>Freq_MHz</th>
<th>Pin_dBm</th>
<th>Pout_dBm</th>
<th>Pout_W</th>
<th>Gain_dB</th>
<th>Eff</th>
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<tr>
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<td>60.236</td>
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</tbody>
</table>

Signal:
- **Pulse Periods**: 3.5 ms
- **Pulse Width**: 70 ms
Measured Results

**BLF188@98.5MHz, 45V**

- **Gain (dB)**
- **Eff (%)**

**Pout, OUTPUT POWER (Watts)**

Eff = 92% @ Pout = 980Watts

**BLF188@98MHz, 45V**

- **Gain (dB)**
- **Eff (%)**

**Pout, OUTPUT POWER (Watts)**

Eff = 93% @ Pout = 1020Watts
### Frequency Sweep

**Vdd = 50V, Idq= 500mA**

<table>
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<th>Freq_MHz</th>
<th>Pin_dBm</th>
<th>Pout_dBm</th>
<th>Pout_W</th>
<th>Gain_dB</th>
<th>Eff</th>
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</table>

Increase ~200 Watts while sacrifice 6% efficiency
Conclusion

• We tried the new ‘continues’ mode on high power/high efficiency amplifier application.

• Achieved 1000 Watts with 92% in a single-ended prototype.