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Kilowatt Level High Efficiency Solid State Power Amplifier at 100 MHz

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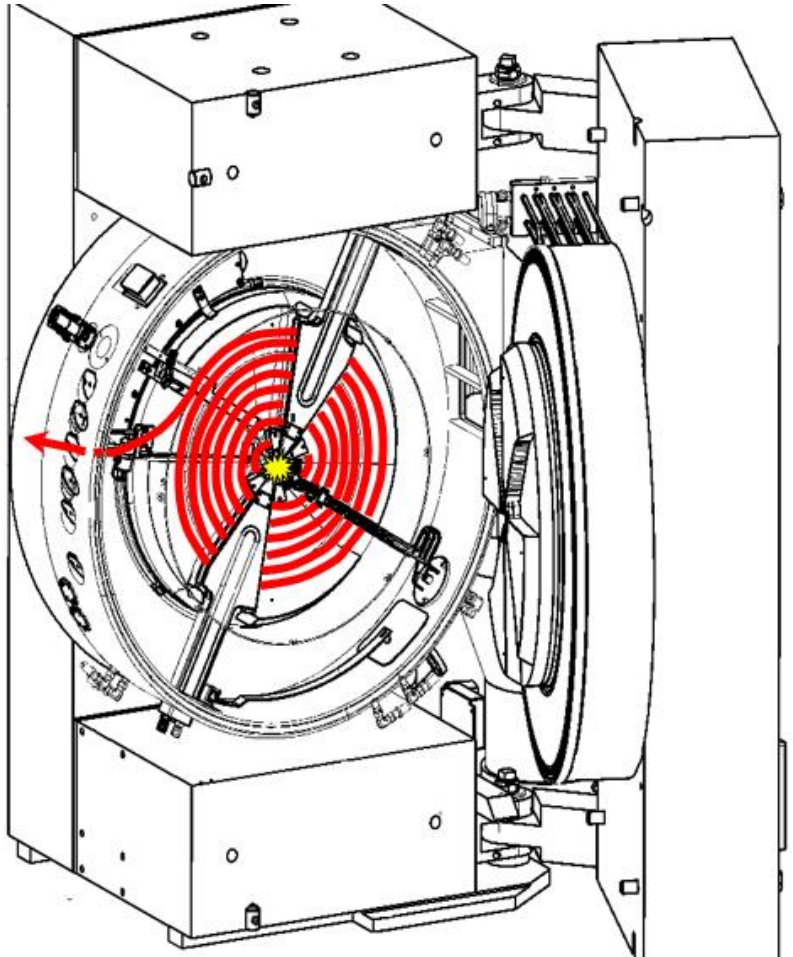
Outline

- Project background
- Simple theory - introduction
- Circuit simulation analysis
- Realized circuit
- Measurements & results
- Conclusion

Background: Cyclotron

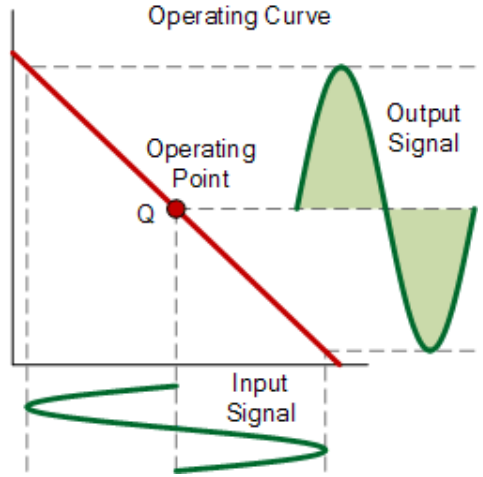


Courtesy of GE

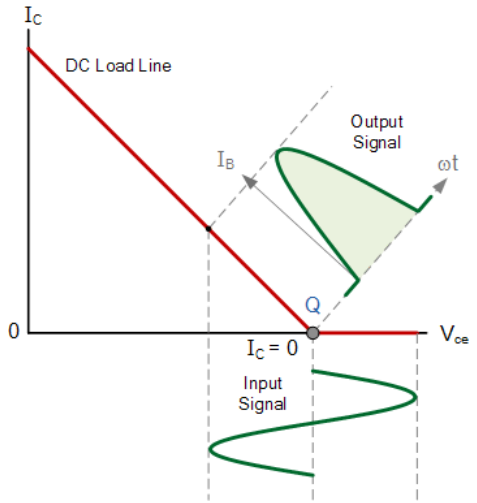
- Eurostar ENEFRF project: 10 kW high efficient RF power sources for cyclotron particle accelerator at 27 and 101 MHz.
- The highest output power for LDMOS technology is about 1.8 kW.
- Combine 10-12 power amplifier modules at half the nominal power.
- Each module output 1 kW, eff>80%.

Amplifier classes of operation

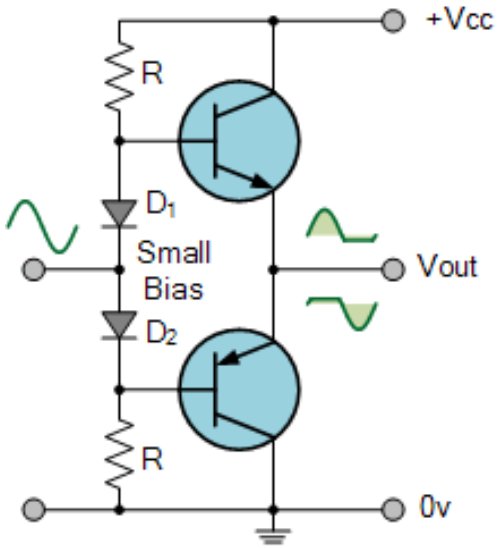
Class A

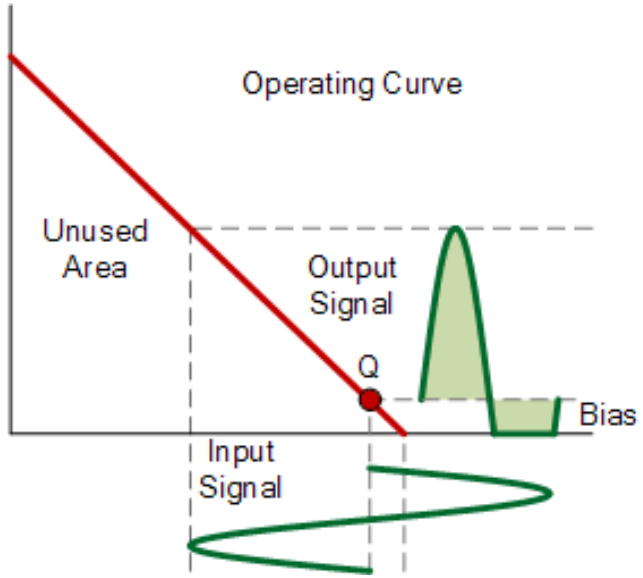


Class B



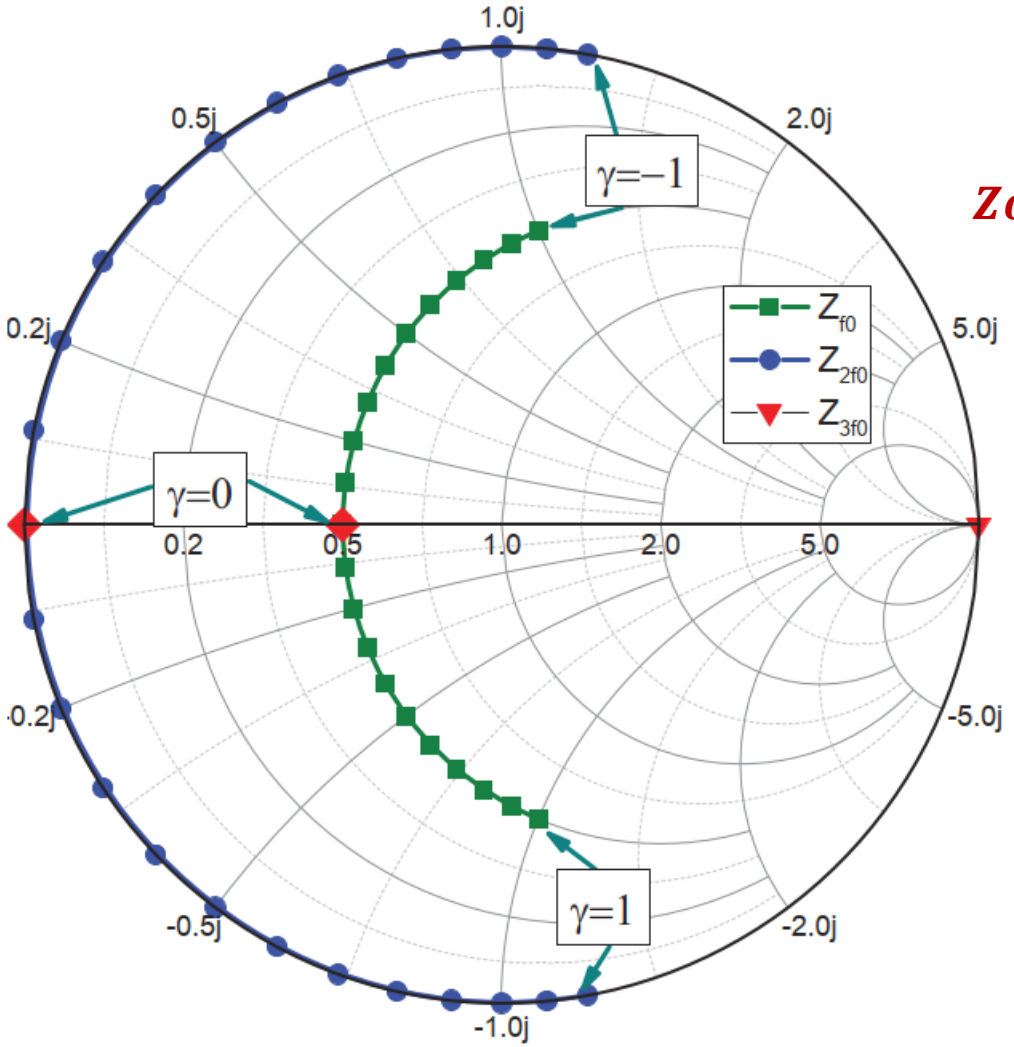
Push-pull class AB





$$Ropt = \frac{Vdd - Vknee}{Imax}$$

Simple theory : ‘Continues’ Class Mode



$$Zopt = (1 - j * \gamma) * Ropt$$

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

$$Zopt\_2h = (0 - j * a * \gamma) * Ropt$$

- The key design point is realize reactive second harmonic impedance

Push-pull and single ended architectures

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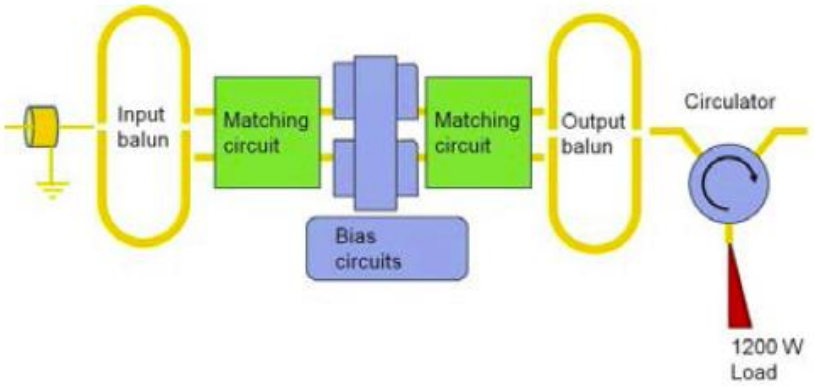
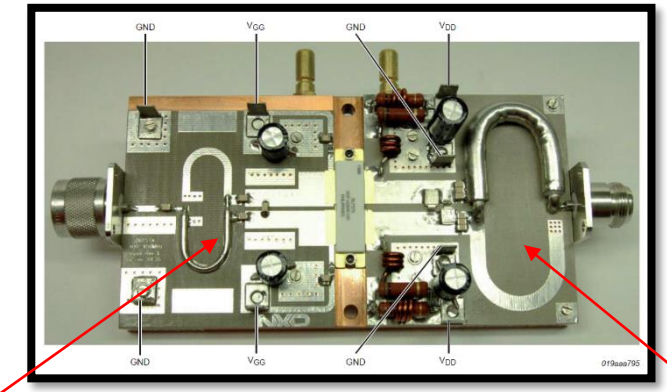
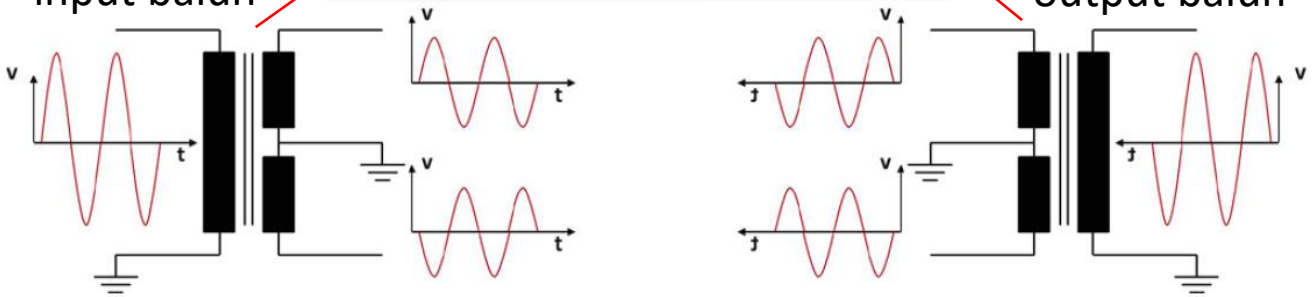
Push-pull



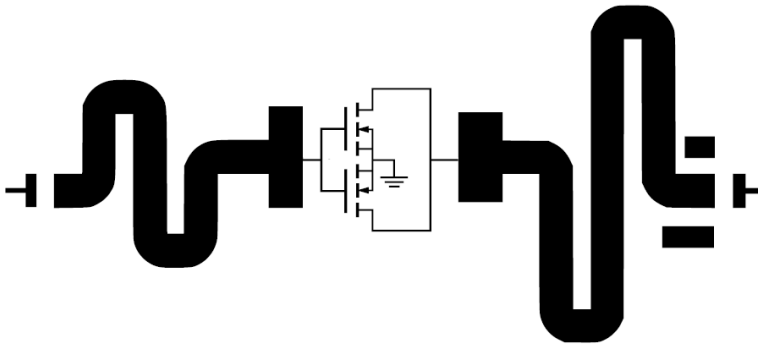


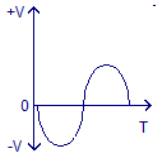
input balun

output balun

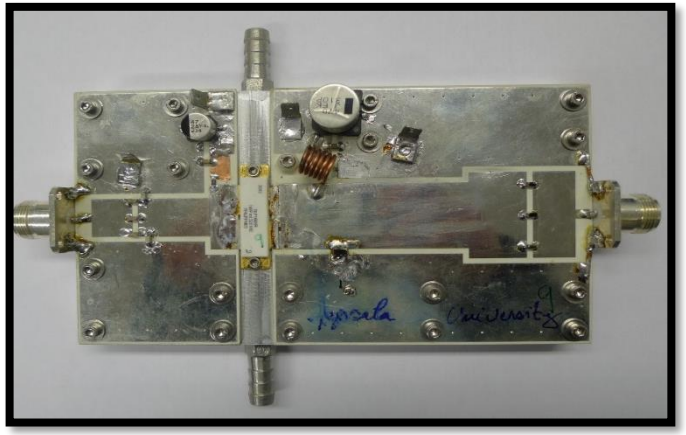


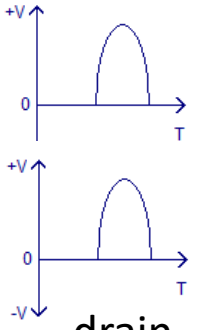
Single Ended (resonant output network)



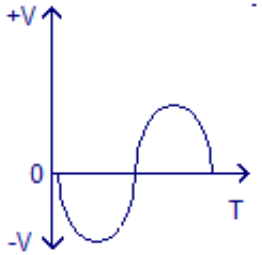


input voltage



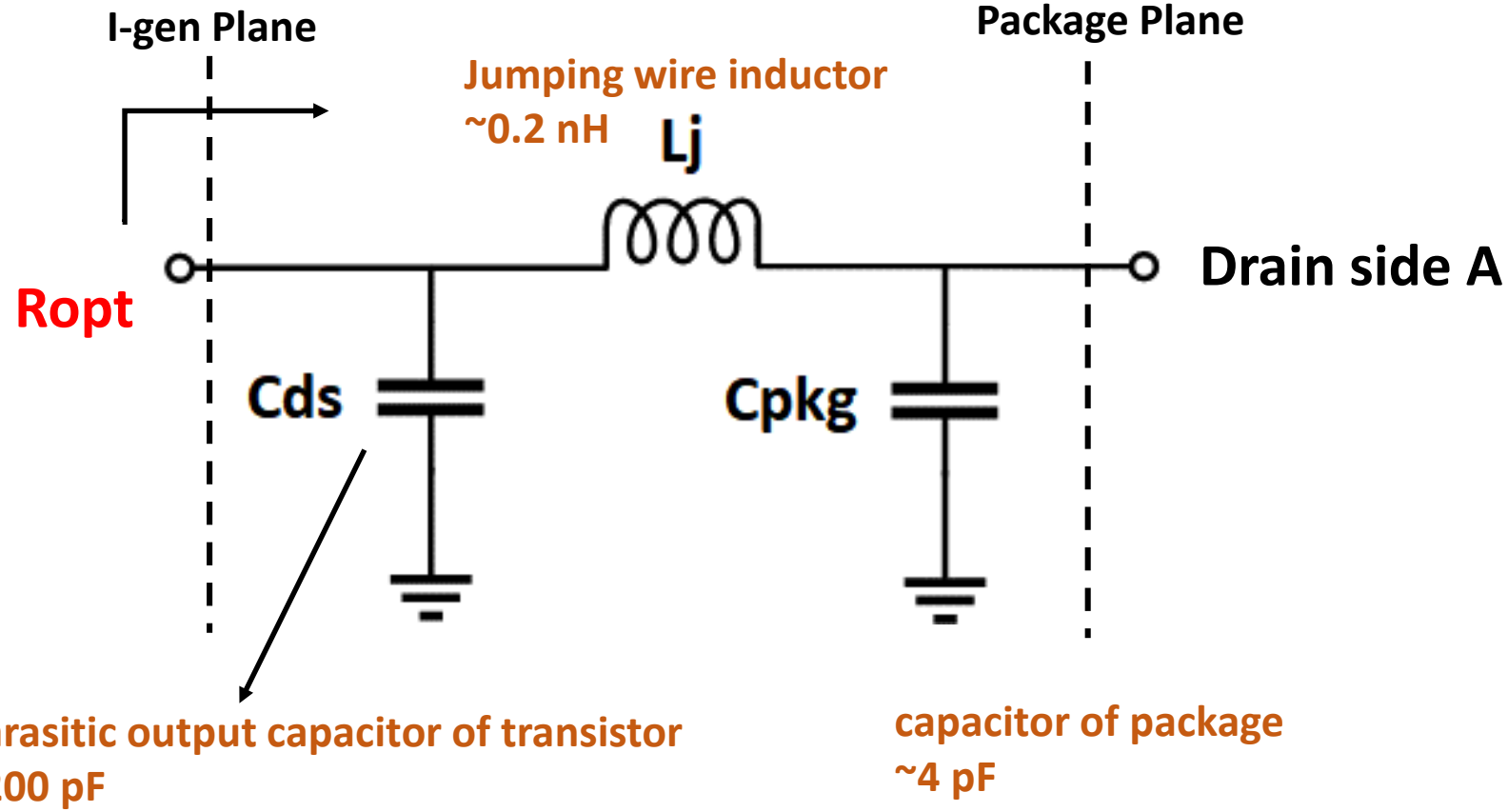


drain voltage

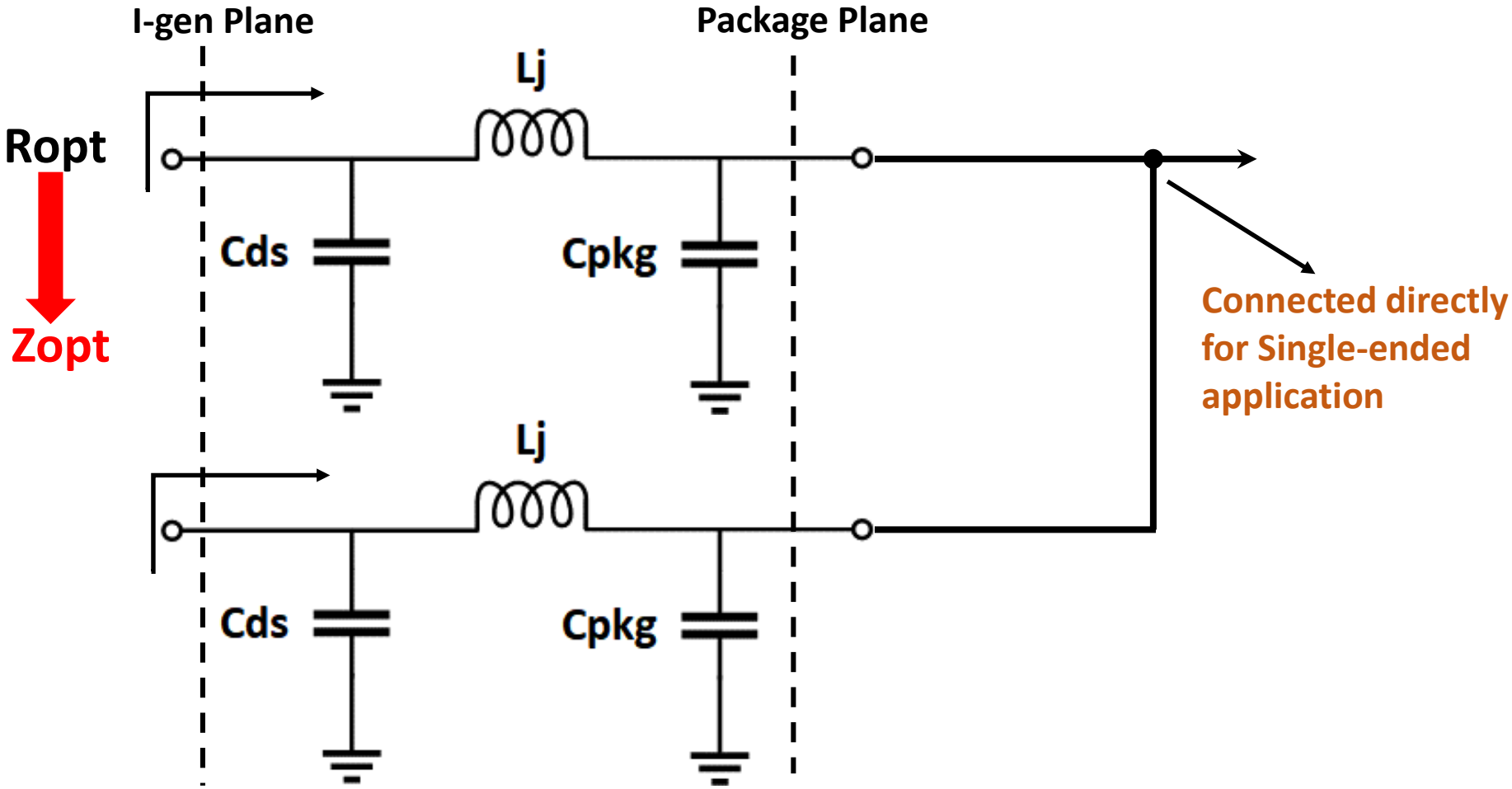


output voltage

Simple output linear model

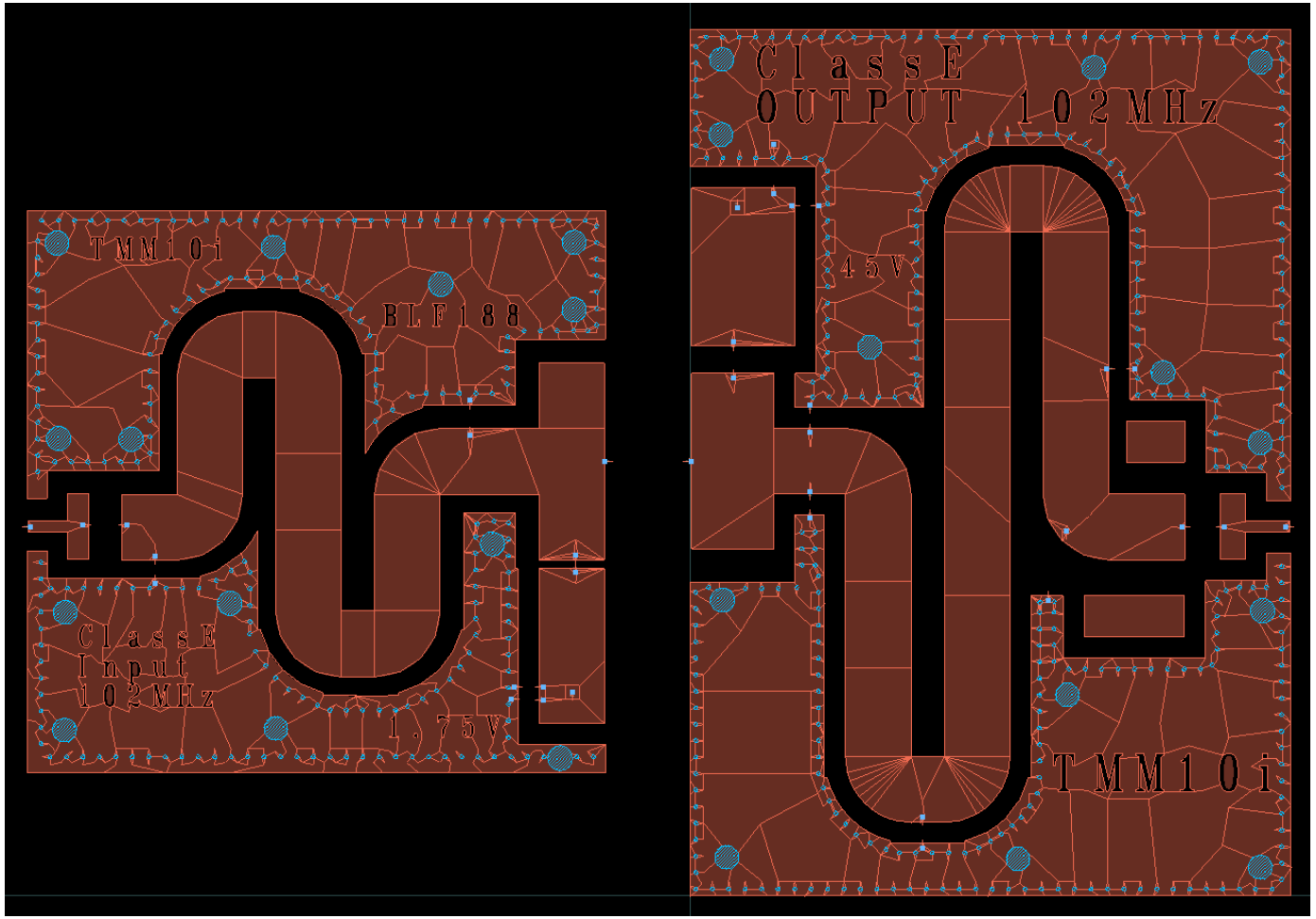


Simple output linear model



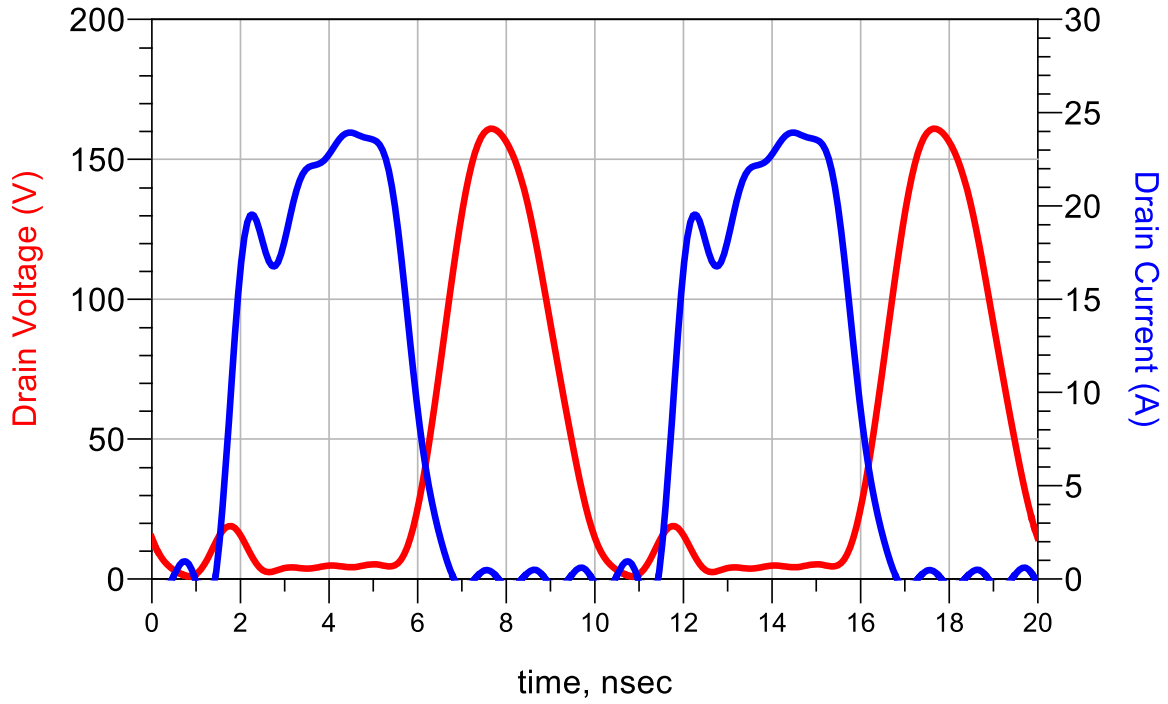
Final layout with EM Simulation

Finalized layout with mesh

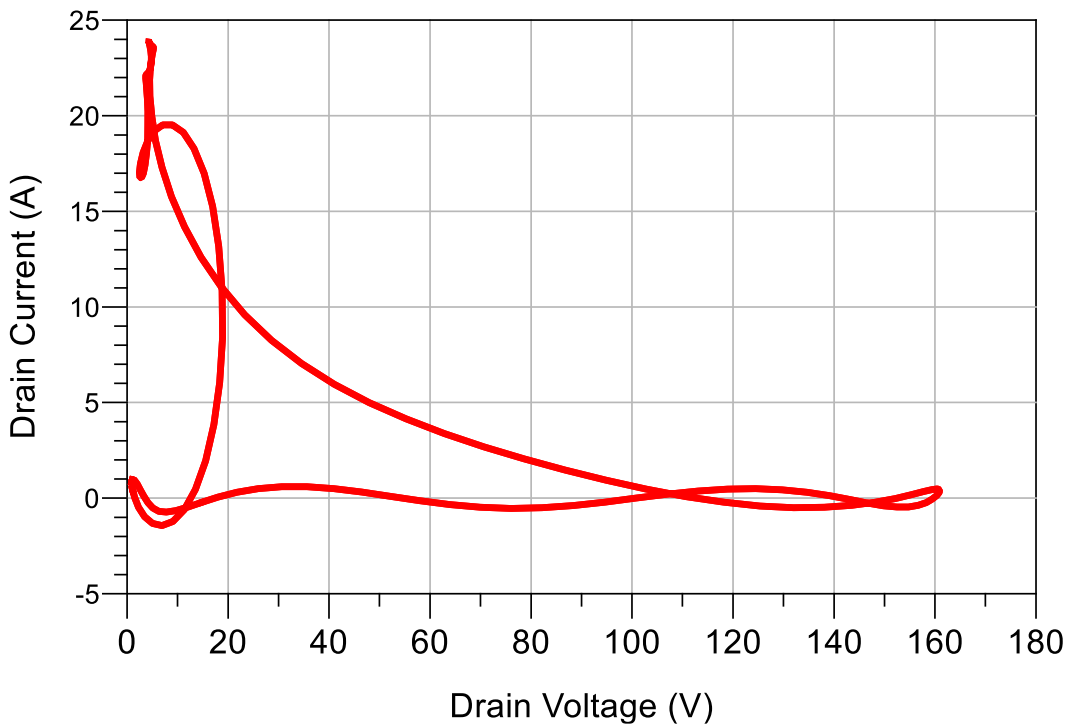


Harmonic Simulation

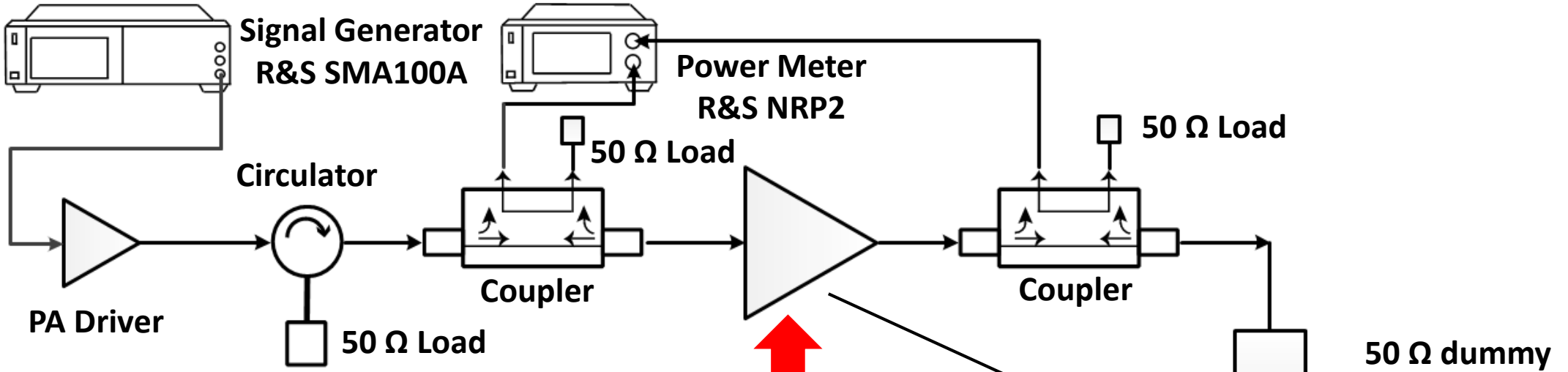
Waveform at transistor's I-gen plane



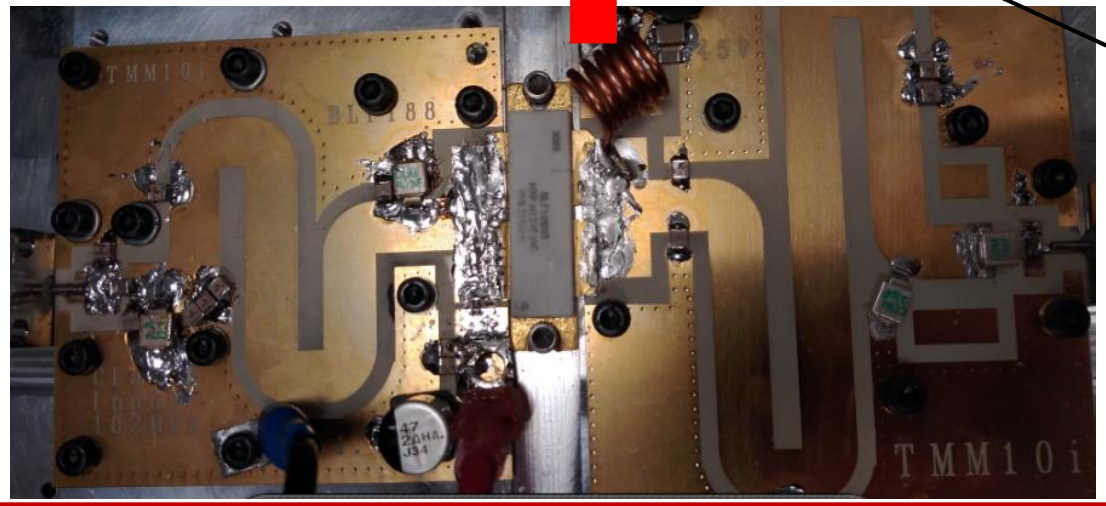
Load-line Curve



Work Prototype for Measurement



Finalized design



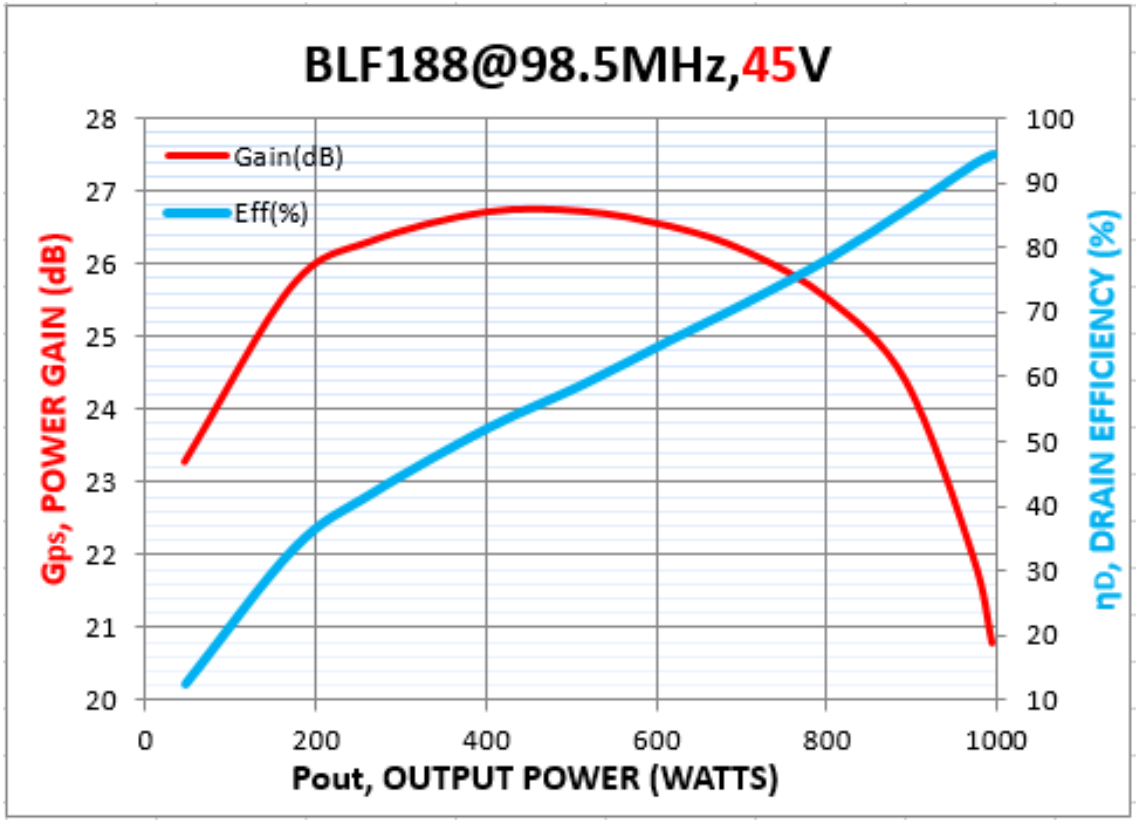
Frequency Sweep

Vdd = 45V, Idq= 200mA

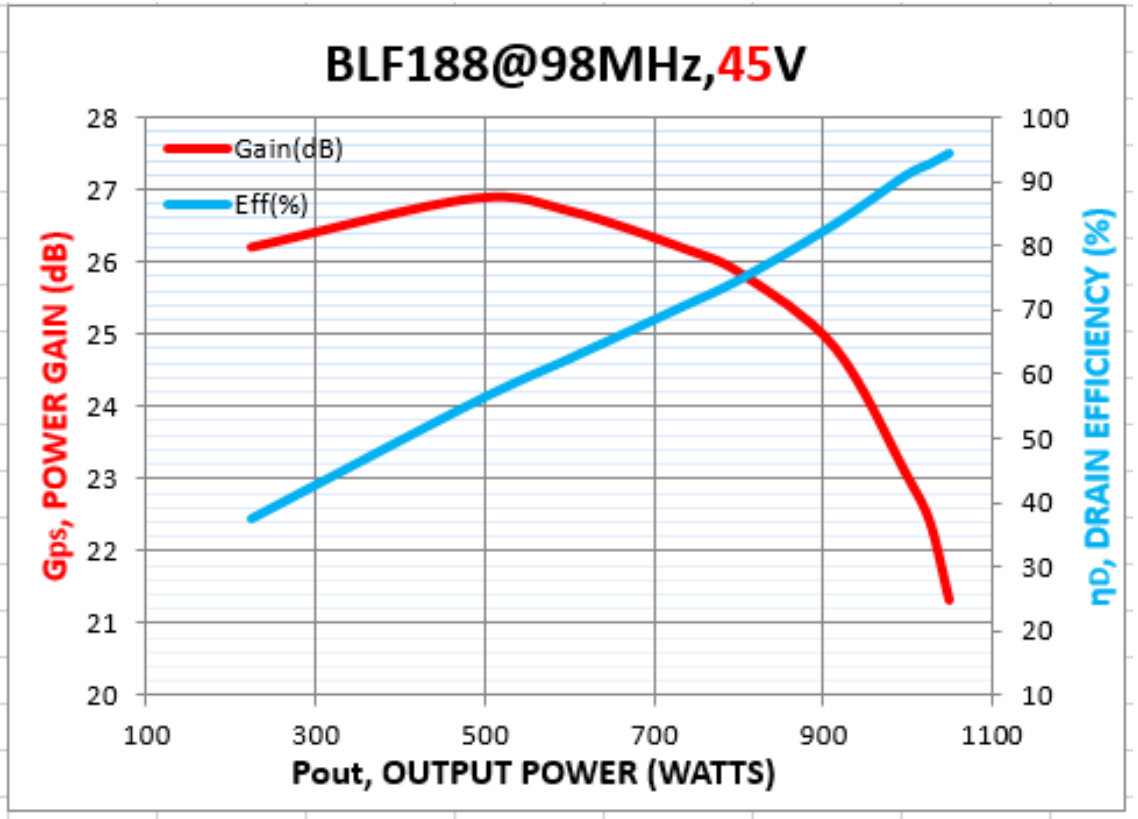
Signal:
Pulse Periods: 3.5 ms
Pulse Width: 70 ms

Freq_MHz	Pin_dBm	Pout_dBm	Pout_W	Gain_dB	Eff
100	38.444	58.569	719.32	20.125	80.187
99	37.94	59.489	889.1	21.549	88.656
98.5	37.947	59.894	975.99	21.947	93.137
98	37.816	60.096	1022.4	22.28	92.606
97.5	37.703	60.187	1044.1	22.484	89.689
97	37.602	60.236	1055.8	22.634	85.556

Measured Results



Eff = 92% @ Pout= 980Watts



Eff = 93% @ Pout= 1020Watts

Frequency Sweep

Vdd = 50V, Idq= 500mA

Freq_MHz	Pin_dBm	Pout_dBm	Pout_W	Gain_dB	Eff
99	38.096	60.061	1014.2	21.965	81.016
98	37.705	60.819	1207.4	23.114	86.546
97	37.602	61.116	1292.9	23.514	83.038

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.