University of BRISTOL

A 2GHz GaN Class-J Power Amplifier for Base Station Applications

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Outline

- PA designer targets
- Traditional approaches
- Introduction to Class-J
- Design methodology
- Realization and measurements
- Conclusions

Main drivers

- **GREEN**
  - Environmental concerns
  - Operational expenses
- **SIMPLE**
  - Deployment costs
  - Maintenance
- **FAST**
  - User experience

In PA words

- **Efficiency**
- **Linearity**
- **Bandwidth**

Which one is more important?

Traditional approaches

- Power Amplifier
  - Linear amplifiers
  - Switching amplifiers
  - Harmonically tuned
- System level
  - Doherty
  - Envelope Elimination & Restoration (EER)
  - Envelope tracking (ET)
  - Digital Pre-distortion

Combinations

Class J theory (1)

- Recently introduced – explains widely observed results
- Under harmonically tuned category (up to second harmonic)
- Better control of trade-offs
- Highly efficient
- Quasi-linear
- Super-set of Class-B operation

GREEN

SIMPLE

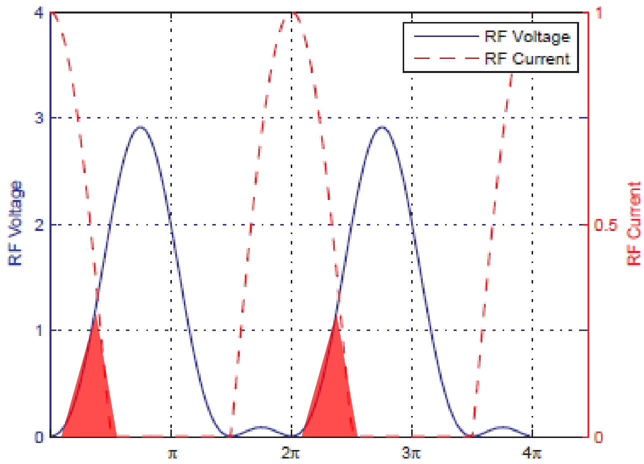
WIDEBAND

Class J theory (2)

- Biased as Class-B, deep AB
- Second harmonic not shorted (purely reactive)
- Complex fundamental impedance
- No "knee" voltage crossing occurs
- Same efficiency/output power as Class-B
- Large drain voltage swing almost 3x supply voltage

$$Z_{fo} = 1.4142\angle 45°$$

$$Z_{2fo} = 1.1781\angle -90°$$



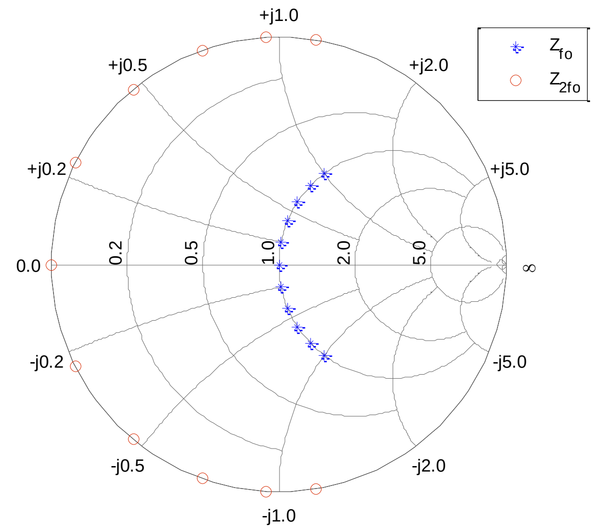
Class J theory (3)

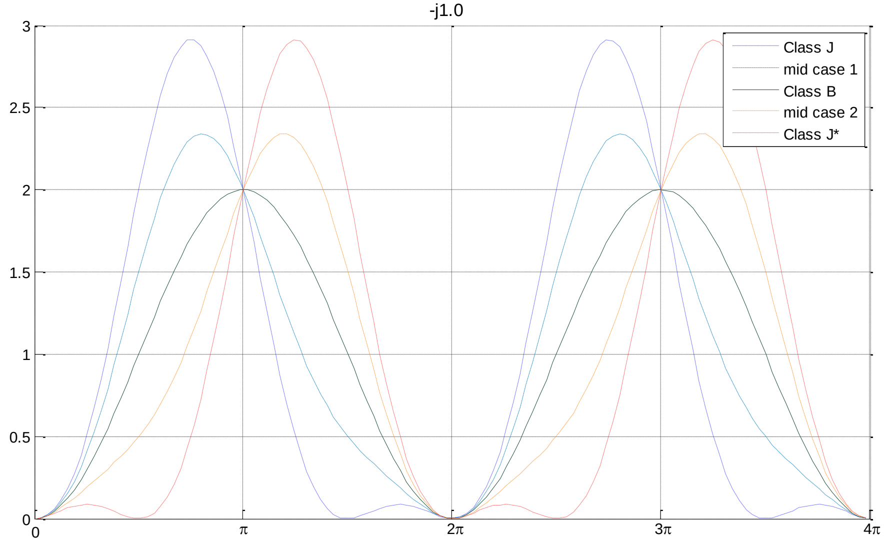
- Design space is continuous
- All cases have same efficiency/output power

$$Z_{fo} = \frac{\pi\sqrt{1+d^2}(1-\cos\frac{\alpha}{2})}{a-\sin\alpha}\angle \operatorname{atan}\left(-\frac{1}{d}\right)+\varphi$$

$$\varphi = \begin{cases} \frac{\pi}{2}, & d \geq 0 \\ -\frac{\pi}{2}, & d < 0 \end{cases}$$

$$Z_{2fo} = \frac{d}{2}\,\frac{\pi(1-\cos\frac{\alpha}{2})}{\sin\frac{\alpha}{2}-\frac{1}{3}\sin\frac{3a}{2}}\angle -\frac{\pi}{2}$$





• Methodology

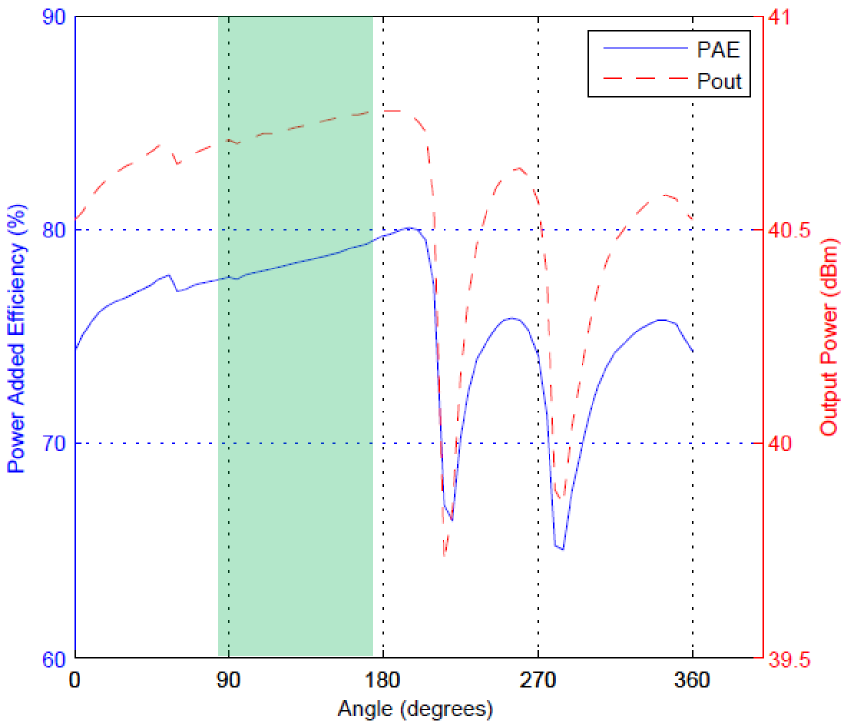
- Large signal transistor model
  - 10W GaN HEMT device
- Transistor extrinsic parasitics model
  - Linear output capacitance
- Class J theory
  - Impedances at the intrinsic drain

1. Deep Class - AB biasing
2. Determine appropriate load-line
3. Intrinsic drain impedances based on theory
4. 3rd output harmonic impedance
5. Source-pull for efficiency/gain
6. Observe intrinsic drain waveforms
7. Design matching networks

• 3rd output harmonic

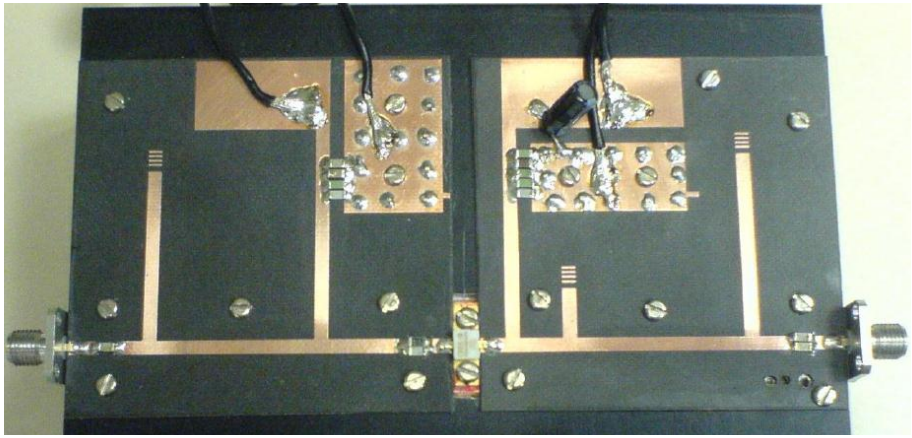
- Class J theory defines fundamental and second harmonic terminations
- Class B biasing assumed
- Perfect half-rectified sine wave drain current (no 3rd harmonic)

IN PRACTICE?

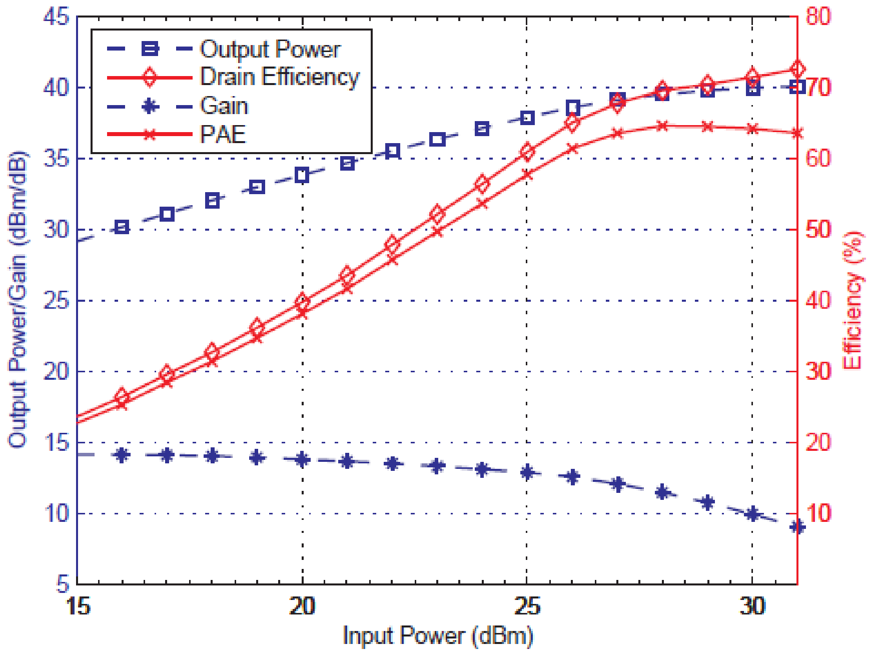


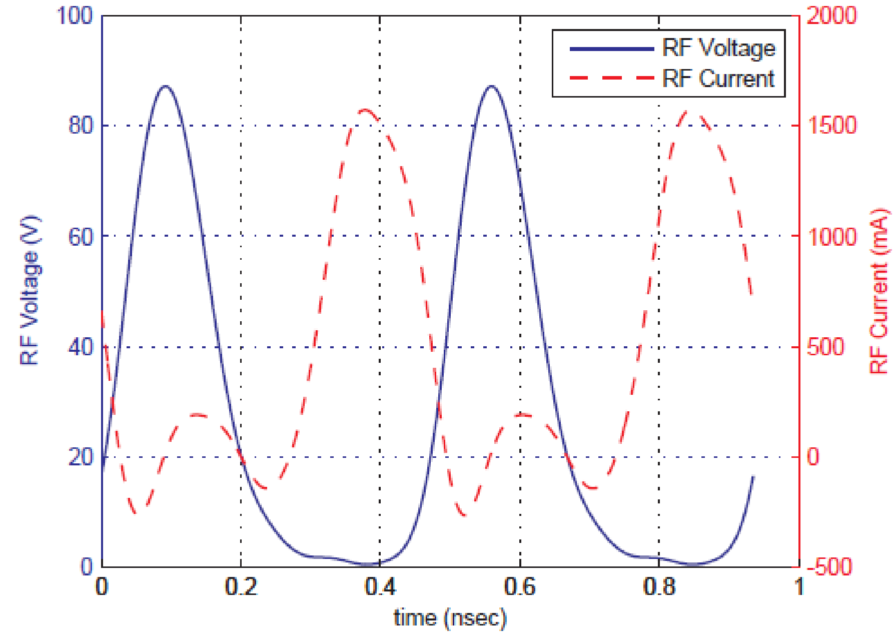
• PA realisation

- Input stabilization network
- Harmonic control
  - Two at the input
  - Three at the output
- RT-Duroid 8550 substrate
  - E_r = 2.2
  - T = 0.787 mm
- Fully distributed architecture
- Size : 13.5 x 6.5 cm

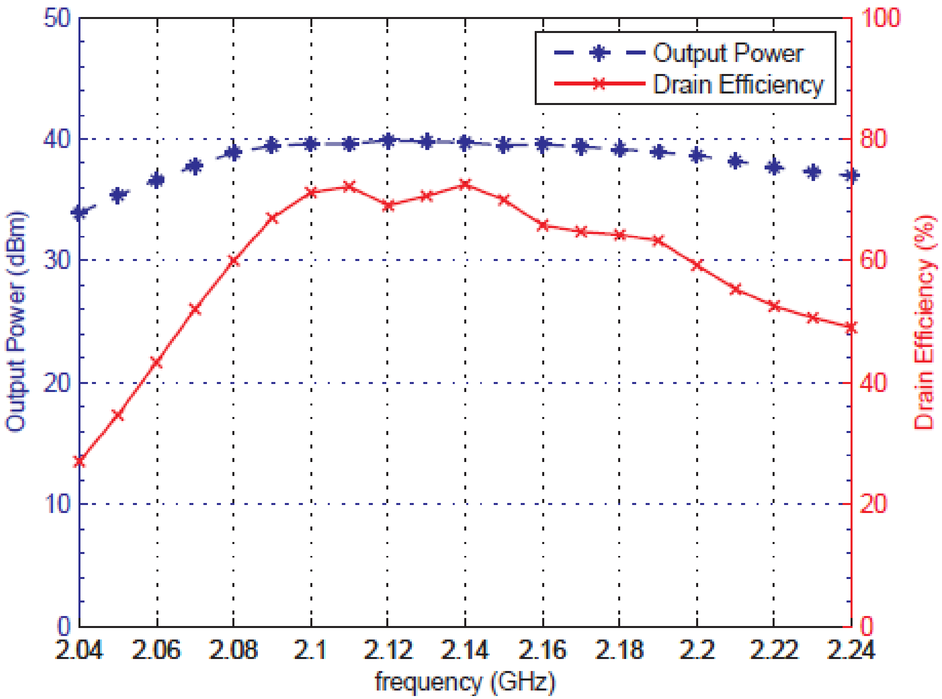


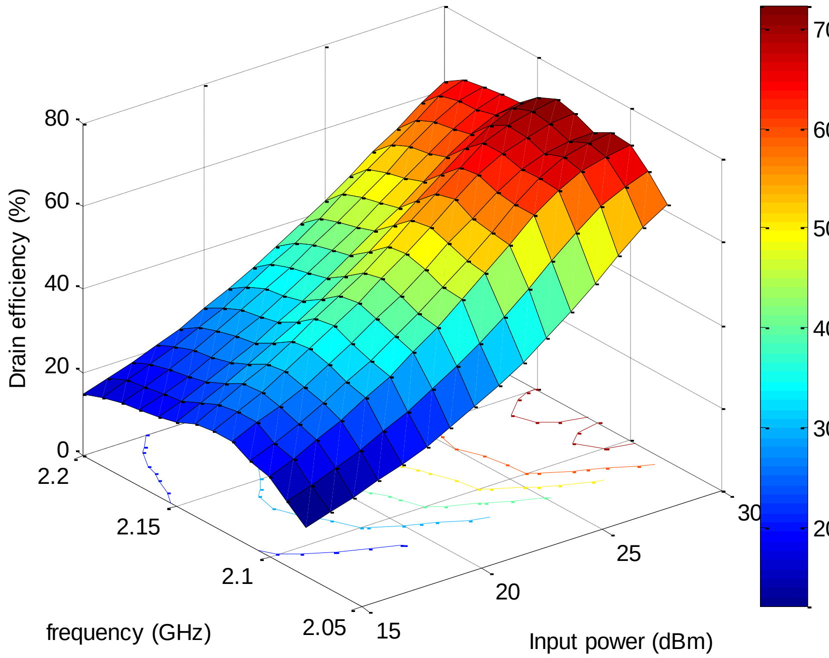
• Input power sweep



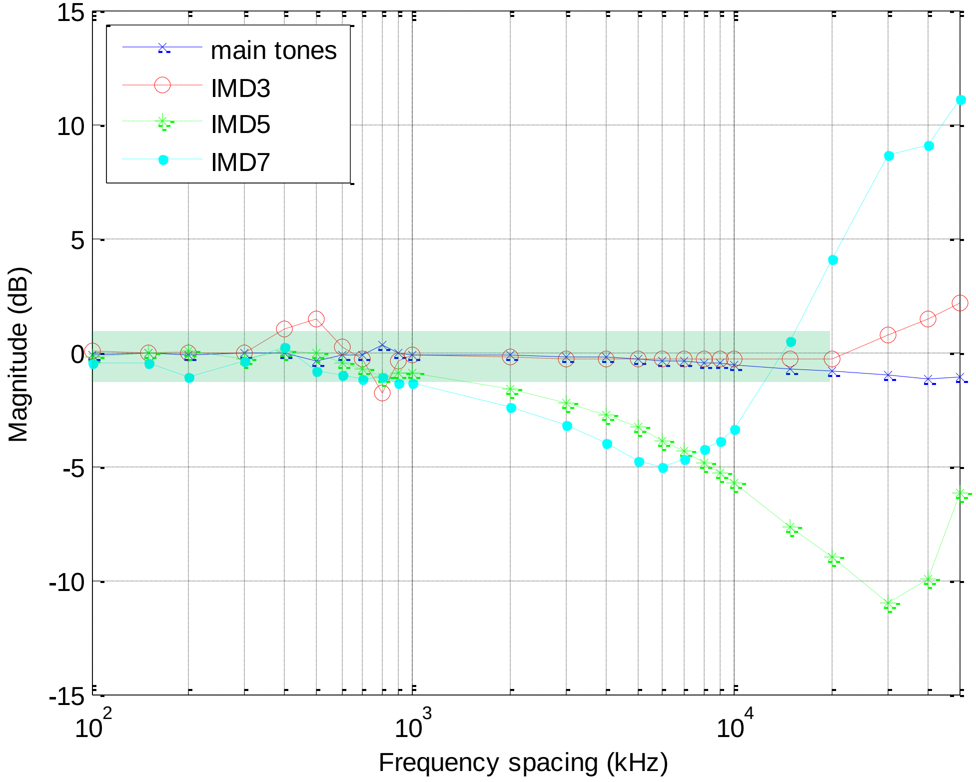


• Over frequency



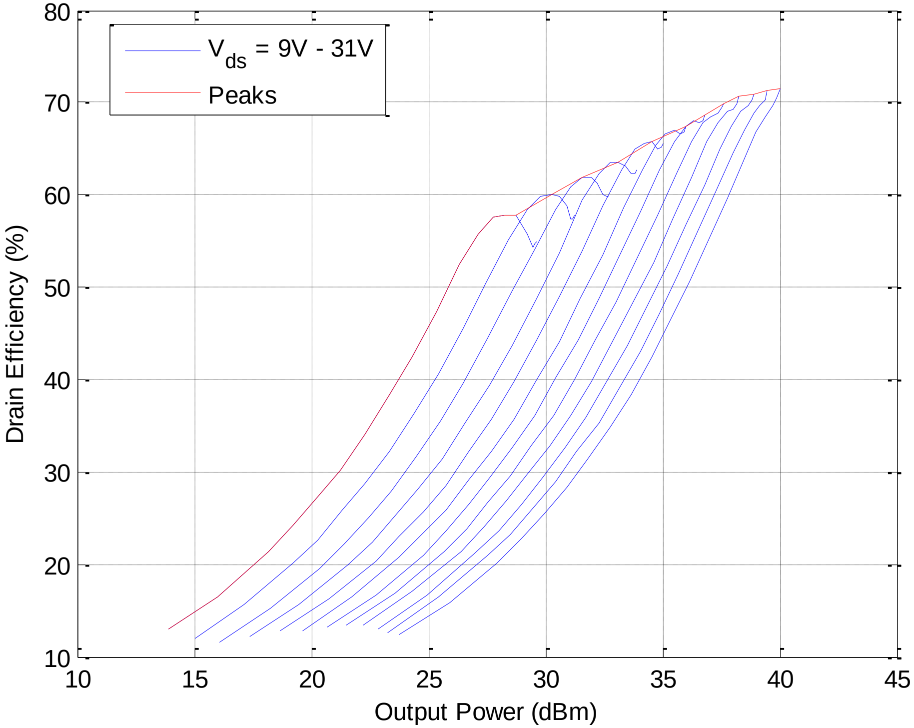


• Two tone measurements



- Typical measure of memory effects
- Asymmetry between upper/lower channels
- Each tone 24dBm
- Variable spacing (100kHz-50MHz)
- Low memory effects up to 20MHz

• Variable V_{DS}



- Good potential under ET/EER
- V_{DS} can go lower (approx. 4-5V)
- 15dB output power back-off
- Modulator efficiency

Conclusions

- New tool for management of efficiency/linearity/bandwidth tradeoffs
- More freedom in PA design / no need for harmonic short
- Theory and extrinsic parasitic model is sufficient
- 3rd harmonic is important
- Low memory effects
- Very promising for ET/EER implementations

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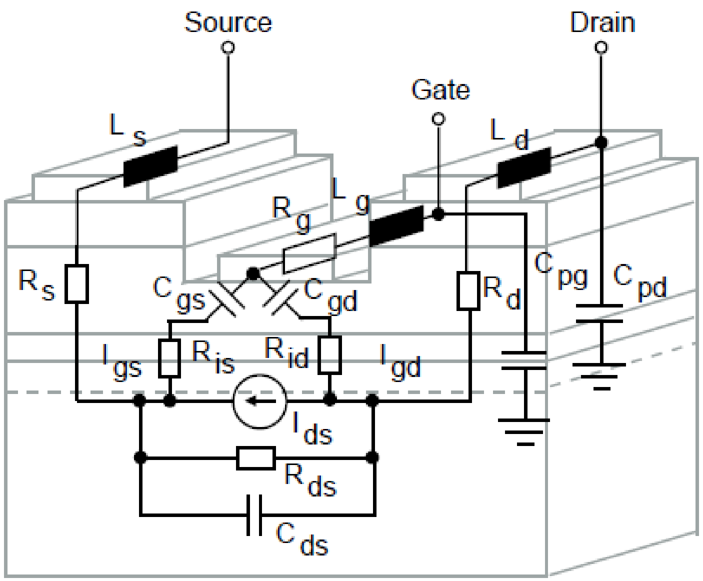
Thank You

QUESTIONS?

APPENDIX

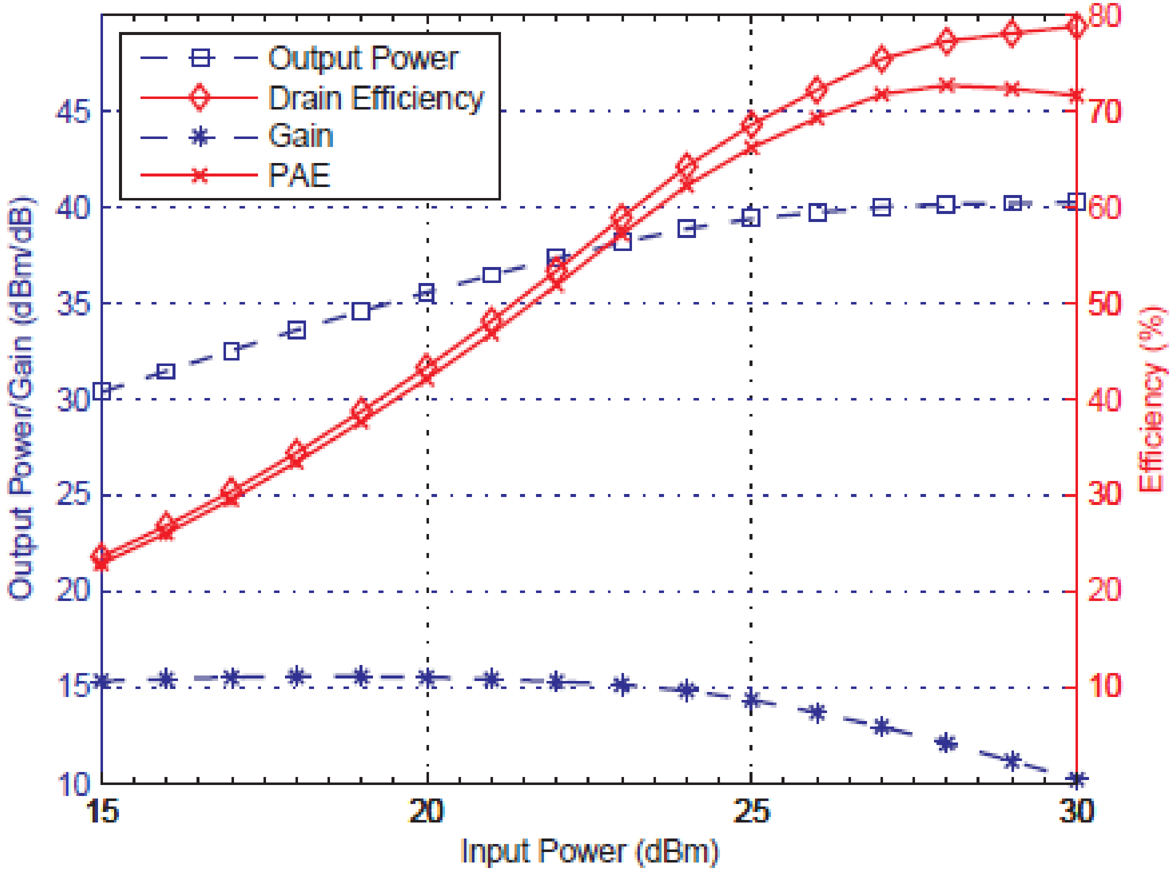
HEMTs

- Current generator plane is of interest
- C_{ds} is important
- An appreciation of parasitics is needed
- Package contribution is dominant



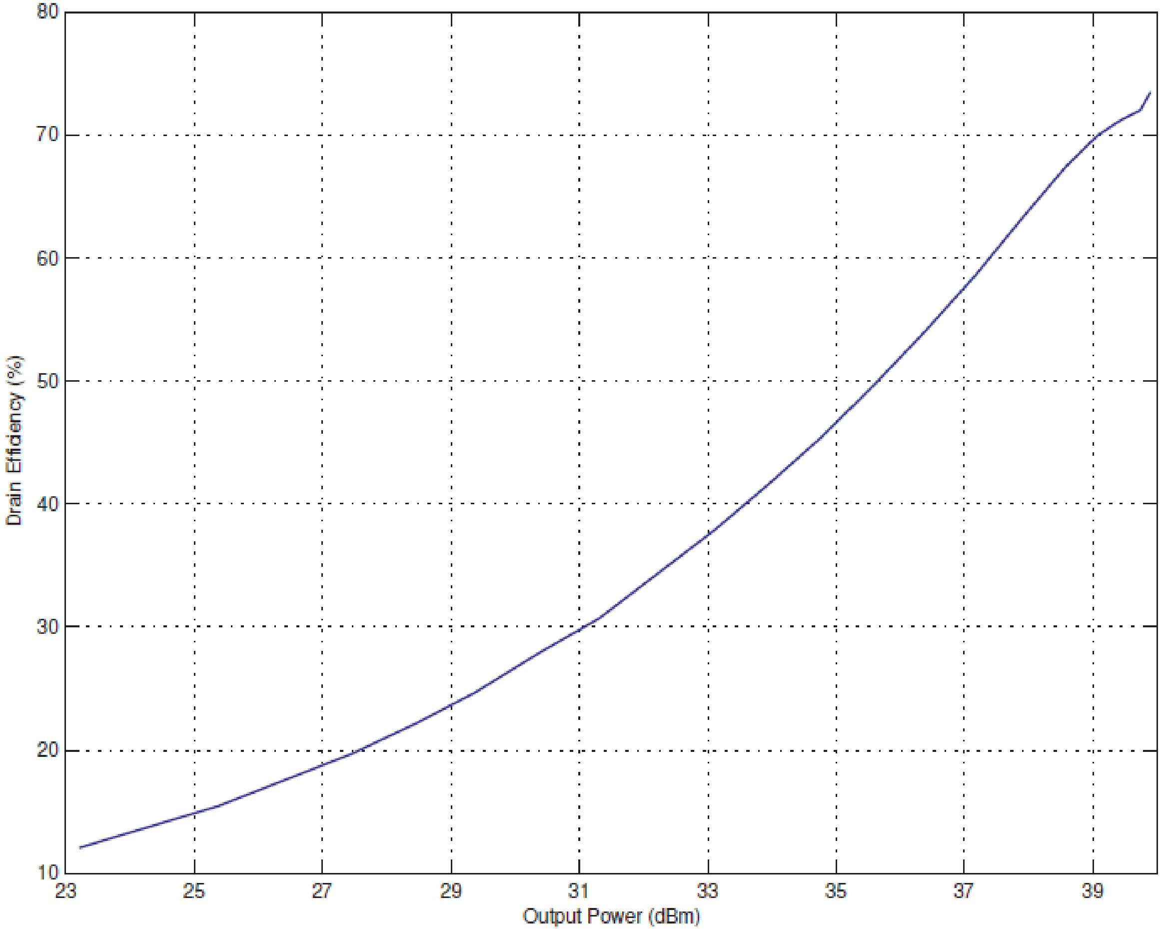
APPENDIX

simulation results



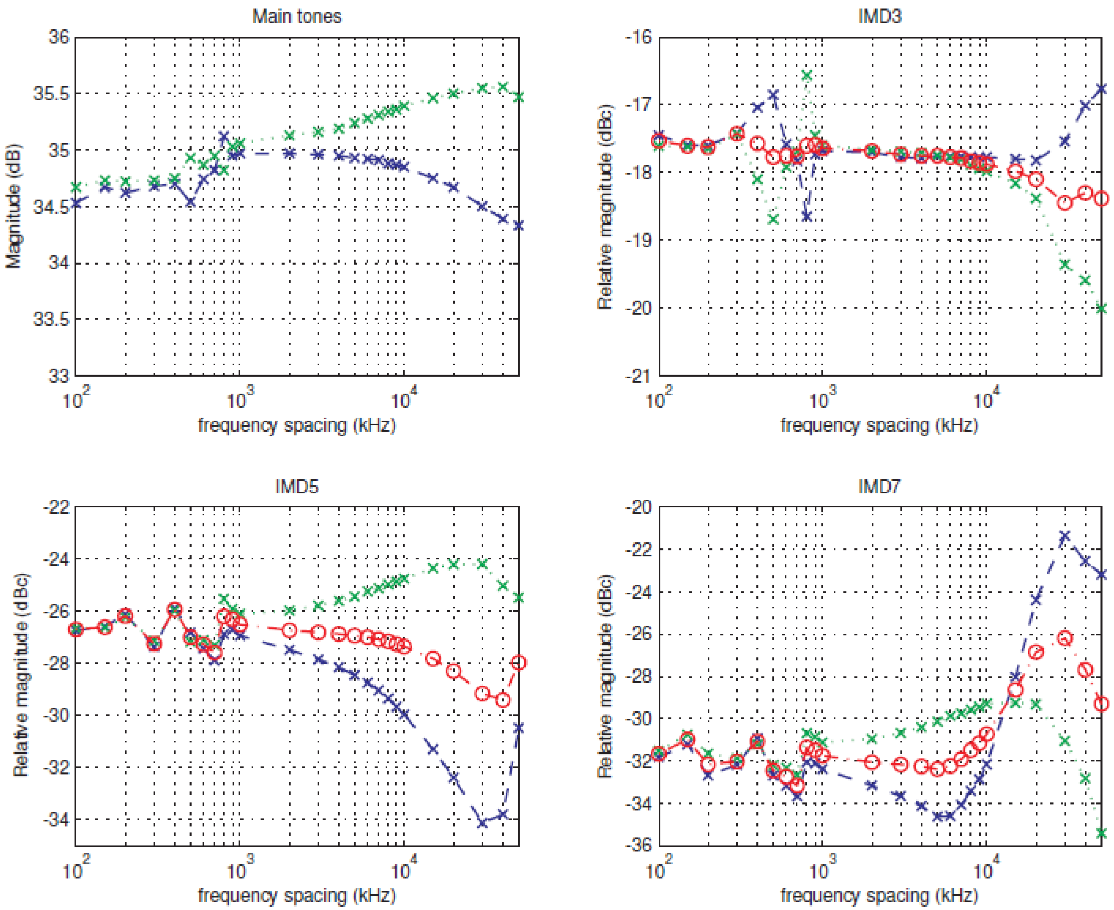
APPENDIX

measured efficiency over P_{out}



APPENDIX

two tone measurements (24dBm)



APPENDIX

two tone measurements (4MHz spacing)