A 60-W L-Band Class-E/$F_{odd,2}$ LDMOS Power Amplifier Using Compact Multilayered Baluns

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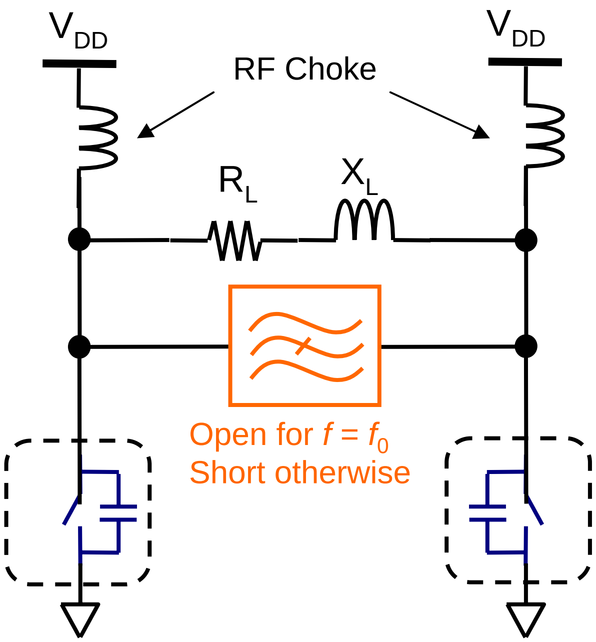
Introduction

- Switching-mode amplifiers are promising candidates for high-efficiency applications with limited bandwidth and linearity.
- Class-E/F power amplifier combines soft-switching of Class-E amplifiers and harmonic control of Class-F^{-1} amplifiers
- This amplifier is designed for a JPL L-band space-radar application which requires
  - High Efficiency
  - Compact size, light-weight, and planar geometry
- Agenda
  - Push-Pull Class-E/F Power Amplifiers
  - Microstrip Balun Design
  - Measurement Results and Conclusion

S. Kee, *et al*. "The Class-E/F Family of ZVS Switching Amplifiers." *IEEE Trans. Microwave Theory Tech.*, June 2003.

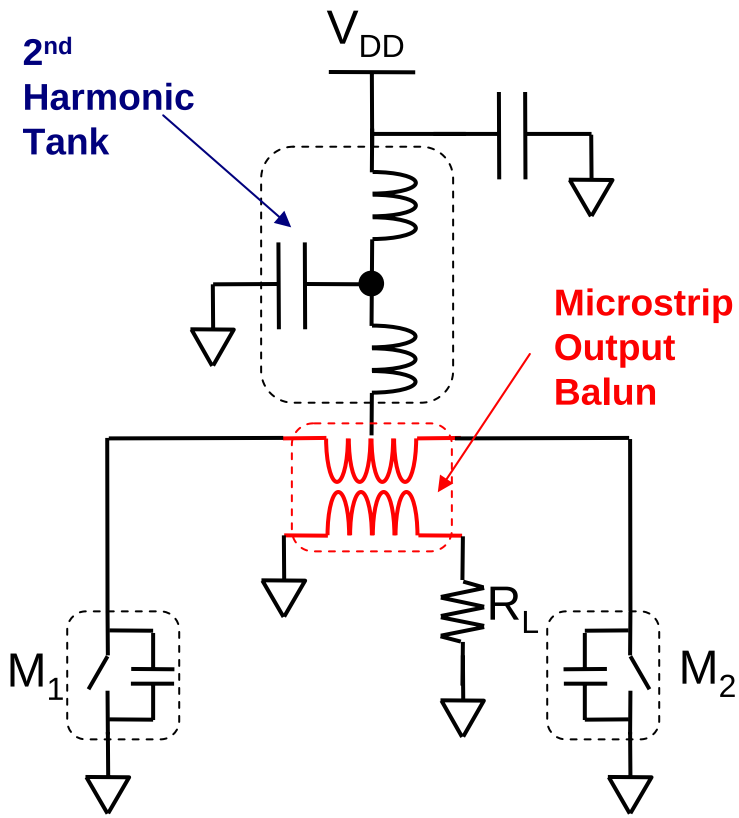
Push-Pull Class-E/F_{odd} Family of Amplifiers



- Theory of Operation:
  - Two transistors operated as two switches in a push-pull pair.
  - High-impedance resonant circuit at the fundamental frequency between the switches.
  - The load is tuned slightly inductive to achieve zero-voltage switching (ZVS).
  - Terminate odd harmonics due to the push-pull configuration.
- Combines the advantages of Class-E Amplifier and Class-F^{-1} Amplifier
  - Zero-Voltage Switching
  - Low Peak Voltage
  - Low RMS Current
  - Simple and Compact

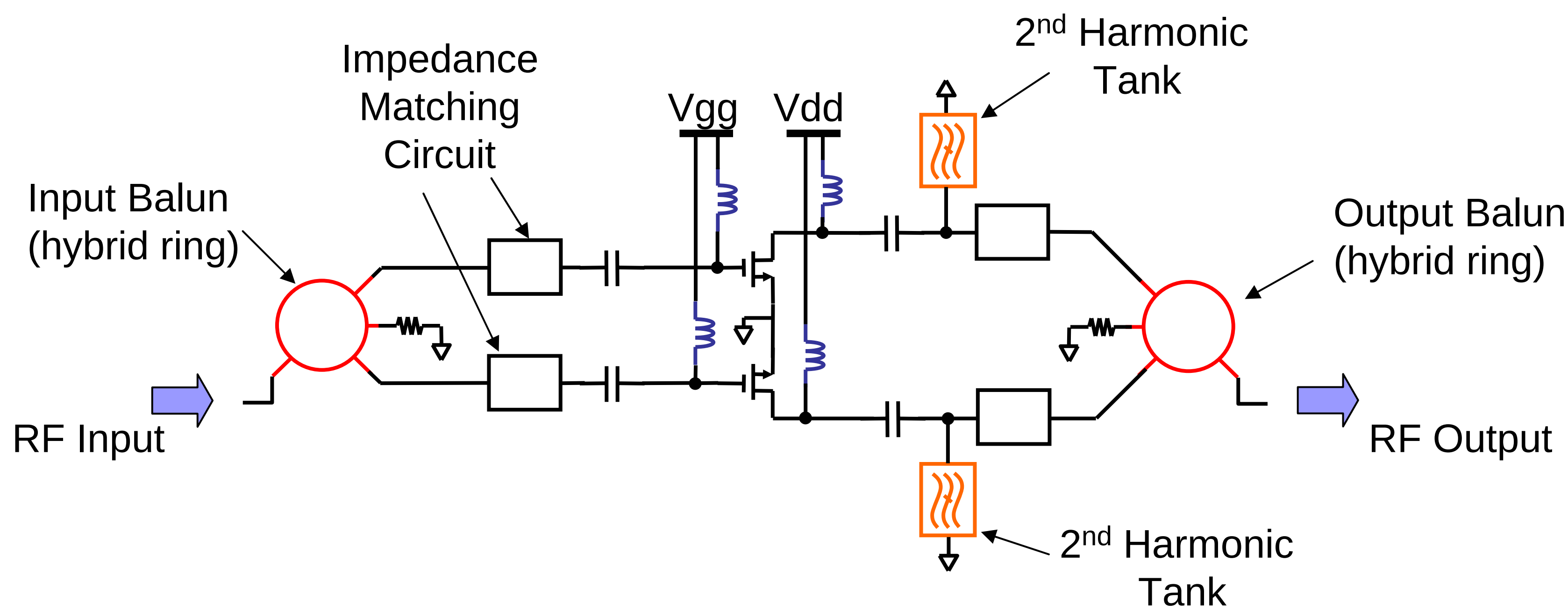
Kobayashi, H., Hinrichs, J.M., Asbeck, P.M. "Current-Mode Class-D Power Amplifiers for High-Efficiency RF applications." *IEEE Trans. Microwave Theory Tech*, Dec. 2001.

Push-Pull Class-E/$F_{odd,2}$ Power Amplifier



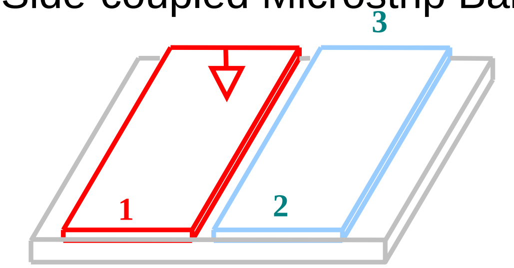
- The drain bias line is used as an additional 2nd harmonic tank, which shapes the waveform to achieve low RMS current.
- Requires input and output baluns for coaxial input and output.
  - Compact
  - Low-loss
  - Planar geometry

A Typical Push-Pull Amplifier Design

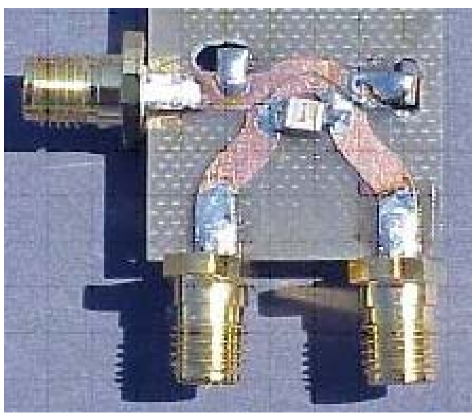


Microstrip Baluns

Side-coupled Microstrip Balun



1 cm

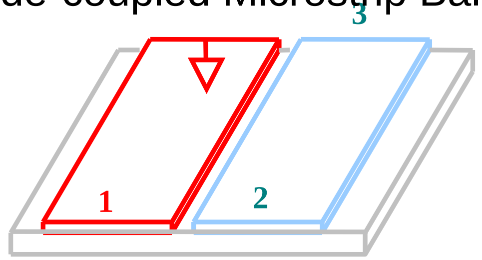


- Traditional microwave baluns such as hybrid rings are large in size at 1 GHz.
- Microstrip Balun
  - Use two short sections of transmission lines as two magnetically coupled inductors
  - One port of the secondary inductor is grounded
- Advantages
  - Low loss, compact and planar
- Disadvantage
  - Low coupling coefficient: k~0.35

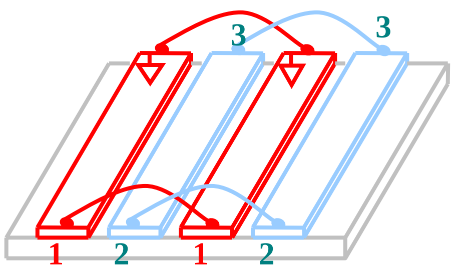
King-Chun Tsai, Paul Gray. “A 1.9-GHz, 1-W CMOS Class-E Power Amplifier for Wireless Communications.” *IEEE J. Solid-State Circuits*, July 1999.

Tightly-Coupled Microstrip Baluns

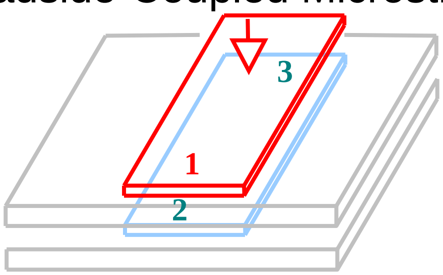
Side-coupled Microstrip Balun



Interdigitated Microstrip Balun



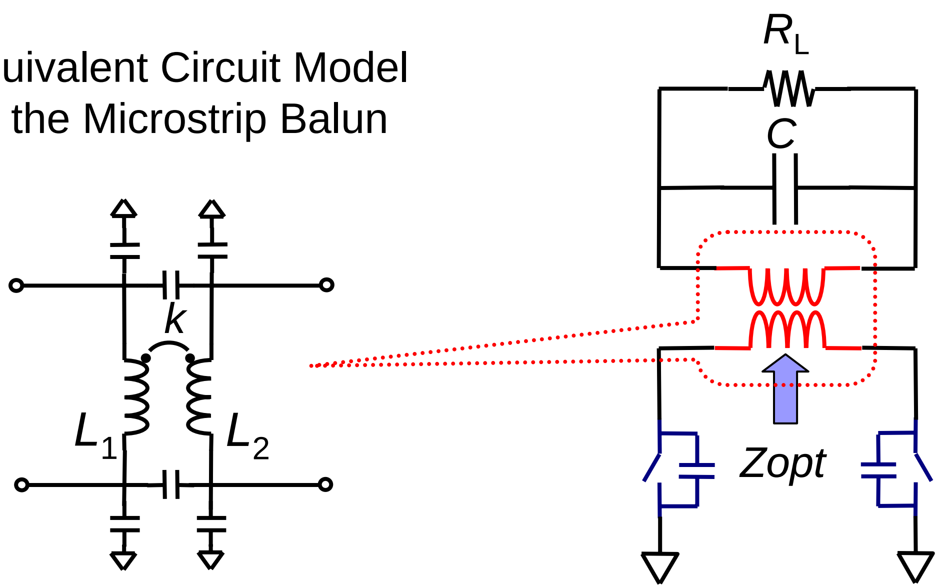
Broadside-Coupled Microstrip Balun



- To achieve tight coupling, interdigitated microstrip baluns and broadside-coupled microstrip baluns may be used.
- Coupling coefficients of different microstrip baluns
  - Side-coupled: k~0.35
  - Interdigitated: k~0.50
  - Broadside-coupled: k~0.70
- Simulated Loss of the balun is 5.2%
  - 2.6% in the copper
  - 2.6% in the capacitors

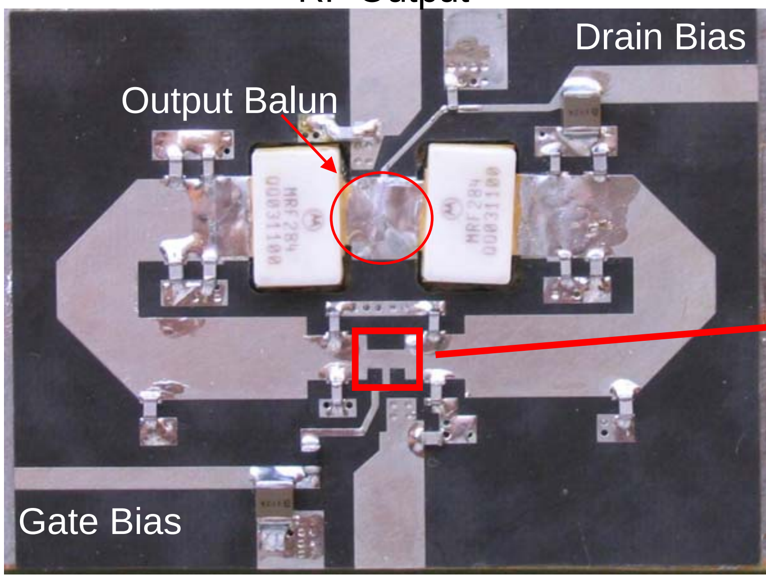
Impedance Transformation

Equivalent Circuit Model
for the Microstrip Balun

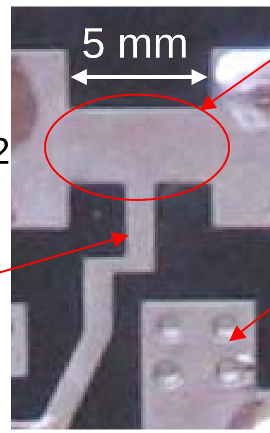


- Substitute in the equivalent circuit model of the balun and analyze the optimum impedance seen by the switches.
- The geometry of the balun is optimized based on the discrete inductance and capacitance values
- Electromagnetic simulator, SONNET, was used for the design.

Power Amplifier Photo

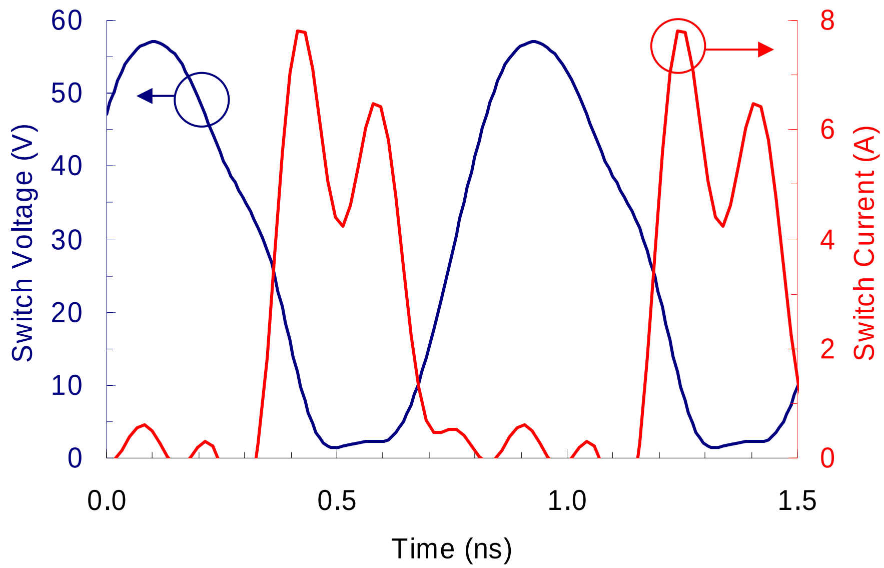


Input Balun



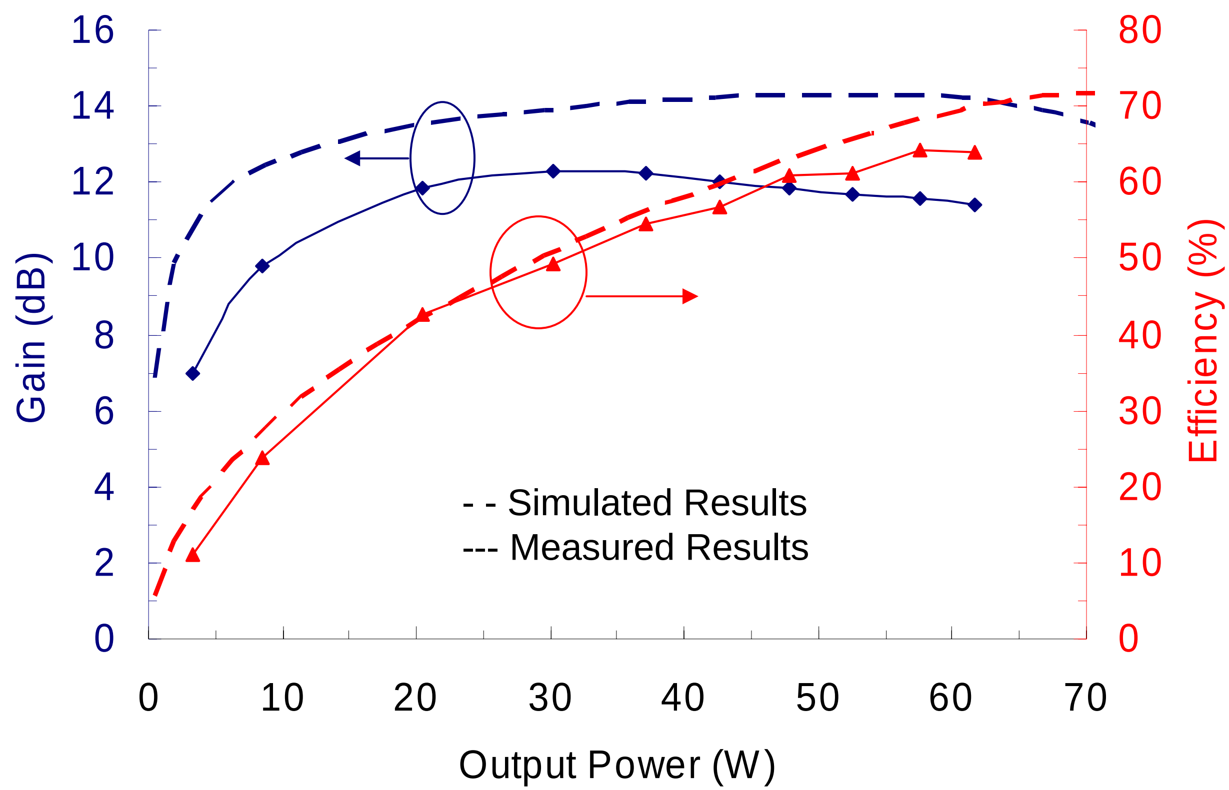
- Transistor used: Motorola LDMOS MRF 284
- Built on a Duroid substrate with a dielectric constant of 2.2
- Size: 3.5 cm x 5 cm

Simulated Class-E/$F_{odd,2}$ Waveforms



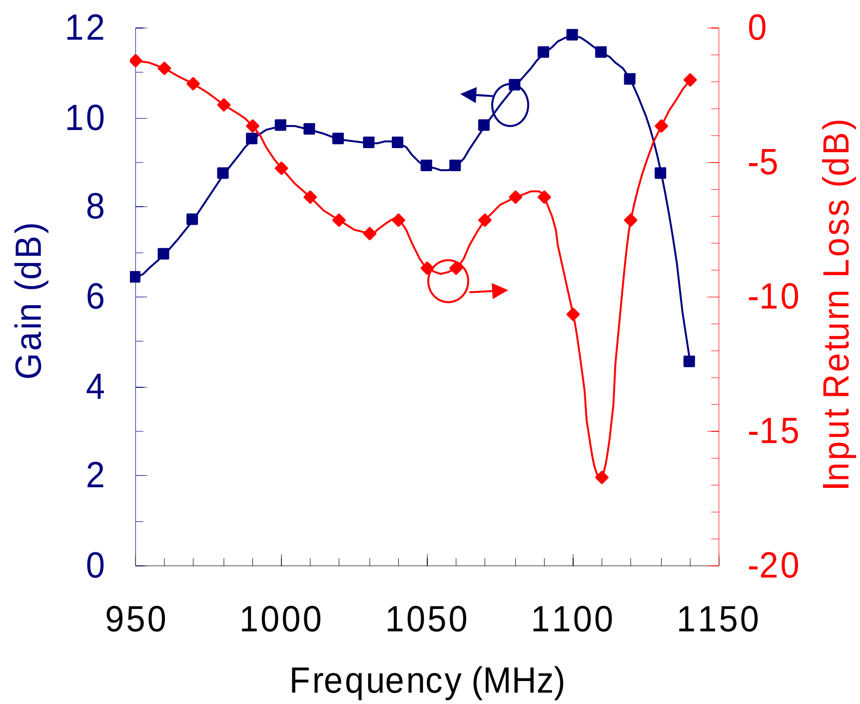
- The voltage waveform is nearly a half sinusoid.
  - Reduce the peak voltage compared with a Class-E amplifier
- The current waveform is a relatively square shape.
  - Reduce the RMS current compared with a Class-E amplifier

Gain and Efficiency



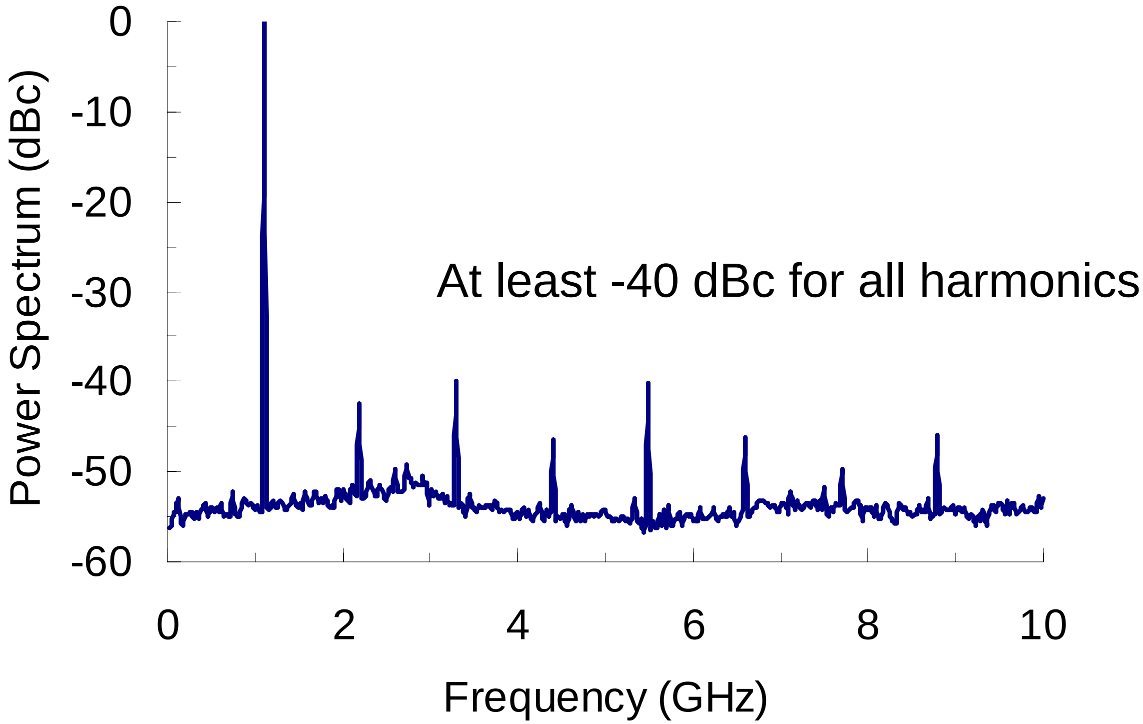
- At 1100 MHz, Pin = 4W, Vdd = 32V, Vgg = 2V
- Drain Efficiency = 70%, PAE = 65%, Gain = 11 dB, Pout = 60W

Frequency Response



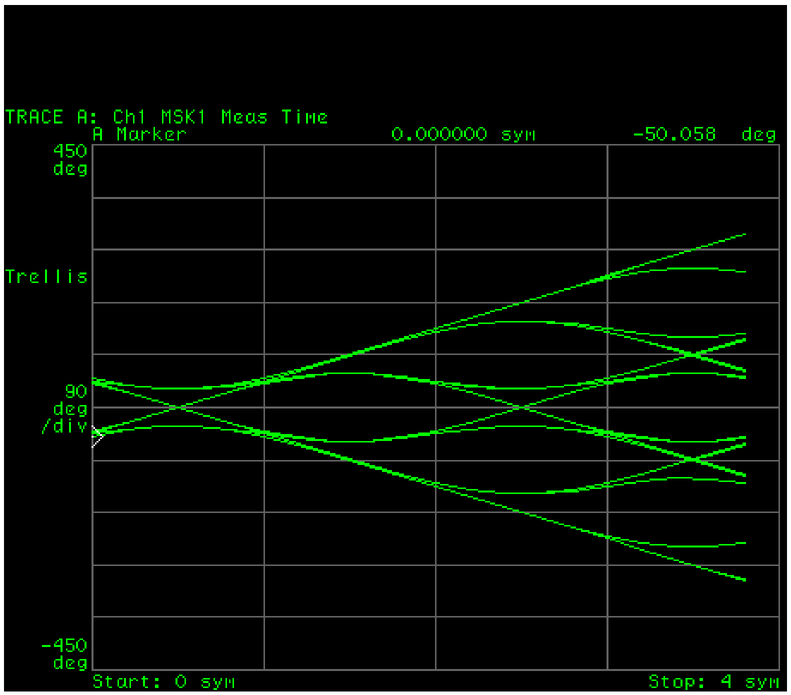
- With Pin = 3W, Vdd = 28V, Vgg = 3V
  - 3dB gain bandwidth = 150 MHz
  - -10dB input return loss bandwidth = 20 MHz

Output Power Spectrum



MSK Signal Test

Phase Trellis



- Measured results show almost no distortion in the output MSK power spectrum
- Measured Error Vector Magnitude (EVM)
  - EVM (Peak): 0.5%
  - EVM (RMS): 0.2%

Conclusion: Performance Comparison

	This Work (Caltech)	Long *et al.* (UCSB)	Le Gallou *et al.* (Alcatel)	Adahl *et al.* (Chalmers)
Power	60 W	13 W	10 W	10 W
Gain	11 dB	14 dB	13 dB	13 dB
PAE	65%	58%	66%	66%
3-dB BW	150 MHz	N/A	>50 MHz	50 MHz
Class	Class $E/F_{odd,2}$	Class D^{-1}	Class F^{-1}	Class E
Freq	1.1 GHz	1.0 GHz	1.5 GHz	1.0 GHz
Device	Motorola Si LDMOS MRF 284	Ericsson Si LDMOS PTF 10135	UMS Custom GaAs HBT	Motorola Si LDMOS MRF 282
Size	5 cm x 3.5 cm	6 cm x 20 cm	Confidential	10 cm x 10 cm

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