A 60-W L-Band Class-E/F_{\text{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

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

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

- The drain bias line is used as an additional $2^{\text{nd}}$ 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

- 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: $k \approx 0.35$

To achieve tight coupling, interdigitated microstrip baluns and broadside-coupled microstrip baluns may be used.

Coupling coefficients of different microstrip baluns:
- Side-coupled: $k \approx 0.35$
- Interdigitated: $k \approx 0.50$
- Broadside-coupled: $k \approx 0.70$

Simulated Loss of the balun is 5.2%:
- 2.6% in the copper
- 2.6% in the capacitors
Impedance Transformation

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.
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
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

At least -40 dBc for all harmonics
MSK Signal Test

- 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

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