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

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Abstract – A Class-E/$F_{odd,2}$ power amplifier is reported that operates at 1.1 GHz, with an output power of 60 W and a power-added efficiency of 65%. Compact, low-loss impedance-transforming microstrip baluns are used in a push-pull configuration. The circuit board dimensions are only 3.5 cm × 5.0 cm. The amplifier uses a pair of Motorola 284 LDMOS transistors. The amplifier is intended for space-based phased-array radar T/R modules.

Switching-mode amplifiers are promising candidates for UHF transmitters that require high efficiency, but only limited bandwidth and linearity. Recently Kee *et al.* reported a new class of switching power amplifiers – the Class-E/F amplifier [1]. Figure 1a shows the schematic of an E/$F_{odd,2}$ amplifier. This amplifier has zero-voltage switching like a Class-E amplifier, while terminating the odd harmonics and the 2nd harmonic like a Class-F^{-1} amplifier. The amplifier uses a pair of transistors, driven as switches 180° out of phase. A second-harmonic trap helps shape the current waveform. Figure 1b shows a photograph of the actual amplifier. The amplifier is built on a Duroid substrate with a dielectric constant of 2.2.

Push-pull amplifiers need a balun at the input and output when amplifier is connected to coaxial cables. However, at frequencies in the 1-GHz range, traditional microwave baluns, such as hybrid rings, are larger than we would like. Broadside coupling is used for our input and output baluns, with a pair of stacked microstrip lines separated by a Duroid dielectric layer 180 μm thick. The dimensions of the baluns are optimized with the electromagnetic simulator SONNET to transform the 50-Ω cable impedance to the transistor impedances of a few ohms. In addition, the balun inductances are used to tune out transistor capacitance. The input balun is shown in Figure 1c. Its dimensions are only 1.25 mm x 2.5 mm, significantly reducing the overall size of the amplifier. Center-tapped bias lines on the baluns connect the drains and gates of the transistors to the power supply, without the need for large RF chokes. The output center-tapped bias line also serves as part of the second-harmonic tank circuit that was shown in Figure 1a.

Figure 2 and Figure 3a show the measured performance. At 1.1 GHz, the peak output power is 60W with a drain bias of 32V. The peak power-added efficiency is 65%. Also shown on Figure 2a for comparison are the gain and PAE predicted by an ADS harmonic-balance simulation. The measured PAE is quite close, but the measured gains are 2dB to 3dB low. This suggests that it may be possible to improve the gain. The 3-dB bandwidth is 150 MHz. Figure 3a shows the measured output power spectrum. The largest harmonic components are the 3rd and 5th, at −40dBc.

The simulated waveforms from ADS are shown in Figure 3b. The voltage waveform is nearly a half sinusoid. This reduces the peak voltage compared with a Class-E amplifier. The current waveform has a relatively square shape, reducing the rms current compared to a Class-E amplifier. This helps to reduce the on-resistance loss in the amplifier. The simulated loss of the output balun is 5.2%, with half the loss in the metal, and half the loss in the capacitors. The loss of the Duroid coupling layer was negligible.

The final table compares the performance of this power amplifier to comparable recently reported amplifiers. Our amplifier has an output power five times larger than the other amplifiers, with an area five times smaller.

Acknowledgements

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Reference

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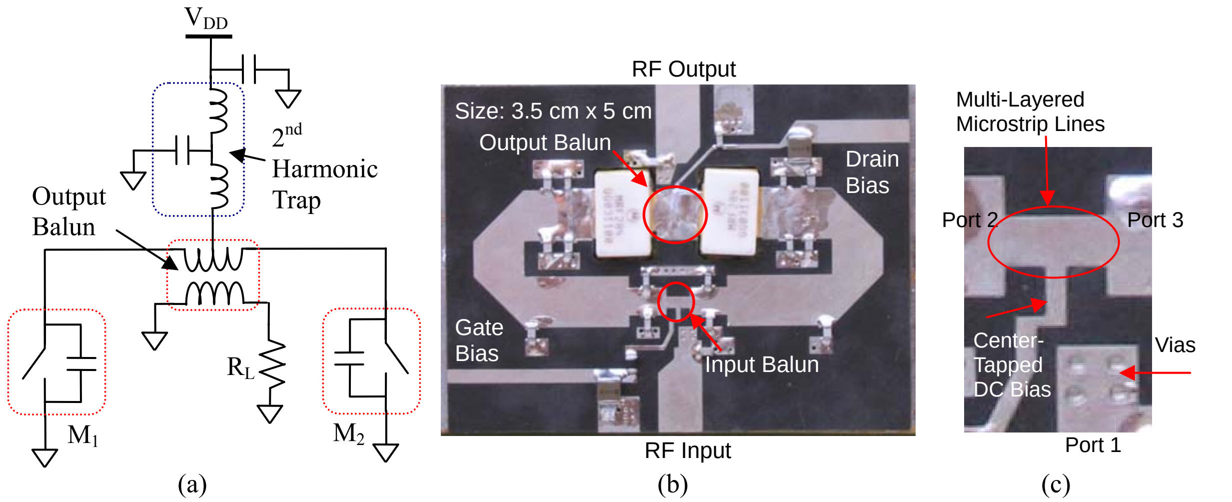

Figure 1. a) Circuit schematic for an Class-E/$F_{odd,2}$ amplifier, b) Photo of the L-band amplifier, and c) Photo of the input balun.

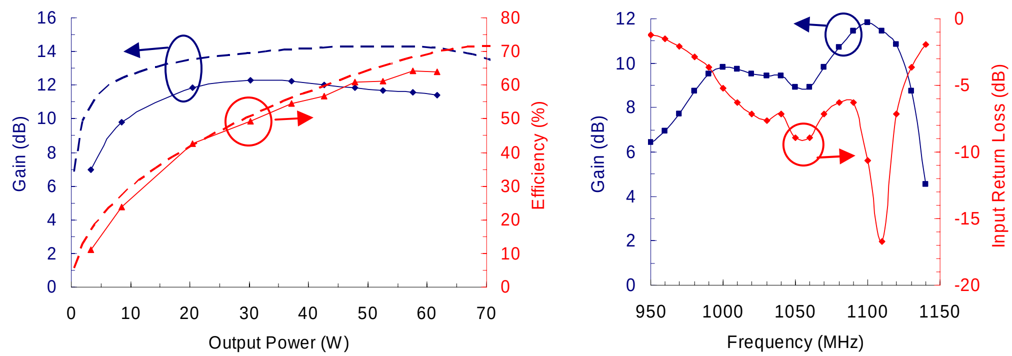

Figure 2. a) Measured (solid) and simulated (dashed) gain and PAE at 1.1GHz with drain bias of 32V. At 60-W output, the gain is 11 dB, and the PAE is 65%. b) Measured frequency response with a 3-W input. The 3-dB bandwidth is 150 MHz.

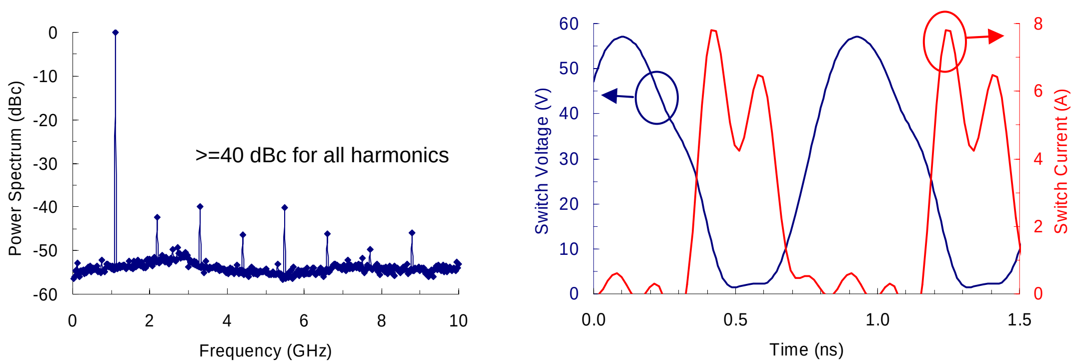

Figure 3. a) Measured output power spectrum, and b) Simulated voltage and current waveform of the class-E/$F_{odd,2}$ amplifier.

	Caltech, this work	UCSB, Long *et al.* [2]	Alcatel, Gallou *et al.* [3]	Chalmers, Adahl *et al.* [4]
Power	60 W	13 W	10 W	10 W
Gain	11 dB	14 dB	13 dB	13 dB
PAE	65%	58%	66%	66%
BW	150 MHz	N/A	> 50 MHz	50 MHz
Class	E/$F_{odd,2}$	D^{-1}	F^{-1}	E
Freq	1.1 GHz	1.0 GHz	1.5 GHz	1.0 GHz
Device	Motorola 284 Si LDMOS	Ericsson PTF 10135 Si LDMOS	UMS Gallium-Arsenide HBT	Motorola 282 Si LDMOS
Size	5 cm × 3.5 cm	6 cm x 20 cm	Alcatel confidential	10 cm × 10cm

Table Comparison with recently published results for comparable power amplifiers.