

Low-Cost 63% Efficient 2.5-kW UHF Power Amplifier for a Wind Profiler Radar

Brad Lindseth^{1,2}, Tom Kelly³, William O.J. Brown¹, Terry Hock¹, Stephen A. Cohn¹, Zoya Popovic²

¹National Center for Atmospheric Research, Boulder, CO 80307, USA

²Department of Electrical and Computer Engineering, University of Colorado, Boulder, CO 80309, USA

³NXP Semiconductors, Smithfield, RI 02917, USA

Abstract — This paper describes a low-cost 449-MHz 2.5-kW peak pulse amplifier for use in a wind profiling radar. New high-power LDMOS transistors are enabling the use of kilowatt level pulse power amplifiers for under US\$25¢/W in transistor costs. With pulse duty cycles of 10-20%, kilowatt modules with efficiencies greater than 60% can be combined to achieve multi-kilowatt transmitters, allowing higher transmit powers and improved radar signal to noise ratio.

Index Terms — Atmospheric measurements, meteorological radar, power amplifiers, pulse amplifiers.

I. INTRODUCTION

A wind-profiling radar measures weak return signals from variations in atmospheric relative permittivity, and the signal-to-noise ratio (SNR) is directly proportional to transmit power [1]. In the 449-MHz allocated band with a 2-MHz -20dB bandwidth, the maximum transmit EIRP is 110dBm, while received signals are typically on the order of -150dBm. Traditionally, the final PA in the transmitter has been the highest cost of the radar. Commercially available PAs with pulse powers above 2 kW cost upwards of US\$30,000 [2,3]. The goal of this work is to develop a low-cost UHF power amplifier using new LDMOS technology.

The power amplifier is the front end of a new wind profiler radar with a unique modular hexagonal antenna design, as shown in Fig.1 [4]. The radar pulse is transmitted from all three antennas, but the return signal is received separately on each antenna. This configuration is referred to as a spaced antenna radar, which is an interferometric technique that allows computation of the horizontal wind vector components, while the vertical component is found from the Doppler shift [5]. The hexagonal design allows the antennas to be configured into a 3 (Fig.1), 7, or 19 hexagon array. Because it is desired to transmit a higher power level with the larger arrays, multiple 1-kW power modules are combined together in a transmitter.

Radar power amplifiers have traditionally used BJT technology [6,7]. New low-cost LDMOS transistor technology [8,9] makes kilowatt-level pulse amplifier modules possible. This work focuses on the use of the low-cost NXP BLF578 transistors [10]. When used in a push-pull configuration, a single module can produce over 1 kW peak pulse power at 10% duty cycle. In the remainder of the paper, we describe the implementation and characterization of two combined PAs

that result in a 2.5 kW peak pulse output with a 63% drain efficiency at peak power.

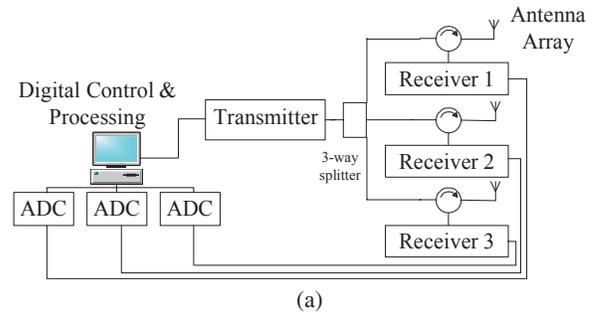


Fig. 1.(a) Block diagram of the spaced receiver 449 MHz wind profiler radar. (b) 449 MHz wind profiler deployed to the Persistent Cold Air Pool Study at Salt Lake City, Utah. Three hexagonal antennas and receivers are shown in this picture.

II. HIGH POWER AMPLIFIER DESIGN

Each NXP BLF578 package consists of two transistors, combined in a push-pull configuration, as shown in Fig. 2(a). Benefits of the push-pull amplifier design include doubling of input and output impedances and reduced even harmonics. The 25-Ω coaxial baluns transform the unbalanced 50-Ω input and output into impedances that are easier to match to the transistor. The baluns at the input and output of the PA have a length that makes them appear as a shunt inductive reactance to the matching network. This prevents unbalanced mode currents from flowing in the outer conductor of the coaxial line and into the balanced circuit. Fig. 2(b) shows the output matching network of the amplifier. The final capacitor values

are found empirically by changing their value and position while measuring efficiency, gain, and output power.

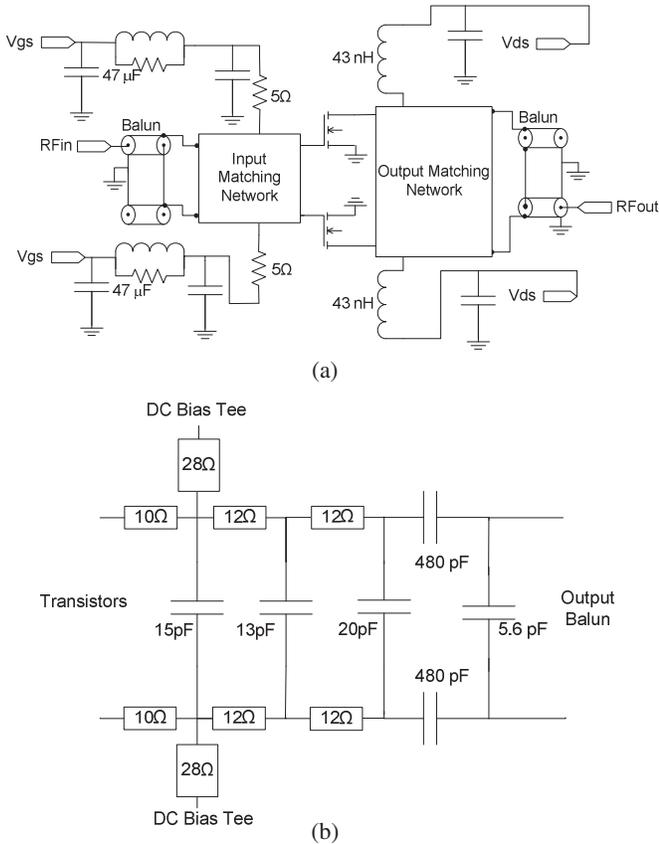


Fig. 2.(a) Schematic of the 1-kW transmit PA with push-pull amplifier architecture. Coaxial baluns transform $50\ \Omega$ input and output into impedances that are easier to match to the transistor. (b) Schematic of output matching network.

III. 1-KW MODULE FABRICATION AND MEASUREMENTS

The amplifier was fabricated on a 30-mil Rogers 4350B substrate ($\epsilon_r = 3.5$) which is mounted on an aluminum block with a copper insert to transfer heat directly from the transistor package. The NXP BLF578 device is held in place using a plastic clamp. The fabricated module is shown in Fig. 3(a). Fig. 3(b) shows a thermal image of the 1 kW module while in operation. Note that the thermal imager (Fluke Ti10 [5]) assumes a constant emissivity of 0.95. The thermal image shows that there is a potential thermal issue with the output matching capacitors at a temperature of 96°C (the emissivity of the porcelain capacitors is 0.92). While the output matching capacitors have an operating temperature range up to 175°C [11], the use of different output matching capacitors may be necessary for duty cycles above 10-20%.

Two 1-kW modules were tuned by changing values of the output matching capacitors for best and equal gain, output power, and drain efficiency. Measurements were performed by taking a power sweep. A spectrum analyzer is used to

monitor harmonics and check for oscillation, while the input can be switched between a signal generator and a Rhode and Schwarz ZVA network analyzer for pulsed large-signal S-parameter measurements. A calibrated high-power driver amplifier and appropriate attenuators are used in the setup.

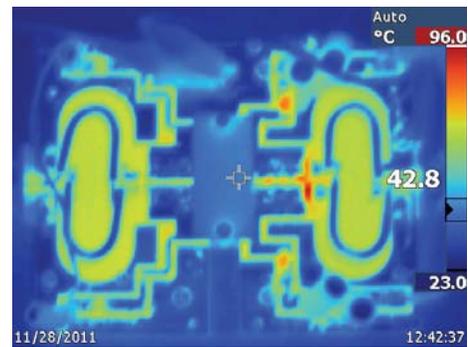


Fig. 3. (a) Photograph of fabricated 1 kW module. (b) Thermal image of 1 kW pulse amplifier module using a thermal imager. Output matching capacitors are heating up to 96°C .

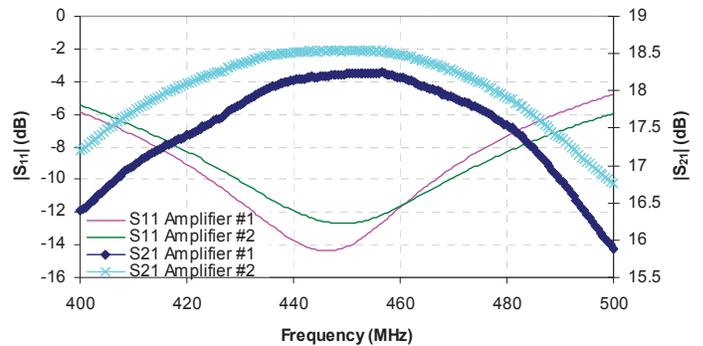


Fig. 4. S-parameters: $|S_{21}|$ and $|S_{11}|$ vs. frequency for both 1-kW modules biased at $V_{dd}=50\text{V}$, $I_{dq}=40\text{mA}$, 40A peak drain current and 4A average current.

Fig.4 shows a measurement of the large signal pulsed S-parameters $|S_{21}|$ and $|S_{11}|$ vs. frequency for two 1-kW modules. The S-parameter data shows 18dB gain and $|S_{11}| < -12\ \text{dB}$. In addition, the S_{21} phase difference at 449 MHz of both amplifiers was measured to be only 9° . Less phase difference

between modules will result in higher combining efficiency. A power sweep of the 1-kW modules is shown in Fig.5.

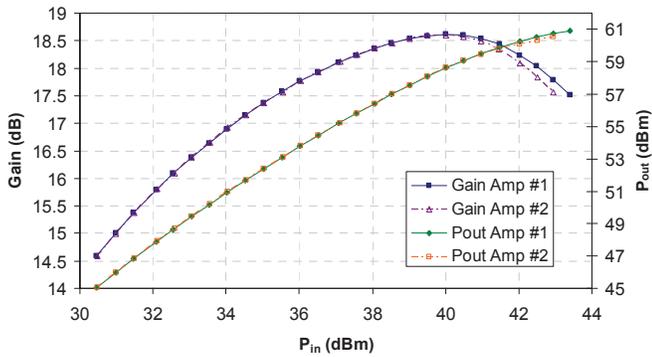
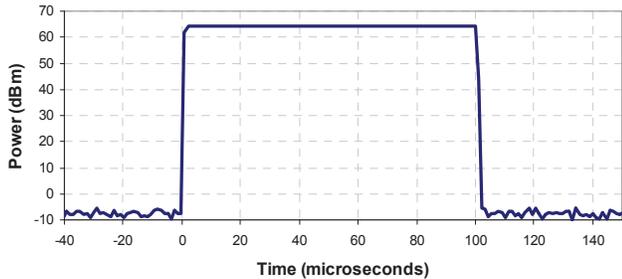


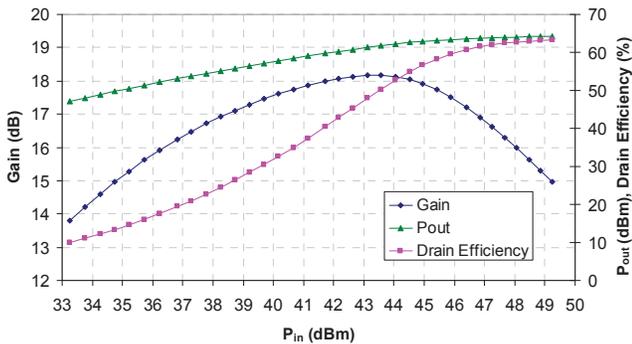
Fig. 5. Power sweeps for the two 1-kW push-pull PAs. $V_{dd}=50V$, $I_{dq}=40mA$, $I_{peak}=40A$, $I_{average}=4A$. Best operating point is with $P_{out} = 61$ dBm (1200W), $G = 17.5$ dB, drain efficiency = 63%.

III. 2.5-KW MODULE MEASUREMENTS

After making measurements on each amplifier, the two amplifiers were combined with a commercially available 449-MHz reactive splitter/combiner (from RF Hamdesign). Another identical splitter/combiner was used to combine both signals on the output. Each amplifier is clamped to a water cooled heatsink plate.



(a)



(b)

Fig. 6.(a) Measured envelope of 2.5 kW amplifier pulse output. A flat pulse top is desirable for best radar performance. (b) Power sweep at 449 MHz for the 2.5 kW amplifier: gain, drain efficiency, and P_{out} vs. P_{in} . The P_{3dB} point is 64 dBm (2640W) at the output, with 63% drain efficiency, $G = 15$ dB, $I_{peak} = 83.5A$, $I_{average} = 8.35A$, $V_{dd}=50V$, $I_{dq}=40mA$.

Fig. 6(a) is a plot of the measured envelope of the combined 2.5-kW pulse output with a 10% duty cycle. For wind profiler radar use, a flat top of the pulse envelope is desired with minimal overshoot or ringing. This measurement is taken with a 100 μs pulse because of instrument limitations, while normal wind profiler radar pulses are 1-4 μs long. Fig. 6(b) shows a power sweep of the two combined amplifiers. This measurement is performed at 449 MHz with $(V_{dd}, I_{dq}) = (50V, 40 mA)$, with a resulting $P_{3dB} = 2.64$ kW, $G = 15$ dB, $\eta_D = 63\%$, and PAE = 61.74%.

IV. CONCLUSION

This paper demonstrates a 1 kW pulse amplifier module based on LDMOS transistor technology with a transistor cost of under US25¢/W. Measured pulsed large signal S-parameters confirm a good input match and gain at the 449 MHz design frequency with $|S_{11}| < -12$ dB and $|S_{21}| > 17$ dB. Two modules were combined to achieve an output power of 2.6 kW, with 63% drain efficiency, and 15 dB gain. In the future we hope to combine more of the 1-kW modules for a 10-15 kW transmitter. These amplifiers will be used to power the next generation of 449 MHz wind profiler radars.

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