Design, fabrication and measurement of 1kW Class-E amplifier at 100 MHz

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I. Introduction

Solid state RF power amplifiers are increasingly utilized as RF power sources for particle accelerators. They offer improved stability and reduced maintenance compared to the traditionally used technologies such as klystrons and tetrodes. Class-E amplifiers have the potential to achieve high-efficiencies which could reduce the power consumption and thermal requirements for an accelerator energy system. This paper demonstrates a class-E PA with a simple single-ended design and low manufacturing cost as an alternative to more complex push-pull solutions. The intended application of the amplifier is energy systems for particle accelerators.

II. Design

The design of the amplifier was carried out using analytical class-E design equations [1] as a starting point. The circuit was converted to transmission lines and optimized in Keysight's ADS using Ampleon's large signal model of the transistor. The simulated amplifier design was confirmed using Harmonic balance and method of moments simulations.

The amplifier was constructed around the commercially available power LDMOS-transistor BLF188XR from Ampleon [2]. The matching networks of the amplifier are comprised of planar transmission lines and SMD capacitors. The transmission lines are realized on a 0.64 mm Rogers TMM10i double sided PCB ($\epsilon_R = 9.8$, $\tan\delta = 0.002$, 35μm copper thickness) [3]. The fully constructed amplifier is shown in Fig. 1.

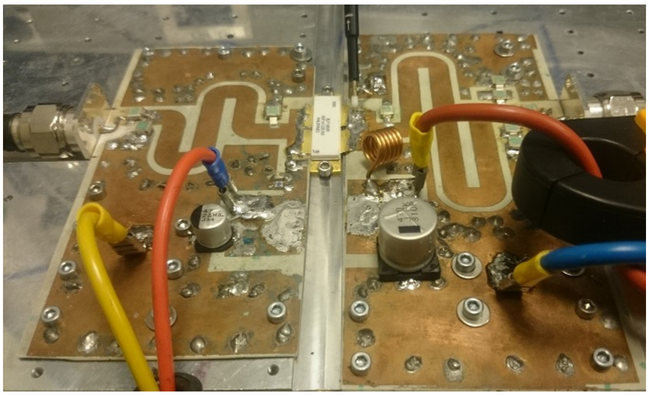

Fig. 1. Fully constructed amplifier mounted on aluminium heatsink.

III. Measurements and Results

The measurement setup consists of power meters (1912A) and bi-directional couplers which facilitates measuring the return loss in addition to the input and output power of the amplifier. The supplied DC-current at the drain was measured using a current probe connected to an oscilloscope. For the sake of simplicity, the amplifier was driven using a sine-wave voltage. However, a square wave input drive would result in higher gain. Cooling is provided via an aluminium heat-sink fitted with a water cooling pipe that is situated beneath the transistor mount. During measurements a water flow rate of 8 litre/min is used.

Preliminary measurements show that the amplifier can provide 1200 W peak output power at 83% drain efficiency with 19.9 dB gain at 100 MHz operation (V_{ds} peak = 139.7 V). It also provides 1010 W peak output power at 87% drain efficiency with 22 dB gain at 102 MHz operation (V_{ds} peak = 140.5 V). The measurements were performed with a 5% duty cycle, using 3.5 ms pulses at repetitions of 14 Hz. The measured gain and power added efficiency as functions of output power for both measurements is displayed in Fig. 2.

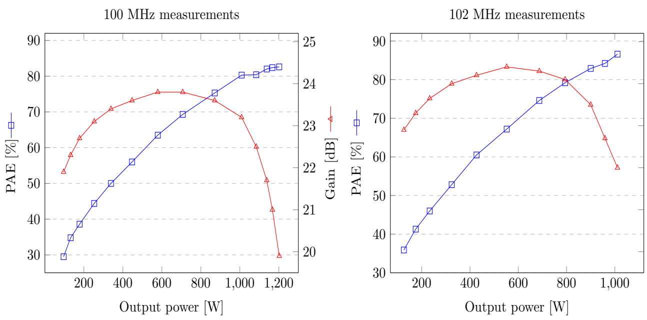

Fig. 2. Measured gain and power added efficiency versus output power at 100 MHz (left) and 102 MHz (right).

The input of the amplifier is not well matched, which is indicated by a low return loss, averaging about 1.5 dB. This could be resolved by tuning the capacitors at the input, though it is complicated the fact that the input matching affects the output matching. During measurements the drain voltage peaks exceed the breakdown-voltage of the transistor (135 V) by about 5 V at maximum output power. This could be adjusted by a slight reduction in drain bias which should not significantly affect the output power. To the best of the author's knowledge these results are an improvement on the state of the art in terms of combined efficiency and power for Class-E VHF power amplifiers.

References

[1] F. Raab, "Idealized operation of the class E tuned power amplifier," *IEEE transactions on Circuits and Systems*, vol. 24 no. 12, December 1977, pp. 725–735.
[2] Ampleon, "BLF188XR; BLF188XRS Power LDMOS transistor," BLF188XR datasheet, Sep. 2015.
[3] Rogers corporation, "TMM Thermoset microwave materials TMM3, TMM4, TMM6, TMM10, TMM10i, TMM13i," TMM10i datasheet, 2015.