Silicon Carbide MRI Transmitters

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Introduction

Traditionally high power MRI RF transmitters are based on vacuum tube or silicon transistor technology. We herewith introduce **silicon carbide (SiC)** based RF power generation for directly driven MRI transmitter antennas, which enable hitherto unattainable efficiencies and power density levels and obviate the need of RF load matching.

SIC TRANSISTORS

Silicon carbide (SiC) has a very large 3.26eV band gap, extremely high breakdown E field strength and copper-like heat conductivity. This gives SiC devices performance levels unattainable with silicon technology. Currently depletion mode (normally on) SiC vertical JFET seems to be the most promising device topology for high frequency RF power generation. SiC vJFET offer several unique properties:

1. SiC vJFETs are intrinsically 10-fold faster than Si LDMOS transistors, at 10x higher current densities. We achieved switching a resistive 30A, 500V load in 1 ns with a single 2.4 x 2.4 mm^2 chip.
2. SiC vJFETs are unipolar devices with a negative Rds temperature coefficient. This allows parallelizing devices without thermal runaway.
3. Extremely fast (Trr ~ 0.2 ns) intrinsic body diodes obviate the need for protecting the power stage from reflected RF power. As a consequence the RF load can be arbitrarily mismatched. The diodes effectively provide bidirectional power flow between the DC and RF sides.
4. The intrinsic drain-source and gate-source diodes are extremely rugged. Device handling does not require excessive ESD provisions, and the gate diode can be used as auto-bias rectifier (audion).

Our VHF device has -22 V gate-source pinchoff voltage and a drain saturation current of >50 A at room temperature. The input capacitance of about 580 pF is significantly lower than Si MOSFETs with similar power. Transfer and output characteristics are shown in Figure 1.

AMPLIFIER TOPOLOGY

The proposed RF amplifier in parallel push-pull (circlotron) topology [3] provides fully symmetric input and output signal paths for both legs (see Fig. 2). This push-pull operation together with the resonant RF coil load provides highly efficient class F operation at minimal circuit complexity. For our 150 MHz application it was essential to wirebond the bare SiC dies directly onto the PCB to minimize detrimental parasitic lead inductances. We are exploring contacting technologies with even lower parasitic impedances. The eight die RF modules have 130 x 190 x 20 mm^3 size including DC capacitors for > 4 ms RF pulses.

TEST RESULTS

The storage capacitors limited the maximum DC supply voltage to 250 V. At 240V DC supply voltage the maximum output power was 11 kW. The single stage power gain ranged between 9.5dB and 11.5dB (see Fig. 3) at efficiencies in excess of 80%. Due to external constraints we did not exhaust the performance envelope of the devices.

OUTLOOK

SiC JFETs will revolutionize RF power generation. It is foreseeable that in the very near future a single device delivers in excess of 50kW RF power, and has a unit power gain frequency in excess of 10GHz. The devices are oblivious to reflected RF power, which obviates RF circulators and load matching.

References.

[1] O Heid. US Patent 6,683,457 B2 (2001)
[2] R. K. Malhan, M. Bakowski, Y. Takeuchi, N. Sugiyama and A. Schoener, "Design, process, and performance of all-epitaxial normally-off SiC JFETs", Phys. Status. Solidi, vol. A 206, pp. 2308–2328, June 2009
[3] C. T. Hall Parallel Opposed Power Amplifiers U.S. Patent 2,705,265 (1951)

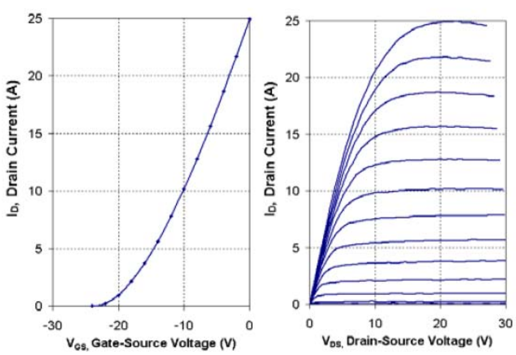

Figure 1. Transfer and output characteristics of the SiC vJFET at 150ºC

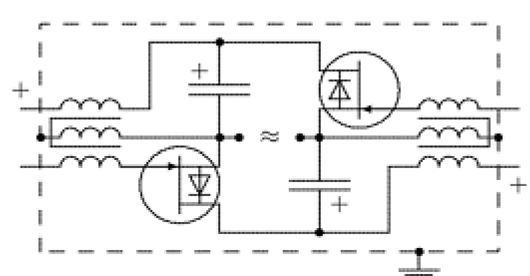

Figure 2. Circlotron Circuit

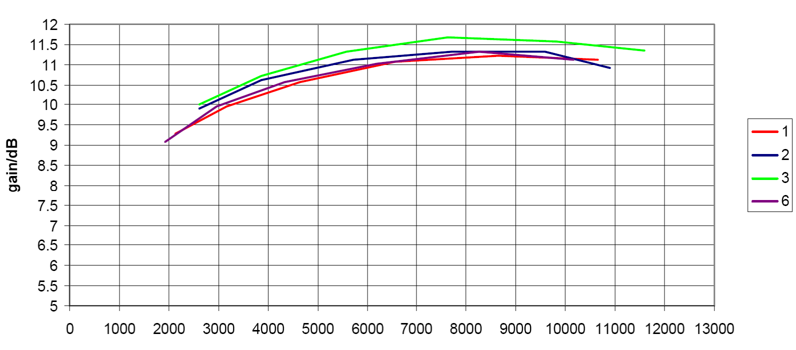

Figure 3. Module output power vs gain at 240V DC supply voltage.