Broad-band Microwave Power Amplifiers in GaN Technology

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Abstract

A first demonstration of GaN broad-band power amplifiers based on the f_τ-doubler topology, yielded ~11 dB gain, 0.2 - 7.5 GHz bandwidth amplifiers with ~1.5 W output power and upto 15% PAE. With better devices and modeling we expect significantly improved performance from these circuits.

2-20 GHz phased-array-radars, in development under ONR support, will require power amplifiers (PA) having high output power and power-added efficiency (PAE) over 10:1 bandwidth. AlGaN / GaN HEMTs have high $f_\tau V_{br}$ product[1], and can provide high powers at these frequencies. We had reported[2] an efficient broad-band GaAs MESFET PA based on the f_τ-doubler configuration. This lumped topology has shown better gain-bandwidth product than simple lumped PAs and higher PAE than distributed PAs[3] in a smaller die area. Here we report the first results on f_τ-doubler PAs using single and dual-gate GaN HEMTs.

GaN HEMTs with $0.7\mu m$ gate-length were fabricated on baseline material grown by MOCVD on C-plane sapphire. The layer structure and process details are discussed elsewhere[4]. Circuits were designed for $Z_o = 50\Omega$ output loading as low-loss impedance transformation over a decade bandwidth is hard to realize. Simulations predicted 10 dB gain with 0.2 - 10 GHz bandwidth. A total device periphery of $W = 2.4mm$ was used to provide saturation current I_{DSS}, determined by the load-line constraint $I_{DSS} = V_{br}/Z_o$. The devices were flip bonded to AlN substrates (fig.1) which has the passives (NiCr resistors, SiN capacitors) and interconnects, and provides a low resistance thermal path for efficient heat-sinking. A ground ring on the GaN die provides a continuous ground plane between the input and output for a CPW wiring environment on the AlN substrate. The single gate HEMT PAs (fig.2) use resistive feedback to match the input and output to 50Ω without significant loss of efficiency. The dual-gate HEMT PAs (fig.3) use capacitive division[3] to decrease gain and improve bandwidth. Here the input was lossy matched using a resistive divider, which also provides a low impedance path for the gate bias preventing bias shifts at high RF drive. No output matching is provided in the dual-gate HEMT PAs. Broad-band π-sections using high impedance lines at the input and output improve the bandwidth. The two devices in the circuits were independently biased to allow bias tuning to meet the loadline. GaN die size was $1.1mm \times 1.45mm$ for either circuit.

The circuits provide ~11 dB small-signal gain with 0.2 - 7.5 GHz bandwidth (fig.4). Measured power performance of the dual-gate cascode PA, in class-A bias at 6 GHz (fig.5) shows a peak output power of 1.5 W with 15% PAE. Fig. 6 shows the power performance of the resistive feedback PA over 1 - 8 GHz. The bandwidth is believed to be limited by the output pole (estimated at 6 GHz) due to the large extrinsic C_{ds} resulting from the flip-bonding. Designs with only the source pads bonded should reduce the capacitance by half and improve bandwidth. In both circuits the output power was seen to saturate much below what was expected from the DC - IV, as the drain bias was increased. This is attributed to the increased dispersion at high currents and increased current leakage at high voltages. This was verified by measuring the output voltage waveforms near compression, with a 2 GHz signal and as the drain bias was varied. With the rapid improvement in the material and device technology lately we expect increased power, efficiency and bandwidth with these circuits.

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[1] Wu Y.-F., et al., "Short channel AlGaN/GaN MODFETs with 50 GHz f_τ and 1.7 W/mm output power at 10 GHz", *IEEE Electron Device Letters*, Sept. 1997, vol. 18, no. 9, pp. 438-440.

[2] Krishnamurthy K., et. al., "A > 25% PAE 0.2–6 GHz Lumped Power Amplifier in a 18 GHz MESFET Technology", *to be presented at 1999 GaAs IC Symposium*, Monterey CA, October 17-20, 1999.

[3] Ayasli Y., et. al., "Capacitively coupled traveling-wave power amplifier", *IEEE Transactions on Electron Devices*, vol. 31, (no. 12), 1984, pp. 1937-42 .

[4] Wu Y.-F., et. al., "3-watt AlGaN-GaN HEMTs on sapphire substrates with thermal management by flip-chip bonding", *56th Annual Device Research Conference Digest*, Charlottesville VA, June 22-24, 1998.

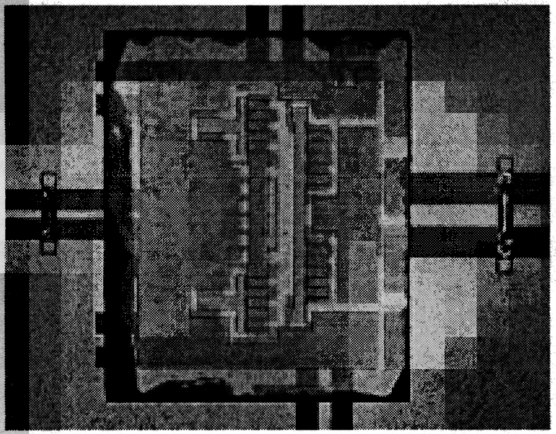

Figure 1: Die photograph of f_T-doubler resistive feedback PA.

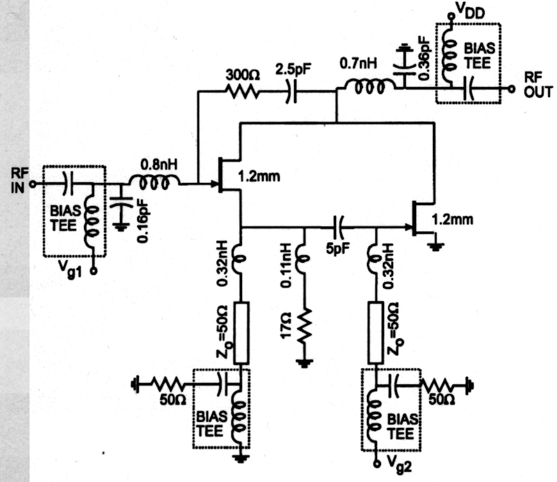

Figure 2: Complete schematic of f_T-doubler resistive feedback PA.

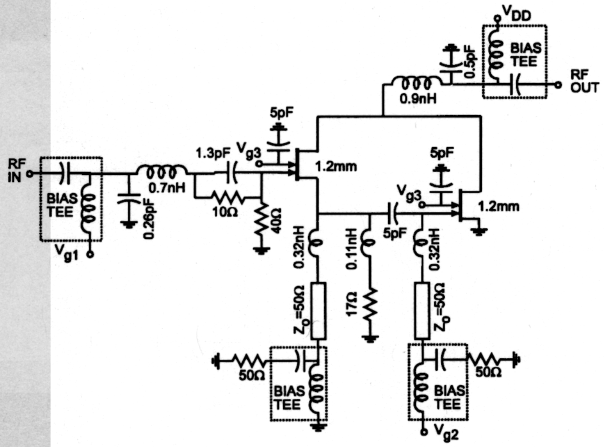

Figure 3: Complete schematic of dual-gate cascode f_T-doubler PA.

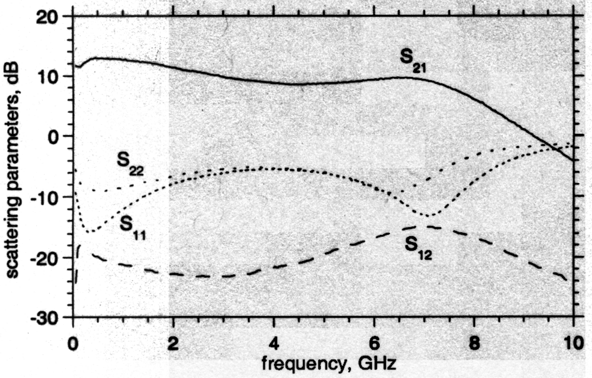

Figure 4: Small-signal performance of f_T-doubler resistive feedback PA.

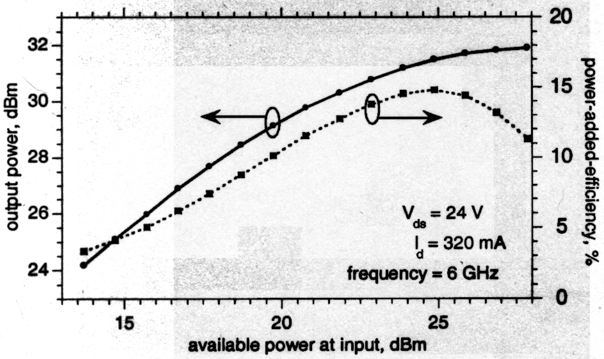

Figure 5: Power performance of dual-gate cascode f_T-doubler PA at 6 GHz.

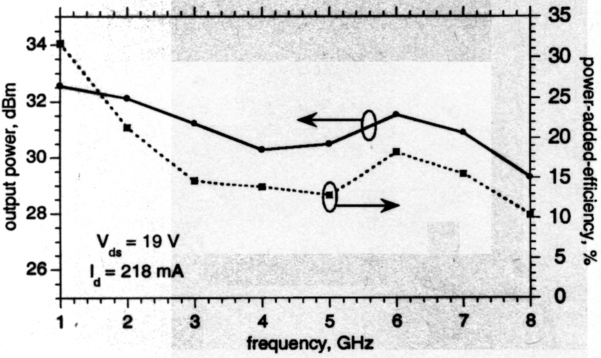

Figure 6: Power performance of f_T-doubler resistive feedback PA from 1 - 8 GHz.