GaN Compelling Features for Developing RF Power Markets

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INTRODUCTION

The leading semiconductor technology used for high power RF in the wireless infrastructure has been Silicon-based RF LDMOS. New cellular bands at higher frequencies as well as broadband communications in recent years create a need for semiconductor options that support higher frequency operation. RF GaN is a technology ideally suited to step in to this role. There are other III-V technologies that could fit in as well, but these are generally not able to reliably support the high output power requirements needed for today's macrocell base stations. While LDMOS remains the technology of choice for cellular bands below 2.7 GHz another application space where GaN is finding use in these lower frequency bands is one that requires multi band operation.

Freescale's end goal as a market leader in power RF is to offer the best technology options for each of the market segments we serve. Accordingly, Freescale has developed RF GaN for wireless infrastructure, military, and industrial applications to complement its LDMOS technologies. This paper details GaN material and device benefits and trade-offs with LDMOS, describes the process for qualifying the technology at Freescale, and gives specific examples of state of the art GaN device performance for commercial and military applications.

GAN MATERIAL AND DEVICE BENEFITS AND COMPARISONS TO LDMOS

The advantages of GaN for commercial and military RF applications arise from its innate material properties. Table I compares the electronic and thermal properties of GaN to Si and GaAs. As seen from the table, GaN has a much higher breakdown field strength and saturated electron velocity than GaAs or Si. The product of saturated velocity and breakdown field strength is proportional to the Johnson figure of merit (JFOM) that is much higher for GaN than Si or GaAs. Theoretically, the higher JFOM for GaN means that it has higher power density per unit capacitance. In practice, this is borne out by a 3-5X higher microwave power density than GaAs and Si technology. The higher power density translates into a smaller device needed for a given output power and therefore wider bandwidth.

GAN DEVICE MANUFACTURING AND TECHNOLOGY CERTIFICATION

Extending our decades-long legacy of high power RF design expertise, one that spans transistor design, circuit implementations, packaging technologies to GaN is a natural progression for Freescale.

Freescale uses a robust qualification process to ensure consistent and reliable RF device operation for both Si LDMOS and GaN technologies based on product-sized devices. As illustrated in Table II, Freescale RF technology qualification based on these includes a prototype phase, a pilot production phase, and a certification phase.

TABLE I
COMPARISON OF GAN, SI, AND SIC ELECTRONIC AND THERMAL PROPERTIES.

Material	GaN	Si	GaAs	SiC
Bandgap (eV)	3.4	1.1	1.4	3.2
Breakdown Field Strength (MV/cm)	2	0.3	0.4	2.2
Saturated Velocity ($x10^7$ cm/s)	2.5	1	1.5	2
Johnson FOM V_{sat} x $E_{br}/2\pi$ (10^{12} V/S)	8	0.5	1	7
Thermal Conductivity (W/cm-K)	1.5	1.3	0.4	4

TABLE II
FREESCALE QUALIFICATION PROCESS FOR RF POWER DEVICES.

Level 1: Prototype	Level 2: Pilot	Level 3: Certification
• Demonstrate core feasibility • Set yield targets • Identify process corners • Complete first intrinsic reliability • Evaluate ESD performance	• Establish initial yield/Cpk compliance • Freeze baseline • Evaluate corners • Establish intrinsic reliability on 3 lots • Statistical process control (SPC) initiated • Complete look-ahead extrinsic reliability	• Establish final yield on lead products from minimum of three lots • Ramp up volume • SPC fully implemented • Establish extrinsic reliability on product devices

Freescale has completed qualification of its GaN 3.0 and GaN 4.0 technologies based on this technology certification. Figure 1 illustrates the performance of the 400 W qualification vehicle (41.6 mm total gate width) used for GaN

3.0 technology certification. As seen from the plot a P_{3dB} output power of 426 W, 61% efficiency is obtained at 2.1 GHz with maximum power tuning. Using maximum efficiency tuning, an output power of 330 W with 72% efficiency is obtained. Based on this device, the technology certification was completed as outlined above with all devices passing extrinsic and intrinsic reliability requirements.

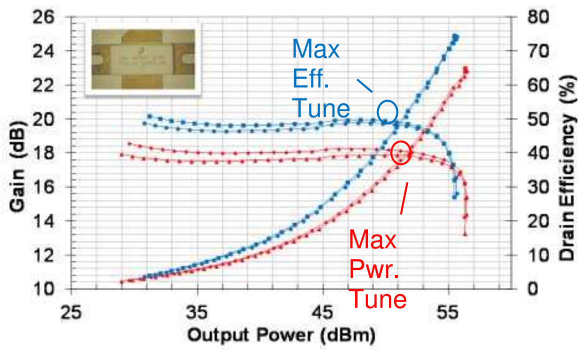

Figure 1. Loadpull-measured performance for 400 W GaN 3.0 qualification vehicle at 2.1 GHz.

PLASTIC PACKAGING FOR MORE EFFECTIVE HEAT DISSIPATION

Freescale has adopted specially designed over-molded plastic packages for GaN applications. These plastic packages are very area efficient, have similar RF performance as their ceramic counterparts as shown in Figure 2.

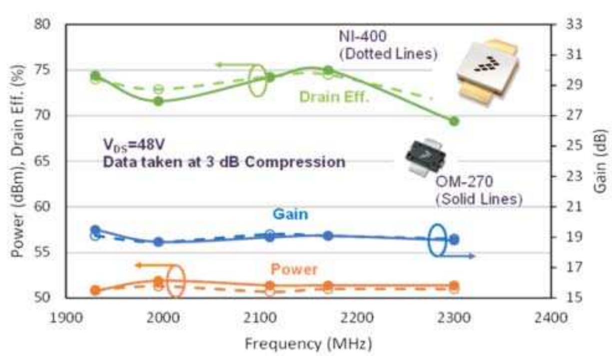

Figure 2. Loadpull-measured performance for a packaged 400 W GaN 3.0 qualification vehicle at 2.1 GHz.

EXAMPLES OF GAN FOR COMMERCIAL AND MILITARY APPLICATIONS

Wireless Applications

40 W Doherty asymmetrical amplifier employing one A2G22S160-01S in the carrier path and two in the peaking path, maximum output power is 56.2 dBm. With 8-dB of output back-off (OBO), gain is 15.4 dB and efficiency is 56.7%. Adjacent-channel power (ACP) is -55 dBc with digital predistortion (DPD) when driven by two 20-MHz LTE carriers with an aggregate 40 MHz carrier bandwidth. The A2G22S160-01S is housed in the NI-400-2 air cavity ceramic package.

Industrial Applications

The features of GaN include a very low Cds, which can benefit many application where broadband performance is key. An example of that application is broadband communication. Figure 3 below summarizes the broadband performance for a 10 W CW GaN-on-SiC power transistor that demonstrates 200 to 2600 MHz ultra-wideband performance in the available compact applications circuit.

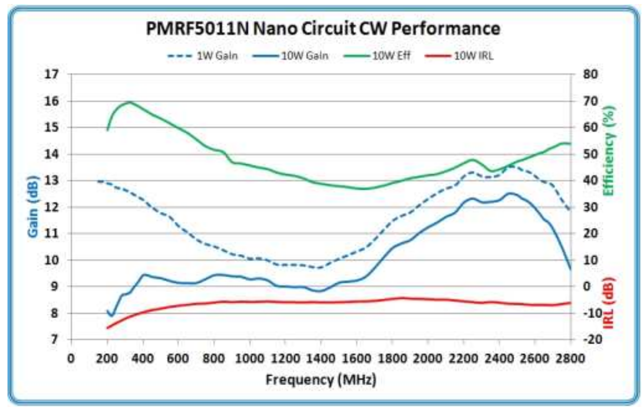

Figure 3. Broadband performance of the PMRF5011 in compact reference circuit.

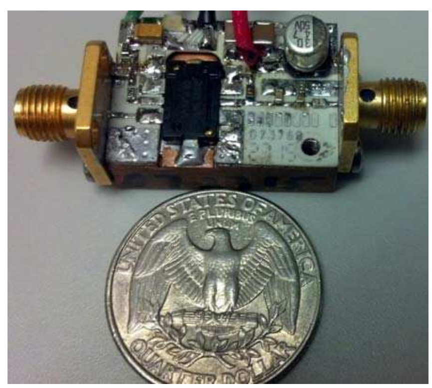

Figure 4. Compact Broadband reference circuit for the PMRF5011.

The next challenge to take full advance of GaN leading power density –especially in CW applications- is to effectively manage thermal dissipation. Plastic package – such as Freescale's OM-270-delivers superior thermal performance as the assembly process is based on eutectic die bond on Copper flanges. This assembly process also supports concurrent -assembly of internal matching blocks on separate substrate for unprecedented wideband performance

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References

[1] Freescale RF Product Guide. www.freescale.com

Acronyms

GaN: Gallium Nitride
RF: Radio Frequency
LDMOS: Laterally Diffused Metal Oxide semiconductor
mmWave: Millimeter Wave
Si: Silicon
GaAs: Gallium Arsenide
PA: Power Amplifier
JFOM: Johnson Figure of Merit
DPD: Digital Predistortion
CW: Continuous Wave
ESD: Electrostatic Discharge
SPC: Statistical Process Control