Over 70% PAE packaged GaN HEMT through wideband internal matching at second harmonic in S-band.

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Published in
Electronics Letters, 21st June 2012 Vol. 48 No. 13, pp.770-772.

doi:10.1049/el.2012.1654

Over 70% PAE packaged GaN HEMT through wideband internal matching at second harmonic in S-band

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Reported is a design methodology to efficiently control source and load impedances of a power GaN HEMT at the second-harmonic frequency inside a metal ceramic package. Second-harmonic source control is more precisely investigated. A specific filter is implemented at the gate side within the package to transform external source impedances into negative reactances seen by the internal device at second-harmonic frequencies. Whatever the external source termination presented at second-harmonic frequencies, source impedances seen by the internal die are confined to high efficiency regions. This methodology is applied to a 20 W packaged GaN HEMT using internal control of input and output second-harmonic impedances to reach more than 70% of power-added-efficiency (PAE) on 30% relative bandwidth in S-band.

Introduction: Modern radar applications in S-band will require packaged power GaN HEMTs with high PAE over wider bandwidths. The use of high-efficiency classes is a good solution to maximise PAE [1] by controlling harmonic terminations. However, packaging has a dramatic impact on matching capabilities of input and output impedances at harmonic frequencies. Indeed, bond wire interconnects and parasitic capacitances of the package define a cutoff frequency that fixes the internal harmonic impedances seen by the active die whatever the external source and load terminations of the package. In this case, internal harmonic impedances seen by the device are not confined to its high-efficiency regions, which results in low PAE [2].

This Letter reports a method for synthesising the package of GaN HEMTs in order to control the harmonic impedances seen by the internal die. This Letter is more particularly focused on the source matching at harmonics [3–5] using an L-C filter which has the advantage of easy implementation within the package.

Optimisation of packaged GaN HEMTs: The device is a 2.4 mm gate-width GaN HEMT of the GH50 process provided by UMS. On-wafer pulsed-IV pulsed-RF and multi-harmonic load-pull measurements were initially performed on the GaN die to derive its nonlinear model and define its optimum impedance contours at harmonics, respectively. By using the measured and simulated impedance contours, internal matching circuits were designed so that the GaN die could be matched to its optimum source and load impedances at second-harmonic frequencies. At the fundamental frequencies, the output matching network must be implemented outside the package while the gate is internally matched.

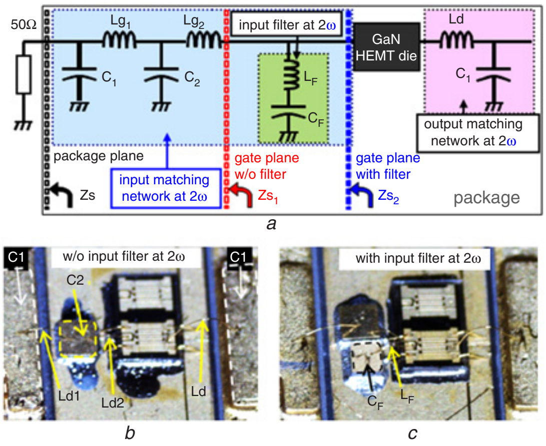

Fig. 1 *Final circuit schematic of packaged GaN HEMT (Fig. 1a) and photos of two packaged versions without (Fig. 1b) and with (Fig. 1c) input L_F-C_F filter at 2ω*

Fig. 1*a* shows the final circuit schematic of the packaged GaN HEMT including the L_F-C_F filter for source matching at 2*ω*. To assess the impact of this input harmonic control, two packages were fabricated using the same GaN HEMT die with and without the L_F-C_F filter. Both packages have identical output matching circuits at *ω* and 2*ω*. Figs. 1*b* and *c* show the photos of both packaged versions. It can be noted that capacitances C_1 are actually synthesised by shaping the widths of the metallised ceramic at the input and output of the package. Indeed, the package capacitances are determined by the ceramic thickness and the surface area of the metal plates so that this parasitic can be usefully shaped to serve as a matching element. The other capacitances C_2 and C_F are synthesised by MIM capacitors, and the required inductances *Ld*, Lg_1, Lg_2, and L_F are made by gold bond wires with optimised lengths.

First, the drain side of the packaged GaN HEMT is desensitised to external harmonic loads by the lowpass filter *Ld*-C_1 which is optimised so that the output impedances of the die at 2*ω* are confined to high-PAE regions whatever terminations are presented outside the package. We have recently demonstrated that internal output loads seen by the active die can be controlled and desensitised at 2*ω* on wide bandwidths [2] while this Letter is focused on the internal source matching at 2*ω*.

Secondly, the gate side is internally matched at *ω* by a second-order lowpass filter C_1-Lg_1-C_2-Lg_2 in the case of a 50 Ω source termination *Zs*.

Then, the L_F-C_F filter is added to present the low source impedances with negative reactances required at 2*ω* within the gate plane of GaN HEMTs. Therefore, source impedances of the die at *2ω* are confined to high-PAE regions whatever impedances are presented outside the package (i.e. *Zs* at *2ω* is swept all over the entire Smith chart).

Measurements results: The RF input power was pulsed using a 10 µs pulse width at 10% duty cycle while bias voltages were continuous. The gate was biased slightly above pinch-off and the drain bias voltage was 50 V. Fig. 2 shows the evolution of internal source impedances Zs_2 and Zs_1 seen by the GaN die at 2*ω* with and without the L_F-C_F filter, respectively. Zs_1 and Zs_2 are superimposed with on-wafer simulations of the second-harmonic source-pull PAE contours of the GaN die at 2.9, 3.2 and 3.7 GHz. It can be observed that the optimum PAE contours for the second-harmonic source impedances of the GaN die are located in the Smith chart regions of low impedances with negative reactances whereas the input matching circuit confines the source impedance Zs_1 at 2*ω* in poor PAE regions. Finally, as shown in Fig. 2, the addition of the L_F-C_F filter transforms the source impedances Zs_2 at 2*ω* into better PAE regions.

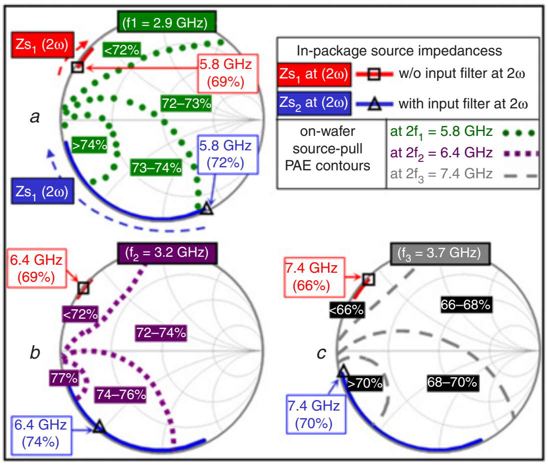

Fig. 2 *Evolution of second-harmonic source impedance of GaN die*

The L_F-C_F filter allows PAE to increase by about 4 points and reach over 70% PAE with no impact on the fundamental input matching over the bandwidth. Table 1 gives the equivalent circuit elements of internally-matched packages. Fig. 3 compares the real and imaginary parts of internal source impedances Zs_2 and Zs_1 simulated at *ω* and 2*ω* with and without the L_F-C_F filter, respectively. It can be noted in Fig. 3 that the L_F-C_F filter has no impact on the fundamental input matching at *ω* within the bandwidth 2.9–3.7 GHz while it moves the imaginary parts towards the required Smith chart regions of negative reactances at 2*ω*.

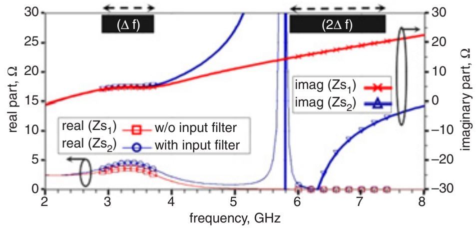

Fig. 3 *Simulated impact of L_F-C_F filter on source impedances of GaN HEMT die at ω and 2ω within bandwidth 2.9–3.7 GHz*

Table 1: Equivalent circuit elements of internally-matched package

C_1 (pF)	Lg_1 (nH)	C_2 (pF)	Lg_2 (nH)	C_F (pF)	L_F (nH)	F_F (GHz)
2.0	1.2	8.2	0.5	1.0	0.37	8.3

In the case of 50 Ω source termination at 2ω, Fig. 4*a* shows the comparison of measured PAE between both packages with and without the L_F-C_F filter. It can be observed that PAE is increased by 3 to 5 points from 2.9 to 3.7 GHz whereas it tends to the same values at low frequencies where the L_F-C_F filter has a negligible impact, and is lower at high frequencies due to the resonance frequency f_F. The final package with the L_F-C_F filter allows us to reach over 70% PAE from 2.7 to 3.7 GHz which corresponds to 30% relative bandwidth. Figs. 4*b* and *c* compare power sweep measurements of PAE, gain and output power for both packages at the centre frequency of 3.2 GHz. At the maximum of PAE, both packages provide 42.3 dBm output power and 14 dB gain while the internally-matched package demonstrates 74% PAE.

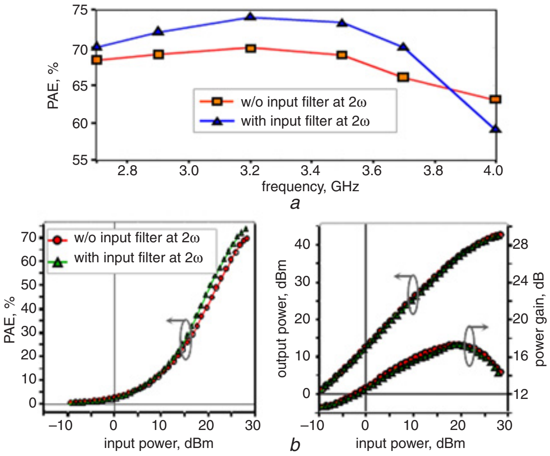

Fig. 4 *Comparison of measured PAE between both packaged GaN HEMTs with and without the L_F-C_F filter (Fig. 4a); power sweep measurements of both packaged versions at 3.2 GHz (Fig. 4b)*

Conclusion: This Letter demonstrates that the implementation of a series LC filter in parallel with the gate of a GaN HEMT die within its package can lead to improvement of PAE by accurately matching source impedances at 2ω with no impact on the fundamental input matching. The internally-matched packaged GaN HEMT at ω and 2ω has demonstrated over 70% PAE and 42.3 dBm from 2.7 to 3.7 GHz.

Acknowledgment: This work was supported by the French MoD-DGA.

15 May 2012
doi: 10.1049/el.2012.1654
One or more of the Figures in this Letter are available in colour online.

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