Low consumption and high frequency GaN-based gate driver circuit with integrated PWM

A. Delias[✉], A. Martin, P. Bouysse, J.M. Nebus and R. Quéré

A gallium nitride (GaN)-based gate driver circuit for high power and high speed GaN power switches is presented. The principle of the proposed circuit is based upon two normally-on GaN HEMTs and a self-biasing resistance. An integrated pulse width modulation functionality has been implemented using the threshold effect of the presented topology. The gate driver has been built with two CGHV1F006S GaN HEMT devices from Cree, Inc. It has been connected to the gate port of a 45 W CGH40045F GaN power switch operating as a DC/DC boost converter for the purpose of demonstration. Low consumption (≈1 W) and high frequency switching operation up to 60 MHz over the 20–80% duty cycle range is demonstrated. The square waveforms having switching times in the order of nanoseconds have been measured.

Introduction: Saving energy in radio-frequency power amplifiers (RFPAs) remains a major challenge. Many solutions have been investigated during the past years, such as envelope tracking [1] or the power conditioning circuit for active phased array antennas [2]. These require additional circuitry, such as a switch-mode power supply, to optimise the efficiency of the RFPA at the back-off operation. Therefore, the design of high speed and efficient energy DC/DC converters has been the subject of many investigations.

The unique properties of semiconductor gallium nitride (GaN) transistors in terms of electron mobility, power density and capacitance make them very attractive for the design of high frequency switching mode power ICs like DC/DC converters. The combination of pulse width modulation (PWM) and high power GaN transistors appears to be the most interesting way to achieve an efficient DC/DC conversion [3, 4].

One major technical difficulty encountered in DC/DC converters concerns the design of high switching rate gate drivers capable of sourcing and sinking capacitive loads which are presented by the gate port of power switching transistors. To use GaN power HEMT devices, the gate driver must provide negative square waveforms. Fast transients are obviously required to minimise the switching power losses.

Consequently, driving high power GaN HEMTs becomes a new challenge. Some papers have already investigated solutions to drive GaN power switch using complementary Si devices technologies (p-MOS and n-MOS) [5, 6].

Recently, we have presented in [7] a fully GaN HEMT-based supply modulator. This Letter highlights our recent work on this topic and focuses on the GaN gate driver characterisation with integrated PWM functionality.

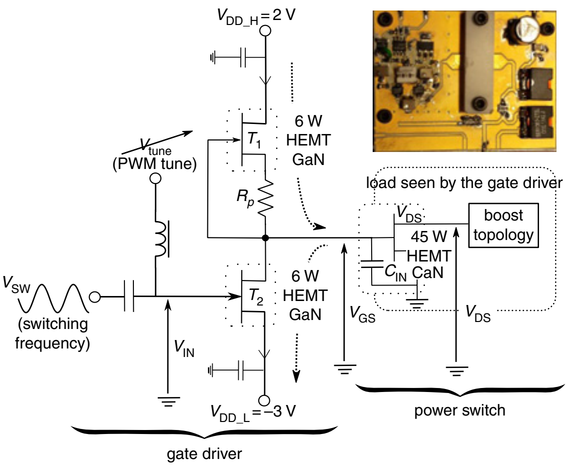

Fig. 1 *Schematic and picture of GaN gate driver connected to power switch*

Gate driver circuit topology: The proposed architecture is based on two 6 W DC-18 GHz normally-on GaN HEMTs (T_1 and T_2) from Cree, Inc. (CGHV1F006S). Fig. 1 presents the schematic and a picture of the proposed GaN gate driver.

Transistor T_1, which is the switching device delivering the sourcing current to the load, is a normally-on transistor driven with a negative gate–source voltage. Transistor T_2, which is the switching device absorbing the sinking current from the load, controls the current in the self-biasing resistance R_P, necessary to self-bias T_1. $R_P = 10\,\Omega$ is chosen to meet a trade-off between the output voltage dynamic range requirement and the output square wave signal rise time. To drive the GaN power switch (45 W) having a 30 pF input capacitance (C_{in}), a gate–source voltage swing between −3.5 V (V_{DD_L}) and +2 V (V_{DD_H}) is required.

The switching frequency is imposed by the frequency of the input sinusoidal signal (V_{SW}). Tuning the DC value of the signal (V_{IN}) driving the gate port of transistor T_2 offers a pulse-width controllability of the driver output voltage (V_{GS}). This is achieved by tuning V_{Tune}. When the DC bias voltage (V_{Tune}) is set to −6 V, (V_{Tune}-V_{DD_L}) which is the DC gate–source voltage of T_2 is equal to the pinch-off voltage (V_{P_T2}) and a square wave signal having about 45% duty cycle is obtained at the gate driver output.

Measurements results and PWM function: The proposed gate driver circuit has been connected to a 45 W GaN power switch used in a DC/DC boost topology for prototype demonstration, as shown in Fig. 1. The measured waveforms are presented in Fig. 2 and demonstrate an experimental square voltage at the gate driver output (V_{GS}) with switching frequencies of 20, 40 and 60 MHz. Fig. 3 shows measured gate and drain waveform voltages (respectively, V_{GS} and V_{DS}) of the 45 W power switch in the case of a 40 MHz switching frequency and a 50% duty cycle. The switching rising and falling times are about 2 ns.

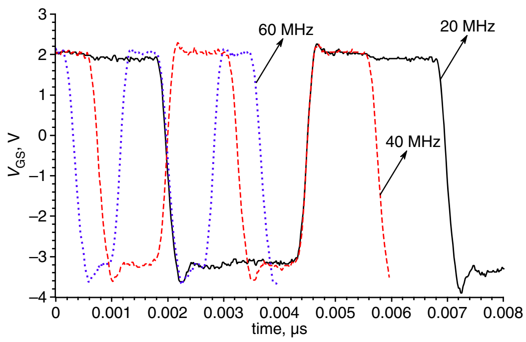

Fig. 2 *Measured square waveforms at gate driver output for different switching frequencies with 50% duty cycle*

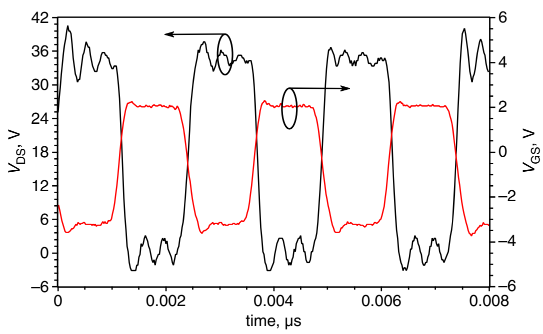

Fig. 3 *Measured gate and drain voltage waveforms of 45 W GaN power switch at 40 MHz switching frequency and 50% duty cycle*

The gate driver behaves like a threshold comparator with two stable (V_{DD_H} and V_{DD_L}) states as illustrated by the measured transfer curve plotted in Fig. 4. Tuning the duty cycle voltage (V_{Tune}) enables modifying the aperture angle of transistor T_2 driven by the input sine wave voltage (V_{SW}).Consequently a square wave signal (V_{GS}) having variable duty cycles is obtained at the gate driver output, using a small input magnitude sinusoidal signal ($V_{SW} < 2$ V).

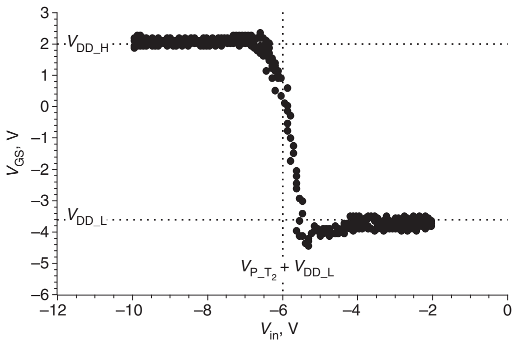

Fig. 4 *Measured dynamic transfer characteristic of gate driver loaded with power switch (f_{SW} = 20 MHz)*

Measurement results plotted in Fig. 5 show duty cycle variations between 20 and 80% at the 40 MHz switching frequency. Fig. 6 indicates that the duty cycle variations are linear against the DC tune voltage (V_{Tune}).

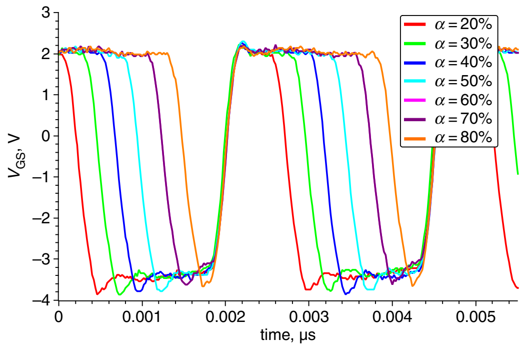

Fig. 5 *Measured output square waveforms for different duty cycles at 40 MHz switching frequency*

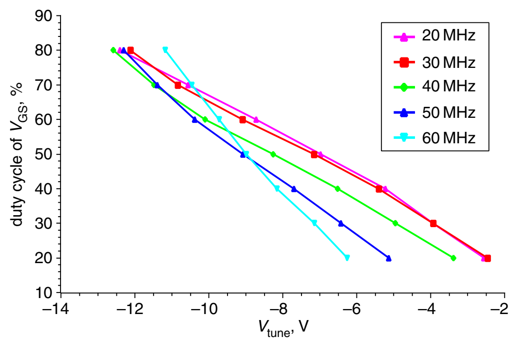

Fig. 6 *Output gate driver duty cycle against DC tune voltage at different switching frequencies*

The gate driver power consumption has been measured to be around 1 W for the most unfavourable operating conditions (high frequency and low duty cycle).

Conclusion: A 1 W gate driver integrating PWM functionality in GaN technology has been built using packaged GaN transistors and applied to drive a 45 W GaN power switch. This solution allows a uniform technology suitable for fully integrated GaN DC/DC converter solution. The proposed circuit topology behaves as a threshold comparator transforming the input sine wave to an output square wave capable of driving large capacitive loads. An integrated GaN solution, in a same manner as that reported in [8], should enhance the overall performances to target switching frequencies higher than 100 MHz.

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One or more of the Figures in this Letter are available in colour online.

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References

1 Kim, B., Kim, J., Kim, D., Son, J., Cho, Y., Kim, J., and Park, B.: 'Push the envelope: design concepts for envelope-tracking power amplifiers', *IEEE Microw. Mag.*, 2013, **14**, (3), pp. 68–81, IMS special issue

2 van der Bent, G., de Hek, P., Geurts, S., Telli, A., Brouzes, H., Besselink, M., and van Vliet, F.E.: 'A 10 W S-band MMIC power amplifier with integrated 100 MHz switch-mode power supply and control circuitry for active electronically scanned arrays', *IEEE J. Solid-State Circuits*, 2013, **48**, (10), pp. 2285–2295

3 Augeau, P., Bouysse, P., Martin, A., Nebus, J.M., Quéré, R., Lapierre, L., Jardel, O., and Piotrowicz, S.: 'A new GaN-based high-speed and high-power switching circuit for envelope-tracking modulators', *Int. J. Microw. Wirel. Technol.*, 2013, **6**, pp. 13–21

4 Gamand, F., Li, M.D., and Gaquiere, C.: 'A 10-MHz GaN HEMT DC/DC boost converter for power amplifier applications', *IEEE Trans. Circuits Syst. II Express Briefs*, 2012, **59**, (11), pp. 776–779

5 Wang, B., Tipirneni, N., Riva, M., Monti, A., Simin, G., and Santi, E.: 'An efficient high-frequency drive circuit for GaN power HFETs', *IEEE Trans. Ind. Appl.*, 2009, **45**, (2), pp. 843–853

6 Acar, M., van der Heijden, M.P., and Leenaerts, D.M.W.: '0.75 Watt and 5 Watt drivers in standard 65 nm CMOS technology for high power RF applications'. IEEE Radio Frequency Integrated Circuits Symp. (RFIC), 2012, Montreal, Canada, June 2012, pp. 283–286

7 Delias, A., Medrel, P., Martin, A., Bouysse, P., Nebus, J.M., and Quere, R.: 'A GaN-based supply modulator for energy efficiency enhancement of active phased-array antennas'. 2014 Int. Workshop on Integrated Nonlinear Microwave and Millimetre-wave Circuits (INMMiC), Leuven, Belgium, April 2014, pp. 1–3

8 Hong, Y.-P., Mukai, K., Gheidi, H., Shinjo, S., and Asbeck, P.M.: 'High efficiency GaN switching converter IC with bootstrap driver for envelope tracking applications'. 2013 IEEE Radio Frequency Integrated Circuits Symp. (RFIC), Seattle, WA, USA, June 2013, pp. 353–356