

AN ULTRA-HIGH SWITCHING FREQUENCY STEP-DOWN DC-DC CONVERTER BASED ON GALLIUM ARSENIDE DEVICES

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ABSTRACT

A 50MHz to 100MHz dc-dc power converter using Gallium Arsenide power switches is studied. GaAs Schottky rectifiers with high breakdown voltage and very small $R_{on} \times C_{on}$ switching quality factor have been fabricated. A 10V to 5V (or 8V) prototype with an output power of 2.6Watts and a power efficiency of 77% has been reported.

INTRODUCTION

Regarding the evolution of electronic systems now, toward more and more integrated technologies, it appears a growing need for high switching frequencies and small size DC-DC power converters, especially those used in portable systems and for space applications.

In DC-DC converter applications, high efficiency and high switching speed are of critical importance. GaAs MESFET devices are similar to Silicon metal-oxide semiconductor field effect transistor (MOSFETs) in that they are majority carrier devices. They switch quickly without the minority carrier storage seen in bipolar devices. The primary advantages for using GaAs over silicon are low ON resistance, low voltage, fast switching speed, and semi-insulating substrate. The use of Gallium Arsenide power devices like MESFETs and Schottky barrier rectifiers have permitted to push the switching frequencies of DC-DC converters from 1MHz up to 150MHz [1][2]

High frequency switching allows first of all to reduce proportionally the size of filtering elements like inductors and capacitors and thus, to perform a quick control of DC output voltage. Such components have interesting applications in communication systems using dynamic-bias Class A amplifiers, where bias voltage level has to vary according to the level of the RF input envelope signal. This permits to improve power efficiency and to decrease power consumption [3].

However, up to now, only step-up converters were used owing to their simplified circuit topology.

CIRCUIT IMPLEMENTATION

In this paper, the study is focused on the implementation of a step-down 10V to 5V (8V) converter using floating source GaAs power MESFET and appropriate gate driver.

The circuit topology is illustrated in figure 1. The main problem encountered was to realise a driver circuit that permits to turn on/off the power MESFET, for which the source is electrically floating and switching between 10 and 0V

In addition, taking into account the very short transition times at 100MHz (< 500ps) and the potentially high di/dt related overshoot, it was necessary to fabricate a specific power GaAs

Schottky rectifier that handles 2A-20V with reduced on state junction capacitance and series resistance (respectively 32pF and 0.3Ω for a $200 \times 200 \mu\text{m}^2$ area).

A low doping level n-GaAs layer has been grown by MBE on an N++ substrate in our laboratory. Back-face ohmic contacts have been realised after the substrate has been thinned to $250\mu\text{m}$. Schottky contact, mesa definition, electrolytic metal thickening, and silicon nitride passivation process have been done. A cross section is shown and commented in figure 2.

An prototype based on hybrid circuit technology was implemented on an alumina substrate. It uses a 1A-15V X-band power MESFET, a X-band MESFET based gate driver, a 110nH-HF ferrite based very low loss inductor and various DC decoupling chip capacitors (figure 3).

RESULTS

Measurements show a high efficiency regime in the whole 40 to 100MHz frequency range (figure 4).

A 10V to 5V (or 8V) conversion ratio with an output power of 2.56Watts has been performed. A power efficiency of 77% has been obtained at 40MHz. It decreases linearly when the switching frequency increased. This is mainly due to the switching losses in the power MESFET during the ON-OFF and OFF-ON transitions where the transistor equals to its ON-state or its OFF-state resistance. Thus, using MESFET power transistor with an 0.5Ω -ON state resistance (R_{ON}) instead of a 4Ω one (used in this prototype) will allows us to achieve more than 85% power efficiency at 100MHz.

In figure 4, we can also observe a large and linear variation of the output voltage V_{out} when duty ratio D varies from 30% to 80% following the theoretical $V_{\text{out}}=D \cdot V_{\text{in}}$, where V_{in} represents the input voltage. Concerning the power efficiency, it increases to reach 74% for higher values of duty ratio. Losses in lower duty ratio are consequences of the knee voltage of the diode (about 0.8V).

On the other hand, time domain simulations using PSPICE permit to emphasise the capability of the circuit in term of response time of the output voltage by using a Pulse Width Modulation feedback loop (figure 5). In fact, 300ns transition times are expected, which should permit to modulate the DC output voltage at 3MHz.

CONCLUSION AND PERSPECTIVES

Regarding the results of this prototype, we can observe a close relationship between the performances of the circuit and the GaAs devices characteristics. The above prototype has permitted to demonstrate the feasibility of step-down converters and to highlight the pressing need for a smart power GaAs technology. The PWM feedback loop circuits should in fact be implemented very close to the gate driver in order to prevent circuit oscillations and voltage overshoots.

Currently, power DC-DC converters using high switching frequencies have two principal limitations: the relatively small breakdown voltage of HF switches, and HF losses of passive components.

In fact, L and X band power MESFETs, which seem to be the most adapted for these applications have a 15V to 20V breakdown voltages which allow only some low voltage DC-DC converters [4]

Novel large gap III-V devices technologies such as GaN should also be investigated in order to realise higher voltage conversion systems.

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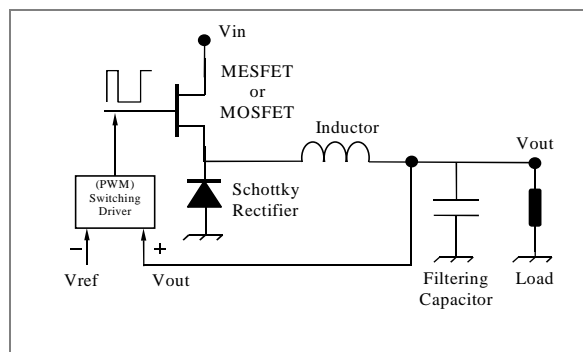


Fig. 1 : Square - Wave DC/DC step-down or Buck Converter

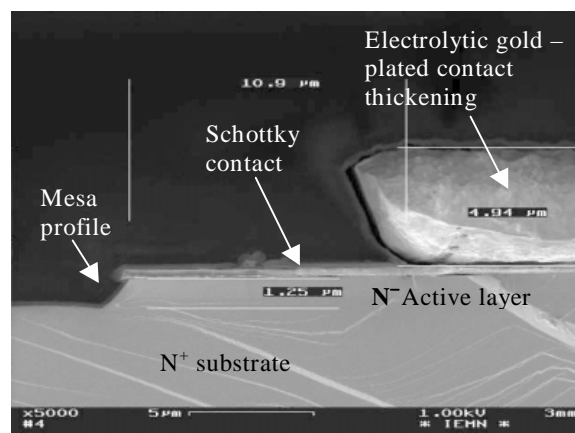


Fig.2: SEM photography of a Si₃N₄-passivated Schottky power diode used in the Buck converter

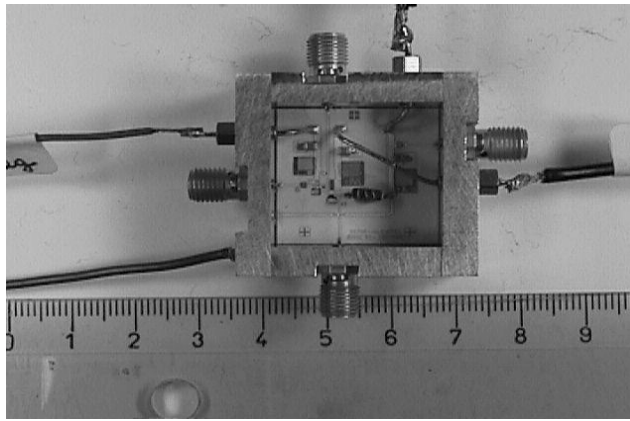


Fig.3: Characterisation cell of the Buck converter prototype realised at IEMN. Many RF accesses are implemented in order to visualize switching signal waveforms

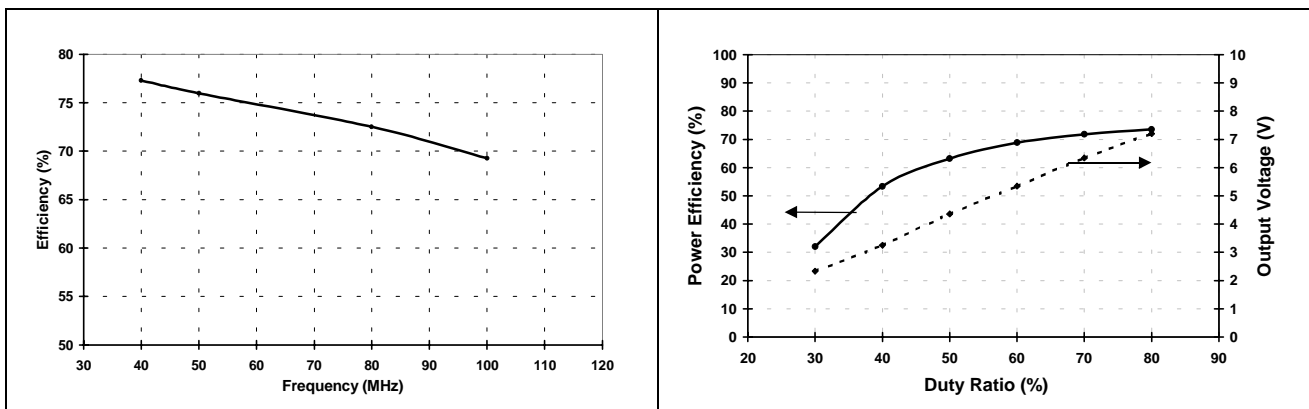


Fig 4:Left : Power efficiency variations versus switching frequency (Input Voltage = 10V, Output Voltage = 8V, Load = 25Ω).

Right : Power efficiency and output voltage variations versus the duty ratio (Input voltage=10V, Load = 25Ω, F=100MHz).

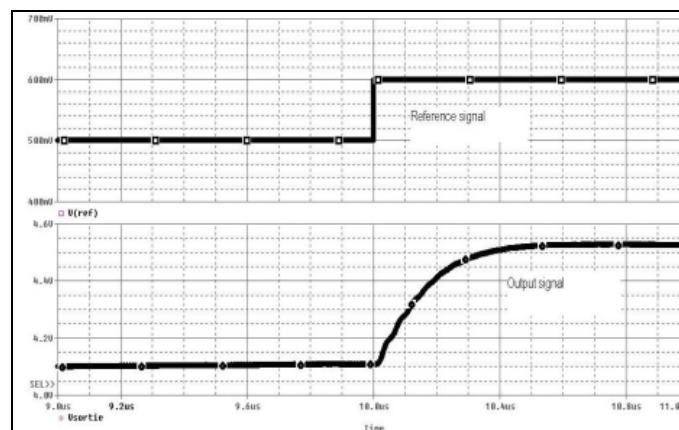


Fig 5: Time variations of converter's output voltage driven by a pulsed reference signal (PSPICE simulation)