Over 10MHz Bandwidth Envelope-Tracking DC/DC converter for Flexible High Power GaN Amplifiers

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Abstract **— This paper describes a fast envelope-tracking circuit capable of 10 MHz (up to 17.5 MHz) bandwidth based on RF GaN switching devices and 50 MHz switching frequency. The efficiency of the VHF converter is 84% to 90% which is comparable to a conventional DC/DC converter for spaceborne application. A demonstrator has been built and mated with a RF GaN HEMT output stage. The C/I measurement for 10-12W RF output power close to saturation show a linearity improvement by 5-8dB and an efficiency improvement of up to 8 points when compared to the case of no tracking circuit.**

Index Terms **— SSPA, HPA, envelope-tracking, HPA, GaN technology, DC/DC converter.**

I. INTRODUCTION

Typically amplifiers for Spaceborne Telecom or Navigation face similar requirements than amplifiers developed for ground applications. Primarily efficiency and linearity are key requirements. The Fig.1 gives an overview of a typical S-band Spaceborne Solid Sate Power Amplifier (SSPA).

In such RF equipment, the DC/DC converter is integrated in the unit to interface with the satellite platform (BUS) which provides 50V or 100V. The converter (Electronic Power Conditioner) transforms the BUS voltage to the required value needed for each RF module (9V or 50V for HPA power lines). The EPC efficiency is often above 90%.

Since most of Spaceborne SSPAs are used in “transparent” payloads, the signals are generally not known in advance and no baseband signal is available. This discards the digital pre-distortion techniques due to the cost and energy necessary to access the signal (down/up conversion, signal processing).

Still, power flexibility (constant efficiency over 4dB power range), improved linearity and efficiency are required and various techniques to improve the performance of SSPAs operating with modulated signals are being investigated.

With the presence of a DC/DC converter in a spaceborne SSPA, the envelope-tracking technique [1] seems to be a very well suited approach to allow power flexibility and improved performance. However the bandwidth required for L & S band SSPA is typically 36-40 MHz. For such a bandwidth the envelope-tracking system should ideally provide an efficiency of 90% to avoid performance degradation. This paper describes a demonstrator of a fast DC/DC converter associated to a GaN HPA capable to handle signal bandwidths of 36-40 MHz with good efficiency.

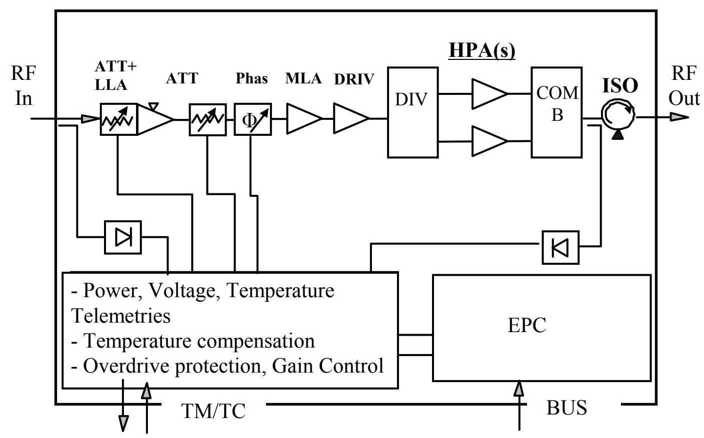

Fig. 1. Spaceborne SSPA block diagram.

II. BANDWIDTH REQUIREMENTS AND SWITCHING FREQUENCY

The envelope-tracking allows an improved performance compared to the conventional fixed V_{ds} approach.

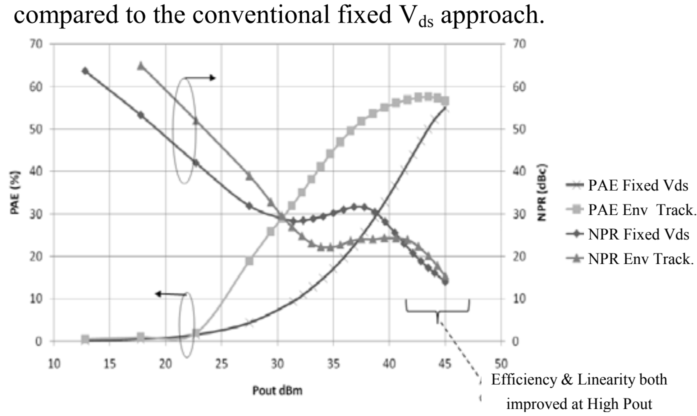

Fig. 2. Multi-carrier simulation – Fixed V_{ds} / Envelope-tracking

As shown in Fig 2. , the efficiency is clearly improved on the whole range of operation of the HPA (including large back-off). For what concerns linearity for operation close to saturation there is a high range (>4dB) where both linearity and efficiency are improved when compared to a fixed V_{ds} operation. Envelope-tracking therefore enables flexible SSPA (4dB range) with improved linearity and efficiency.

The wide bandwidth of the envelope signal makes the tracking technique implementation difficult due to a degradation of efficiency of the modulator with increasing bandwidths [2].

The simulation based on the topology given in Fig. 3 demonstrates that the bandwidth of the envelope amplifier can be lower than the original envelope signal bandwidth. In this example a 3000 carriers signal centered at 2.185 GHz with a channel bandwidth of 36 MHz is exciting the HPA. A tracking path generates a time varying drain voltage for the HPA according to the RF input envelope level.

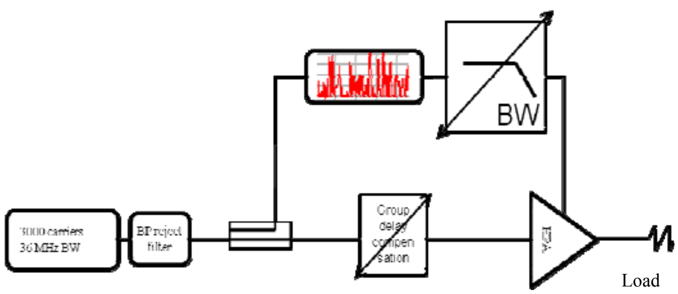

Fig. 3. Envelope-tracking Bandwidth Reduction Simulation

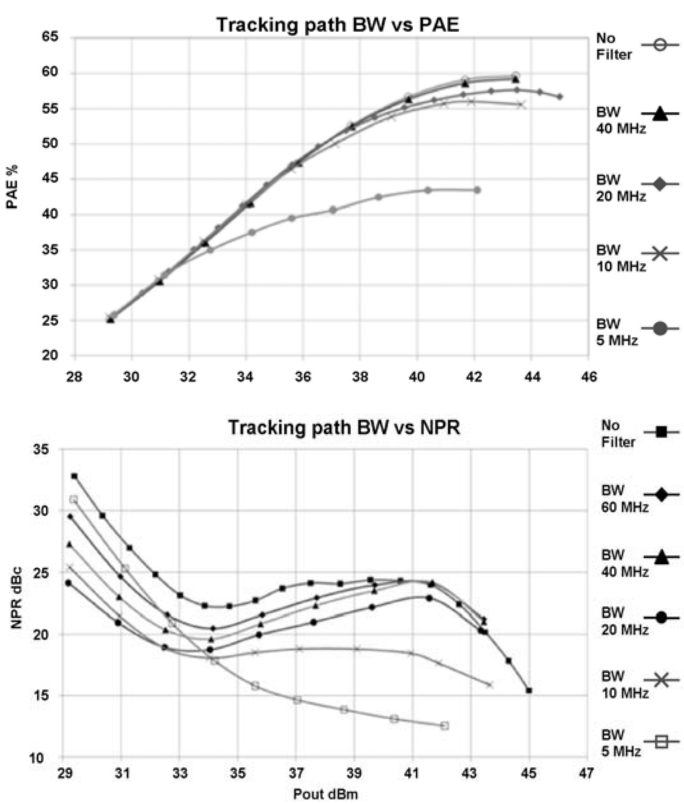

Fig. 4. Envelope-tracking Bandwidth Simulation results.

As shown in Fig 4., the best performance is obtained when the envelope-tracking bandwidth is larger (40 MHz) than the original signal bandwidth. It is also visible that around saturation (44dBm) the linearity with a NPR>20dB is relatively high for a spaceborne application which typically requires 15dB. The PAE is maintained between 59 & 56 % over 4dB output power back-off, which is much better than operation at fixed Vds (Table I).

With 10 MHz bandwidth in the envelope-tracking loop (72% bandwidth reduction), the PAE is only 3 points lower at full power and almost the same in back-off condition. The linearity remains above the requirement of 15dB (Table I). If a 20 MHz filtering is used, there is no performance degradation compared to the case of envelope-tracking without filtering.

These simulations show that the envelope modulator bandwidth does not need to be the same as the RF input signal. A good trade off can be 50% (up to 70%) of bandwidth reduction (bandwidth 10 MHz to 18 MHz). The simulation shows also that if the envelope-tracking is not fast enough, the performance will be severely affected (i.e. BW<5MHz).

TABLE I

ENV. TRACKING VS FIXED V_{DS} PERFORMANCE SUMMARY

	Fixed Vds	Envelope-tracking	
		BW=40MHz	BW=10MHz
Pout	44 dBm	44dBm	44dBm
PAE	53%	59%	56%
NPR	15dB	20dB	15.5dB
Gain	12dB	11dB	11dB
PAE@4dB OBO	34%	56%	55%
NPR@4dB OBO	27dB	24dB	18.5dB

III. ENVELOPE-TRACKING SWITCHING STAGE

In order to ensure good efficiency in the order of 90% and fast response time (bandwidth >10-20MHz), the envelope-tracking circuits shall be based on conventional DC/DC converter topology but working at higher switching frequencies. However in order to avoid the switching losses induced in the components, the devices used shall be able to work at high frequencies.

For this work, the topology chosen is based on the step-up BOOST topology chosen for its simplicity (Fig.5). In DC/DC converters used for spaceborne applications 60 to 150KHz is commonly used as optimum switching frequency. A switching frequency of 1 or 2 MHz would be considered to be very high using conventional Si-MOSFET technologies. For this application, switching frequencies of the order of 50 MHz or above are necessary. The choice of the components and the overall layout play therefore an important role in the realization of a good design.

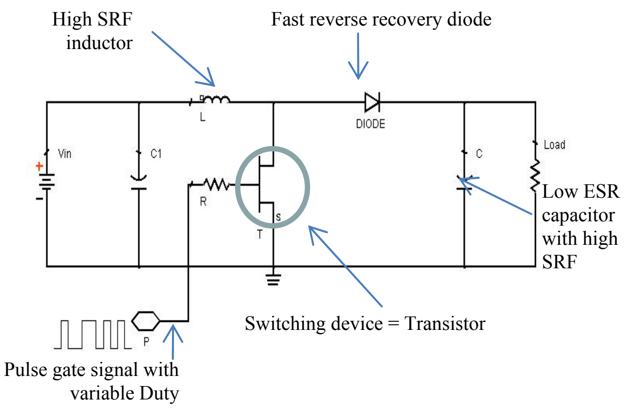

Fig. 5. Open loop DC/DC converter based on BOOST topology

As shown in Fig.5, the switching device plays a central role. For this work, the switching transistors are based on RF GaN technology, while the passive components are realized using elements capable to work at RF frequencies (High Series Resonant Frequencies). This approach is currently the subject of a patent application.

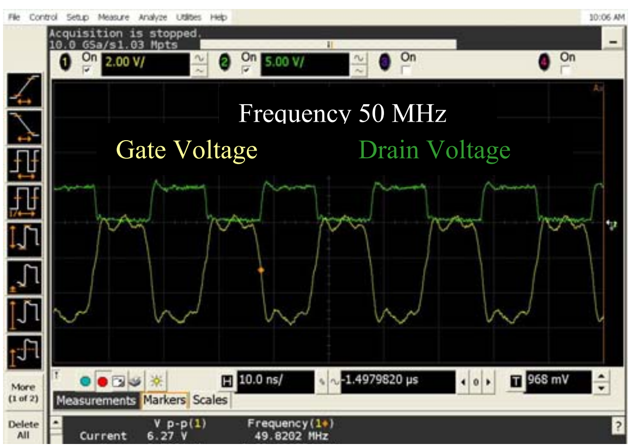

Fig. 6. GaN HEMT switching time

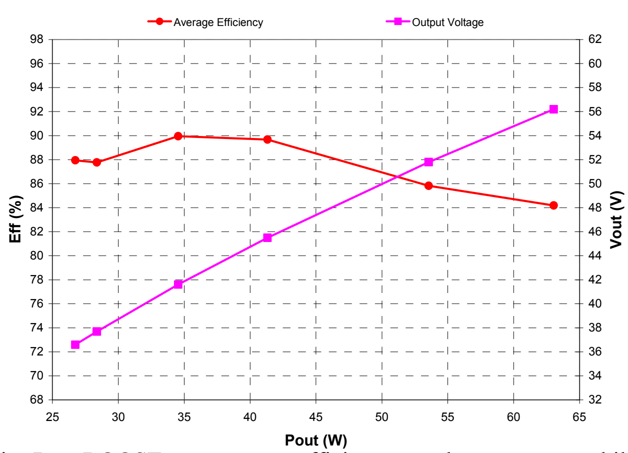

Fig. 7 BOOST converter efficiency and power capability. Fswitch=60 MHz. Vin=32V

The Fig.6 gives some characterization of the RF GaN HEMT transistor when switched at 50 MHz. It shows that the transistor does not limit the on-set/switch-off of the Ids current which presents very fast rising edges below 1 ns.

The Fig.7 shows that the converter based on Cree CGH40025F allows up to 65W DC output power with an associated efficiency between 84% and 90%. The corresponding output voltage varies from 37V to 56V as a function of the synthesized duty cycle of the gate pulse train when driven at a supply voltage of 32V.

IV. BOOST CONVERTER DYNAMIC RESPONSE

In order to demonstrate the dynamic response of the DC/DC converter, the test bench depicted in Fig.8 is build. The test bench shall emulate an accurate PWM gate driver at the input of the GaN HEMT switching device by providing fast rising edges with respect to the 50 MHz operating frequency.

This is achieved thanks to a fast arbitrary waveform generator which can provide pulse trains associated with variable duty cycles. The PWM function itself is emulated in ADS before loading the signal within the ARB. A wide bandwidth lab amplifier provides the necessary gate voltage amplitude to drive the switching device. The pulse train is realigned to match the negative pinch-off voltage of the GaN HEMT with a bias tee.

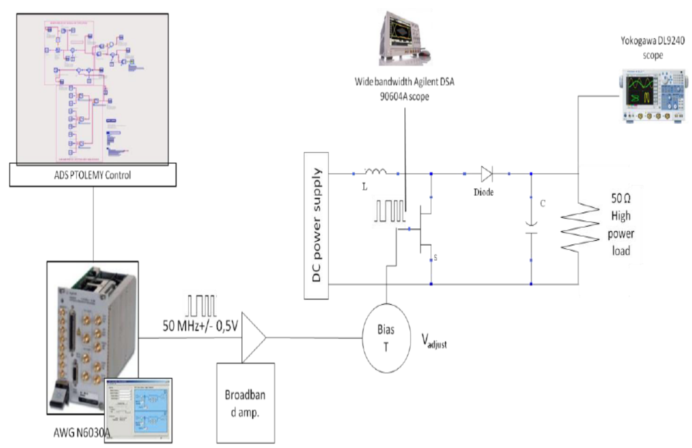

Fig. 8. PWM emulation and gate driver for the BOOST converter

Using very fast Arbitrary waveform generator and wide bandwidth drivers allow fast rise time on the pulse edges (<1ns). At 50 MHz switching speed (20ns pulse duration), this allows to achieve very small duty cycles down to 3% or less.

The simulator is used to emulate a sinusoid coded via the PWM signal, in order to characterize the amplitude response of the DC/DC converter as a function of frequency.

In Fig. 9, the DC/DC converter is driven with a PWM coded sinusoid of 6.27 MHz. The record done with an oscilloscope located at the output load of the envelope-tracking circuit, shows that the sinusoid is reproduced with fidelity (no spike, noise or distorted shape). The measured frequency is 6.27MHz. Note that the switching frequency of the DC/DC converter (50 MHz) has been properly filtered.

In order to extract the frequency response of the DC/DC converter the sinusoid frequency has been swept from 700

KHz till 19MHz. The sinusoid amplitude at the output of the DC/DC converter (amplitude range around a fixed DC value) has been measured and is reported in Fig.10.

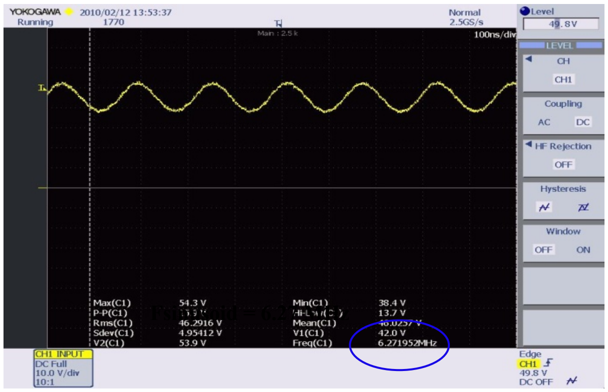

Fig. 9. BOOST response to a sinusoid coded through a PWM

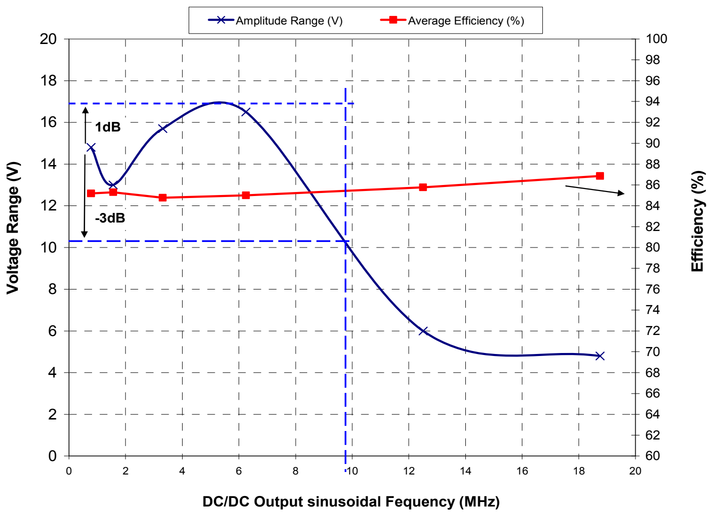

Fig. 10. Open loop VHF BOOST converter Frequency response

The 3dB bandwidth has been found to be at 10 MHz. In fact the bandwidth in this case has been limited by a low-pass output filter designed for 3dB bandwidth of 10 MHz. An other measurement done with a larger bandwidth low-pass filter showed that a bandwidth of 17.5 MHz is also achievable to the expense of more ripple and noise on the signal.

For a safer operation with the RF power amplifier the breadboard with a 10 MHz output filter has been kept.

V. Mating with RF GaN HPA

The envelope-tracking circuit equipped with the emulated PWM has been mated with a RF power stage build around a 30W GaN RF transistor (Fig. 11).

The breadboard consisting of the BOOST envelope-tracking circuit commanding the drain voltage of the RF GaN amplifier has been tested with a two tone signal with a tone separation of 6.27 MHz. The results are reported in Fig.12.

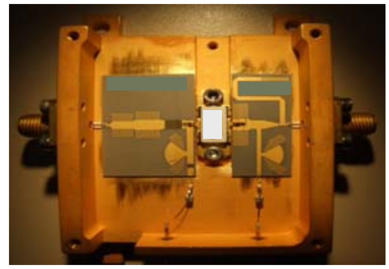

Fig. 11 GaN HEMT 30W HPA stage

The comparison is made between a RF power stage driven by a conventional DC/DC convert with 90% efficiency and the same RF power stage driven by the BOOST envelope amplifier circuit of 10 MHz bandwidth. The measurements show a C/I improved by 5 to 8dB in the compression area. The efficiency for an output power of 39-41dBm is also improved up to 7-8 points of percentage.

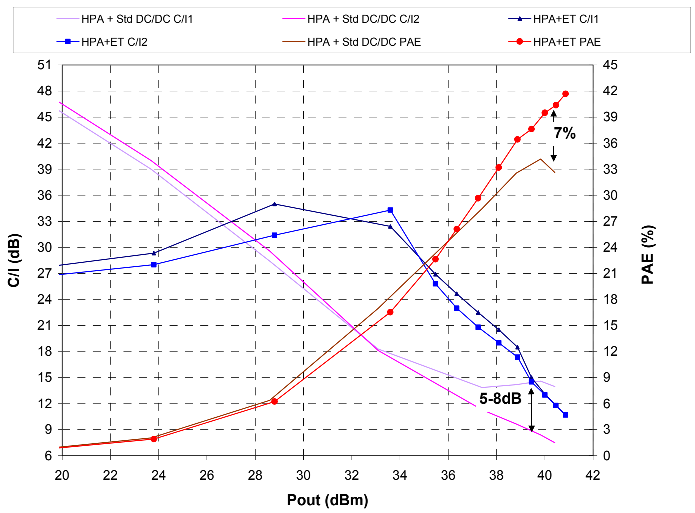

Fig. 12. RF HPA+DC/DC performance with a two tones RF test signal (6.27 MHz spaced) centered at 2.185GHz

VII. Conclusion

In this work, envelope-tracking circuits of more than 10 MHz bandwidth (up to 17.5 MHz) have been realized with efficiency close 90%. This allows a significant improvement of both linearity (5-8dB) and efficiency (up to 8 points) of a conventional GaN HEMT RF HPA. The envelope-tracking circuit is based on the open loop BOOST topology realized with RF GaN transistors and RF passive elements. This implementation is currently the subject of patent application.

References

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