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High Speed and Highly Efficient S-Band 20 W Mixerless Vector Power Modulator

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Abstract—This paper presents a performance evaluation of an original highly efficient and linear GaN-HEMT Vector Power Modulator (VPM) based on the design of a two-stage saturated variable gain (SVG) amplifier and a multi-level discrete supply modulator (SM). The proposed novel architecture for transforming a digital baseband data stream into an RF Vector modulated power waveform (RF Power DAC) is validated using a specific laboratory test bench. The main objective of this study is to merge signal modulation and DC to RF energy conversion functions into a single and compact GaN based mixer-less circuit.

Using high-voltage 50 V GaN technology, a 20 W S-band vector power modulator having overall average PAE of around 40 % is reported. The concept demonstrator is experimentally validated up to 100 Msymbols/sec 16-QAM modulation scheme. Functional time alignment with phase and amplitude compensation procedure focusing on measured constellation at 40 Msymbols/sec enables to reach excellent EVM performances of around 3.2 %.

Index Terms—Vector Power Modulator, RF power DAC, EVM, Efficiency, Supply Modulator, GaN-HEMT.

I. INTRODUCTION

The development of emerging wireless communication systems aiming at providing high data rate connectivity such as 5G is conceived as a possibility for heterogeneous networks implementing long and medium range micro and macro cells [1]. This requires more reconfigurable capabilities while the DC consumption of the system still remains one of the most important issue. The energy consumption of RF transmitters is governed by power amplifiers (PA) which are the most dominant power consuming devices in communication transmitters. The design criteria for PA requires addressing of the efficiency and linearity antagonism. The complex modulation schemes used in modern communication transmitters like n-QAM improve the spectral efficiency but cause high PAPR issues. This leads to the operation of PA's at back-off levels and hence degradation of average efficiency. This implies that PA's must be designed for high Peak to Average Power Ratio (PAPR) implementing techniques for providing efficient operation at average power levels. Several techniques have been implemented over the past few decades to efficiently amplify high PAPR signals such as Envelope Tracking, Doherty, EER [2], [3], [4] and sometimes a mixed approach of these techniques. In conventional transmitter architectures, signal modulation and DC-RF energy conversion (by PA's) are implemented as separate building blocks of the overall system. Things are slightly different for outphasing or EER techniques

where the modulated signal is processed at the PA input and reconstructed at the PA output with severe challenges in terms of bandwidth extension and time alignment accuracy of phase and magnitude components. In this work, a possible attractive solution for the development of next generation (5G) communication systems has been examined. This approach is based on the merging of digital modulation and DC to RF energy conversion functions into a single compact mixer-less module. A novel vector power modulator approach is proposed to improve linearity-efficiency reconfigurability trade-offs in transmitters. By taking the advantages of high voltage 50 V GaN technology, a concept demonstrator has been built and validated with a specific laboratory test bench. A 20 W output power for 16-QAM modulated power signals at S-band is reported.

The paper is organized as follows: in section-II, the working principle of the proposed vector power modulator is described. In section-III, the integration of the two-stage SVG amplifier with a GaN-HEMT based 3-level supply modulator is commented upon and in section-IV, the most significant dynamic measurement results and associated power performances of the overall system are highlighted.

II. VECTOR POWER MODULATOR WORKING PRINCIPLE

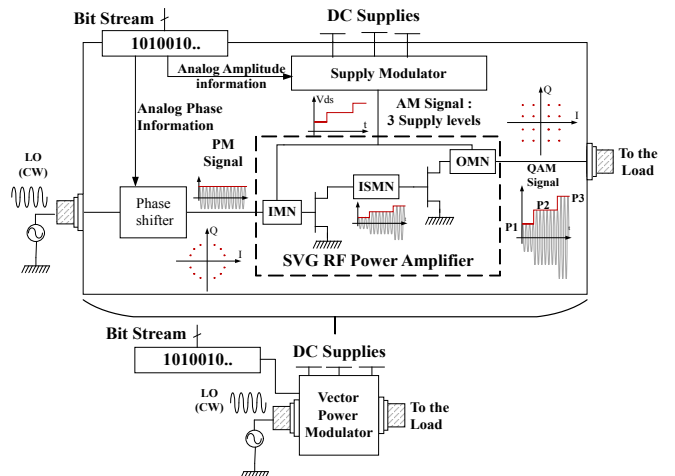


Fig. 1. Proposed Vector Power Modulator Block Diagram

Fig. 1 shows the key building blocks of the proposed vector power modulator consisting of a two-stage SVG amplifier and a multi-level supply modulator. The overall vector power modulator merges functionalities of modulation and energy conversion within the same module unlike conventional existing architectures. The input for the overall VPM is a phase shifted constant CW signal which acts as Local Oscillator (LO). The VPM delivers 3 gain controlled power levels at the output corresponding to 3 different bias supplies to generate a power modulated 16-QAM signal at 2.2 GHz.

A. Two-stage SVG Power Amplifier Design Principle and Circuit Implementation

The SVG power amplifier is designed using packaged GaN-HEMT transistors from Wolfspeed. The description of the design principle for the 2-stage SVG circuit alone is well defined and validated by us with CW measurements in [5]. Originality stands in a specific two-stage architecture to achieve large variations in terms of output power and gain. The design methodology of the two-stage circuit addresses the deep class-B operation of GaN-HEMT devices and power gain control using supply modulation technique. This technique was applied similarly at drain access for both stages, driver stage (*CGHV1F006S*) and power stage (*CGHV1F025S*) at a center frequency of $f_0 = 2.2$ GHz to generate 16-QAM constellations at the output. The driver stage, operating at a constant input power provides an output power variation of around $\Delta P_{interstage} = 3$ -5 dB to drive the power stage through the interstage matching circuit (ISMC) which in turn generates 3 power levels (P_1 , P_2 and P_3). This corresponds to 3 different drain supply voltages thereby providing large gain (output power) variations across the load always at saturation, here both ΔP_{out} and $\Delta G > 10$ dB for drain voltage levels between 15 V and 45 V. Fig. 2 illustrates the quasi-static measurement results at a constant input power of 19 dBm

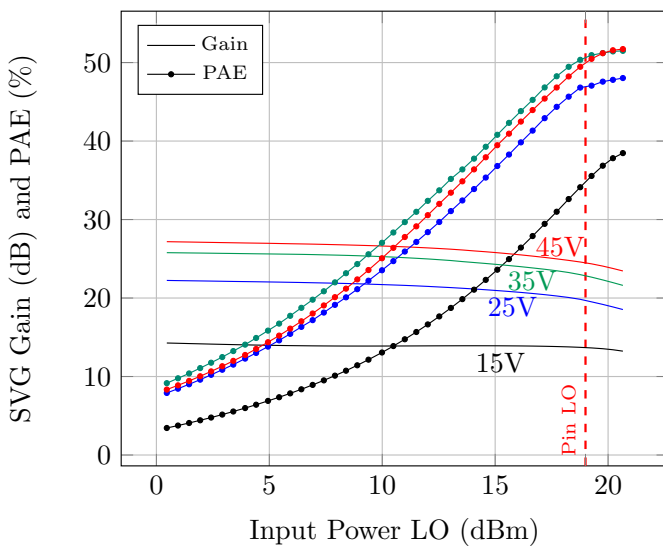


Fig. 2. Measurements of Gain and Efficiency performances of the 2-stage SVG circuit alone at saturation for a constant Pin LO=19 dBm

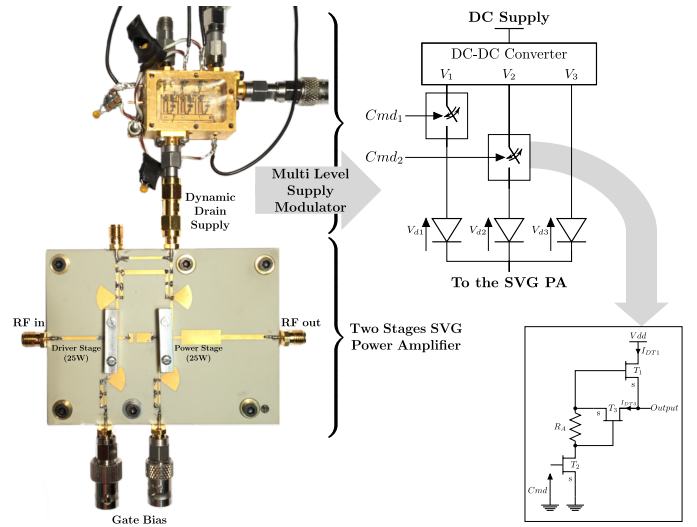


Fig. 3. Integration of the Two-stage SVGA and architecture of the multi-level supply modulator along with the description of the switches.

thereby indicating power modulation and hence validating the design concept. The RF bandwidth achieved for the two-stage SVG power amplifier was around 430 MHz.

B. Multi-level Supply Modulator

The fabricated multi-level supply modulator (shown at the top of Fig. 3) is based on UMS-GH50 GaN technology and SiC diodes from Wolfspeed. The switching cell topology takes advantage of a minimum number of components for the reduction of switching power losses. We have described and validated the design approach of the supply modulator circuit with measurements in [6]. In order to apply dynamic supply voltage to the SVG power amplifier as shown in Fig. 3, a supply modulator composed of 2 GaN based switches was used which provides high speed switching between the 3 supply voltage levels. The supply modulator was tested alone for switching frequencies of up to 150 Msymbols/seconds with efficiency of more than 70% for voltage ranging from 10 V to 45 V respectively.

III. VECTOR POWER MODULATOR MEASUREMENTS

A. Procedure for Modulated Signal Measurements

The generation and processing of I and Q signals for creating amplitude and phase control signals was carried out using a PC-controlled Arbitrary Waveform Generator (AWG) as shown in Fig. 4b. In order to minimize the overall EVM performance, two steps were followed: first, the amplitude information of the output modulated wave was optimized by tuning the 3 specified voltage levels of the supply modulator. Secondly, the appropriate phase shift was implemented at the input phase information plane to compensate for the V_{ds} -PM distortions that occurs at the output. The resulting output constellation associated with the power modulated wave is shown in Fig. 4c.

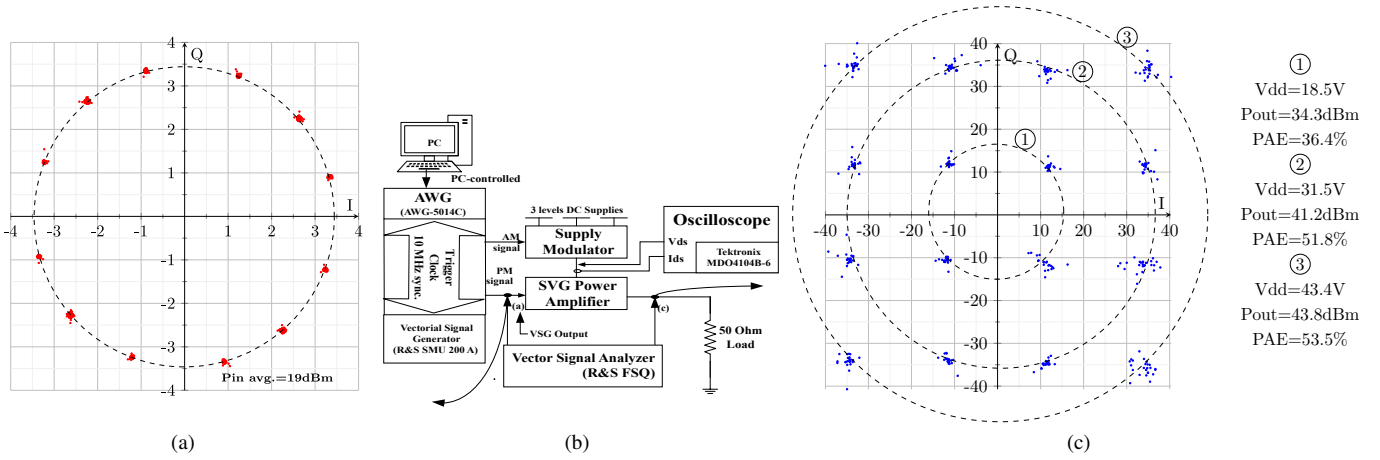


Fig. 4. (a) Initial symbol phase orientation for a 16-QAM modulation scheme at the input, (b) Experimental test bench setup and (c) Measured 16-QAM constellations at 40 Msymbols/sec for average Pin LO 19 dBm with amplitude and phase corrections at the input yielding 3.2 % EVM, 38.1 % overall average PAE and 40 dBm average output power with a dynamic range of 9.5 dB.

B. Principle validation for 16-QAM modulated signals at 40 Msymbols/sec

The initial phase orientations for the symbols depicted at the VSG output of the experimental setup (Fig. 4b) looks as shown in Fig. 4a and the corresponding voltage supply was provided according to the amplitude of the symbols. After a first set of measurements, the initial phase shift at each symbol in the IQ plane was derived and was used to compensate for the nonlinear phase variation at the input. Once the phase corrections were implemented, corrected output constellations were re-measured and were obtained at 50 Ohms output load as indicated in Fig. 4b.

Fig. 4c shows the measured amplitude and phase compen-

sated output constellations for 40 Msymbols/sec, 16-QAM modulation scheme. An overall average PAE of 38.1 % and a 40 dBm average output power is obtained with inner, middle and outer circles corresponding to the power levels P_1 , P_2 and P_3 as indicated in Fig. 1 and section-II-A with a dynamic range of 9.5 dB in terms of output power (gain).

Similar measurements were repeated for variable symbol rates from 0.25 Msymbols/seconds up to 100 Msymbols/seconds with excellent performances in terms of EVM and data rate capabilities indicating the quality of modulation.

Fig. 5 shows the measured EVM and average PAE of the overall system and the average PAE of the two-stage SVG RF power amplifier alone as a function of symbol rate. Excellent EVM (less than 5 %) can be observed and power performances with high quality modulation has been achieved for high symbol rates.

IV. CONCLUSIONS

The overall GaN based mixer-less Vector Power Modulator circuit demonstrator with large dynamic range (9.5 dB from P_1 to P_3) and high data rate operating always at saturation has been successfully validated and according to the authors knowledge has never been reported in literature before. Investigations of different performance parameters were carried out to come up with a potential state-of-the-art compact mixer-less circuit solution for next generation communication transmitters. The test bench used for measurements can manage both the baseband and RF signals at the same time.

The overall circuit can be seen as an RF power generation device based on bias controlled saturated variable gain which can generate modulated RF power waves with PAPR greater than 10 dB.

Possibilities are being investigated in order to apply a suitable spectral mask to the RF signal at the output [7]. Furthermore, we will investigate to take forward the proposed design principle for very high frequencies and up to 256-QAM.

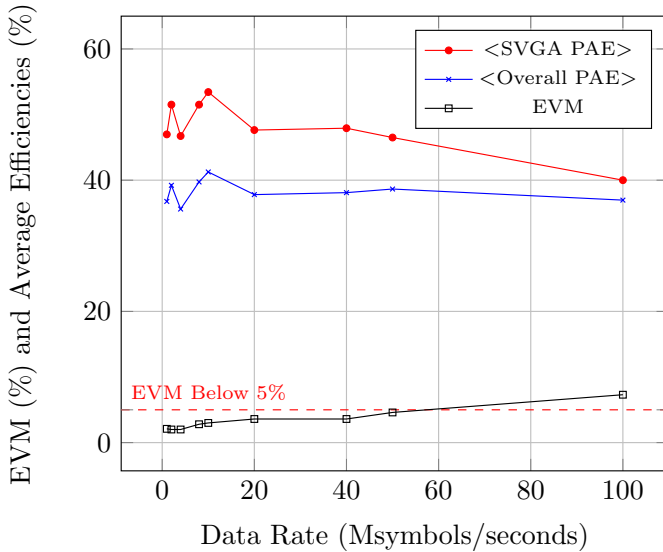


Fig. 5. EVM, individual average efficiency of the two-stage SVG amplifier and overall system average efficiency as a function of symbol rate, at constant average Pin LO = 19 dBm and 2.2 GHz

As both the two-stage SVG circuit and the supply modulator are built with same technology (GaN-HEMT), further work is being under development to co-design the supply modulator and the two-stage circuit in order to optimize the impedance presented by the drain port of the two stage circuit to the supply modulator. This proposed system can also find great interest in application to reconfigurable phased array antennas with enhanced power efficiency.

ACKNOWLEDGEMENT

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