A Versatile Large-Signal High-Frequency Arbitrary Waveform Generator Using GaN Devices

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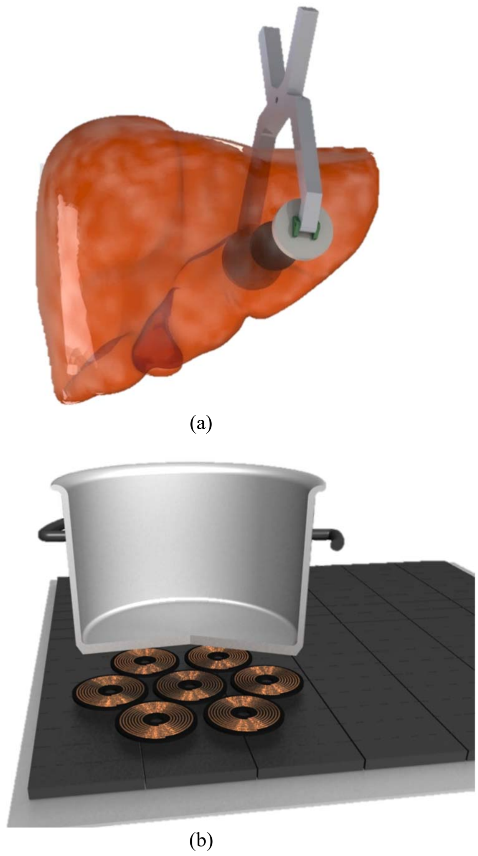
***Abstract*— Waveform generators are required for a wide range of application including industrial and biomedical areas. Traditionally, these systems usually aimed at generating high frequency signals but with low amplitude levels, making them unfeasible for large-signal real operation analysis. Advances in wide bandgap semiconductors together with digital control enables the design of new systems. This paper presents the design of a 2000-V versatile large-signal high-frequency arbitrary waveform generator taking advantage of GaN devices. The proposed system has been designed and implemented, proving the feasibility of this proposal.**

***Index Terms*—Electroporation, Magnetic components, Arbitrary waveform generators, capacitors, wide bandgap semiconductor, home appliances.**

I. INTRODUCTION

Arbitrary waveform generators are required for a wide range of industrial and biomedical applications where precise waveforms are required to be applied to either characterize or stimulate loads. Fig. 1 shows several examples including high-voltage application in parallel electrodes for electroporation in liver tissue [1, 2] (a) or characterization of induction heating loads [3-5] (b).

In the past, several attempts have been made providing high-frequency signal generators but with limited voltage/current amplitudes [6]. In [7], an accurate Josephson arbitrary generator is proposed, but limited to 1 V and 1 kHz. One of the few large-signal generators is detailed in [8]. However, it is limited to sinusoidal waveforms and requires adapting the resonant tank, including frequency resolution and dynamic performance limitations. The aim of this paper is to provide a versatile large-signal high-frequency arbitrary waveform generator taking advantage of the new WBG devices [9-12]. In particular, high voltage GaN devices will be used to enable a fast and high performance high-voltage generator implementation.



(a)

(b)

Fig. 1. Applications of the proposed versatile generator: Electroporation of liver tissue (a) and characterization of induction heating loads (b). “BodyParts3D liver” by Lambchops (a) is licensed under CC-BY SA 2.1JP. This image has been modified.

The remainder of this paper is organized as follows. Section II details the proposed power converter, including the main topology details and the proposed modulation and control strategy. Section III explains the main implementation and experiental results, including the main waveforms obtained with the proposed converter. Finally, Section IV draws the main conclusions of this paper.

II. PROPOSED POWER CONVERTER

A. Topology

The proposed converter (Fig. 2) is based on a multi-level structure composed of n levels, each one composed of a full-bridge providing $\pm V_{bus}$ voltage stored at an ultracapacitor. Consequently, the maximum output voltage is $v_o = \pm n V_{bus}$ and arbitrary waveforms can be generated with an amplitude resolution V_{bus}. This topology reduces the voltage ratings at each level, enabling the use of high-performance GaN devices.

B. Modulation and control strategy

In order to obtain the desired arbitrary waveforms, each level is activated sequentially to obtain the desired output voltage. To achieve a good temporal/frequency resolution, WBG devices will be used in order to increase the switching frequency, providing a faster response. Moreover, in order to increase the resolution when synthesizing certain waveforms with soft transients, PWM is applied [13, 14], enabling to increase the amplitude resolution thanks to the increased switching frequency of WBG devices. Fig. 3 shows an example where this modulation is used to synthesize a sinusoidal waveform, showing the benefits of this approach.

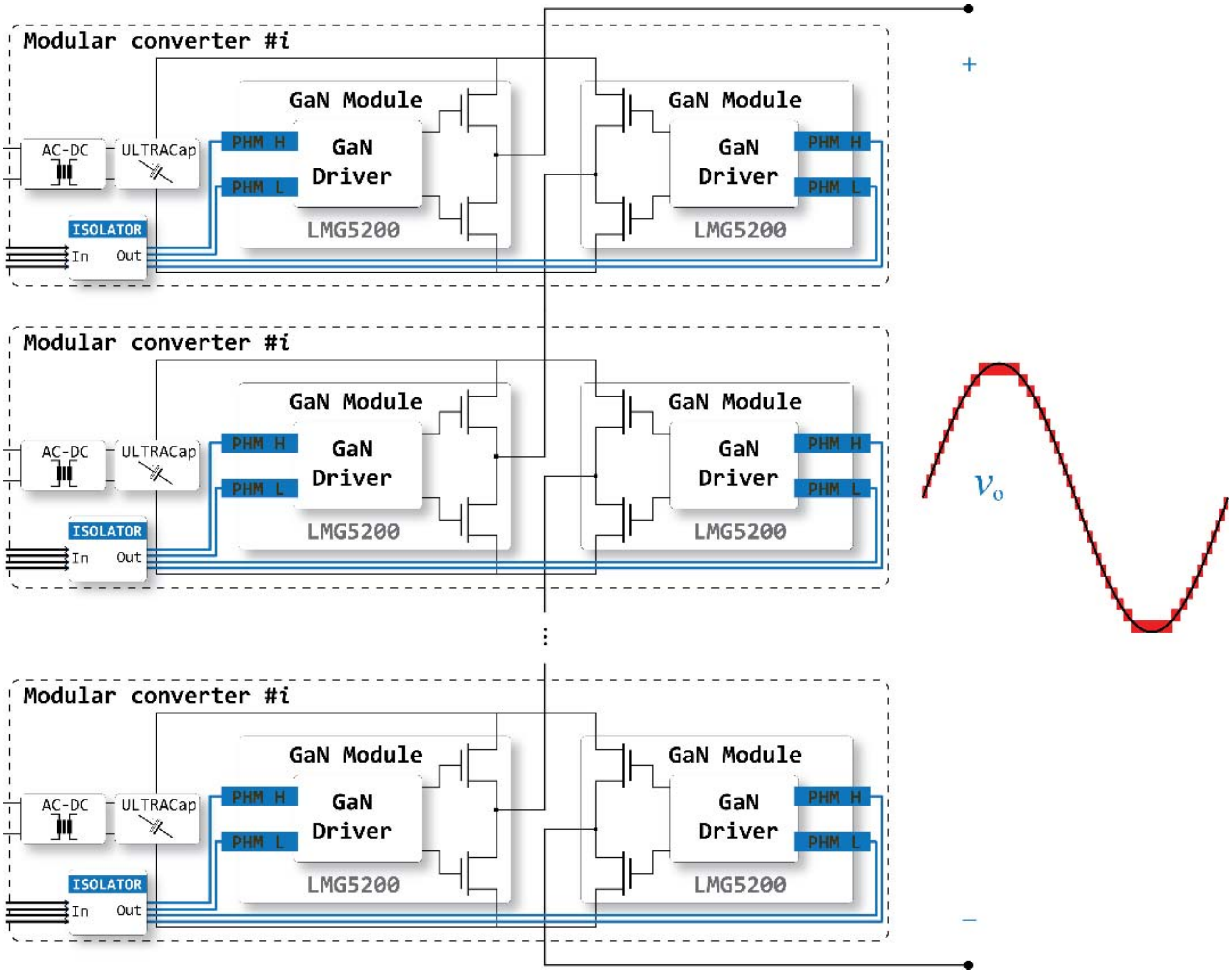


Fig. 2. Proposed GaN-based multi-level topology.

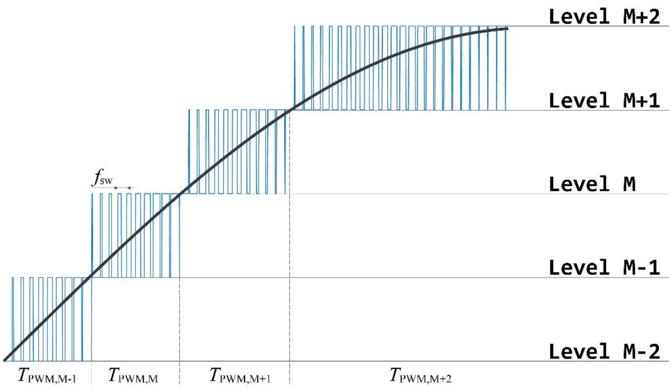


Fig. 3. Proposed modulation strategy for sinusoidal waveform generation.

III. IMPLEMENTATION AND EXPERIMENTAL RESULTS

The proposed versatile large-signal arbitrary waveform generator has been implemented using 20 levels with Vbus = 60. This provides up to 2400 Vpp with 60 V resolution that will be increased by using PWM. To achieve a good temporal/frequency resolution, 80-V LM5200 GaN devices from Texas Instruments have been used. These devices include the driving circuitry, enabling a high power-density implementation, key in this multi-level approach. These devices have a switching frequency of 1 MHz, enabling characterization in the range from dc to 1 MHz depending on the load, selected output filter and required waveform. Fig. 4 shows the implemented prototype, including GaN devices and sockets for FPGA and capacitors connection.

Fig. 5 shows a summary of representative experimental results, including generation of 50 Hz sinusoidal waveform with PWM detail (a), 100 kHz sinusoidal waveform, 1 kHz sinusoidal waveform with capacitive load, and a train-pulse typical of electroporation applications. These results prove the correct operation of the proposed converter and its feasibility for large-signal high-frequency arbitrary waveforms generation.

IV. CONCLUSION

This paper has proposed a versatile large-signal high-frequency arbitrary waveform generator following a multi-level structure and taking advantage of GaN devices. The proposed converter has been implemented and designed, achieving both high voltage and high temporal/amplitude resolution, opening the window to future industrial and biomedical applications.

ACKNOWLEDGEMENT

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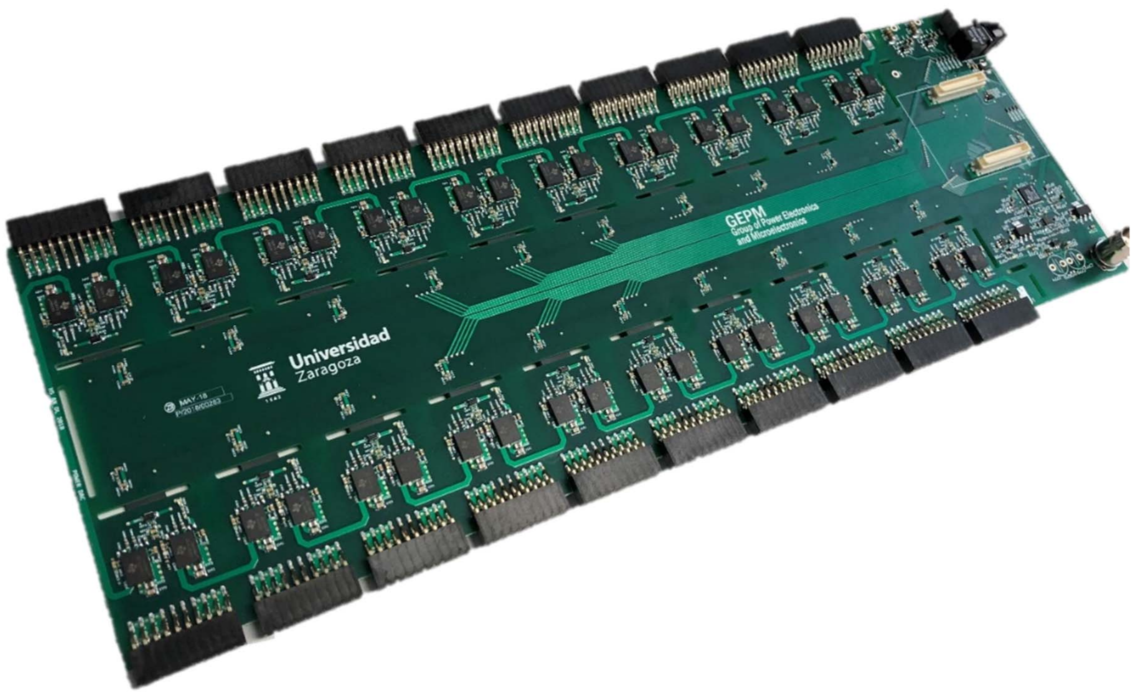

Fig. 4. Proposed GaN-based multi-level topology.

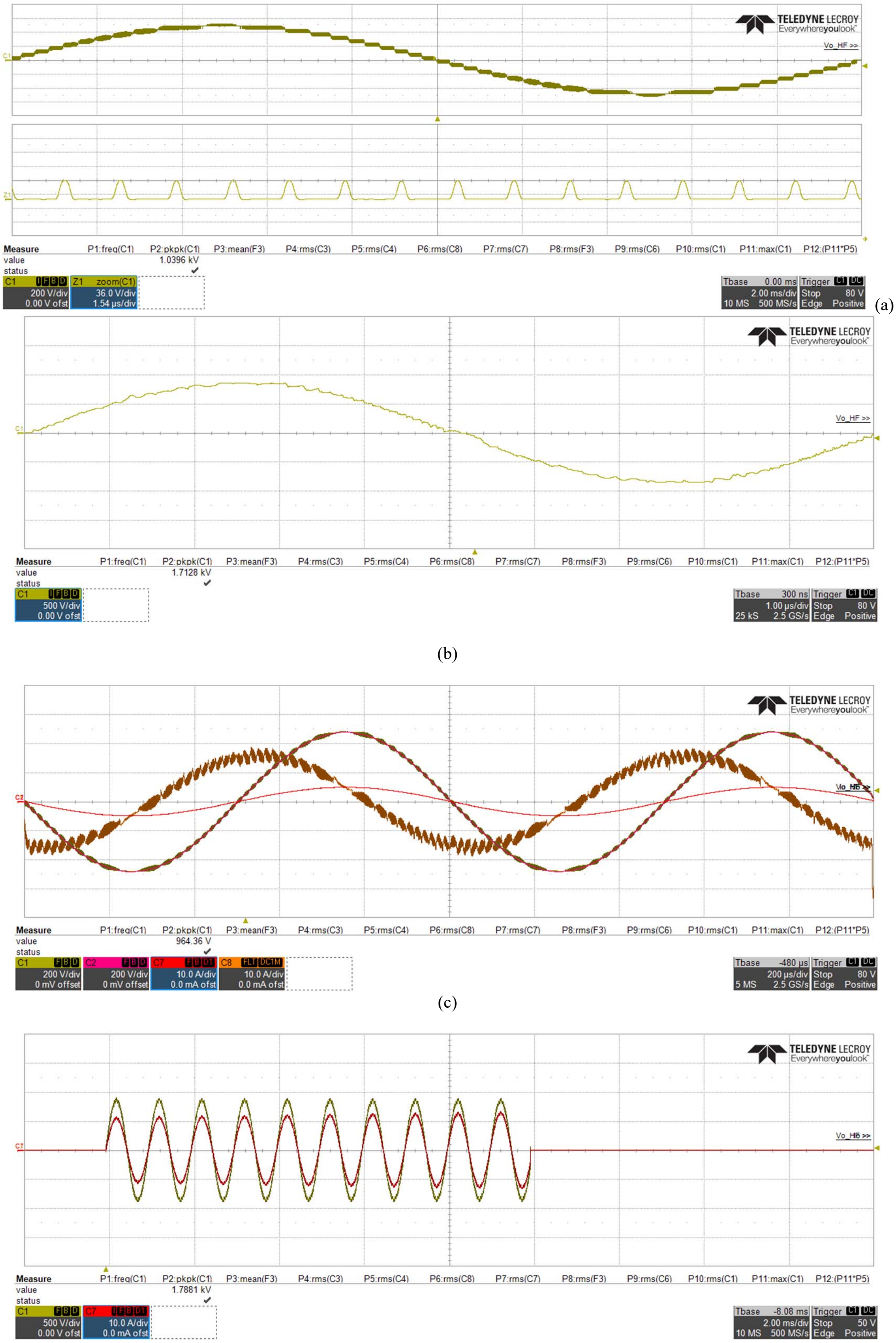

Fig. 5. Main experimental results: 50 Hz sinusoidal waveform with PWM detail (a), 100 kHz sinusoidal waveform (b), 1 kHz sinusoidal waveform with capacitive load (c), and burst mode operation (d).

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