Simple Spread-Spectrum Pulse-Modulation Technique for EMI Mitigation in Power Converters

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Abstract— **The adoption of wide-bandgap (WBG) switching devices such as gallium nitride (GaN) transistors in power converters enables to achieve higher switching frequencies and higher power density with reduced cooling requirements and smaller passive components. However, the potential for increased electromagnetic interference (EMI) resulting from the faster switching transients possible with WBG devices is a concern in many applications. Hence techniques for reducing EMI are of increasing interest. In this paper we present a simple implementation of a spread-spectrum pulse-modulation technique to reduce the peak EMI generated by switch-mode power converters. The method is based on an aperiodic gate drive signal generated from two periodic signals, e.g. a sawtooth and a sinewave, which are anharmonically related. Simulations and experimental measurements of conducted EMI from a prototype of a SEPIC converter incorporating a hybrid GaN HEMT demonstrated a 10 dB reduction in peak EMI.**

Index Terms— **Electromagnetic Interference (EMI), gallium nitride (GaN), high-electron-mobility transistor (HEMT), SEPIC, wide bandgap (WBG).**

I. INTRODUCTION

High-frequency switching power converters are popular in applications requiring portability and compactness. Wide-bandgap (WBG) power switching devices, such as gallium nitride (GaN) transistors, have attracted much attention in recent years for providing high-frequency operation along with various benefits, such as low on-state resistance and faster switching speeds, allowing the power converter to be efficient, lightweight and compact [1-2].

The integration of a renewable energy source usually requires a buck/boost operation and is realized with the help of switching power converters. Various DC-DC converter topologies are proposed which vary in accordance with the type of their applications. Power converters are reported to generate electromagnetic interference (EMI) as a common phenomenon, and it worsens with high-speed switching devices [3]. Moreover, with the increased integration of renewable energy sources, the EMI issue becomes more critical and, therefore, various electromagnetic compatibility (EMC) standards for keeping the noise emissions under specified limits are proposed, such as CISPR and IEC [4].

Traditional EMI suppression techniques include filters and shielding but, for price-sensitive portable applications, these solutions are not adopted. Various spread-spectrum techniques are reported in [5] which modify the switching-noise frequency spectrum from a train of spikes concentrated at the switching frequency and its harmonics to a smoother spectrum. The implementation methodology of these techniques defines the complexity, which increases in proportion to the number of switches in a power converter. Numerous analog and digital implementation methodologies are reported in [5-7].

II. EMI ISSUES IN WBG-BASED POWER CONVERTERS

All modern power converters can be viewed as a combination of power switching devices being switched in a pattern, i.e a specific frequency and duty ratio, to charge and discharge various reactive elements to produce the required voltages and currents. This common switching phenomenon leads to rapid current and voltage transitions (high di/dt and dv/dt respectively) which are the main source of noise in a power converter. Of course, various other factors are also associated, including the circuit-board layout, soft-switching, filtering and shielding, parasitic inductance and capacitance. WBG power semiconductor devices allow high-switching-frequency operation along with sharp switching transitions, which allows better efficiency, lower conduction and switching losses, higher power density and small size of passive filters. On the other hand, the sharp switching transients, though they reduce the switching losses involve high di/dt and dv/dt as compared to ordinary silicon-based switches. Hence, the EMI issue becomes more severe in WBG-based power converters.

Fig. 1 gives a pictorial view of how the switching transients are associated with voltage and current alterations.

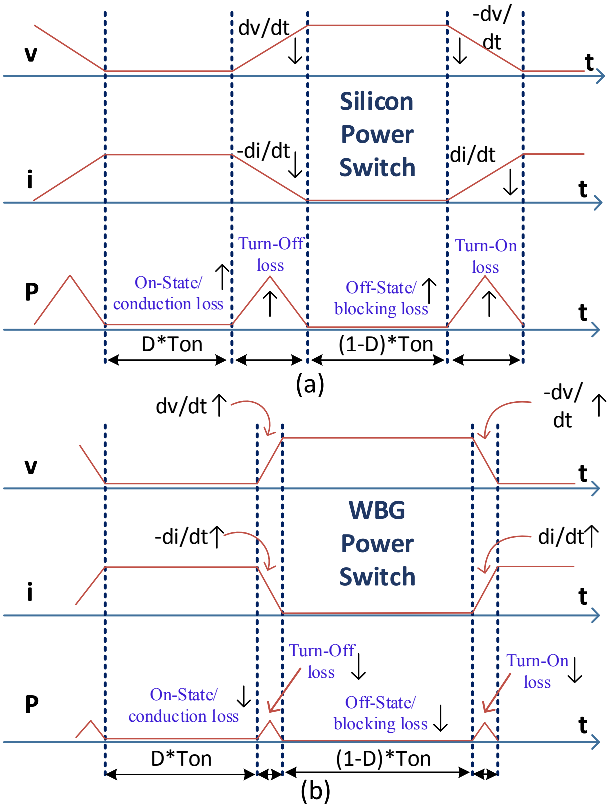


Fig. 1. Comparative overview of switching transitions between Silicon and wide-bandgap switching devices

III. COUPLED-INDUCTOR SEPIC CONVERTER

A coupled-inductor based SEPIC converter [8] was used for experimental investigations. The converter circuit was implemented by modifying an evaluation board from Transphorm [10] incorporating a cascode GaN (TPH3006PS) high-electron-mobility transistor (HEMT) and gate driver (FAN3100CSX). The circuit topology is shown in Fig. 2; the board modifications are shown within the dashed red line, and the design parameters were reported in [9].

IV. EMI SUPRESSION AND ITS IMPLEMENTATION METHODOLOGY

Several techniques can be found in the literature for mitigating EMI in DC-DC converters [5-7]. Considering the PWM signal in Fig. 3 as a driving signal for a switch in a power converter, various classifications can be made based on the variation of different parameters as shown in Table. I.

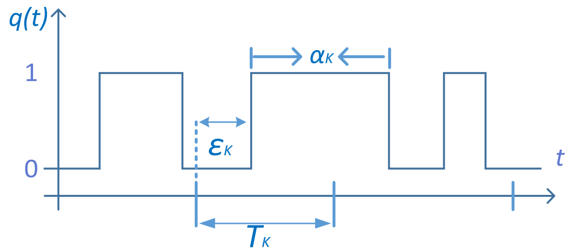


Fig. 3. A generic switching signal showing various modulation parameters

In Fig. 3, α_K is the duty cycle of a K^{th} cycle having a duration defined as T_K. ε_K defines the delay from the starting point of the switching cycle till the turn-on instant, hence ε_K can be regarded as the parameter associated with pulse position. Furthermore, the switching frequency of the K^{th} cycle is defined as $F_K = 1/T_K$ and duty ratio $= d_K = \alpha_K/T_K$. *q(t)* can be regarded as a switching function consisting of a series of switching cycles.

For example, of the spread-spectrum modulation techniques which can be implemented without a digital controller, one involves the use of a chaotic carrier produced by a Chua's oscillator [6]. Here we show that a simple spread-spectrum

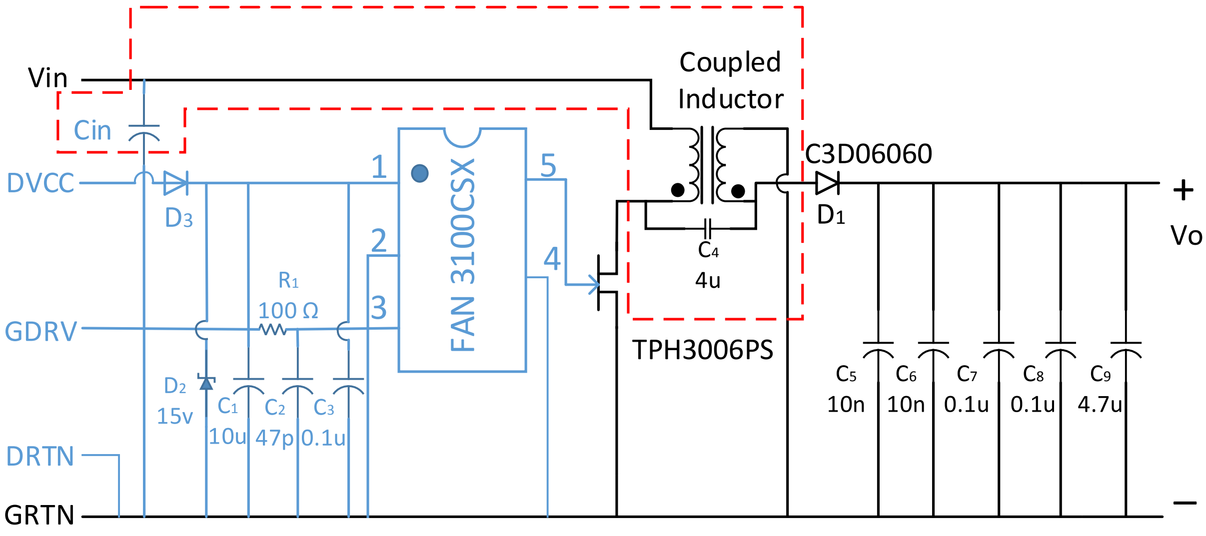


Fig. 2. Coupled-inductor SEPIC converter topology [9]

TABLE I. Classification of spread-spectrum techniques for EMI suppression

Modulation Style	**Scheme**	**Sub-classification**	**Modulation parameters**			**Duty ratio**
			Switching Cycle (T_K)	***Duty Cycle*** (α_K)	***Pulse position*** (ε_K)	$\left(\frac{\varepsilon_K}{T_K}\right)$
Periodic OR Aperiodic (pseudo-random, chaotic, deterministic) OR random	PWM- Pulse Width Modulation	--	Fixed	Vary	Fixed	Vary
	PPM- Pulse Position Modulation	--	Fixed	Fixed	Vary	Fixed
	CFM- Carrier frequency modulation	CFMFD- CFM with fixed duty cycle	Vary	Sync	Fixed	Fixed
		CFMVD- CFM with varying duty cycle	Vary	Fixed or Vary (not synced)	Fixed	Vary
	Duty ratio modulation + PPM + fixed carrier frequency	--	Fixed	Vary	Vary	Vary
	CFM + PPM + fixed duty ratio	--	Vary	Vary (Synced)	Vary	Fixed (Synced)
	CFM + PPM + duty ratio modulation	--	Vary	Vary	Vary	Vary

pulse modulation can also be generated simply using anharmonically related sawtooth (carrier) and sinusoidal (modulation) signals, resulting in an aperiodically varying pulse position and pulse width in consecutive switching cycle [11]. The proposed technique is shown schematically in Fig. 4.

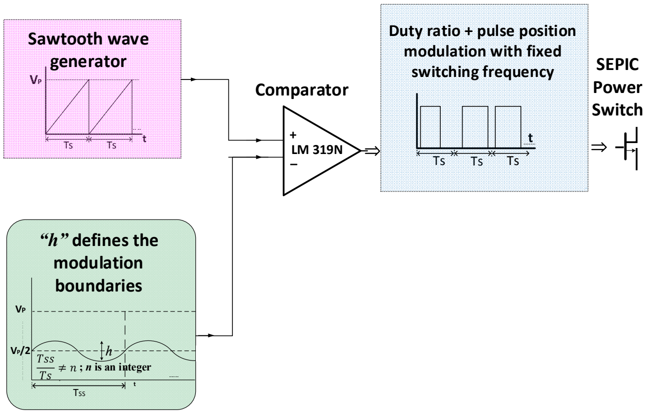
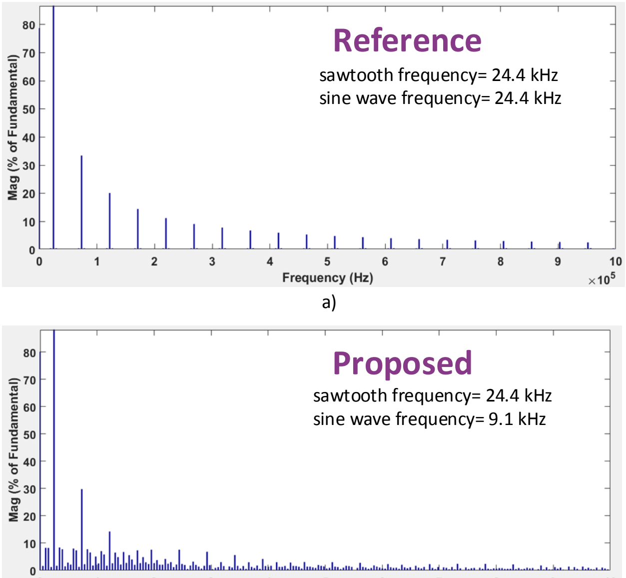


Fig. 4. Aperiodic pulse modulation generation

Both the carrier signal and the modulation signal can be simply generated by a standard function generator. The peak-peak value of the sine wave, denoted by 'h', gives the amount of variation in the duty cycle and hence the pulse position of the resulting PWM signal. It must be noted that the sawtooth and modulation signals are anharmonically related to each other, which is pictorially shown in Fig. 4 as $T_{SS}/T_S \neq n$, where n is an integer and T_S and T_{SS} are the switching periods of the sawtooth wave and sine wave, respectively.

The FFT analysis of the reference PWM signal (fixed pulse position and duty cycle) and aperiodic PWM signal (aperiodically varying pulse position and duty cycle) which is used to drive the power switch is shown in Fig. 5, which depicts a suppressed and spreaded EMI spectrum. For simulation purposes, the frequency of sawtooth and sine wave is set at 24.4 kHz and 9.1 kHz respectively (i.e. anharmonically related). The number of harmonics increases with more spreading (governed by 'h'), resulting in smoothing of the spectra. It must be noted that, with increasing 'h', the spreading of harmonics increases, but on the other hand it also has impact on the duty ratio of every switching cycle which in turn has a direct impact on the voltage gain of a DC-DC power converter [12].



a)

b)

Fig. 5. Fourier transforms comparing the spectra of the periodic and aperiodic pulse modulations for 10% 'h'

V. EXPERIMENTAL RESULTS AND DISCUSSION

The PWM generated with $T_{SS}/T_S = 1$ and h = 10% of V_P gives a PWM with a fixed duty cycle and pulse position, whereas the PWM generated with $T_{SS}/T_S \neq n$ with the same ‘*h*’ gives a varying pulse and position. The key waveforms of both the reference and the proposed modulation schemes are shown in Fig. 6. The blurred edges in the gate drive signal in Fig. 6(b) are an indication of the aperiodicity in the proposed pulse modulation scheme, which is the basis of the EMI suppression.

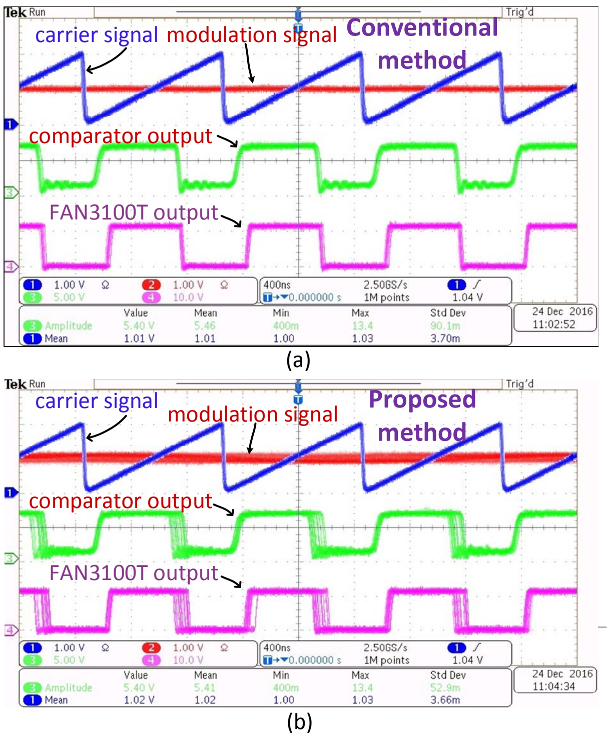


Fig. 6. Key waveforms illustrating generation of switching patterns using (a) conventional and (b) proposed method

The SEPIC converter was tested for both the reference (traditional PWM) and the proposed aperiodic modulation schemes under identical conditions for a 10 watt load with 56% duty cycle at 1 MHz switching frequency. The sine wave frequency was 9.1 kHz and *‘h’* was set to 10% of the peak of the sawtooth (carrier) wave. The conducted EMI was measured via a standard line-impedance stabilization network (LISN) [13] and the EMI spectra were plotted on a spectrum analyzer. The EMI spectra for the conventional and the proposed aperiodic modulation schemes are shown in Fig. 7. Additionally, a quasi-periodic version of the modulation scheme, similar to that reported previously [14], was generated with *n*=4, however the EMI suppression was less than with the aperiodic version [15]. This is fundamentally due to the fact that the corresponding PWM sequence will repeat itself when the frequency of sawtooth and sine wave are related to each other by an integer multiple.

VI. CONCLUSIONS

A simple method for generating an aperiodic switching signal to reduce the peak EMI generated by single-switch power converters has been demonstrated. The aperiodic gate drive signal was generated using simple circuitry from anharmonically related sawtooth and sinusoidal signals. Experimental results with a SEPIC converter demonstrated 10 dB suppression in the peak EMI.

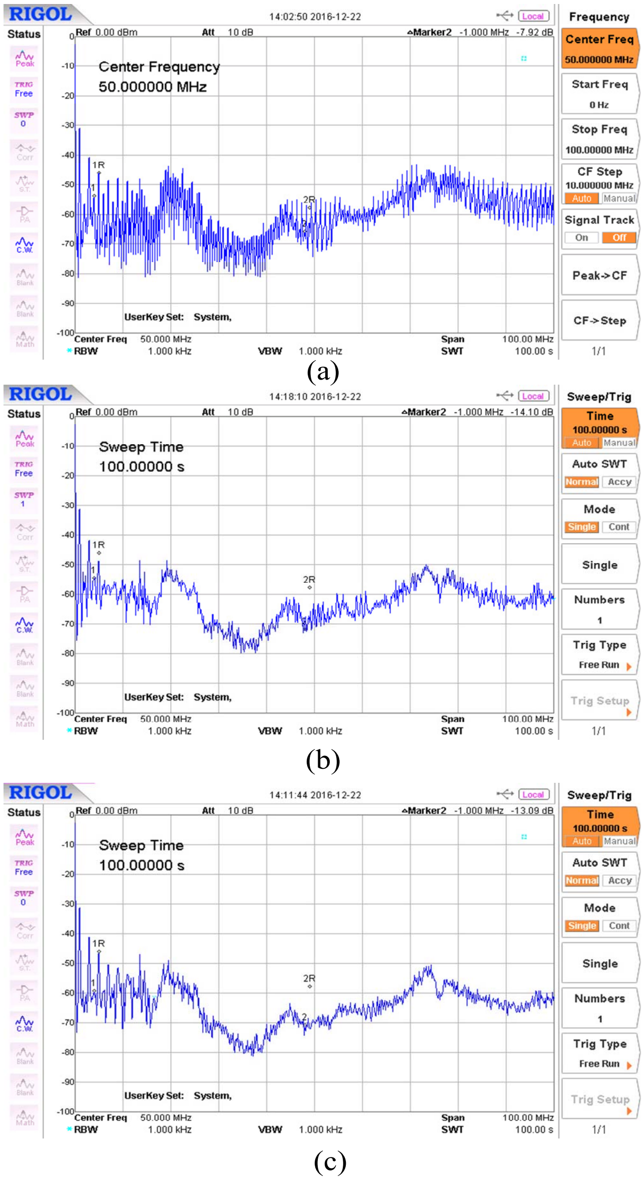


Fig. 7. Conducted EMI spectra (0-100 MHz) for a) conventional periodic, b) quasi-periodic [13], and c) aperiodic pulse modulation

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