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A New Random PWM Technique for Conducted-EMI Mitigation on Cuk Converter

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Abstract – Electromagnetic Interference (EMI) is a system to system or environment to system phenomenon. The literature survey proved that the Randomized Pulse Width Modulation (RPWM) technique is a promising technique to reduce EMI. A new Constant Trailing Edge, Randomized Pulse Width Modulation (CTERPWM) technique is proposed in this paper. The effect of the proposed RPWM technique for mitigation of conducted-EMI on Cuk converter operating in Continuous Conduction Mode (CCM) is simulated and tested. In this paper, the analytical expressions for the Power Spectral Density (PSD) are derived for the proposed RPWM technique and are validated by experimental measurements. The effectiveness of the proposed RPWM technique on the mitigation of conducted-EMI is verified comparing simulation and experimental results and it is identified that both the results are almost similar with allowable experimental deviations. The comparative investigation proves that the proposed RPWM technique can mitigate and spread the dominant peaks of conducted-EMI over the complete spectrum for the Cuk converter. Based on the investigation the CTERPWM technique is recommended for adoption.

Keywords: Conducted EMI, Cuk converter, Electromagnetic Interference, Power spectral density, Random PWM.

1. Introduction

Over the last two decades, the power electronic converters have progressively stimulated in the direction of high frequency synthesis. Although, this high switching frequency results in massive advancement in converter enactment, size, weight and cost it also has an inevitable drawback of generating Electromagnetic Interferences. Owing to increasing number of different converter topologies, inherent switching process and its control techniques, converters have become most important sources of Electromagnetic Interference (EMI). The substantial use of these converters made the EMI as a potential problem and therefore be addressed at the nascent phase of designing itself. The generation of conducted-EMI is due to the *dv/dt* and *di/dt* effects in switching device. The shape of the switching signal has no significant change when it is compared with the drain- source voltage (V_{ds}) of the Cuk converter. Hence, the power spectrum of V_{ds} is considered for analysis.

Switching power converters are generally controlled by pulse-width modulation technique. Random switching schemes which have originated from statistical communication theory have been implemented recently on power converters to spread the power of the dominant harmonic components and to reduce magnitude of its power spectral density (PSD). The RPWM technique can be mainly categorized into four modulation schemes including Randomized Pulse Position Modulation (RPPM), Randomized Pulse Width Modulation (RPWM) techniques, The Random Carrier-Frequency Modulation with Fixed Duty cycle (RCFMFD), and with variable duty cycle (RCFMVD) respectively. Literature survey proved that EMI can be suppressed by using RPWM techniques. However, there are certain drawbacks in adopting these conventional techniques. Hence modifications and development of new RPWM is absolutely necessary to effectively mitigate EMI. In the conventional randomized PWM techniques, certain switching signal parameters are randomized [1]. The followings are the possibilities of switching signal parameters i) duration of the k^{th}cycle (T_k), ii) the duration of the on-state within the cycle (α_k), iii) duty ratio is $d_k=\alpha_k/T_k$ and the delay from the start of the switching cycle to the turn-on within the cycle (ε_{ks}), iv) Trailing edge of the switching cycle (ε_{kt}).The engineers have their discretion to device the randomization parameter. Dithering any one or more of the above said parameters is known as the randomized PWM technique. Analytical expressions derived, so far to aid in understanding the frequency domain characteristics of time domain switching signal g(t), have not considered the trailing edge of the switching cycle (ε_{kt}) as a random variable. It is also understood that ε_{kt} having the probability density function $P(\varepsilon_{kt})$, is not considered to find the expected value of the

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Fourier transform ($E[g(f)]$) of the time domain signal g(t). Although there are many papers on RPWM techniques, the above mentioned considerations have long been evaded by the power electronic engineers. This paper presents the comparative investigation of using proposed RPWM technique on the conducted-EMI suppression in Cuk converter. This work also addressed on the comparison of analytical PSD spectrum and experimental PSD spectrum of the Cuk converter with the proposed RPWM technique.

2. Characteristics of the Proposed Random PWM Technique

Many randomization techniques have been addressed in many papers but the trailing edge of the switching signal have not been considered as constant for investigation. This new technique includes the trailing edge of the switching signal (ε_{kt}) as the randomization parameter and the effects of different random modulation strategies on the voltage analysis based on power spectral density (PSD) and conducted-EMI are experimented. For the new random modulation scheme the analytical expressions of the Power Spectral Density (PSD) for the voltage across the switch are derived and validated for the Cuk converter operating in continuous conduction mode (CCM). The PSD analysis and the measured conducted EMI results proved that the proposed switching technique allow a better spread shape of PSD and mitigate the conducted EMI when compared with the standard PWM switching scheme.

The switching parameters shown in Fig. 1 such as the duration of the k^{th} cycle (T_k), the duration of the on-state within this cycle (α_k), duty ratio is ($d_k=\alpha_k/T_k$) and the delay from the start of the switching cycle to the turn-on within the cycle (ε_{ks}), Trailing edge of the switching cycle (ε_{kt}), are according to the characteristics summarized in Table 1. Randomness level and the average duty cycle for all the random modulation schemes were kept constant to maintain the desired output voltage. A_1 and A_2 are the magnitudes of the switching pulses.

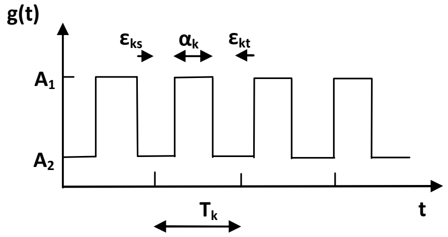

Fig. 1. Switching Signal of Proposed RPWM Technique

Table 1. Classifications of randomized switching schemes

Switching Schemes	$T_k=1/F_k$	α_k	ε_{ks}	$d_k=\alpha_k/T_k$	ε_{kt}
Conventional Standard PWM	fixed	fixed	Zero	fixed	fixed
CTERPPM	fixed	random	random	random	fixed

It is understood from Table 1, that the duration of the cycle (T_k) and Trailing edge of the switching cycle (ε_{kt}) are fixed and the other switching parameters change randomly. The delay from the start of the switching cycle to the turn-on within the cycle (ε_{ks}) and duration of the on-state within this cycle (α_k) can be randomized. The PIC micro controller (16F877A) is programmed to generate the randomized switching functions of the DC-DC converters operated under Continuous Conduction Mode (CCM). The Capture / Compare / PWM (CCP) module is programmed for generating random PWM pulses. The period of the pulse width and duty cycle of the pulse are set by writing to the PR2 register and CCPR1L register respectively. The CCP Prescaler and Postscaler settings are used in the determination of random PWM pulses.

3. Analytical Derivations of Power Spectral Density

The switch in a DC-DC converter, chops the line current and the input voltage, which is the reason for the Electromagnetic Interference. Depending on the converter's topology, its switching voltage can be approximated with square wave and the input current may be approximated with triangular wave [3]. The Cuk converter, the drain - source voltage (V_{ds}) wave shape is similar to the pulse train as shown in Fig. 1.

The output voltage regulation is achieved by switching on and off the switch and by varying the on time. However, switching the MOSFET causes the generation of high frequency noise. The drain to source voltage (V_{ds}) has high *dv/dt* characteristics. Hence, the analysis is made on the switching voltage of Cuk DC-DC converter.

In practice, the rise and fall times as well as the change of the plateau of V_{ds} for the above said converter, topologies are insignificant [3]. Therefore, the square waveform, shown in Fig. 1. can serve as the basis for estimation of the power spectral density (PSD). The general equation of Power Spectral Density is shown in Eq. (1).

$$S_p(f,R) = f_s\{E[|G(f)|^2] - |E[G(f)|^2 + f_s|E[G(f)|^2 \sum_{K=-\infty}^{\infty} \delta(\mathrm{f} - kf_s)\} \quad (1)$$

The analytical expressions are to aid in understanding the strength of the signal in frequency domain characteristics. The main objective is to minimize the power of the harmonics in a frequency range of interest. The derived analytical expressions are used to calculate the PSD at one or more frequencies.

Where f_s is the nominal switching frequency and $G(f)$ is the Fourier transform of a cycle of $g(t)$ with randomness level $\Re$. E [.] is the expectation operator taking over the whole ensemble [2].

$$G(f) = A_1 \int_{\varepsilon_{ks}}^{d_k T_s + \varepsilon_{ks}} e^{-j2\pi ft} dt + A_2 \int_{0}^{\varepsilon_{ks}} e^{-j2\pi ft} dt + A_2 \int_{d_k T_s + \varepsilon_{ks}}^{T_s} e^{-j2\pi ft} dt \tag{2}$$

It is noted that ϵ_{ks} and d_k are the random variables, having the probability density function of P (ε_{ks}), and P (d_k). Where

$$P(\varepsilon_{ks}) = \frac{1}{(\varepsilon_{ks2} - \varepsilon_{ks1})} \quad P(d_k) = \frac{1}{(d_2 - d_1)} \tag{3}$$

For the proposed random modulation scheme, $\Re$ of value 0 to 0. 2 were considered for investigation.

$$\Re_{CTERPWM} = \frac{(\varepsilon_{ks2} - \varepsilon_{ks1})}{T_k} = \frac{(\alpha_2 - \alpha_1)}{T_k} = d_2 - d_1 \tag{4}$$

The expected value of $G(f)$ and $|G(f)|^2$ can be determined for the proposed schemes as follows:

$$E[G(f)]| = \int_{\varepsilon_{ks1}}^{\varepsilon_{ks2}} P(\varepsilon_{ks}) G(f) d\varepsilon_{ks} + \int_{d_1}^{d_2} P(d_k) G(f) dd_k \tag{5}$$

Power Spectral Density is the Fourier Transform of the autocorrelation function of a signal. Power of the signal at particular frequency range can be obtained by integrating

$$= \frac{(A_1 - A_2)}{4\pi^2 f^2 \Re_{CTERPWM} T_S} \left(1 - e^{-j2\pi f \Re_{CTERPWM} T_S}\right) [(e^{-j2\pi f d_k T_S} - 1) + (e^{-j2\pi f (d_1 T_s + \varepsilon_{kt})})] + \frac{A_2}{4\pi^2 f^2 \Re_{CTERPWM} T_S} \left(1 - e^{-j2\pi f \Re_{CTERPWM} T_S}\right) [\left(e^{-j2\pi f (d_k T_s + \varepsilon_{kt})}\right) + \left(e^{-j2\pi f (d_1 T_s + \varepsilon_{kt} + \varepsilon_{tt})}\right) - \frac{j}{2\pi f}\left[2A_2 + (A_1 - A_2) e^{-j2\pi f \varepsilon k_s}\right] \tag{6}$$

$$E\left[|G(f)|^2\right] = \int_{\varepsilon_{ks1}}^{\varepsilon_{ks2}} P(\varepsilon_{ks}) G(f) G^*(f) d\varepsilon_{ks} + \int_{d_1}^{d_2} P(d_k) G(f) G^*(f) dd_k \tag{7}$$

$$\begin{aligned}
&= \frac{(A_1 - A_2)}{2\pi^2 f^2}[1 - \cos 2\pi f d_k T_s] + \frac{A_2^2}{\pi^2 f^2} - \frac{A_2^2}{4\pi^3 f^3 \Re_{CTERPWM} T_S}\left[\sin 2\pi (d_k T_s + \Re_{CTERPWM} T_S + \varepsilon_{kt}) - \sin 2\pi f (d_k T_s + \varepsilon_{kt})\right] \\
&+ \frac{A_2 (A_1 - A_2)}{2\pi^2 f^2}\left[2\cos 2\pi f \varepsilon_{kt} - \cos 2\pi f (d_k T_s + \varepsilon_{kt}) + \cos 2\pi f \varepsilon_{ks}\right] \\
&+ \frac{A_2 (A_1 - A_2)}{4\pi^3 f^3 \Re_{CTERPWM} T_S}\left[\sin 2\pi \Re_{CTERPWM} T_S - \sin 2\pi f (d_k T_s + \Re_{CTERPWM} T_S)\right] \\
&+ \frac{(A_1 - A_2)^2}{2\pi^2 f^2 \Re_{CTERPWM}}\left[\Re_{CTERPWM} T_S - \frac{\sin 2\pi f d_2 T_s}{2\pi f T_S} - \sin 2\pi f d_1 T_s\right] \\
&+ \frac{A_2^2}{4\pi^3 f^3 \Re_{CTERPWM}}\left[\sin 2\pi f (d_2 T_s + \varepsilon_{ks} + \varepsilon_{kt}) - \sin 2\pi f (d_k T_s + \varepsilon_{ks} + \varepsilon_{kt})\right] \\
&+ \frac{A_2 (A_1 - A_2)}{4\pi^3 f^3 \Re_{CTERPWM}}\left[\sin 2\pi f (d_2 T_s + \varepsilon_{kt}) - \sin 2\pi f (d_1 T_s + \varepsilon_{kt}) + \sin 2\pi f (d\ T_s + \varepsilon_{ks}) - \sin 2\pi f (d_1 T_s + \varepsilon_{ks})\right]
\end{aligned} \tag{8}$$

$$|E[G(f)]|^2 = E[G(f)] \times \overline{E[G(f)]} \tag{9}$$

$$\begin{aligned}
&= \frac{(A_1 - A_2)}{4\pi^2 f^2 \Re_{CTERPWM} T_S}\left(1 - e^{-j2\pi f \Re_{CTERPWM} T_S}\right)\left[\left(e^{-j2\pi f d_k T_S} - 1\right) + \left(e^{-j2\pi f (d_1 T_s + \varepsilon_{kt})}\right)\right] \\
&+ \frac{A_2}{4\pi^2 f^2 \Re_{CTERPWM} T_S}\left(1 - e^{-j2\pi f \Re_{CTERPWM} T_S}\right)\left[\left(e^{-j2\pi f (d_k T_s + \varepsilon_{kt})}\right) + \left(e^{-j2\pi f (d_1 T_s + \varepsilon_{kt} + \varepsilon_{tt})}\right)\right] \\
&- \frac{j}{2\pi f}\left[2A_2 + (A_1 - A_2) e^{-j2\pi f \varepsilon k_s}\right] \times \frac{(A_1 - A_2)}{4\pi^2 f^2 \Re_{CTERPWM} T_S}\left(1 - e^{j2\pi f \Re_{CTERPWM} T_S}\right)\left[\left(e^{j2\pi f d_k T_S} - 1\right) + \left(e^{j2\pi f (d_1 T_s + \varepsilon_{kt})}\right)\right] \\
&+ \frac{A_2}{4\pi^2 f^2 \Re_{CTERPWM} T_S}\left(1 - e^{j2\pi f \Re_{CTERPWM} T_S}\right)\left[\left(e^{j2\pi f (d_k T_s + \varepsilon_{kt})}\right) + \left(e^{j2\pi f (d_1 T_s + \varepsilon_{kt} + \varepsilon_{tt})}\right)\right] + \frac{j}{2\pi f}\left[2A_2 + (A_1 - A_2) e^{j2\pi f \varepsilon k_s}\right]
\end{aligned} \tag{10}$$

PSD within that specific range. Computation of PSD is determined by Fast Fourier Transform or computing autocorrelation function and then transforming it. The solutions for the expectations like $E[G(f)]$, $E\left[\left|G(f)\right|^2\right]$ and $\left|E\left[G(f)\right]\right|^2$ are derived from Eqs. (6), (8) and (10) and the values are substituted in Eq. (1) for computing the power spectrum of the proposed scheme. The derivations of the analytical formulas for PSD for the CTERPWM technique must be validated by laboratory measurements.

4. Comparison of Theoretical and Experimental PSD

The power spectrum formulas derived are based on infinite time records of the proposed randomized switching schemes and it is mandatory to verify and explore them through experimental verifications. The power spectrum formulas derived for the proposed randomized schemes are based on infinite time records with a view to making a better comparison of the analytical power spectrum S V_{ds} (f) and the measured ones S_{mes} V_{ds} (f) is performed by convoluting S V_{ds} (f) with the window function '*W*' [4], [5]. In short, each time record of length *N* is multiplied by a chosen window function '*W'*, and then the modified record is transformed by using the FFT. By averaging a number of successive records, which may be overlapped in order to reduce the variance, an estimate of the PSD of the signal is found [6].

The mathematical compensation for the analytical power spectrumS^1 V_{ds} (f) is given below.

S^1_{VDS} (f) = $S_{VDS}(f) \times \left|W(f_0)\right|^2$ Where f_0 is one of the discrete frequency points given by FFT analysis.

In this analysis, the Welch (non parametric) method of power spectrum estimation is implemented. The Welch method is based on estimating the autocorrelation sequence of a random process from a set of measured data, and then taking the Fourier transform of autocorrelation sequence to obtain the power spectrum estimate [7] Welch method of estimation allows the segments to overlap and windowing the segments before computing periodogram. The periodogram of the windowed segments will be a modified periodogram and averaging these modified periodograms will give the Welch estimate of power spectrum [8].

The N-point sequence is divided into L overlapping segments and the periodogram is computed for each segment. The expectation operation is approximated by averaging L individual segments. Under suitable conditions, this computation produces a steady, asymptotically unbiased estimate of the power spectrum, so the estimate converges to the analytical (true) spectrum as 'L' tends to ∞ and '*W*' tends to ∞. In practical estimation procedure 'L' and '*W*' are finite. The analytical spectrum S V_{ds} (f) is convoluted by the use of Hanning window. The number of data points

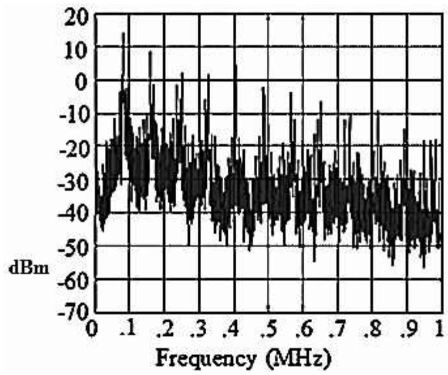

Fig. 2. Analytical Spectrum of PSD for Standard PWM Technique

in the random signal is of length N(N=L*NFFT), NFFT is the number of FFT points and L denotes the overlapping segments [9]. In this analysis, a number of FFT points are considered as 8192. Thus if L=8, a total of N= 65536 data points are needed. The experimental results are taken from the spectrum analyzer GOODWILL GSP-810 with frequency range of 150 kHz to 1 GHz and by using the same windowing parameters as mentioned above.

Fig. 2 delineates that the power of the harmonic spectrum is high in frequency in the range of 0 to 1MHz. The PSD which culminates up to 18dBm in the low frequency range gradually declines up to -18 dBm in high frequency range. The power of the spectrum for the standard PWM technique is very high over the complete spectrum and many discrete components are present in the range of analysis. These discrete peaks are more effective in the degradation of the performance of the system. These discrete peaks of the spectrum should be reduced and it has to be converted as continuous spectrum so as to reduce the EMI effects. If the power of the unwanted frequency components is high, the design of the EMI filter becomes a tedious process in the reduction of EMI. The maximum number of peaks of high frequency noise represents the maximum power of unwanted noise. This unwanted noise causes severe interference problem.

Fig. 3 clearly indicates the analytical PSD results of CTERPWM technique. It is evident from the Fig. 3 that the PSD of the harmonics are less than 0 dB for the Switching signal when CTERPWM technique is administered as RPWM technique. It has both the continuous and the discrete harmonic components. The discrete peak of the harmonics reaches up to -2dBm below the frequency range of 200 kHz. The minimum value of -38dBm is achieved in the range between 900 and 1000 kHz. It can be clearly identified that the discrete harmonic spectrum is gradually converted as continuous spectrum above the 500 kHz. The number of peaks is reduced when compared with the range below 500 kHz.

Cuk converter is a type of DC-DC converter which is obtained by using the duality principle [10] on the circuit of a buck-boost converter is shown in Fig. 4. The

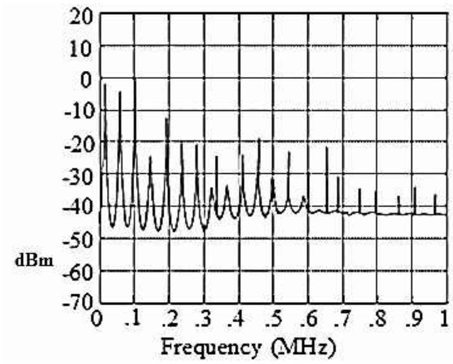

Fig. 3. Analytical Spectrum of PSD for CTERPWM Technique

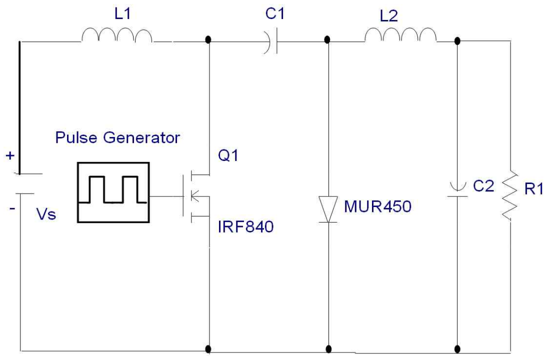

Fig. 4. Basic cuk converter

Cuk converter is the best choice for MPPT charge controllers [11]. It uses a capacitor as its main energy-storage component as well as to accomplish power transformation [12]. It is called as capacitive energy fly back converter. The magnitude of the output voltage is either greater or lesser than the input voltage and the polarity is opposite to that of the input voltage [13]. The cuk converters have low switching losses and the highest efficiency. It can provide better output current characteristics due to the inductor on the output stage.

The analytical PSD expressions derived are verified by laboratory experiments carried out to measure the PSD of V_{ds} on Cuk converter. The cuk converter operating under CCM has been considered for analysis and the specification of the Cuk converter is shown below.

Input inductor (L1)=500e-6H, Filter inductor (L2)= 500e-6H, Capacitor(C1)=220e-6F, Filter capacitor (C2)= 220e-6F, Resistive load(R1) = 2Ω, Switching frequency (f_s)=20kHz, Switch MOSFET IRF840, Optocoupler MCT2E and Diode MUR450.

4.1 Experimental results of PSD implementing standard PWM technique

Fig. 5 delineates the experimental results of PSD for standard PWM technique. The standard PWM has been amalgamated as switching control of the Cuk converter and the PSD harmonic spectrum of V_{ds} have been measured for

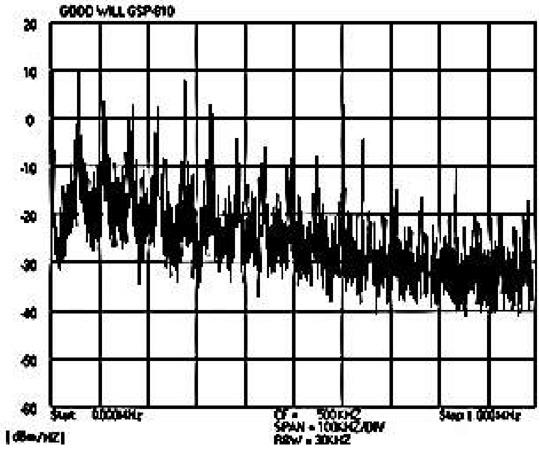

Fig. 5. Experimental PSD of cuk converter for standard PWM technique

analysis under the frequency region of 0 to 1MHz.

This technique introduces cluster of discrete harmonics at the multiples of f_s and over other frequency region under scrutiny. The randomness level is zero. Hence, all the switching parameters are constant. The duty ratio of the converter is 0.5. To maintain the duty ratio the α_k and ε_{kt} have the time value of 25 µs. From the Fig. 5, it is inferred that the dominant harmonic cluster is significant and the maximum power of the spectrum is in the frequency range of 20 to 100 kHz. The density of the harmonic clusters is high all over the spectrum. All the switching parameters are non-randomized. The power of the frequency spectrum at the switching frequency and the multiples of switching frequency are very high in the range of 0 to 1 MHz.

4.2 Experimental results of PSD implementing constant trailing edge, randomized duty ratio, and randomized pulse position modulation with fixed carrier frequency technique

For the analysis of CTERPWM, switching frequency of 20 kHz is considered. In this technique, the duty cycle d_k is uniformly randomized within the interval of 0.4 to 0.6.The range of ε_{ks} varies from 0 to 10 µs and α_k varies from 20 to 30µs. The ε_{kt} value is fixed to 20 µs. Fig. 5 delineates the PSD spectrum of V_{ds} for the Cuk converter topology after incorporating CTERPWM technique. The area under the individual lobe of the spectrum provides the PSD of the harmonics for a particular range of frequency. It is observed from the Fig. 5 that the areas of the individual lobes are less all over the range of frequency. As discussed in the previous section, the spectrum is divided into two regions. There is no significant change in the width of the lobes in the second region when compared with the first region. There is significant difference in the crest of the lobes between two frequency regions. The crest or peaks of the lobes in the second region have been reduced. These facts proved that the PSD of the harmonics at the second

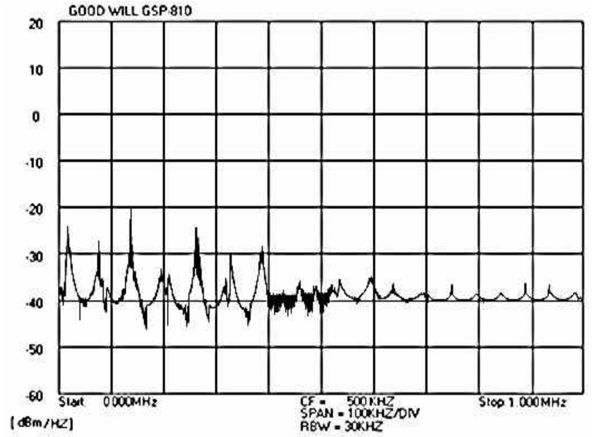

Fig. 6. Experimental PSD of cuk converter for CTERPWM technique

region is less when compared with the first region.

From the Fig. 6, it is clear that the power spectral density at high frequency is very low when compared to medium and low frequency ranges. It consists of continuous and minimum of discrete components all over the frequency range. The number of peaks and magnitude of the discrete components are reduced at high frequency range. It is also evident that the discrete components are changing as continuous spectrum at high frequency range and the power of the harmonics are less and do not introduce significant distortions all over the spectrum when compared to the conventional standard PWM scheme. The low frequency characterization shows a peak power of -20dBm/Hz for the frequency range below 400 kHz. In the high frequency range of 700 to 1MHz the harmonics powers are below-25dBm/Hz. It is understood that there is absence of narrow band harmonics and this leads to effect of reduction in conducted-EMI.

Table 2 shows the variations in the maximum values of the PSD of V_{ds} with respect to changes in the random PWM scheme. When randomness level R equals zero, the PSD of the harmonics is high in and around and all over the spectrum for all the converters.

The Analytical results show close agreement with the experimental ones. From the real time measurement results, it is observed that the discrete harmonic contents are present over the whole spectrum. At low frequency range, the better attenuation results are observed. The CTERPWM is found to be a better technique in attenuating the discrete harmonic power for the Cuk converter.

Table 2. PSD comparison of modulation schemes on converter topologies

Modulation Schemes	Randomness Level	Cuk	
		Max Peak (dBm/Hz)	Attenuation (dBm/Hz)
Standard PWM	0	10	-
CTERPWM	0 to 0.2	-20	20

5. Conducted EMI Measurements for Random Switching Schemes on Cuk Converter

EMI is any unwanted electric signal that is emitted from an electronic component that can impede the functionality of surrounding or connected equipment [14]. Power MOSFET device switches at high fundamental frequency (Fast turn-on and turn-off of the main switching element. This results in fast rise and fall time high frequency voltage and current pulses containing significant amounts of sub-harmonic energy.

The simulation is carried out for the standard PWM scheme and for the proposed random modulation schemes and the simulated results are discussed below. The simulation circuit is shown in Fig. 7. A Line Impedance Simulation Network (LISN), also called as an Artificial Mains Network (AMN), is a transducer used to execute conducted emissions testing. It is required to provide definite impedance at radio frequencies to the terminals of the system that is being tested. The LISN isolates the Equipment under Test (EUT) from the main power line disturbances and it keeps the load impedance 50Ω/50μH constant in relation to the disturbances from the common mode and differential mode currents.

The signals generated by the culprit or EUT are coupled to the EMI receiver using a high-pass filter (HPF). This

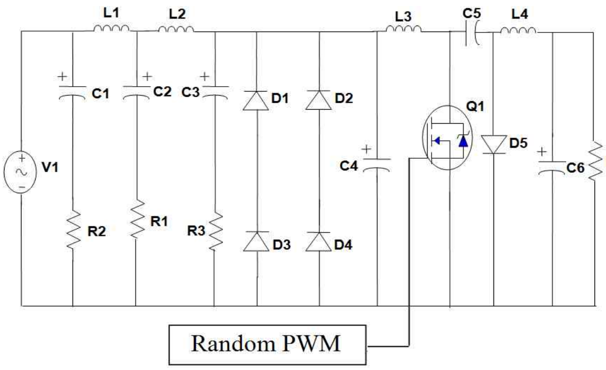

Fig. 7. Simulation circuit for conducted-EMI measurement on cuk converter

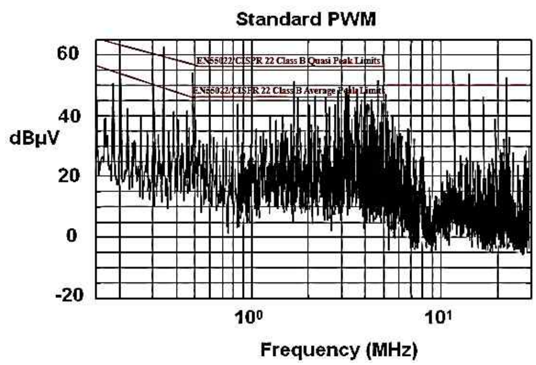

Fig. 8. Simulation Result of Conducted-EMI for Standard PWM Technique on Cuk Converter

high pass filter is the part of the LISN. The 50Ω load is offered to the signal which are at the pass band of the HPF and it is the input to the EMI signal receiver. The inductor of 50μH and the capacitor of 1μF forms the LC filter in the LISN and it isolates the main supply ports from the EUT. The noise generated by the EUT is isolated from the main by the 50μH inductor. The noise generated from the EUT is transferred to the EMI receiver by the 0.1μF capacitor. For the 150 kHz and above signals are presented with 50Ω impedance.

It is identified from Fig. 8 which the conducted EMI for the standard PWM scheme has exceeded the average limits instructed by CISPR 22. In the bandwidth of 150 kHz to 5 MHz, the peaks exceed the limit of 55 dBμV and exceed 50 dBμV in the bandwidth of 5 to 30 MHz. The simulation result identifies the frequency that has the highest disturbance relative to the limits given for conducted EMI disturbance at the mains ports.

Finally the CTERPWM scheme is simulated for the Cuk converter and the conducted EMI result is shown in Fig. 9. The use of CTERPWM scheme results in a large mitigation of the conducted EMI spectrum and it also illustrates that the converter satisfies CISPR 22, Class B of Information Technology Equipment (ITE). The total reduction of conducted EMI can be achieved by comparing the peaks of the standard PWM technique with the peaks of CTERPWM technique. According to Fig. 10 the amplitude reduction of conducted EMI is 14, 10, and 13 dBμV in the low, medium, and high frequency ranges respectively. It is recognized that the dominating harmonics in the spectrum is distributed.

Fig. 10. Shows the hardware setup of Cuk converter. In order to verify the simulation approach the real time experiments are carried out and the results were shown in Fig. 11(a) and (b). With standard PWM technique the spectrum of conducted-EMI is obtained as shown in Fig. 11(a). It is seen that the spectrum of conducted-EMI noise peak is less than the quasi peak (QP) limits and exceeds the average peak limits of CISPR 22. It is noticed from the Fig. 11(b) that the application of the proposed Random PWM techniques can provide a substantial level of conducted-EMI attenuation. The result of CTERPWM technique is shown in Fig. 11(b). This technique has proven that the conducted-EMI to the ports is greatly reduced in all frequency ranges. An attenuation exceeding 14 dBμV is observed in the frequency range from 150 kHz to 250 kHz. These attenuation magnitudes make a noteworthy difference in the EMI compliance in terms of conducted emissions.

Table 3 presents the peak values of conducted EMI for Cuk converter topology with the application of standard and proposed random modulation PWM technique. The Table 3 gives information about the maximum value of

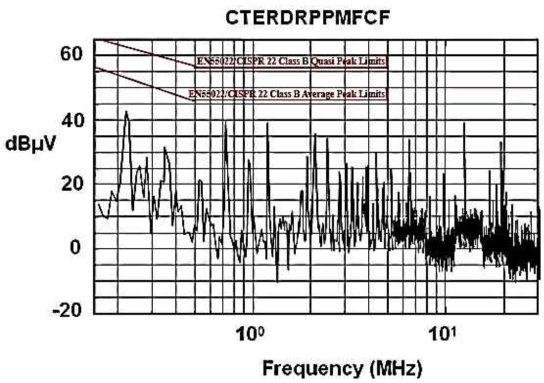

Fig. 9. Simulation Result of Conducted-EMI for CTERPWM Technique on Cuk Converter

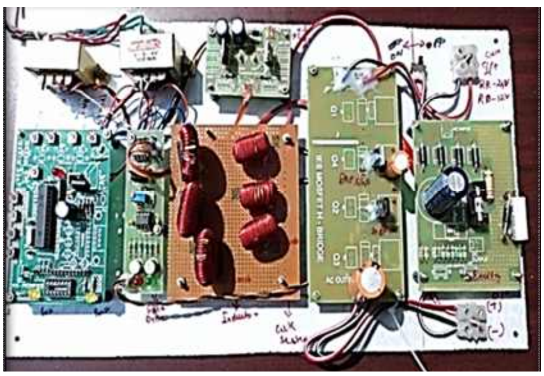

Fig. 10. Hardware Setup of Cuk Converter

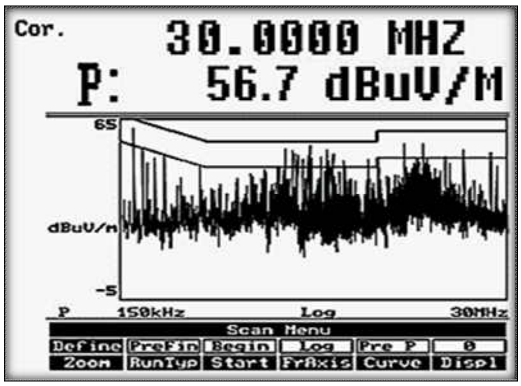

Fig. 11(a). Experimental Result of Conducted-EMI for Standard PWM Technique on Cuk Converter

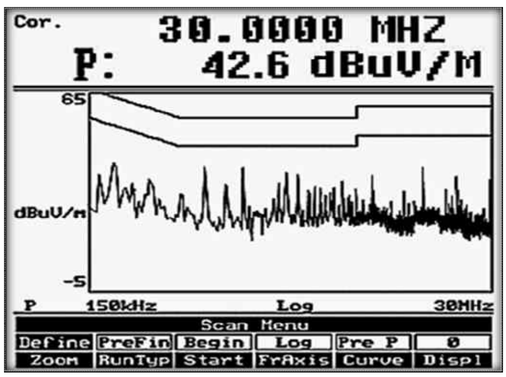

Fig. 11(b). Experimental Result of Conducted-EMI for CTERPWM Technique on Cuk Converter

Table 3. Comparison of Conducted-EMI on Converter Topologies

PWM Techniques	Frequency Range MHz	Cuk converter Max peak dB(μV)	Attenuation dB(μV)
Standard PWM	0.15 to 0.5	56	-----
	0.5 to 5	50	-----
	5 to 30	52	-----
CTERPWM	0.15 to 0.5	42	14
	0.5 to 5	40	10
	5 to 30	39	13

conducted-EMI peaks at low, medium, and high frequency ranges. For the standard PWM scheme the conducted-EMI have crossed the quasi-peak limits of 65-56 dBμV. It is evident from the Table 3 that Cuk converter have not exceeded the average limits of the CISPR standards in all the frequency ranges.

It is monitored from the Table 3 that the standard PWM technique has the highest conducted-EMI peaks all over the spectrum. In case of CTERPWM the converters have conducted-EMI peaks within the limits stated in class B CISPR standard. In the frequency range of 0.15 to 0.5 MHz, the attenuation of conducted-EMI is high when compared with other frequency ranges mentioned in the above table. Hence, it is understood that the CTERPWM technique is fairly attenuating low frequency range and high frequency range of conducted-EMI. CTERPWM technique to a greater extent has reduced the conducted-EMI over the whole spectrum in all the frequency ranges.

6. Conclusion

The trailing edge of the switching signal as a random variable for long has been negated as a promising method of future extrapolations by the technocrats and the analysts in the realm of power electronics engineering. This current scholarly work under scrutiny ventures to undertake the trailing edge of the switching signal as the basis for experimentation and further exploration in the relevant field of study for the mitigation of conducted-Electromagnetic Interference. The derived analytical formulas for the CTERPWM are validated by experimental results. Experiments have been conducted to measure and assess the PSD for the Cuk converter. It has been learnt from the experimental analysis carried out in the research work underway, standard PWM technique has consistently delivered the optimum PSD results as compared to RPWM techniques thus proving the method to be not viable or durable for the Cuk converter. Moreover, the proposed RPWM technique significantly reduces the harmonic peaks and some of the peaks are well distributed.

The simulation results and the experimental conducted-EMI results are almost similar approximating with little experimental deviations. Based on the strong experimental analysis it has been proved that through the CTERPWM technique, the Cuk converter has fairly a better attenuation rate in all the frequency ranges. The CTERPWM technique emerges as the most reliable and clinically proven technique as for as the mitigation of conducted-EMI.

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