ABSTRACT

This paper presents the comparison of conducted electromagnetic interference (EMI) emission effect on various high frequency transformer windings. The interested windings are conventional winding, sandwiched winding and interleaved winding techniques of the flyback converter. All techniques have a different in parasitic capacitance which can cause different in common mode emission of power converter system. The comparison is done based on the different winding techniques of transformer and verified by the experiment. The results are not only the conducted EMI aspect, but also the electrical performances such as efficiency and voltage stress. Finally, the Fourier transform is analyzed to confirm the measured conducted EMI.

Keywords: EMI, transformer winding techniques, flyback converter.

1. INTRODUCTION

The operation of the switching power supply can generate noises into the system in both conducted and radiated EMI emissions. Since the switching device such as MOSFET operating at high frequency, it leads to generate high \( \frac{dv}{dt} \) and \( \frac{di}{dt} \) which are the main caused of EMI emission.

The switching power supply normally uses high frequency transformer to step-down or step-up the input voltage, transferring energy from input to output and also the isolation. Therefore, the high frequency transformer play an important role in the switching power supply. There are many different techniques to wind the high frequency transformer, for example, the simple conventional winding, sandwiched winding and interleaved winding, respectively. The main objective of using the complicated techniques is to reduce the leakage inductance and to minimize the peak of voltage stress across the switching device.

The results of conducted EMI from diverse winding techniques of the flyback converter, which has identically components, are investigated. The winding techniques of high frequency transformer are compared in three different types: conventional, sandwiched and interleaved windings, respectively. The comparison of electrical characteristics such as power loss, efficiency, voltage stress across MOSFET and ringing frequency are verified by the experiments. Furthermore, the results of conducted EMI from those techniques of high frequency transformer are also analyzed.

2. THEORY

2.1 Flyback converter

The conventional circuit of flyback converter is shown in Fig. 1. It is the simplest isolated switching power supply circuit that uses the high frequency transformer. There is a control circuit to control the duty cycle of a MOSFET operation while the high frequency transformer is used to transfer energy from input to output. When the switch is turn-on, the transformer stores the energy. On the other hand, when the switch is turn-off, the transformer then transfers the energy to the load.

2.2 Conducted EMI

The operation of switching devices can generate both of \( \frac{dv}{dt} \) and \( \frac{di}{dt} \). It is clarified that those phenomena can cause the EMI emission [1] which can affect to any systems. Two types of the conducted EMI are differential-mode and common-mode emission. The differential-mode propagation takes place between two conductors, e.g. line and neutral, while the common-mode propagation takes place between a group of conductors, i.e. line or neutral, and ground [2] as shown in Fig. 2.

2.3 High Frequency Transformer

The main objective of using the high frequency transformer in the switching power supply is to step-up or step-down the input voltage and to isolate the output from the input of the circuit. When the operating frequency of transformer is increased, it allows the transformer size to be smaller. However, the conducted EMI and their harmonics are increased when the components working at switching frequency. Moreover, the equivalent circuit of the transformer [3], as shown in
Fig. 3, can be seen that the leakage inductance $L_p$ and $L_s$ will cause the voltage stress across the switch. The $R_p$, $R_s$ and $R_e$ represent the power loss in the transformer. While $C_L$, composed of the lumped capacitance of the primary and secondary windings, is the total parasitic capacitance that occurs from the transformer winding.

$$f_r = \frac{1}{2\pi \sqrt{L_p C_L}}$$  \hspace{1cm} (1)

3. THE HIGH FREQUENCY TRANSFORMER WINDING TECHNIQUES AND THE EXPERIMENT

3.1 High frequency transformer winding techniques

Three types of high frequency transformer winding techniques are used for the flyback converter circuit in the experiment as shown in Fig. 4. Each transformer performs with the same Ferrite core 6H20 where the size is ETD44. The winding techniques are different, the conventional, the sandwiched and the interleaved winding. The demonstrations are shown in Fig. 4 (a) to (c), sequentially. The transformers is arranged with the same air gap. The solid copper wire number is AWG17 with 20 turns winding, while the turn ration is equaled to 1 ($N_p/N_s = 1$).

The main different feature of the winding techniques is the position of a primary winding and a secondary winding. The conventional winding technique typically places the primary winding at inside where the secondary winding are wounded at outside. The sandwiched winding technique places the secondary winding between separated primary windings. For the interleaved winding technique, the primary and the secondary winding are alternately located shown in Fig. 4 (c).

![Fig. 4: Three types of winding techniques](image)

3.2 The experimental conditions

The experimental conditions are setup to verify the electrical performance and conducted EMI of those different winding techniques as shown in Table 1.

<table>
<thead>
<tr>
<th>Conditions of the experiment</th>
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<tbody>
<tr>
<td>Input voltage</td>
<td>35 V DC</td>
</tr>
<tr>
<td>Output Voltage</td>
<td>20 V DC</td>
</tr>
<tr>
<td>Output current</td>
<td>1A</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>100 kHz</td>
</tr>
<tr>
<td>Type of winding techniques</td>
<td>TR1 Conventional Winding TR2 Sandwiched Winding TR3 Interleaved Winding</td>
</tr>
</tbody>
</table>

The value of a leakage inductance from the three transformers TR1, TR2, and TR3 are measured. The measured results equal to 4.45 μH, 1.7 μH and 1.8 μH, respectively.

4. THE EXPERIMENTAL RESULTS

4.1 The results of the voltage stress across switch and the ringing of the circuit

The experimental results, shown in Figs. 5 – 7, verify that the conventional winding technique is the highest peak of voltage stress ($V_{DS}$), equal to 120V. While, the peak of voltage stress of sandwiched and interleaved
winding techniques are equal to 91V and 96.8 V, respectively.

![Fig. 5: Voltage stress of conventional winding technique.](image)

![Fig. 6: Voltage stress of sandwiched winding technique.](image)

![Fig. 7: Voltage stress of interleaved winding technique.](image)

The ringing frequency \((f_r)\) of the sandwiched winding technique is highest around 9 MHz while the conventional winding technique is lowest at 6.25 MHz. The ringing frequency, \(f_r\), can be predicted by Eqn. (1). The comparison between calculated results and measured results are proved. For instance, conventional winding technique, 4.5 \(\mu\)H leakage inductance, results the lowest ringing frequency, 6.5 MHz. The sandwiched winding technique results the highest ringing frequency, 9 MHz, due to the smallest leakage inductance, 1.7 \(\mu\)H. The time domain, as shown in Figs. 5 – 7, can be analyzed and transformed using Fast Fourier Transform (FFT) in MATLAB program.

The frequency domains, shown in Figs. 8 – 10, support the conducted EMI results as shown in Fig. 12.

![Fig. 8: TR1: FFT of conventional winding technique](image)

![Fig. 9: TR2: FFT of sandwiched winding technique](image)

![Fig. 10: TR3: FFT of interleave winding technique](image)

4.2 The results of Conducted EMI

The conducted EMI measurement is setup as shown in Fig. 11. The CISPR22 class B standard is taken as a reference line which considers the frequency between 150 kHz to 30 MHz. The measured conducted EMI, as shown
in Fig. 12, indicates that the second peak of conducted EMI for each winding techniques is correspondent with the ringing frequency of voltage stress ($V_{DS}$). For example, the second peak of conducted EMI of conventional winding technique, shown in Fig. 12, is 6.25 MHz which nearly equals to ringing frequency as shown in Fig. 5 and Fig. 8. The second peak of conducted EMI, from low to high frequency, is generated by ringing frequency of conventional, sandwiched and interleaved winding techniques as shown in Fig. 12. The second peak of those techniques result EMI level about 82 dB $\mu$V. The conventional winding technique, high leakage inductance, not only provides the lowest second peak response, but also results a higher EMI peak level at 91 dB $\mu$V which is 3 dB $\mu$V and 8 dB $\mu$V greater than those of sandwiched and interleaved winding techniques, respectively. Moreover, the first peak is identical appeared at all types of winding techniques because of a self resonant frequency (SRF) of the flyback converter.

### Table 2: Comparison of electrical characteristic of each winding technique by the experiment.

<table>
<thead>
<tr>
<th></th>
<th>$P_{in}$ (W)</th>
<th>$P_{out}$ (W)</th>
<th>$P_{loss}$ (W)</th>
<th>$\eta$ (%)</th>
<th>$V_{DS}$ (V)</th>
<th>Ringing Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>TR1</td>
<td>25</td>
<td>20</td>
<td>5</td>
<td>80</td>
<td>120V</td>
<td>6.25 MHz</td>
</tr>
<tr>
<td>TR2</td>
<td>23</td>
<td>20</td>
<td>3</td>
<td>86</td>
<td>91V</td>
<td>9 MHz</td>
</tr>
<tr>
<td>TR3</td>
<td>23.5</td>
<td>20</td>
<td>3.5</td>
<td>85</td>
<td>96.8V</td>
<td>8 MHz</td>
</tr>
</tbody>
</table>

5. CONCLUSION

The comparison between electrical performance and conducted EMI on those high frequency winding techniques are mentioned. The sandwiched and the interleaved winding techniques that are more complicated method of winding techniques can competently decrease the leakage inductance and the voltage stress. Although, the efficiency of the flyback converter circuit is obviously increased, it only has a little effect to the conducted EMI reduction. With the complicated winding techniques, the experiment proving that it is not only effect to shift the peak of conducted EMI but also effect to slightly reducing the EMI magnitude. The peak of conducted EMI conventional winding technique is appearing at the lowest frequency and the sandwiched winding technique has the highest frequency. However, the different among all mentioned techniques can be only observed at the frequency beyond 3MHz. The frequency range of conducted EMI beyond 3 MHz, almost affected from the common mode propagation and normally caused by parasitic capacitance [5-6]. The analysis of FFT on ringing waveform confirmed the EMI results.

Although, the complicated winding techniques have the better efficiency improvement and voltage stress reduction, they can not expect to reduce the peak of conducted EMI emission.

6. REFERENCES


