Radiated Emission Due to Common Mode Current in Smps

Shantala, M. L. Sudheer

Abstract: The high frequency switching of semiconductor switches in Switched Mode Power Supplies (SMPS) cause high dV/dt and dI/dt resulting in differential mode (DM) and common mode (CM) conducted and radiated Electromagnetic Interference (EMI). The CM noise current circulating through the ground path is the major contributor for radiated EMI in the frequency range of 30 MHz to 1 GHz which will usually be above the stipulated international standards and are addressed here. The high dV/dt and dI/dt are major sources of EMI producing noise currents which will get coupled to ground through parasitic capacitances. The prominent parasitic capacitors are present in high frequency transformer and the semiconductor's coupling to ground. They provide path for both DM and CM noise currents. The CM currents flowing in the different prominent parasitic capacitors are obtained by simulation for the four different topologies namely, non-isolated Buck, non-isolated Boost, Flyback and Forward converters. The radiated Emissions are calculated for each of the topologies and are presented. All the four converters are operated at same switching frequencies with same values of parasitic capacitances. The non-isolated Boost converter is found to generate higher radiated emissions due to CM current than the non-isolated buck converter and Forward converter has higher radiated emissions than Flyback converter. The results presented here can be used to decide on the topology of SMPS for a given application when EMI mitigation is a priority.

Keywords— DC-DC converter, Switch mode power supply, Emissions, EMI Noise.

I. INTRODUCTION

Switched Mode Power supplies (SMPS) are widely used in most of the Electronic appliances used for commercial, military and domestic purposes. The SMPS are also used in power distribution for aerospace and transportation applications. Their Size, efficiency, high power density and low cost are important factors for their wide spread use. The Semiconductor switches used in SMPS are made to switch at high frequencies and because of this, they generate Electromagnetic Interference (EMI) which is the major disadvantage. This has called for a need of reducing its EMI and making it Electromagnetically Compatible [1-2]. There are many methods for minimizing the EMI.

The EMI generated in SMPS is due to high (dv/dt) and (di/dt) caused while the semiconductors inside them are switching. These sources of EMI will get coupled to ground through parasitic capacitances. The inter winding and intra winding capacitances of the high frequency transformer and the coupling capacitor between the semiconductor switches and ground are the prominent parasitic capacitors in SMPS. The EMI sources through these coupling paths cause conducted and radiated EMI in both differential mode (DM) and conducted modes (CM). The CM circulating current through the ground is the chief cause for radiated emission. The CM current are strongly related to variations of dv/dt [3-5]. The main difficulty of SMPS design is making its radiated emissions compliant to international standards [6-7]. This paper studies CM EMI emitted radiation mechanism in the frequency range of 30 MHz - 1 GHz [8] in 4 different topologies of SMPS.

Four different topologies namely, non-isolated Buck, non-isolated Boost, Flyback and Forward converters are considered here together with their parasitic capacitances and they are simulated in LTSpice software. Their switching frequencies, load current and parasitic capacitances are same. The equivalent circuit models of CM radiated emissions are obtained. This is simulated and the Fast Fourier Transform (FFT) of the CM circulating current through the ground is obtained. This FFT of the high frequency CM circulating current in converted to dBuA versus frequency. Using this data, the FFT of CM noise currents in Amps against frequency is then obtained. From this data, the values the Electric field strength at distance of 3 meters from the SMPS is calculated from a formula presented in section IV. The results are presented in section II, III and IV. A comparative study of the CM EMI radiation in buck, boost, flyback and forward circuit models are presented. The Field strength is calculated for a typical PCB trace length of 10cm at a distance of 3 meters from the SMPS unit. This will enable us to find whether the emissions from SMPS are within the stipulated International limits [9-11].

II. SIMULATION AND RESULTS OF BUCK AND BOOST CONVERTER AND ITS CM RADIATION MODEL

The Buck converter circuit shown in Figure-1 delivers 28W of power while switching at 130kHz, 50V DC input and 28V DC output with 1A DC load Current. This was simulated using LTSpice software. Figure 2 shows equivalent circuit of Buck Converter of Figure 1. The Fast Fourier Transform (FFT) of the CM circulating current in the ground path, $I_{(c3)}$, for this converter is plotted in Figure 3. This was then converted into dBuA. The plot of FFT of CM dBuA against frequency is shown in the Figure 4. The Electric field strength at a distance of 3 m from Buck converter due to this CM current circulating in a PCB trace length of 10 cm is calculated from the formula (1) of section IV and is tabulated in Table-I for a frequency range from 30 MHz to 1 GHz.
The Boost converter circuit has 114W power, 130kHz of switching frequency , 50V DC input and 114V output 1A load current was simulated using LTSpice for the circuit in Fig 5.

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The equivalent circuit model of Boost converter is shown in figure-6 and its Fast Fourier Transform of the Noise current $I_{(c3)}$ is obtained by simulation is shown in Fig-7.
The FFT of this Current in dBuA against the frequency is shown in the Fig-8. The Electric field strength at a distance of 3 m from Boost converter due to this CM current circulating in a PCB trace length of 10 cm is calculated from the formula (1) of section IV and is tabulated in Table-I for a frequency range from 30 MHz to 1 GHz. The comparison of radiated emission from Buck and Boost Converters due to CM current is shown in the Table-I. From Table-I it is evident that boost converter has higher radiated EMI noise than the Buck converter due to the CM circulating ground current.

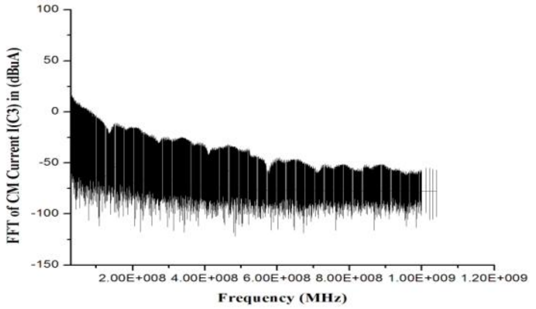

Fig 4. FFT of I(c3) of Buck converter in dBuA vs Frequency (from Fig 3)

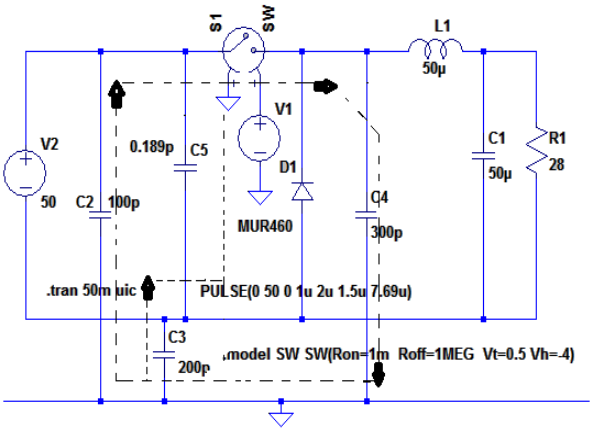

Fig 1. The Buck Converter Circuit Diagram

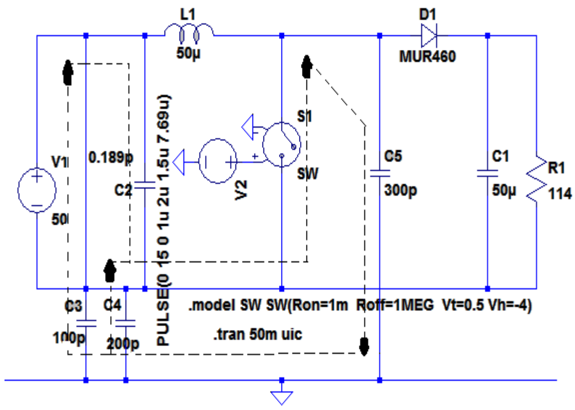

Fig 5. The Boost Converter Circuit Diagram

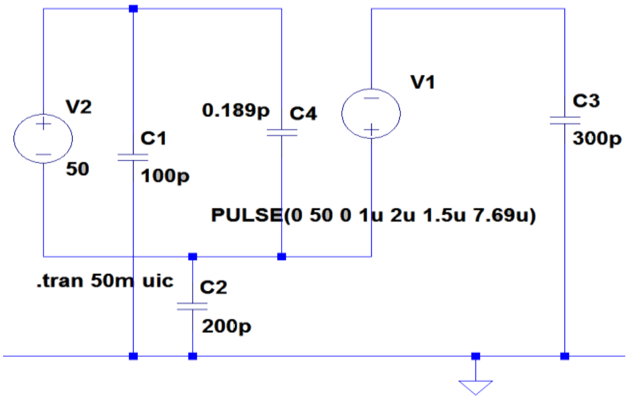

Fig 2. Equivalent circuit of Buck Converter (from Fig 1)

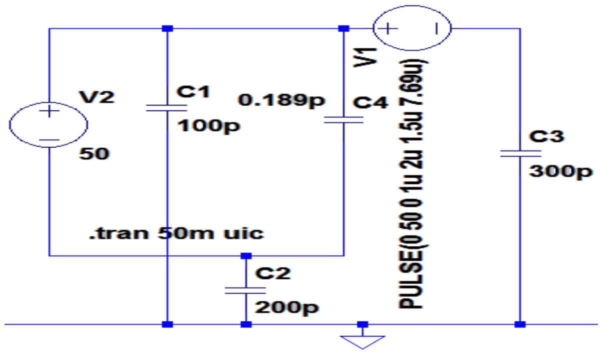

Fig 6. Equivalent circuit of Boost Converter (from Fig 5)

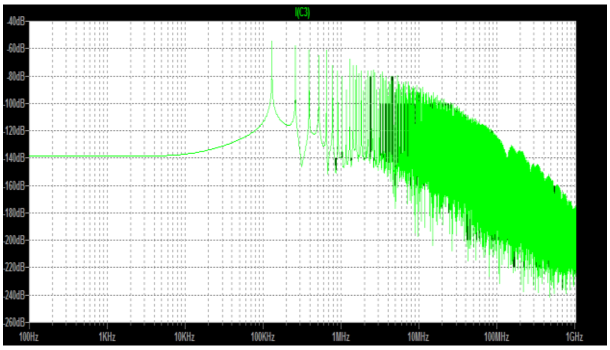

Fig 3. FFT of I (c3) of Buck Equivalent Circuit (from Fig 2)

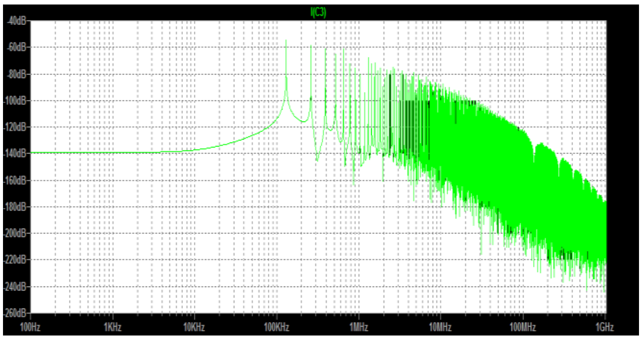

Fig 7. FFT of I (c3) of Boost Equivalent Circuit (from Fig 6)

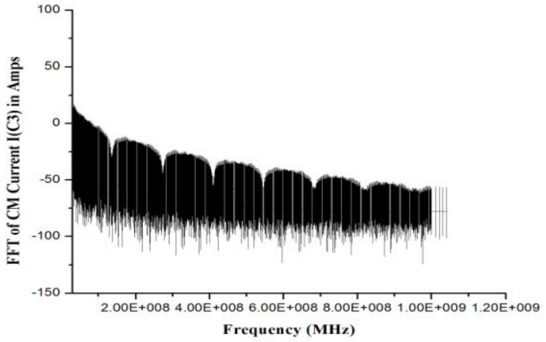

Fig 8. FFT of I(c3) Boost converted in dBuA vs Frequency (from Fig 7)

III. SIMULATION AND RESULTS OF FLYBACK AND FORWARD CONVERTER AND ITS CM RADIATION MODEL

The circuit of low power Flyback and Forward SMPS is simulated by using LTspice software shown in Fig 9 and Fig 13 respectively. Both converters are having AC input 230V/50Hz and DC output is 16V/360mA and 5.76 W. The equivalent circuit of flyback converter is shown in the figure 10. Its FFT of the noise current $I_{(C2)}$ is shown in Figure 11. Then FFT of CM Current in dBuA against the frequency is calculated and is shown in the Figure 12. The Electric field strength at a distance of 3 m from Flyback converter due to this CM current circulating in a PCB trace length of 10 cm is calculated from the formula (1) of section IV and is tabulated in Table-II for a frequency range from 30 MHz to 1 GHz.

The equivalent circuit of forward converter and its Fast Fourier Transform of the CM Noise current $I_{(C8)}$ is revealed in Figure 14 and Figure 15 respectively. The FFT of CM Current in dBuA vs frequency is also shown in the Figure 16.

The Electric field strength at a distance of 3 m from Forward converter due to this CM current circulating in a PCB trace length of 10 cm is calculated from the formula (1) of section IV and is tabulated in Table-II for a frequency range from 30 MHz to 1 GHz.The comparison of radiated emission from Flyback and Forward Converters due to CM current is shown in the Table-II.

From Table-I it is evident that Forward converter has higher radiated EMI noise than the Flyback converter due to the CM circulating ground current.

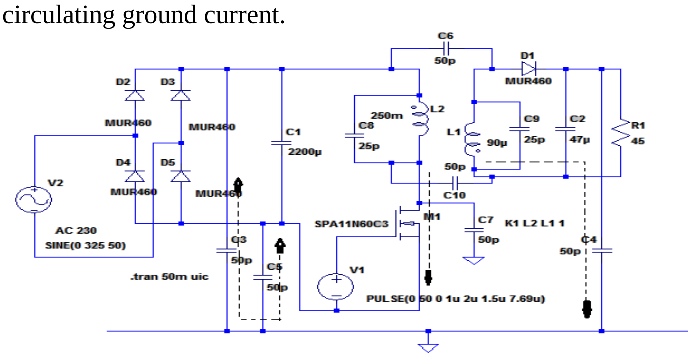

Fig 9. The Flyback Converter Circuit Diagram.

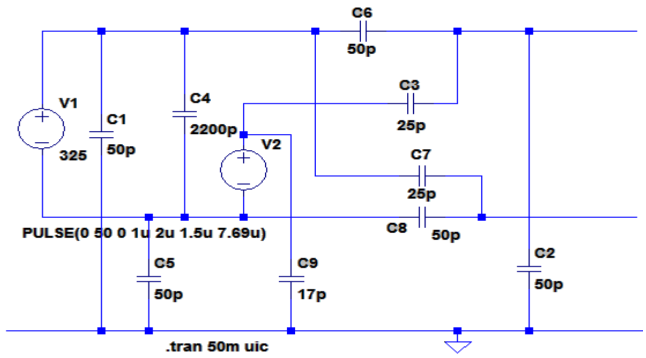

Fig 10. Equivalent circuit of Flyback Converter (from Fig 9)

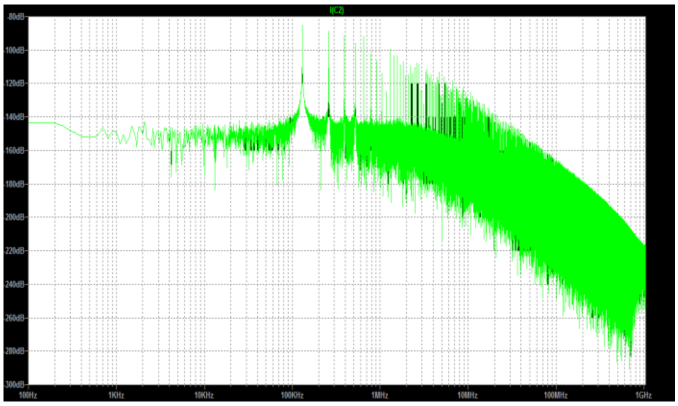

Fig 11. FFT of I (c2) of Flyback Equivalent Circuit (from Fig 10)

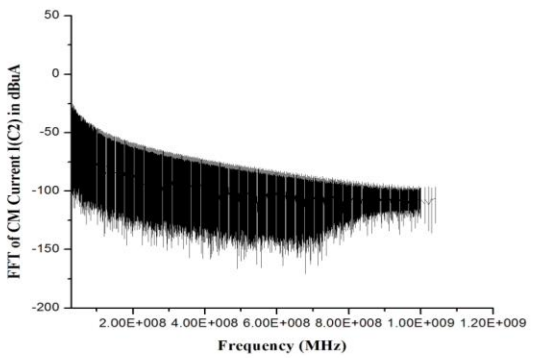

Fig 12. FFT of I(c2) of Flyback converter in dBuA vs Frequency (from Fig 11)

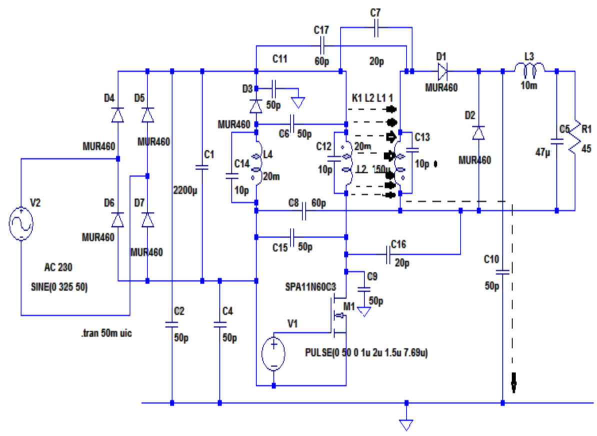

Fig 13. The Forward Converter Circuit Diagram

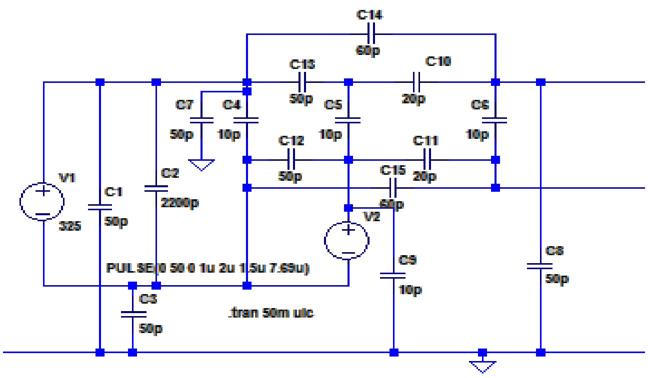

Fig 14. . Equivalent circuit of Forward Converter (from Fig 13)

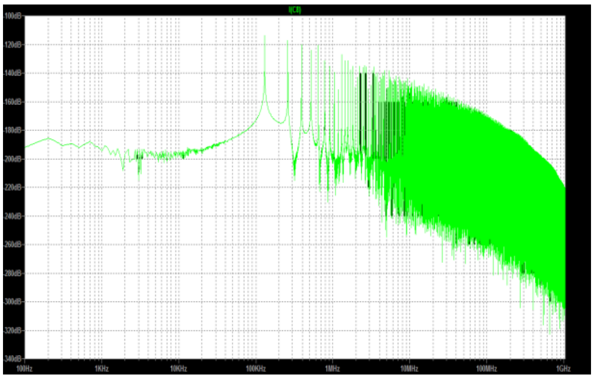

Fig 15. FFT of I (c8) of Forward Equivalent Circuit (from Fig 14)

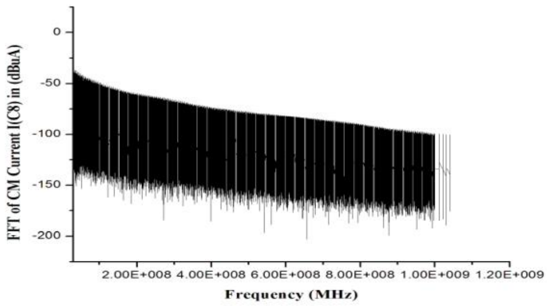

Fig 16. FFTof I (c2)-Forward converter in dBuA vs Frequency(from Fig 15)

IV. RADIATED COMMON MODE NOISE

The Electric Field Strength is calculated using formulae (1)

$$|E_C| = (6.28) \times (10^{-7}) \times \frac{(I \times F \times L)}{d} \quad \ldots\ldots (1)$$

Where,

I = CM current circulating on the Printed Circuit Board segment in Amps

Ec = Field Strength in terms of volts/meter

F = Frequency in Hertz

L = Length of Printed Circuit Board traces in meters

d = The distance from the SMPS testing unit to the point of measurement of radiated field in meters

Table I– Comparison of Radiated EMI in dBuV/m from Buck and Boost Converter at a distance of 3m.

SI NO	Frequency (MHz)	Buck converter Equivalent CM Noise Electric Field Strength in (dBuV/m)	Boost converter Equivalent CM Noise Electric Field Strength in (dBuV/m)
1	30	47.0611	55.25
2	50	54.537	55.45
3	100	5.224	6.0700
4	500	20.70	22.07
5	1G	37.25	51.52

Table II– Comparison of Radiated EMI in dBuV/m from Flyback and Forward Converter at a distance of 3m.

SI NO	Frequency (MHz)	Flyback Equivalent converter CM Noise Electric Field Strength in (dBuV/m)	Forward Equivalent converter CM Noise Electric Field Strength in (dBuV/m)
1	30	64.62	105.66
2	50	77.85	98.729
3	100	50.02	79.5624
4	500	68.00	84.866
5	1G	93.112	99.75

V. CONCLUSIONS

A method to estimate the radiated noise from the non isolated Buck and Boost converters and Flyback and Forward converter due to CM circulating Noise currents is presented here. This has been modelled and simulated in LTSpice software. The radiated noise due to CM EMI is studied in the frequency range from 30 MHz to 1 GHz. Comparisons of radiated emissions are made between non isolated buck and non isolated boost converters. It has been found non isolated boost converter produces higher radiated EMI than non isolated buck converter.Comparisons of radiated emissions due to common mode noise circulating currents in isolated converters, like forward and flyback are done. Radiated emissions from forward converters are found to be higher than flyback converter.simulations have been carried out and results have been presented. For a given topology, design and parasitic capacitances, the maximum size of PCB can be estimated so as to keep the radiated emissions within the prescribed Interntional standards.

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