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A New Technique to Suppress the Common Mode Conduction Noise of the Boost Converter

***Abstract**. EMI filter is an essential part of the modern switching power supplies contributing to significant price and size. This paper presents a new method to reduce the common mode (CM) electromagnetic interference (EMI) of the boost converter. Conventional methods rely on impedance mismatch or active noise cancellation, but the proposed method uses a passive branch with matched impedance to suppress the CM current. An external inductor is connected between the transistor drain and middle of input dc bus before EMI filter. A Wheatstone bridge is then identified in the CM equivalent circuit of the converter with these additional components. By selecting the inductor value properly the Wheatstone bridge will be balanced and results in suppression of the input CM current. The analysis shows that the presented method can guarantee the required attenuation for CM conduction noise. Finally, a comparison between the balanced and unbalanced structure is presented using computer simulation by Pspice.*

***Streszczenie.** W artykule zaprezentowano nową metode redukcji składowej wspólnej elektromagnetycznych interferencji w przekształtniku typu boost. W metodzie zastosowano pasywny układ do dopasowania impedancji w celu zmniejszenia składowej wspólnej prądu. Wstawiony w układ mostka dławik umożliwia zrównoważenie tego mostka. **Nowa technika zmniejszania składowej wspólnej szumu w przekształtniku typu boost**.*

Keywords: Electromagnetic interference (EMI), common mode (CM), parasitic capacitor, Impedance balancing.
Słowa kluczowe: interferencje elektromagnetyczne, składowa wspólna, kompresja szumu, przekształtnik boost

Introduction

The size of energy storage elements in switching power supplies decreases along with the increase of switching frequency. Therefore, high density power supplies generally need to high switching frequency and fast semiconductor devices. Increased switching frequency with high voltage and current change rates (dv/dt, di/dt) has injurious effects on the electromagnetic compatibility (EMC) issue of the switching converters. Thus, it is necessary to use the EMI filter to limit the high frequency components of converter input current below a permitted level which is defined by international standards [1], [2].

Since the system engineers do not know the details and exact nature of the switching converter then the design of EMI filters is not a trivial work. Also, interconnection among the EMI source impedance and EMI filters impedance may cause to poor noise attenuation. Existing EMI filter design methods usually ignore the noise impedance of the switching power supplies (SPS), then trail and error attempt is often used in filter matching design [3], [4].

Passive EMI filtering method decreases the conduction noise level by employing inductors and capacitors to create impedance mismatch in the current pass. On the other hand active filtering method needs to active devices or changes the switching algorithm to reduce the noise power over the defined frequency domain. Conducted EMI noise has two parts: differential mode (DM) and common mode (CM) part. CM component behaviour is usually more complex to be modelled rather than DM type because it involves chassis ground path which is not completely obvious [5]. On the contrary, the DM part has not any path to chassis ground and almost its amplitude is little, then, this paper focuses only on the CM noise filtering subject. A measurement circuit named line impedance stabilization network (LISN) is used and inserted between the converter and input source to provide specific measuring impedance for conducted noise amplitude and to isolate them at radio frequency from each other. The LISN setup used here is a 50uH/ 50Ω type.

This paper introduces a passive noise suppression way to establish the balanced Wheatstone bridge using only a low size inductor. The LISN gauge is placed in middle of the bridge branches, then, noise current doesn't flow through it if be balanced. Finally, simulation is done using Pspice.

Boost converter and its parasitic capacitor

Boost converter is a well-known and high-aptitude circuit especially for power factor correction (PFC) applications. Figure 1, shows a simple non-isolated boost converter.

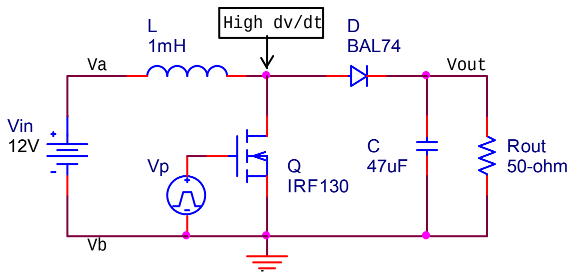

Fig.1. Boost converter circuit

As seen, transistor drain node has greater voltage pulsation (high dv/dt) rather than other nodes. Figure 2, displays nodes voltage of V_d, (V_a-V_d) and (V_b-V_d). The last two mentioned voltages are in-phase and have the same pulsation amplitude. Both voltages define the CM noise current contents which flows via a parasitic capacitor rests between the transistor case and heatsink body, then this current returns back through 'a' and 'b' nodes. In order to reduce the junction temperature, the transistor is usually mounted on a heatsink which is firmly connected to chassis.

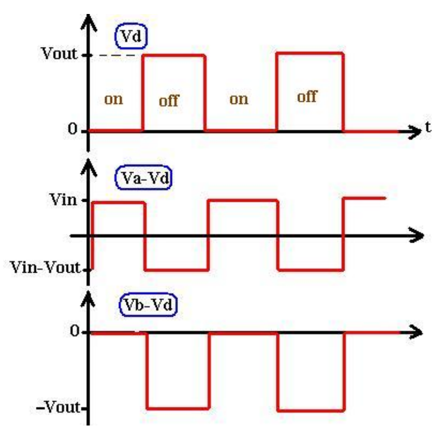

Fig.2. Nodes voltage of the boost voltage shown in Fig.1

Figure 3, displays the parasitic common-mode capacitor (C_{hs}) among the transistor case and heatsink body.

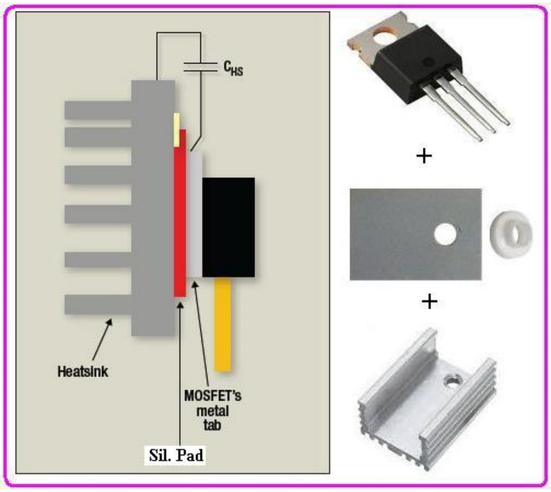

Fig.3. Switch supplement and its parasitic capacitor

To calculate the parasitic capacitor between the device case and heatsink which usually are separated by a thin layer of silicon composition, the modified parallel-plate equation can be used where is presented in formula (1) [6].

(1)

$$C_{hs} = \frac{\pi.\varepsilon_o.\varepsilon_{eff}}{Ln\left[1+\frac{1}{2}(\frac{8h}{w_{eff}})(\frac{8h}{w_{eff}}+\sqrt{(\frac{8h}{w_{eff}})^2+\pi^2})\right]}.\ell$$

$$\varepsilon_{eff} = \frac{\varepsilon_r - 1}{2} + (\frac{\varepsilon_r - 1}{2}) / \sqrt{(1+\frac{10h}{w})}$$

$$w_{eff} = w + \frac{t}{\pi} Ln \frac{4e}{\sqrt{(\frac{t}{h})^2 + (\frac{1}{\pi(\frac{w}{t}+1.1)})^2}}$$

$$\varepsilon_o = 8.85 \times 10^{-12} \quad ; \quad e = 2.7172$$

Where w, l and t are width, length, thickness of the case respectively, and h is the spacing between the case and heatsink. Figure 4, traces the capacitor C_{hs} dependence on the mentioned parameters. This pad has excellent physical and mechanical quality; it is a composite of silicon rubber and fibreglass. The reinforced fibreglass gives high cut-through resistor with the dielectric breakdown voltage about 4000V and constant permittivity (ε_r) about 5± 0.5 [7].

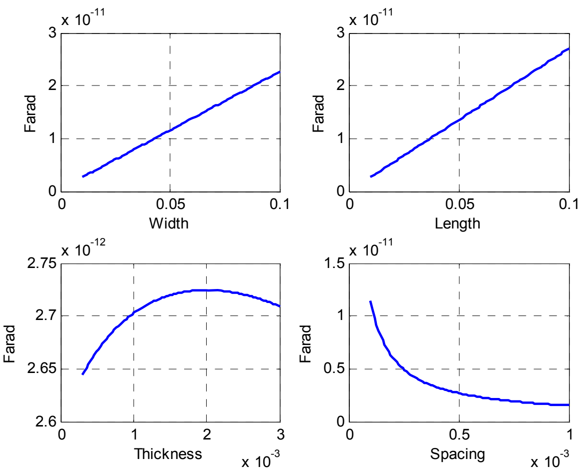

Fig.4. Parasitic capacitor curves on the basis of w, l, t and h items

EMI filter analysis and LISN measurement circuit

Figure 5, shows a simplified circuit of the proposed converter diagram in unbalanced condition.

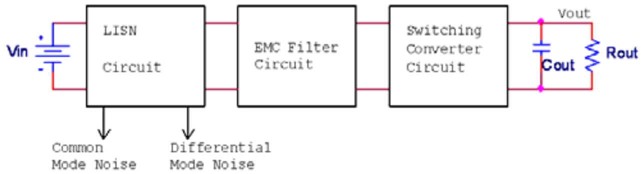

Fig.5. Proposed converter circuit in the unbalanced condition

Conducted EMI noise voltage or currents are separated into common-mode (CM) and differential-mode contents that are presented by formulas (2), (3). LISN measurement circuit is depicted in figure 6 [8].

(2) $$V_{cm} = \frac{V_{an} + V_{bn}}{2};\ V_{dm} = \frac{V_{an} - V_{bn}}{2}$$

(3) $$V_{an} = V_{cm} + V_{dm};\ V_{bn} = V_{cm} - V_{dm}$$

V_{an} and V_{bn} are noise voltages of two input lines.

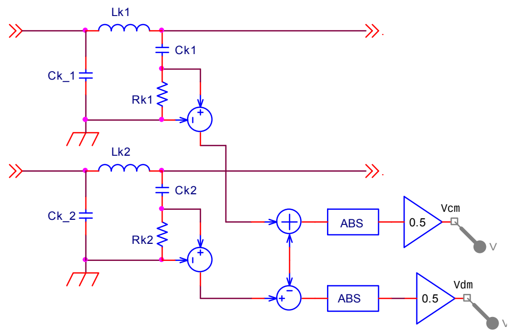

Fig.6. LISN equivalent circuit used to extract the CM and DM noise

The pair of LISN blocks shown in the above figure has same values which are presented below.

$$L_{k1} = L_{k2} = 50uH \ , R_{k1} = R_{k2} = 50\Omega$$
$$C_{k1} = C_{k2} = 100nF \, , C_{k-1} = C_{k-2} = 1uF$$

CM noise has the same direction and DM noise has opposite direction on the two feeding lines. Transmission of the DM noise is through the input line to the utility system and through the dc side to load. Moreover, conduction path through stray capacitances between components and to magnetic coupling between circuits must also be regarded. On the other hand, CM noise is entirely through stray parts and magnetic fields [8]. As mentioned before, these stray capacitances exist between various converter pieces and chassis ground. The following figure displays the equivalent Thevenin and Norton circuit of the noise source and may be replaced with the boost converter.

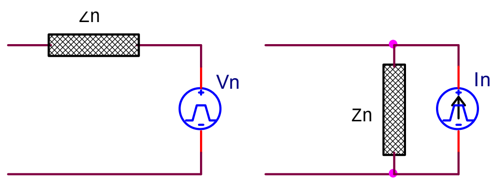

Fig.7. Equivalent parallel and series model of noise source

Figure 8, shows the overall EMI filter that often is used to attenuate the CM and DM noise contents of the converter current. T_Y inductors are usually strived to route the CM noise current through chassis earth via C_{Y1} and C_{Y2} capacitors. However, since earth leakage current is limited for security reasons, Y capacitors rarely exceed a few nano-farads. T_Y windings have the same direction, then, it does not offer any opposition to the DM noise. C_{X1} and C_{X2} are used to join the DM noise loop and to prevent it from seeping outside. Practically, leakage inductance of the CM choke is in the range of 0.5%-2% of L_Y value, then, this leakage inductance can be used as a DM inductor [9].

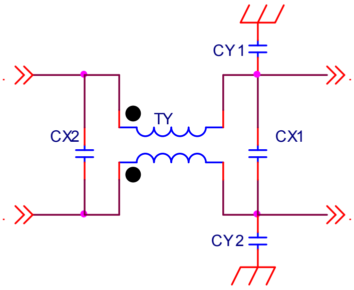

Fig.8. EMI filter circuit used here

There are various FCC, EN, IEC, VDE, CISPR and military standards that define the maximum limit value of the conducted EMI noise. Figure 9, shows FCC and VDE standards for the switching converters used in industrial (class A) and residential (class B) equipments [10]. Level of EMI noise measured by LISN gauge must be under the pointed lines. Class B limits is harder to be satisfied, then, this paper applies the FCC-class B standard.

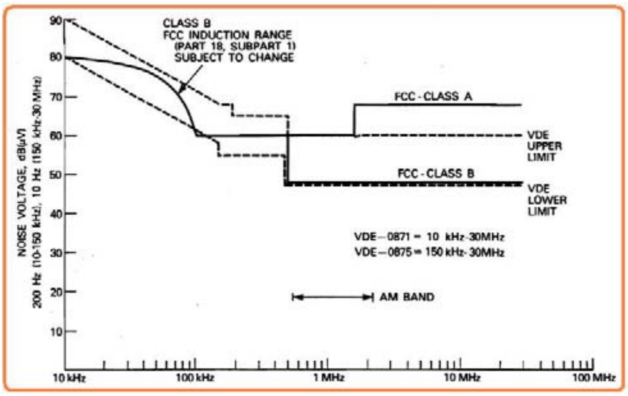

Fig.9. FCC and VDE standards limit for conducted noise

To better compare the simulation results with FCC class -B standard, its permitted values are presented in table 1.

Table1. FCC class A and B limited values [10]

Frequency (MHz)	FCC- Class A Residential App.	FCC- Class B Industrial App.
0.450 --- 0.500	60.0 dbuv	48.0 dbuv
0.500 --- 1.705	60.0 dbuv	48.0 dbuv
1.705 --- 30.00	69.5 dbuv	48.0 dbuv

Figure 10, depicts the simplified equivalent circuit of the converter presented in Fig.5, and will be balanced later on.

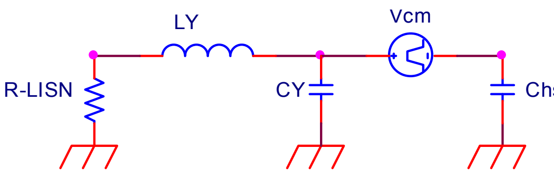

Fig.10. Equivalent noise model of the introduced converter

Forming a balanced bridge to cancel the CM noise

The proposed balancing method can be explained using the circuit shown in figure 11, which contains an external inductor L_{ex} connected between the converter output wires and the dc input terminals. This external inductor forms a balanced Wheatstone bridge with L_Y and two capacitors of C_Y and C_{hs} (stray capacitor of the switch to heatsink body).

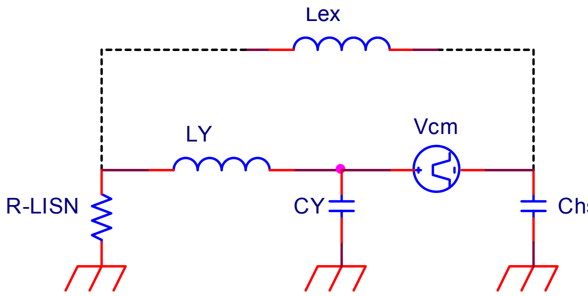

Fig.11. Balance circuit of the converter noise model

The balanced model of Figure11 is better seen from the rearranged circuit of Figure12.

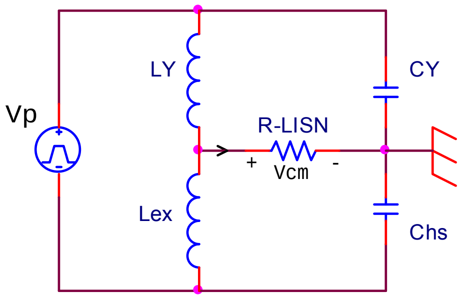

Fig.12. Rearranged circuit of Fig.11

The main goal of this schema is to prevent the CM noise current from flowing through the R_{LISN}. Based on the Wheatstone bridge rule, the CM current produced by the converter is zero if confirms the following condition.

$$\frac{L_{ex}}{L_Y} = \frac{C_Y}{C_{hs}} \Rightarrow L_{ex} = L_Y.(\frac{C_Y}{C_{hs}}) \tag{4}$$

Since L_{ex} is supposed to be appeared only in the ac model, then it is necessary to add four additional capacitors (C_{ex1} to C_{ex4}) as seen in figure 13. To damp the probable resonance between these capacitors and L_{ex}, a resistor 'R_{ex}' has to be added in series with this inductor. To prove the balancing criteria mentioned in equation (4), the capacitors impedance and resistor value should be smaller enough than '$j\omega L_{ex}$' in the frequency domain of FCC standard. Since the dielectric constant (ε_r) of silicon pad affixed to the heat -sink may change depending on transistor temperature, then it not feasible to balance the equivalent circuit ideally.

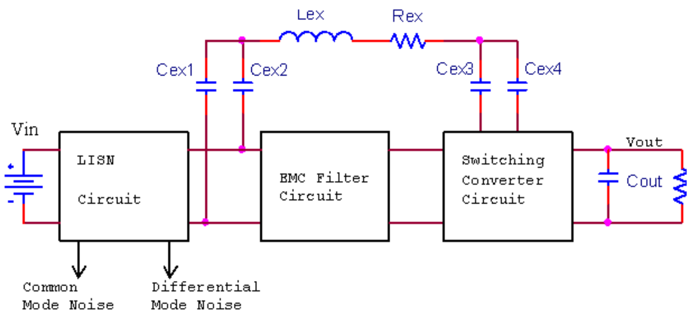

Fig.13. Final balanced arrangement of the proposed converter

Simulation results

Simulation is done using Pspice software. Schematic of the entire converter circuit is shown in figure 14.

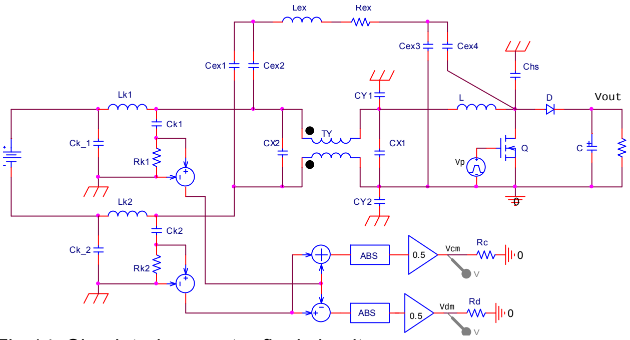

Fig.14. Simulated converter final circuit

The converter components value is listed in table 2.

Table2. Components value of the circuit presented in Fig.14

component	value	component	value
Vin	12V	Cx1, Cx2	10uF
Vout	36V	Cy1, Cy2	100nF
L	1mH	Ly of Ty	25uH
Cout	47uF	Chs	100pF
Rout	50Ω	Lex	25mH
Q - switch	IRF130	Cex1:Cex4	1uF
D – diode	BAL74	Rex	4.7Ω
Lk1, Lk2	50uH	Fs (switch. freq.)	100kHz
Ck1, Ck2	100nF		
Ck-1, Ck-2	1uF		
Rk1, Rk2	50Ω		

It is simple to find the external inductor (L_{ex}) value using formula (4), as seen in the following equation.

$$L_{ex} = L_Y.(\frac{C_Y}{C_{hs}}) = 25u.(\frac{100n}{100p}) = 25mH \quad (5)$$

Figure 15, displays the converter output voltage along with its input current. Next figure shows the CM conducted noise of this converter in both balanced and unbalanced condition, which, the FCC-B limit line is seen among it.

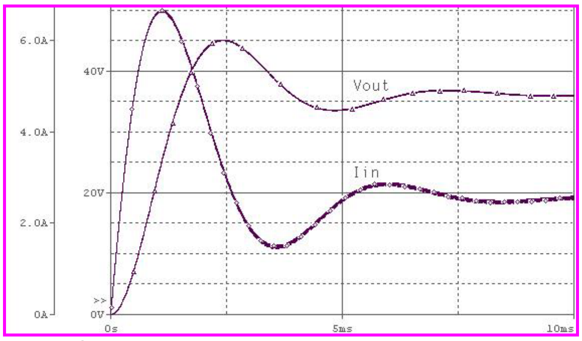

Fig.15. Converter output voltage with its input current

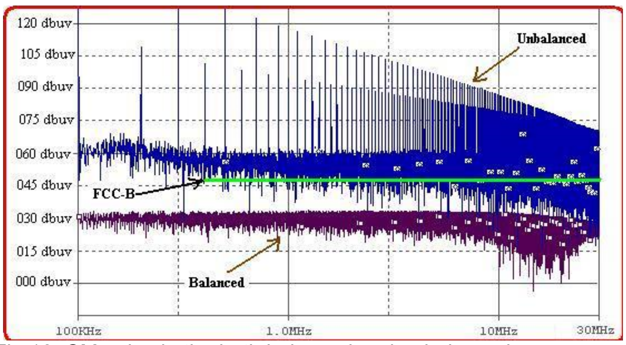

Fig.16. CM noise in the both balanced and unbalanced cases

Conclusion

This paper presents a new method to suppress the CM conducted EMI noise of the boost converter. The reduction effect is achieved by adding a new path to form a balanced Wheatstone bridge. The inserted external inductor (L_{ex}) carries only the extra CM noise current, and then it will be much smaller than the CM inductor used in traditional EMI filters. Also, CM inductor (L_Y) can be selected smaller than the conventional type because its only role is to make a balanced bridge and not to create a mismatched high impedance route. Since other parasitic factors such as stray resistors, stray inductors, temperature drift and other stray capacitors are not presented in this structure, then, the CM noise may not be cancelled ideally. The DM capacitors ($C_{X1,2}$) are usually larger than the CM ones, then can be considered a short circuit for CM noise modelling. Finally, the simulation result confirms that the proposed technique is correct and ensures the required noise attenuation.

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