# Investigation the Relationship Between Common Mode Current and Radiated Field of Buck Converter

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**Abstract**
    An EMC analysis of a switched mode power supply (SMPS)  have been usually using unbalance circuit topologies and the major factor of  disturbance  is parasitic capacitance. We have proposed a balanced switching converter circuit, which is an effective way to reduce the common mode conducted noise. In this paper presents the relationship between common mode current and radiated field.

**Keyword :** SMPS, CMI, $i_{CM}$, MOSFET, EMI

## 1. Introduction

    Since their introduction  at the end of the 1960's, of switching mode power supplies (SMPS) have become progressively popular, up to the point in which the vast majority of today's electronic equipment use this type of regulator. With regard to the electromagnetic interferences (EMI), this type of power supply has always been serious concern because of its conducted and radiated emissions. In a SMPS the primary source of internal radiated on the cables, it's usually contained the high frequency.  If  we can reduce the common mode current, the radiated noise is proportional reduced. The common mode noise is mostly occurred due to circuit is unbalanced [1,3] which is caused by the capacitive coupling to the frame ground which passes through a heatsink of the switching devices [4]. In the last few year have researchers tuned their interests on the electromagnetic (em) radiation from such devices. The modification of Buck converter circuit can be done by balancing the common mode impedance (CMI) method which achieved by source, transmission line and termination balance. The conventional Buck converter is modified in three steps condition such that 1 : two switches buck converter with termination balanced, 2 : two switches buck converter with termination and transmission line balanced, 3 : two switched converter with termination, transmission line and source balanced. It's useful to find the relationship between common mode current and radiated field of Buck converter.

## 2. SMPS model and experimental set up

    EMI is the principle loop of the converter section consisting of the switching semiconductor component (in this case a MOSFET), the DC source, the inductor, the filtering capacitor and the load. Its equivalent and geometrical layout with the dimensions, are in Fig.1
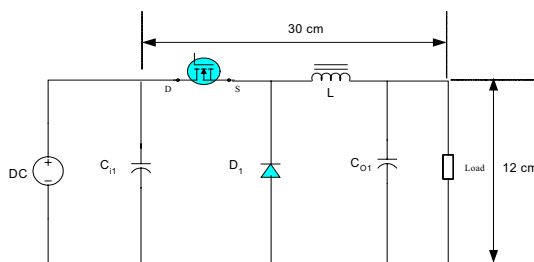


Fig. 1 SMPS geometrical layout

    The MOSFET is driven by the electronic control system represented by equivalent gate voltage Veq = 22 V, which has rise time and fall time respectively such that  T rise = 750 ns and T fall = 100 ns. The DC source voltage Vdc = 30 V. The conductors are printed traces on a standard circuit board. The filtering capacitor C is in parallel to the load.

## 3. Field calculation

    An original technique to calculate the field radiated by the converter section of a SMPS is developed an amply discussed, in this paragraph, for readers convenience only, it will be briefly summarized. The conductors of the SWMPS circuit are considered to be made up of a number of ideal radiated dipoles, short enough for the current to be approximated as constant along the length dl of each dipole. The expressions for the fields in cylindrical coordinates as following

$$\widehat{E}_r = 2\frac{\widehat{I}dl}{4\pi}\eta_0\beta_0^2\cos\theta\left(\frac{1}{\beta_0^2 r^2} - j\frac{1}{\beta_0^3 r^3}\right)e^{-j\beta_0 r} \quad (1a)$$

$$\widehat{E}_\theta = \frac{\widehat{I}dl}{4\pi}\eta_0\beta_0^2\sin\theta\left(j\frac{1}{\beta_0 r} + \frac{1}{\beta_0^2 r^2} - j\frac{1}{\beta_0^3 r^3}\right)e^{-j\beta_0 r} \quad (1b)$$

$$\widehat{H}_\Phi = \frac{\widehat{I}dl}{4\pi}\beta_0^2\sin\theta\left(j\frac{1}{\beta_0 r} + \frac{1}{\beta_0^2 r^2}\right)e^{-j\beta_0 r} \quad (1c)$$

where $I$ is the current. $\beta_0$ the propagation constant, $\eta_0$ the free space intrinsic impedance, $\theta$ the azimuth angle. In near field region the so-called electrostatic term $\left(j/\beta_0^3 r^3\right)$ is predominant. It represents the field of electrostatic charges physically accumulated at the ends of an isolated dipole. If two dipoles are connected in series and carry the same current, the electrostatic charges at the common end have different signs and this makes their total electrostatic field vanish. In using equations (1) the electrostatic terms $\left(j/\beta_0^3 r^3\right)$ are evaluated from the dipole's center and not from its ends (because in (1) $r$ is the distance between the center of each dipole and the test point) so their contributions to the total field do not vanish, mainly when r is small. This gives rise to unnaturally large electrostatic field that can cause an overestimation of many dBs. To avoid this error the solutions to omit the electrostatic terms in (1) altogether and calculate

the electrostatic field directly from the charges where they do not vanish (e.g. at the filtering capacitor leaders)

## 4. The experimental and discussion

Each version of Buck converter circuit must be setup for measurement both a common mode current and radiated field. The common mode current is measured by high frequency current probe and display by oscilloscope. For radiated field measurement, each version of Buck converter is setup on the non-conductive table in 3 meters semi-anechoic chamber and the radiated field is pickup by Bi-log antenna in frequency range from 30 MHz to 1 GHz and display by EMI receiver as shown in Fig.2
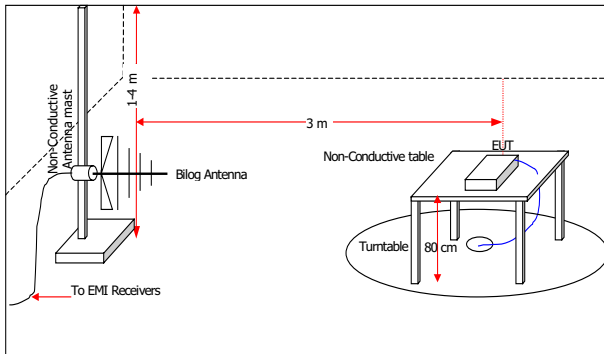


Fig. 2 The diagram of setup for radiated field measurement

### 4.1 Test No.1 (Fig. 3)

In this test, we use the circuit as shown in Fig 3 (a), conventional buck converter topology will have inherent unbalanced circuit between sending power line and return power line with only one switching device and one inductor on the sending power line the common-mode noise is occurring mostly due to circuit is unbalanced which is caused by the capacitive coupling to the frame ground, which pass through a heatsink of the switching devices and the parasitic capacitance at the lead terminal which can see in Fig 3 (a). Measurement results of radiated EMI and common mode current of conventional buck converter is shown in Fig 3 (b) and Fig 3 (c) respectively
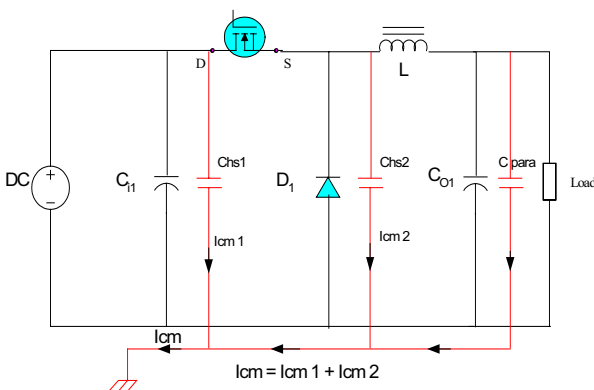


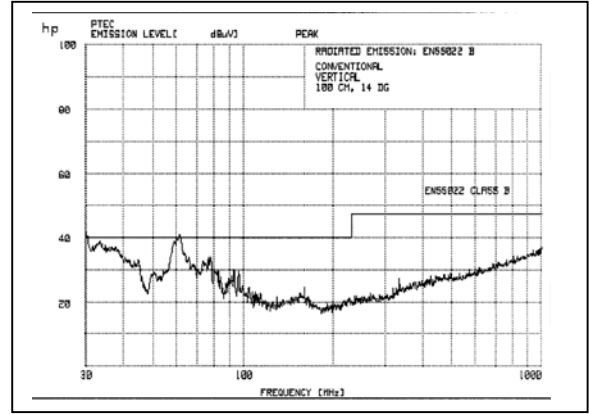Fig. 3 (a) Test No. 1 Conventional buck converter



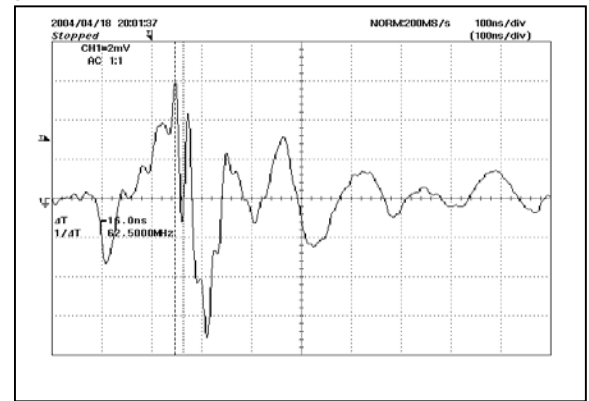Fig. 3 (b) Radiated emission from conventional buck converter



Fig. 3 (c) Common mode current of conventional buck converter

Fig. 3 Measurement results of the radiated EMI and common mode current of conventional buck converter

### 4.2 Test No.2 (Fig. 4)

Topology modification in conventional buck converter to two switches balanced buck converter, which is topology modified for balancing can be applied to achieve the concepts of common mode impedance balancing and noise source Balancing. The impedance balancing concept can be achieved by source, transmission line and termination balanced as shown in Fig 4 (a), the common mode current will be cancelled out in the from ground measurement result of the radiated EMI and common mode current of two switches buck converter with source, transmission line and termination balanced is shown in Fig 4 (b) , Fig 4 (c) respectively
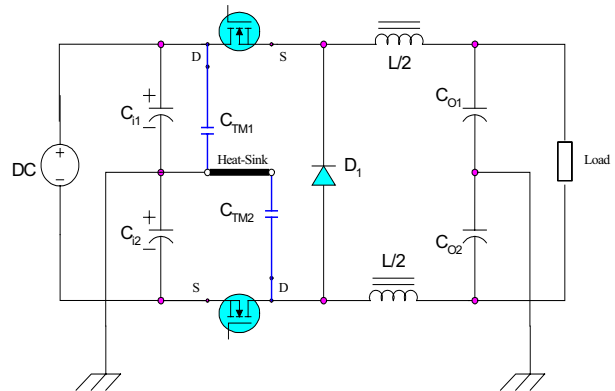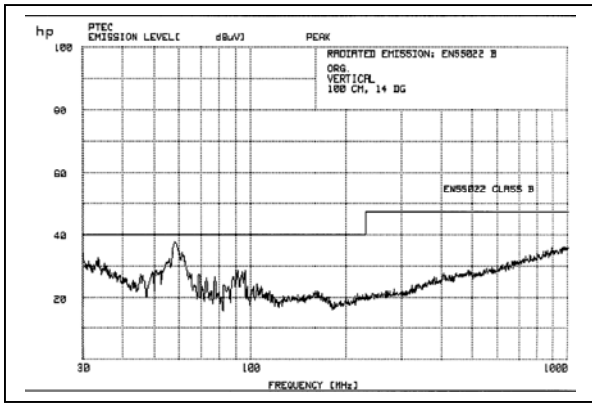


Fig. 4 (a) Test No. 2 Diagram
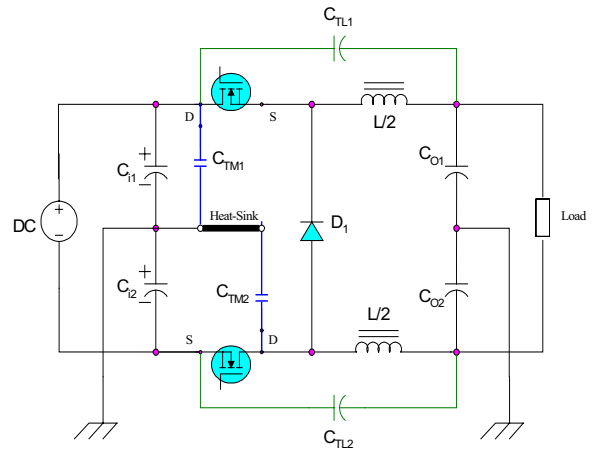
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Fig. 4 (b) Radiated emission
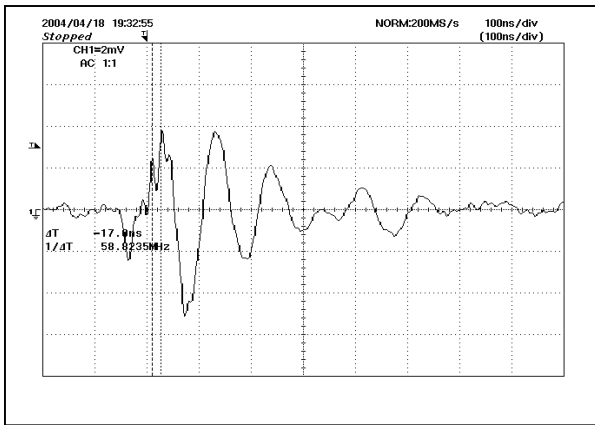


Fig. 5 (a) Test No. 3 Diagram
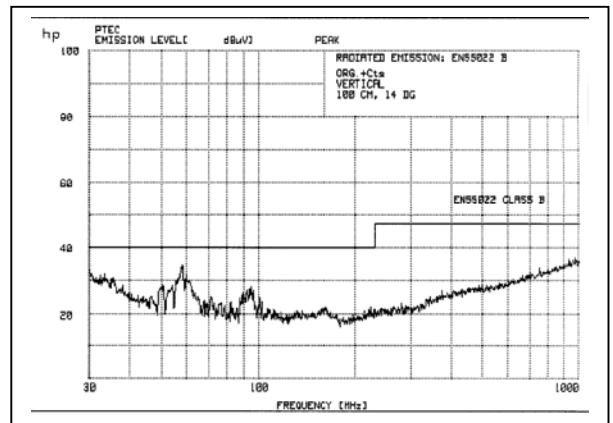


Fig. 4 (c) Common mode current



Fig. 5 (b) Radiated emission

Fig. 4 Measurement results of the radiated EMI and common mode current of two switches buck converter with termination balanced

### 4.3 Test No.3 (Fig. 5)

To increases the efficiency of cancellation mechanism, common mode current paths on sending and returning transmission line can be added the capacitive paths across both inductors, where these paths provide for high frequency current or common-mode current. If these transmission line capacitor $C_{TL1}$ and $C_{TL2}$ can be selected properly, the efficiency of cancellation mechanism is more improved. Experiment results of this improvement are shown in Fig 5 (b) and Fig 5 (c) respectively . Comparing Fig 5 (b) with Fig 4 (b), it can be seen that these are approximately 3 $dB_{\mu V/m}$ drops around 58 MHz.
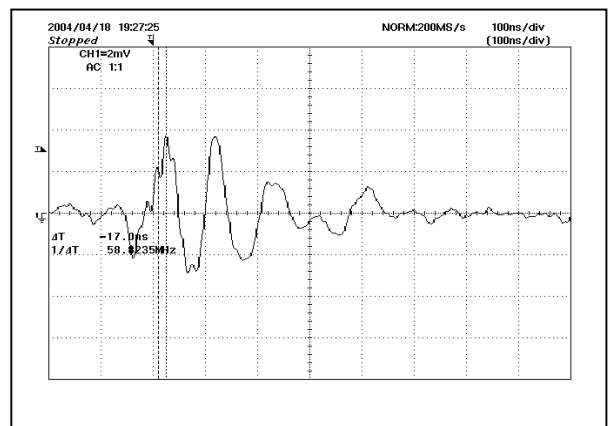


Fig. 5 (c) Common mode current

Fig. 5 Measurement results of the radiated EMI and common mode current of two switches buck converter with termination and transmission line balanced

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## 4.4  Test No.4 (Fig. 6)

The heatsink are usually used with MOSFET, so the parasitic capacitance, $C_{TM}$ is formed between the drain of MOSFET and the frame ground through its heat sink. These parasitic capacitances play a major role in production of common mode noise component. In proposed buck converter, there are two parasitic capacitances are formed from heatsink of two MOSFETS $C_{TM1}$ and  $C_{TM2}$ as shown in Fig 4 (a) The proposed buck converter can be reduced the effect from heat sink that mounted by MOSFETS.
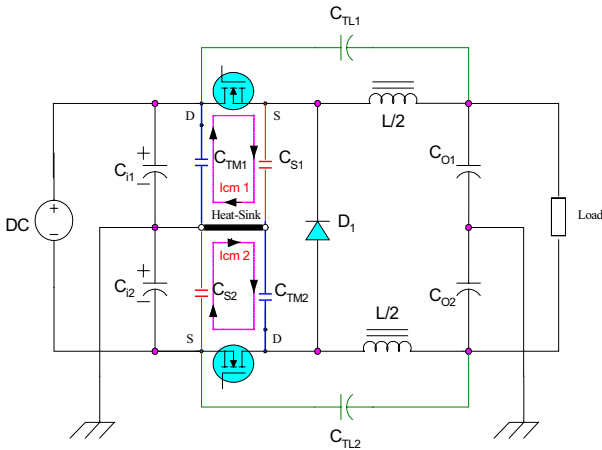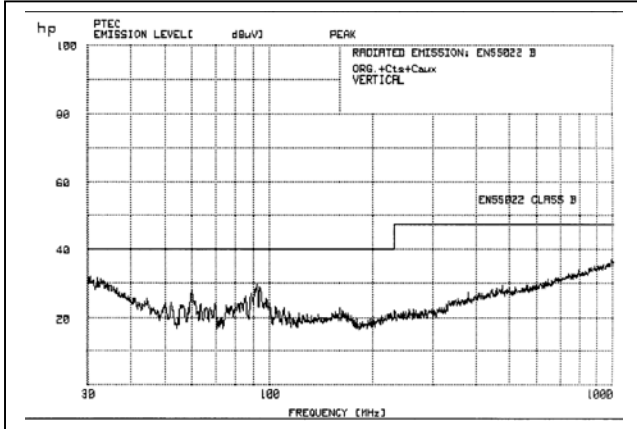


Fig. 6 (a) Test No. 4 Diagram
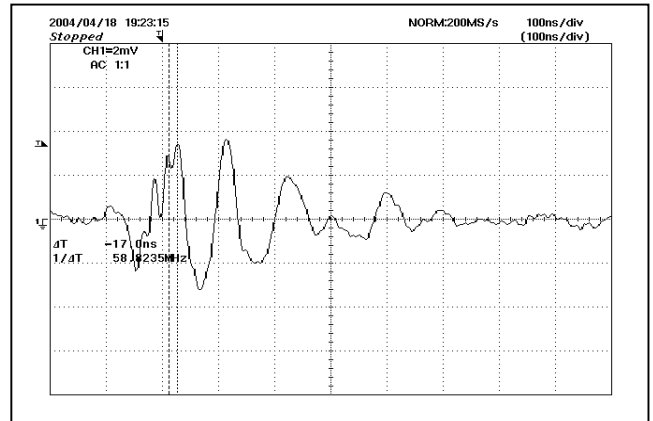


Fig. 6 (b) Radiated emission



Fig. 6  (c) Common mode current

Fig. 6 Measurement results of the radiated EMI and common mode current of two switches buck converter with termination, transmission line and source balanced

The reduction can be achieved by add the compensation capacitor to build the sub-circuit of MOSFET-heatsink as shown in Fig. 6 (a) There are two loops of common-mode currently upper loop is $i_{CM1}$ and lower loop is $i_{CM2}$ bath of the currents are opposite in direction. If the sub-circuit can be correctly proportioned to equalize the impedance, the common-mode current $i_{CM1}$ and $i_{CM2}$ will be cancelled out in the heat sink. The experimental results of this idea are shown the radiated emission EMI and common mode current measurement in Fig. 6 (b) and Fig. 6 (c) respectively. In case of radiated emission EMI comparing between conventional buck converter and two switches balanced buck converter that has been proposed in this paper, we can see that the radiated EMI is greatly reduced due to decreasing the common mode current in the circuit. It is shown that the radiated emission EMI in mostly switching mode power supply is dominated by the common mode noise current so that if the common-mode noise current in general switching mode power supply can be greatly reduced, it is not only to reduce the conducted EMI but also it is always greatly reduced the radiated emission EMI.

From Fig. 3 to Fig. 6 we can find the relation of radiated field to the common mode current as the relation ratio is defined by deviation of radiated field divided by deviation of common mode current, that is equation 2 as shown in Fig. 7

$$\text{Re}lation \ \ ratio = \frac{\Delta E}{\Delta I} = 2dB \, / \, m \, / \, mA \qquad (2)$$
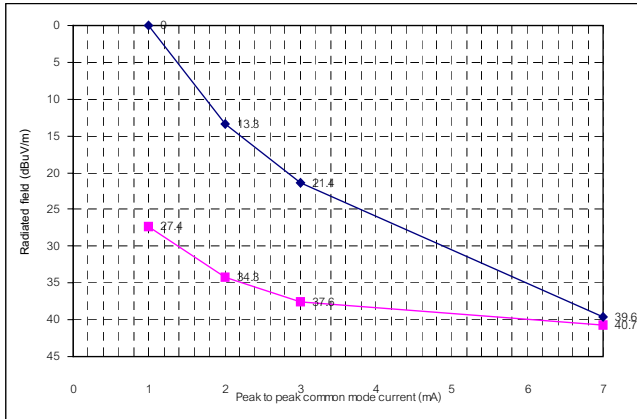
Fig. 7 The relationship between $i_{cm}$ and radiated field measurement results to compare with calculated results

The radiated emission from SMPS circuit are calculated using Equation 1(a) – (c) and is plotted in Fig. 7. The measured results and calculated results are different each other, because the calculated results used for free-space condition. In the other way the measured results was conducted on semi-anechoic chamber with consist of several unknown parasitic parameter. Usually the Equation 1 (a) – (c) use for antenna-like structure so the calculated of radiated emission by using this equation base on differential mode and common mode emission, which grater than this research causing only common mode current.

## 5. Conclusion

In this paper, the relationship of common mode current base on measured and radiated emission is presented. The SMPS is used as radiated source. The standard current probe is used for measured common mode current is attached on the signal line and used for predicting the radiated emission. The configuration of SMPS is replaced by antenna like structure model , then the common mode current base on conducted emission testing is fed in to the antenna model for predicting. This method show that it is possible to predict the radiated emission using common mode current measurement. For evaluation the performance of prediction result, the standard procedure of radiated emission testing are compared to the measured result and shown that it in good agreement for each other.

## 6. Acknowledgment

## 7. References

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