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NOISE REDUCTION IN HIGH FREQUENCY RF DEVICES

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***Abstract*- Electromagnetic interference (EMI) or radio frequency interference (RFI) is a type of electric or electronic emission that can degrade the performance of electronic circuit.The effects of electromagnetic interference (EMI) is particularly troublesome for printed circuit board (PCB) designed for high frequency RF circuits. The components on a PCB may be digital and analog. Transmission lines connecting the two different sections are used to transmit signals back and forth. Unfortunately, as frequency increases and signals are enhanced, noise related to those frequencies is also enhanced, thus creating EMI and RFI. In terms of propagating path, it classifies into conducted EMI and radiated EMI. The conducted EMI results from that the radiated signal stick on the power line and hard to detect and recognize. Therefore, it is necessary to build the causes and effects methodology by way of the correct measurement to maintain the electromagnetic compatibility (EMC), to target the electromagnetic interference, and to detect radio frequency interference.Electronic systems are expected to operate normally within a given environment without internally or externally radiating excessive amounts of electromagnetic energy. In this state, they are called electromagnetically compatible (EMC).**

This paper presents a methodology to minimize radiated EMI by proper designing of PCB and conducted EMI by using EMI filter.

Keywords- ***Electromagnetic interference (EMI), radio frequency interference (RFI), Electromagnetic compatibility (EMC)***

I. INTRODUCTION

Basically electronic devices/modules typically generate undesirable electromagnetic energy. This electromagnetic energy often generates an unwanted EM field or a transient within the RF band (10 kHz - 10 GHz) of the EM spectrum and are commonly referred to as EMI's (Electromagnetic interference). Such electromagnetic interference (EMI) is being known to interfere with the designated operation of the electronic circuitry of other proximate electronic devices. Radio frequency interference (RFI) is often used interchangeably with EMI, although it is restricted to the radio frequency (RF) portion (10 kHz - 10 GHz) of the EM spectrum.

The printed circuit board (PCB) acts as a propagation channel for unwanted noise sources and couples this unwanted noise interference onto other peripheral circuitry, leading to the radiation of generated EMI into free space. The main causes of EMI due to PCB are following [1]:

- Common impedance coupling via power and ground traces.
- Antenna loops formed by ICs and their bypass capacitors, which include power and ground leads.
- Printed circuit board traces carrying signal currents.
- Crosstalk between adjoining signal traces.

In general, power supply decoupling holds the transient currents up to some extent within the bypass loop. However, significant parts of the high frequency components tend to escape onto the power and ground traces. In order to avoid common impedance noise coupling due to these currents, care must be taken to reduce the impedance of the power and ground traces to minimum value.

The simplified approach to overcome this problem is to avoid use of power and ground planes (2-layer or multi-layer PCB) instead of traces. A typical 4-layer board with power and ground plane "sandwich" inside the board with the signal trace on the top and bottom, results in intrinsic high frequency decoupling. Due to the overlapping, power and ground planes act as an inherent distributed capacitor, thus they result in decoupling. Keeping into the consideration of interconnects the main advantage of ground plane is the substantial reduction in signal loop area that it supports. In a typical PCB layout, signal current flows out through one trace and returns through a ground trace, resulting high inductance for the traces with follow-on consequences of signals ringing, EMI radiation and crosstalk. The design objective is to reduce the inductance by reducing the loop area through which the signal current flows.

A number of international government agencies impose guidelines on the allowable EMI that electronic modules can emit. In the United States of America (USA), the Federal Communications Commission (FCC) has divided EMI for computing electronic devices into two categories: (1) Radiated and (2) Conducted Emission. Table-I lists the maximum permissible Radiated Emission (RE) interference from the electronic devices, measured in terms of Electric Field Strength [2]-[4]. The maximum permissible limit of Conducted Emission (CE) interference is typically 260 µV over the frequency range of 450 kHz to 30 MHz, and related with the noise interference fed back to the power supply lines.

Table-I. Maximum permissible Radiated Emission

Freq. (MHz)	***Distance (M) Field***	***Strength (µV/m)***
30-88 MHz	3 Meter	100µV/m
88-216 MHz	3 Meter	150µV/m
216-1000 MHz	3 Meter	200µV/m

II. MODEL OF EMI

Noise emissions can be conducted by power lines into systems or systems can conduct noise emissions onto power lines. Noise emissions can also radiate into the internal circuit space and internal circuits can also be susceptible to radiated noise. For example, a PCB ground loop makes an antenna that effects other portions of the circuit. As illustrated in Fig.1, radiated noise can be coupled into a system and appear as conducted noise. This noise causes logic gates to trip at the wrong voltage level or sensitive analog circuits to have incorrect voltage levels. Two main coupling mechanisms from parallel conductors on the PCB board can increase noise. Parallel conductors can couple a signal onto each other if the signal on one conductor is a time-varying signal. (A time-varying signal has electromagnetic fields that can couple on the other conductor as defined in Maxwell's equations). The conductors are not physically connected but are electromagnetically connected; this is known as the transmission line effect. On the Schematic a capacitor or transformer appears to be connected between the two conductors [5].

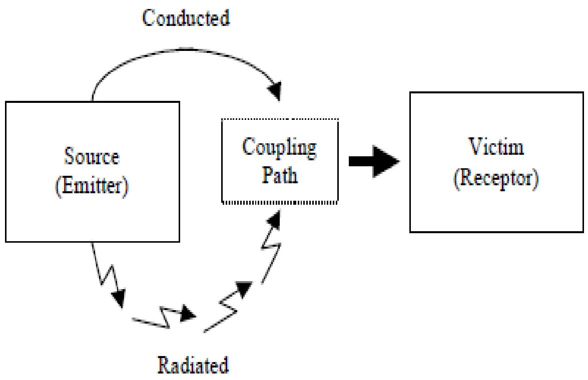

Fig.1 Types of EMI: conducted and radiated

A. Differential-Mode EMI Radiation:

The two main sources of electromagnetic radiation from a PCB are radiation from signal loops and circuit tracks. This section presents a minimization of radiated EMI from PCB.

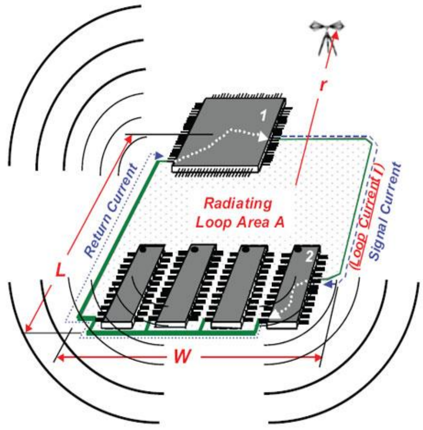

Fig.2 Differential-mode EMI radiation from a PCB

Figure 2 shows current flowing in a single circuit path on a PCB. Radio frequency EMI fields are emitted by the circuit loop and measured by an antenna at a distance[16]. The strength of that EMI field at the antenna is:

$$E = 1.32\left(\frac{f^2 A I}{r}\right) \qquad (1)$$

where: E = V/meter
f = MHz
A = loop area (L • W) in cm^2
I = loop current (amp)
r = antenna to loop distance (m)

Using equation (1), the EMI field strength can be calculated. For example,
where: f = 30 MHz
$V_{p\text{-}p} = V_{OH} - V_{OL} = 5V - 0.2V$
$= 4.8Vp\text{-}p$
$Z_c = 100$ Ohm, r = 3 m , L = 5 cm,W = 5 cm
A = L • W = 5 cm • 5 cm = 25 cm^2

$$I = \frac{Vp-p}{Zc} = \frac{4.8}{100} = 0.048A$$

$$E = (1.32x\ 30^2\ x\ 25\ x\ 0.048)/\ 3$$

$$E = (1.32\ x\ 1080)/3 = 475\ \mu V/m$$

The FCC Class A limit at 3 m is 300 µV/m while the Class B limit is 100 µV/m.

Reducing the Loop Area:

So what is solution? The solution is to reduce the loop area of circuit. The higher the frequency, the better the performance and the higher the emissions potential. Loop current, to a large extent, depends on the device technology, the loads, and the operating frequency. Faster devices with higher peak currents produce higher emissions. PCB layout is the best control over loop area, and smaller loops are better [7]. Attention to detail in the layout will help minimize emissions radiating from the PCB. The PCB layout must be designed to keep high-speed loop areas small [5]-[7].

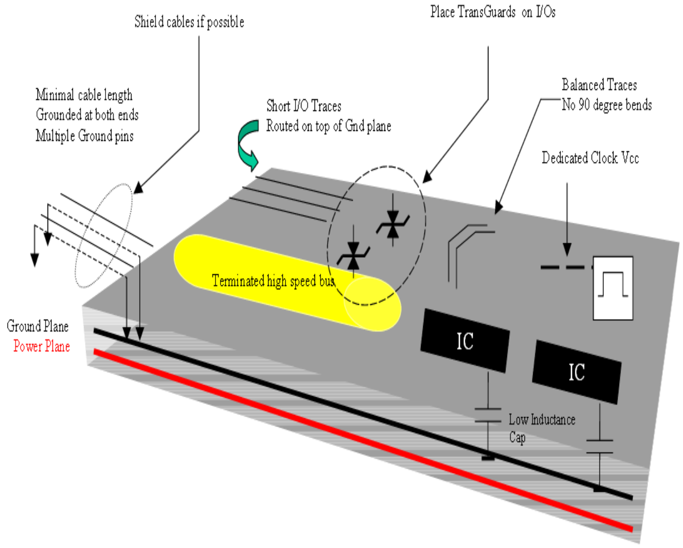

Fig.3 Ground plane added to PCB

For the circuit shown in Fig. 3, the loop width now is 0.15 cm compared to 5.0 cm in Figure 2. Using the same length dimension of 5.0 cm, there is a 32 times improvement in the EMI performance for this PCB.

$$E=(1.32 \times 30^2 \times 0.75 \times 0.048)/3$$
$$= 14.3\ \mu V/m$$

In Figure 3, the actual path of the current flow is from IC 1 decoupling capacitor through the chip to the IC 1 output pin. The current then flows to the input pin of IC 2, through the chip to the ground pin, and via the ground plane to the input pin. From here the return current flows to the ground terminal of the decoupling capacitor IC1.

B. Conducted EMI measurement:

In this paper, the design and implementation of EMI filter for power converters switching in MHz frequency is also presented. The measurement of conducted EMI under a constant condition requires Line Impedance Stabilization Network (LISN) for EMC compliance testing. The LISN is designed and implemented on PCB. Measurements are performed by spectrum analyzer using a LISN between input and the converter under test. The frequency spectrum of input conducted noise is analyzed. The filter is designed and implemented on PCB and after application of filter the spectrum is analyzed.

The basic setup shown in Fig.4 consists of Line Impedance Stabilization Network (LISN), Equipment under Test (EUT) which is a 2-transistor SMPS circuit, mains power supply and a noise separator circuit[5].

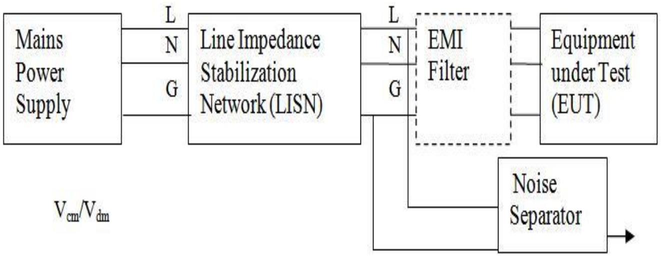

Fig.4 Conducted emissions measurement setup

The LISN shown in Fig.4 is required for measurements of conducted noise on a power line to separate the high frequency noise signals from the input current. It allows spectrum analyzer to measure the noise current through 50 Ω source impedance. The internal circuit of LISN is a high pass filter. It isolates the measurements from any high frequency shunting which might exists in power distribution network. It ensures that the equipment under test receives the proper dc voltage and current levels and also sees the controlled impedance for the ripple frequencies of interest. The mono cell LISN structure is designed and implemented according to CISPR standards. It is the simplest and commonly used topology [11]. It comprises inductors, capacitors and 50 Ω resistors. The 0.1uF Capacitor and 50 Ω resistor provide a path for the conducted EMI with constant impedance with respect to frequency. This characteristic impedance is defined by standards. The schematic of LISN designed for EMI measurements is shown in Fig.5.

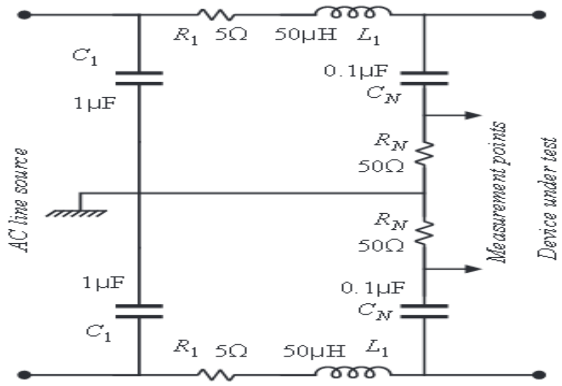

Fig.5 LISN Schematic

1) Basic EMI filters:

The conducted EMI consists of both common mode and differential mode noise signals. The frequency range of EMI signals generated by power electronic equipment extends up to 1GHz [6]. There are various standards e.g. CISPR, FCC IEC, VDE and military standards that specify the limit on conducted EMI [7].

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The common mode noises are high frequency noises that are in phase with each other having circuit paths through ground. Common mode noise is generally the more difficult noise to deal with. It originates due to charging and discharging of parasitic capacitances, primarily, the heat sink and transformer inter-winding capacitance [8]. The main cause of common-mode EMI is the parasitic capacitances between those points of the system that have high *dv/dt* and ground [9].

The differential mode noise is predominantly caused by the magnetic coupling *L.di/dt* where *L* is the parasitic loop inductance which experiences high switching current slew rate *di/dt* [8]. The parameters such as cable spacing and filtering determine differential mode coupling. The differential mode current generated at the input of the SMPS is measured as an interference voltage across the load impedance of each line with respect to earth at measured point [10].

2) EMI filter design and implementation

The direction of the common mode noise is from load and into the filter. The EMI filters bypass the noise by using shunt capacitors and block it by using series inductors[17]. The common mode inductor becomes high impedance to this noise. It absorbs the noise and then dumps it to ground through low impedance Y capacitors. The commonly used EMI filter topologies used to attenuate the high frequency conducted noise include LC low pass filters. To attenuate a certain frequency, band reject filters can also be used. The single stage EMI filter topology is shown in Fig.6.

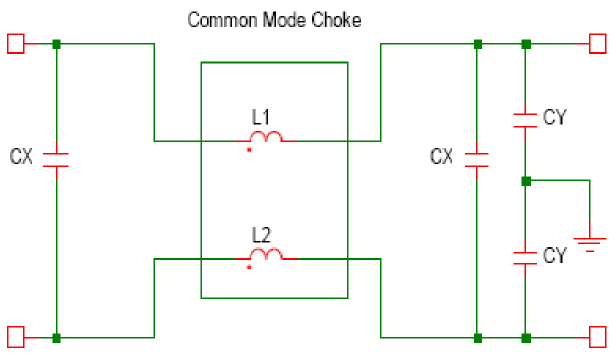

Fig.6. EMI Filter for power converters

The actual size of the filter depends on the design approach, the materials and the components used. However, in general, the size of the filter can be expected to decrease with increasing cutoff frequency and vice versa [13]. A single stage common mode filter is implemented. The value of the common mode choke used in the filter is 80 µH and CX and CY are 330nF and 560pF respectively.

The self-resonant frequency of common mode choke is about 7 MHz. The capacitors used in the filter determine the attenuation behavior of the filter above the self-resonant frequency of the common mode choke.

The inductors and capacitors used in a filter are complex components. Their effectiveness is dependent on material properties and placement. There exist various parasitic parameters in the filter which cannot be determined by measurements. Therefore two identical filters may behave differently in a given application [14]. The electromagnetic couplings among filter components and circuit layouts play very important roles in the high frequency performance of EMI filters [15]. The layout of EMI filter is very crucial, therefore, it needs special consideration.

Following measures are used in the implementation of EMI filters:

- In order to avoid inductive coupling between capacitors and inductors, the common mode choke is soldered on the top side of PCB and capacitors are soldered on bottom side.
- In order to avoid coupling between inductors and ground plan, common mode choke is soldered on the top side of PCB without ground plane. There is ground plane only on the bottom side of PCB.

3) EMI measurements after application of filter

It is observed that by using this filter the input noise of the converter is suppressed according to CISPR 22 class-A limits. The fundamental frequency component is at 64 dBµV and it is attenuated by 40 dBµV. The EMI plot after the application of the filter is shown in Fig.10.

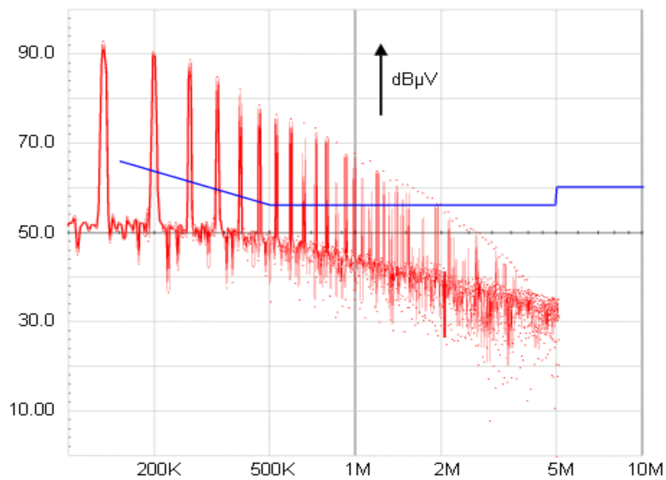

Fig.10 EMI plot after using filter

From the measurement results of the converter circuits, it is observed that the converter switching at higher frequency needs smaller EMI filter. Therefore, the overall size of the converter can be reduced by increasing the switching frequency of the converter.

III. CONCLUSION

The main aim of this paper is to measure and analyze the radiated and conducted EMI of high frequency devices. The radiated EMI is controlled by keeping small loop area in PCB layout. The conducted EMI is controlled by using EMI filter circuit.

In order to measure the noise spectrum, a LISN is designed and implemented. The frequency spectrum of common mode input noise of the converter is plotted and it is observed that the fundamental frequency components as well as other higher order harmonics are not within regulatory limit. A single stage compact common mode EMI filter is designed and implemented on PCB. It is observed that the size of the converters as well as the EMI filter, required for these converters, is reduced by increasing their switching frequency.

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