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Impact of Parasitic Components on EMI Generated by SMPS

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ABSTRACT

The ideal switching converter whether hard switching or soft switching, produces negligible EMI. Basically, the parasitic components are responsible for the generation and propagation of EMIs. This fact cannot be verified by noise measurement of a SMPS prototype because parasitic components are an inseparable part of it. This paper describes the results of EMI noise measurement of ideal simulated converters. The parasitic components are then introduced one by one. Noise measurements are done after every addition and compared with the initial result.

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1. INTRODUCTION

SMPS is popular because of its small size, light weight and low cost. These qualities are achieved due to switching converters operating at high frequencies. A major concern with these switching converters is generation of Electro Magnetic Interference (EMI). Electromagnetic energy originated externally or internally from electric or electronic equipment which interferes with the working of the equipment is called EMI noise or simply noise. They may propagate by radiation or conduction. Conducted noise flows through interconnecting wires or PCB tracks. Though the certifying agencies are interested in total emission, the conducted noise is categorized in two broad categories Differential Mode (DM) and Common Mode (CM).The categorization has been done to find out methods to mitigate noise by identifying their sources and propagation path.

DM noise is mainly caused by the harmonics of the switching current. If the slope of the switching current di/dt is high, the amplitudes of various harmonics are high [11]. A large number of methods are reported in literature to decrease di/dt to reduce EMI. ZCS converters have less DM noise for similar reasons. The bulk filter capacitor associated with the mains rectifier at the front end of the SMPS attenuates most of these harmonics. The Equivalent Series Inductance (ESL) and Equivalent Series Resistance (ESR) associated with this filter capacitor adversely affect this filtering action. Reduction of the values of ESL and ESR helps in reducing DM noise. One simple way of doing it is to use more than one capacitor in parallel. The propagation path inductance is responsible for the appearance of Ldi/dt noise at the input and output nodes. The circular loops with high di/dt causes magnetic field coupling through the parasitic inductance of the internal wiring. Thus the parasitic components play a major role in the generation and propagation of noise.

CM noise, in general is the displacement current flowing through the stray capacitances between high dv/dt nodes and earth terminal. Reducing CM noise is more difficult than DM noise. Dv/dt may be reduced and ZVS converters may help, but reducing parasitic capacitance is tricky. The parasitic capacitors depend upon layout and with increasing miniaturization the role of parasitic has become increasingly significant.

We shall show in this paper that a hard switching converter in itself does not produce much noise but the noise measured at the input and output nodes are the contribution of the parasitic components. We shall show the noise measurement results of simulated converters and then parasitic components will be introduced one by one. Each time the noise measurement results will be shown to compare with the initial result.

2. SIMULATION

Line Impedance Stabilization Network (LISN) is used at the input node of the SMPS for measuring noise. This equipment prevents noise generated by SMPS to enter the utility power line and mains voltage to enter the noise measuring set-up. It also provides stable impedance to the noise at the input of noise receiver. A simulated LISN is necessarily required to be placed at the input of the simulated circuit also. The DM noise current flows in the opposite directions and the CM noise current flows in the same direction in the phase and neutral wires. By definition, DM noise is measured between phase and neutral and the CM noise is measured between phase/neutral and earth terminals. Therefore, phase voltage Vp is given by CM + ½ DM and neutral voltage is given by CM – ½ DM. Thus, we get following two equations for noise measurement:

$$V_{DM} = Vp - Vn \quad (1)$$

And

$$V_{CM} = (Vp + Vn)/2 \quad (2)$$

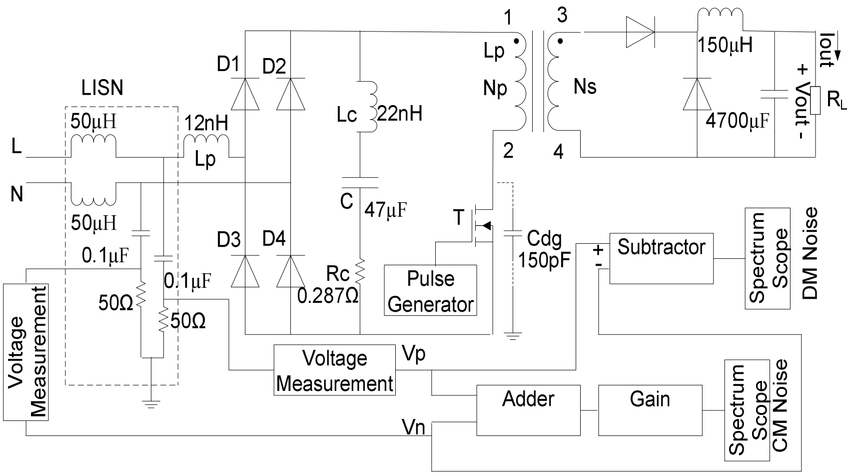

Figure 1(a) Block diagram of a Forward converter and noise measurement set-up including LISN

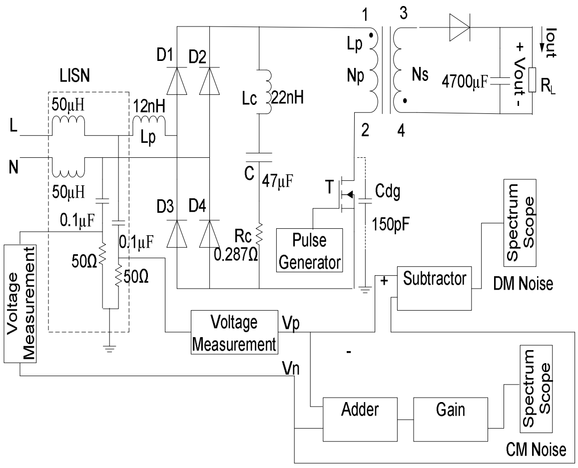

Figure 1(b) Block diagram of a Fly-back converter and noise measurement set-up including LISN

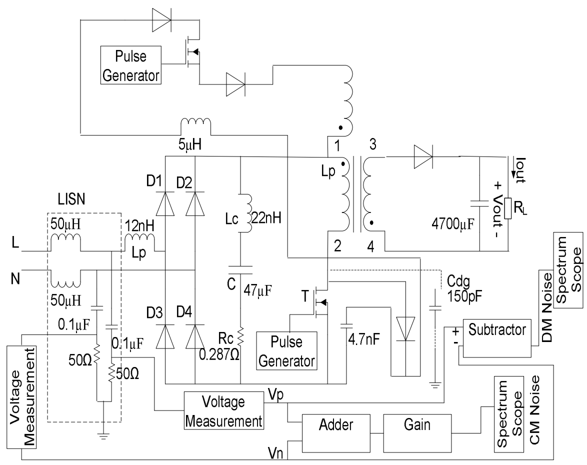

Figure 1(c) Block diagram of a ZVT Fly-back converter and noise measurement set-up including LISN

Figure 1 (a) shows a Forward converter and the noise measurement set-up. The ESL and ESR of the bulk filter capacitor of the mains rectifier are also shown. Cdg is the parasitic capacitance between the drain of the MOSFET switch and earth terminal. Similar configurations have been used for various converters to get noise measurements introducing different parasitic components. The results are given in the following paragraphs. Lc and Rc are respectively the ESL and ESR of the bulk filter capacitor C. Lp is the path inductance. The typical values of these parasitic components are taken from [1].

3. SIMULATION RESULTS

The results show that the CM noise generated by the converters considered namely Forward, Fly-back and Soft switching Fly-back are comparable (Figures 6, 11 &16). Please note that the frequency scales in all simulated noise measurement results are linear. The DM noise generated by soft switching Fly-back is the least (Figure 12) and that of Forward (Figure 2) is also not much higher than it. Again, the DM noise of hard switching Fly-back (Figure 7) is comparatively more, but the level of the noise profile is so low that it can hardly cause any interference. The bulk filter capacitor of the input mains rectifier is responsible for filtering out most of the harmonics of the switching current, but the ESR and ESL associated with it reduces the effectiveness of this filtering action (Figures 3, 8 & 13.).

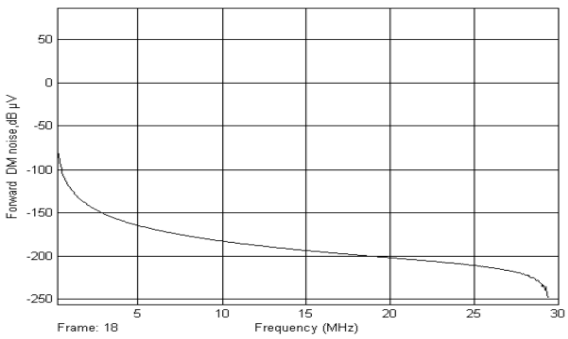

Figure 2 DM noise generated by a simulated Forward Converter with 47 µF bulk filter capacitor

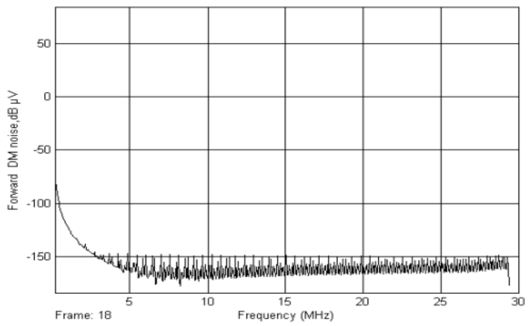

Figure 3 DM noise generated by a simulated Forward Converter with 47 µF bulk filter capacitor with 0.287 Ω ESR and 22nH ESL

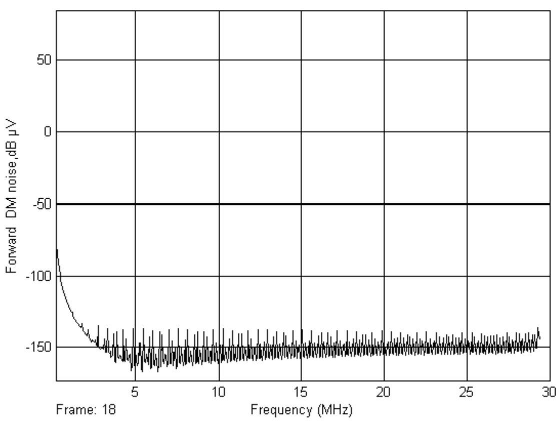

Figure 4 DM noise generated by a simulated Forward Converter with 47 µF bulk filter capacitor with 0.287 Ω ESR and 22nH ESL and 12 nH path inductance

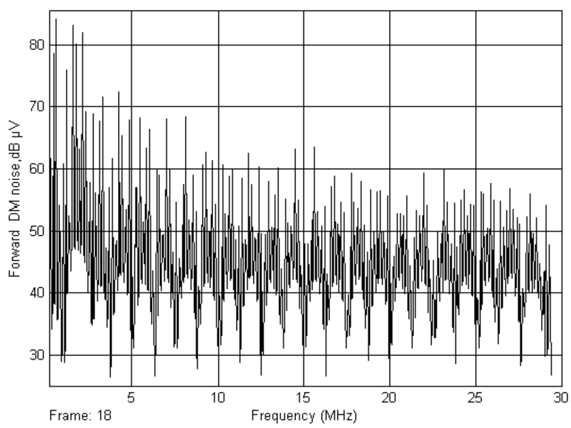

Figure 5 DM noise generated by a simulated Forward Converter with 47 µF bulk filter capacitor with 0.287 Ω ESR and 22nH ESL, 12 nH path inductance and 150pF MOSFET drain to earth capacitance

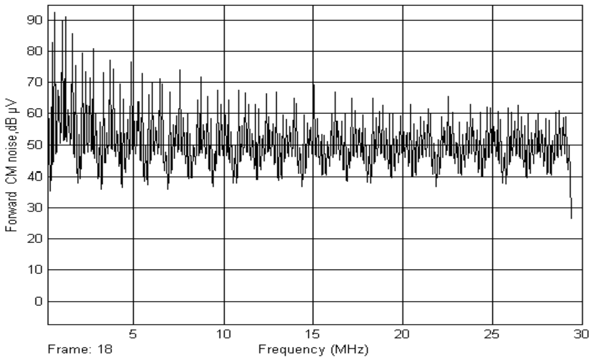

Figure 6 CM noise generated by simulated Forward Converter with 150pF MOSFET drain to earth capacitance

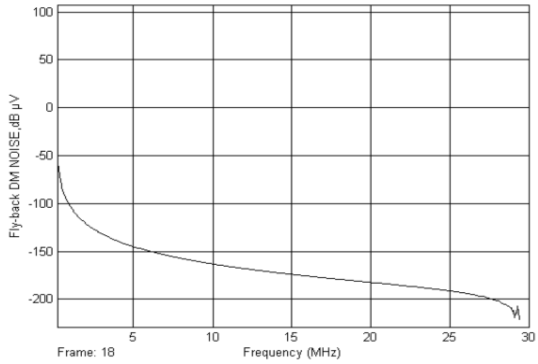

Figure 7 DM noise generated by a simulated Fly-back Converter with 47 µF bulk filter capacitor

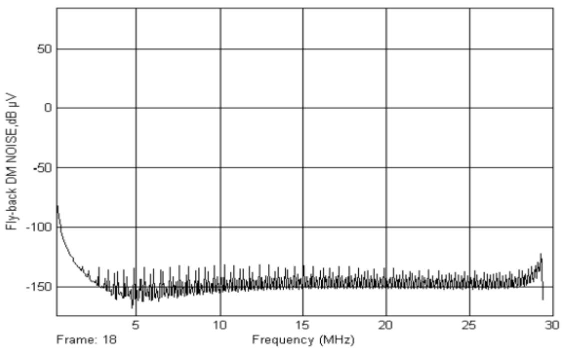

Figure 8 DM noise generated by a simulated Fly-back Converter having 47 µF bulk filter capacitor with 0.287 Ω ESR and 22nH ESL

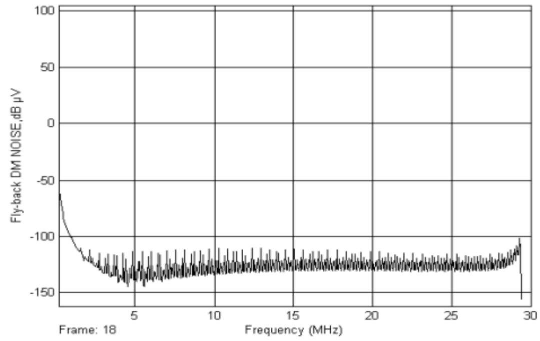

Figure 9 DM noise generated by a simulated Fly-back converter having a Bulk Filter capacitor of 47 µF with 22 nH ESL and 0.287 Ω ESR and a 12nH path inductance

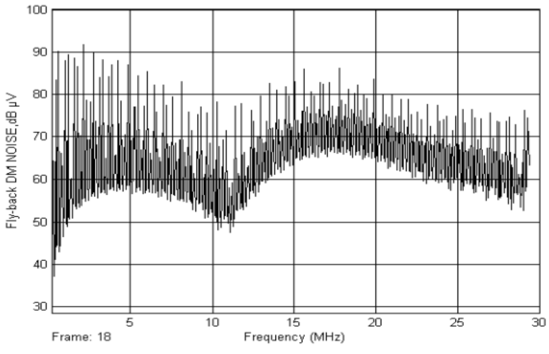

Figure 10 DM noise generated by a simulated Fly-back converter having a Bulk Filter capacitor of 47 µF with 22 nH ESL, 0.287 Ω ESR, a 12nH path inductance and a 150pF capacitor added representing the stray capacitor between MOSFET switch drain and earth terminal

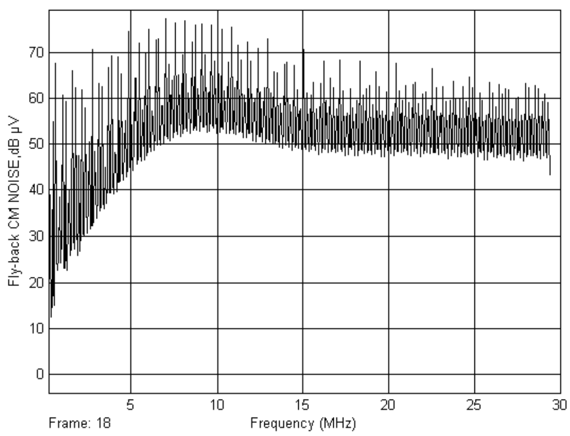

Figure 11 CM noise generated by a simulated Fly-back converter with a 150pF capacitor added between MOSFET switch drain and earth terminal

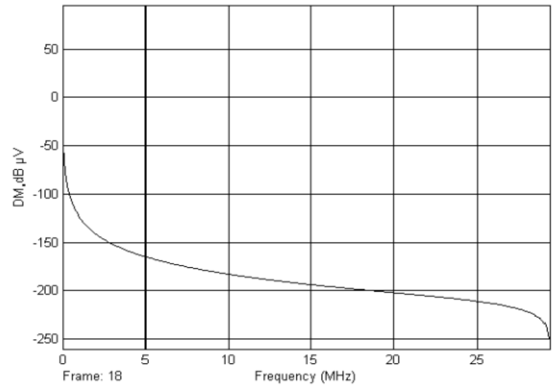

Figure 12 DM noise generated by a simulated Soft Switching Fly-back converter with a 47µF Bulk Filter Capacitor

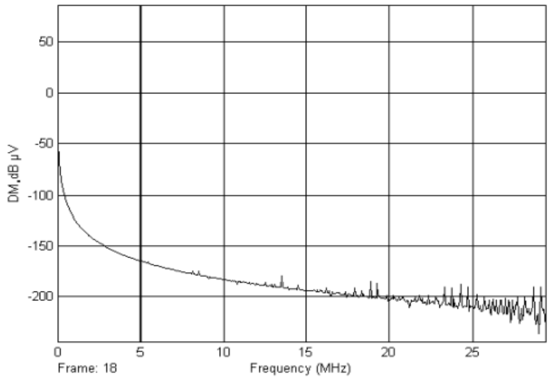

Figure 13 DM noise generated by a simulated Soft Switching Fly-back Converter having 47 µF bulk filter capacitor with 0.287 ESR and 22nH ESL

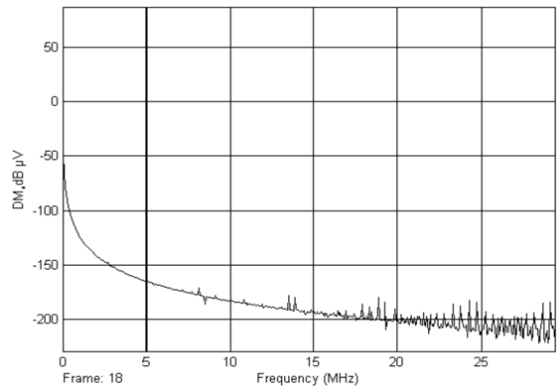

Figure 14 DM noise generated by a simulated Soft Switching Fly-back Converter having 47 µF bulk filter capacitor with 0.287 ESR, 22nH ESL and 12nH path inductance

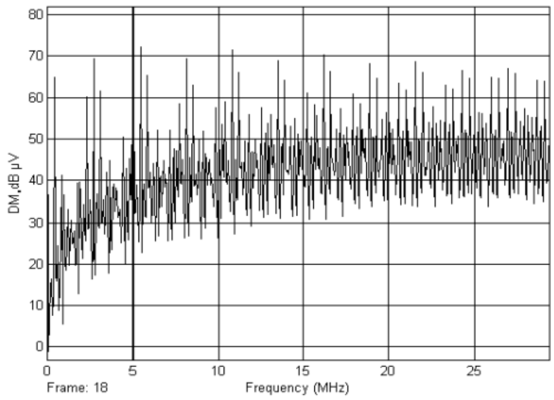

Figure 15 DM noise generated by a simulated Soft Switching Fly-back Converter having 47 µF bulk filter capacitor with 0.287 ESR, 22nH ESL, 12nH path inductance and 150pF MOSFET drain to earth capacitance

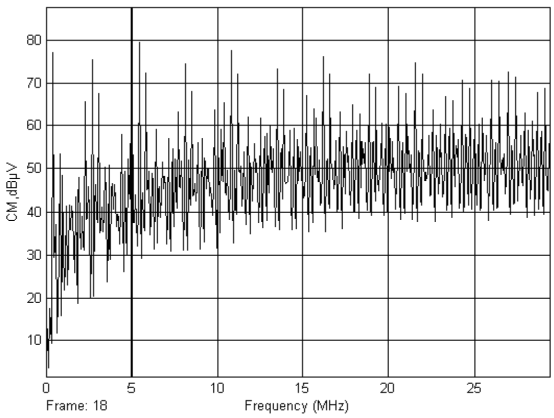

Figure 16 CM noise generated by a simulated Soft Switching Fly-back converter with a 150pF capacitor added between MOSFET switch drain and earth terminal

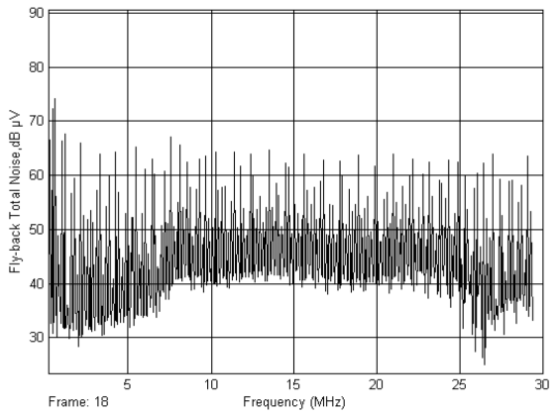

Figure 17 Total Noise generated by a simulated Fly-back converter with a 150pF capacitor added between MOSFET switch drain and earth terminal

The stray inductance of the noise propagation path is responsible for the increased interference with increasing frequency and is significantly higher even in case of the Soft Switching Fly-back at the higher end of the measurement frequency range (Figures 4, 9 & 14). The stray capacitance between drain of the MOSFET switch and the earth terminal is responsible for the Mixed Mode noise which is a result of the displacement current through this capacitor and is measured as DM noise. This component of noise makes the noise produced by even Soft switching converter comparable to the noise produced by their hard switching counterparts (Figures 5, 10 & 15).

4. COMPARISON WITH EXPERIMENTAL RESULTS

Figure 17 shows the total noise generated by a hard switching Fly-back converter. The effect of the inter-winding capacitance between terminals 1 & 4 is depicted in Figure 18. The effect of this stray inter-winding capacitance is similar to the Y-capacitor [8]. The noise is reduced in the mid frequency ranges but increased beyond about 25 MHz. The Figs. 19 & 20 are the conducted emission measurement results of a hard switching Fly-back converter prototype at ERTL (N), New Delhi. The results confirm the simulation measurement results.

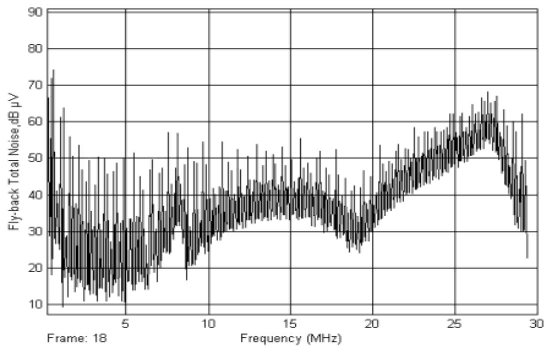

Figure 18 Total Noise generated by a simulated Fly-back converter with a 150pF capacitor between MOSFET switch drain and earth terminal and a 2.2 nF inter-winding capacitance added between 1 & 4 terminals (refer Figure 1) of the transformer

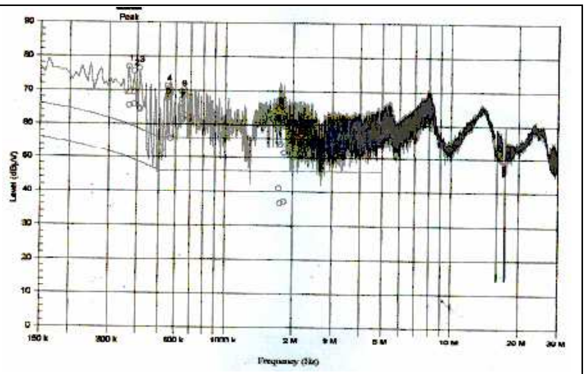

Figure 19 Conducted Emission Measurement of Fly-back Converter Prototype

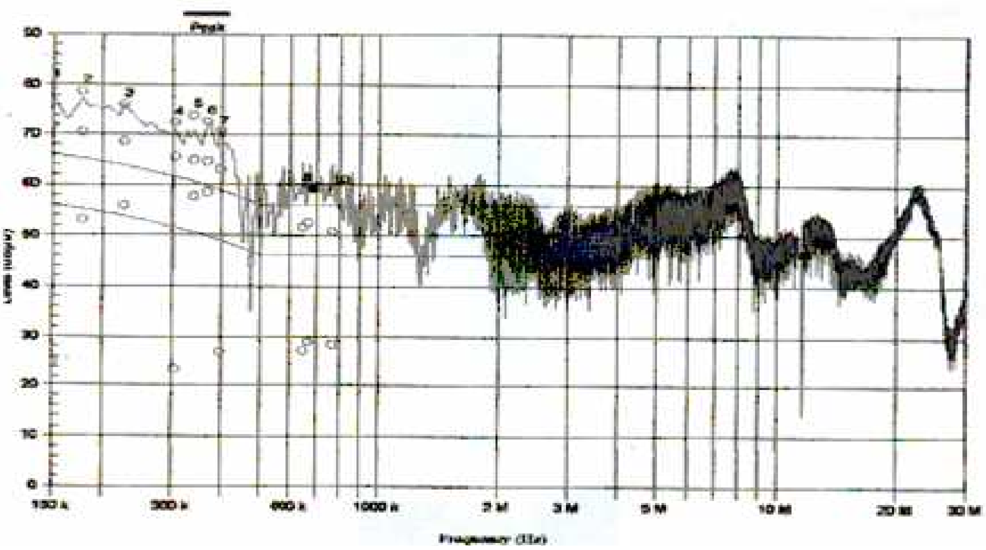

Figure 20 Conducted Emission Measurement with 2.2nF/3kV capacitor between 1 & 4 terminals of transformer

5. CONCLUSION

The noise measurements of both hard switching and soft switching converters are carried out by simulation using MATLAB SIMULINK. The results show the dominant role played by parasitic components in the generation and propagation of noise. The stray capacitance between high dv/dt nodes and earth terminal is the main culprit. Even soft switching converters generate lot of interfering noise if parasitic components are not controlled. The experimental measurement results confirm the simulation measurement results.

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