Elimination of CM Noise from SMPS Circuit using EMI Filter

Case Study

Venkata Sai Charishma Pathala
Department of EECE, Gandhi Institute of Technology and Management
Visakhapatnam, India
cpathala@gitam.in

V.Y. Jayasree Pappu
Department of EECE, Gandhi Institute of Technology and Management
Visakhapatnam, India
jpappu@gitam.edu

Abstract *– The electronic devices are exposed to external electromagnetic signals that produce an unwanted signal called noise in the circuit, which causes electromagnetic interference [EMI] problems. It occurs in two modes: radiated mode and conducted mode. In the radiation mode, the shielding technique is used for radiation mode, in conduction mode filtering technique is used. The design of an EMI filter depends upon the type of noise generated by the Switched Mode Power supply circuit [SMPS]. The SMPS circuit used in this paper is a DC-DC power converter, the Boost converter is a step-up converter and Buck converter is step down converter are considered as equipment for generation of noise, the Line Impedance Stabilization Network [LISN]is used for generating the common output impedance to the power converters, the EMI filters are designed to eliminate noise generated by the circuits. There noise generated by this power converters is Common Mode [CM] noise and Differential Mode [DM] noise. The separation of noise from the equipment is done by using a noise separator. In this paper, CM noise generated by these power converters is eliminated by designing an EMI filter called an inductor filter and a PI filter. The comparison between the LC inductor filter and the PI filter for the boost and buck converters is observed. The PI filter has better performance characteristics when compared to the inductor filter for both SMPS circuits as per the Comité International Special des Perturbations Radioélectriques [CISPR] standards. This standard gives the conducted emission range for different electronic devices.*

Keywords*: electromagnetic interference [EMI], Switched Mode Power Supply circuit [SMPS], Boost converter, Buck converter, Common Mode and Differential Mode Noise, LC Inductor filter, PI filter, CISPR standards*

1. INTRODUCTION

The electrical and electronic systems are affected by the external electromagnetic signals, which produce electromagnetic interference [EMI] in the circuit. This interference occurs from one electronic system to another due to the electromagnetic fields generated during the operation of electronic systems [1]. EMI obtained in two ways Man –Made Source and Natural Source, it occurs in two ways Radiated mode and Conducted mode [2]. The mitigation of EMI through radiation mode is done by shielding technique [3]. The EMI filters are used to eliminate interference in the conduction mode [4]. The interference that occurs in the conducted mode is due to the noises present in the circuit. The noises are DM noise and CM noise [5]. Power converters, power electronic devices, and power supply devices are widely used in many applications, like military, industrial, and aerospace. The compatibility of the power converter is based on the noise generated and its propagation path. The different types of power converters are considered for the analysis of their electromagnetic compatibility. The DC-DC power converter is more compatible than AC-DC power converters [6]. In this paper, the DC-DC power converters called Boost converters and Buck converters are considered as equipment that generates noise inside the circuit [7]. A boost converter increases the voltage at the output stage, whereas a buck converter decreases the output voltage. The LISN is considered an input to the equipment, which has a constant output impedance of 50 ohms. The power converters generate noises called CM noise and DM noise [8]. The separation of these noises from this equipment is done using a noise separator. In this paper, DM noise is eliminated by using a DM noise separator. The EMI filter is designed to eliminate the CM noise generated in the DC-DC power converter [9]. The electronic equipment has some EMI specification limits, and to satisfy those limits, EMI filters are designed. There are two types of EMI filters. Active and passive EMI filters, the performance of the filter depends upon the insertion loss, cut-off frequency of the circuit, and input and output impedance [9]. The attenuation of the signal at the filter output of a given frequency is measured by its insertion loss. Insertion loss is defined as the ratio of the signal at the input stage of the filter [V1] to the signal at the output stage of the filter [10].

$$\mathrm{IL[dB]} = 20\log_{10}\frac{V_1}{V_2} \tag{1}$$

The design of power converters with LISN is done in the MULTISIM software. The noise generated by this power converter is measured by using the noise separator, and the elimination of noise is done by designing the EMI filters like the inductor and PI filter. The total design process and calculation of noise and insertion loss are obtained from the MULTISIM software. The EMI filter results with EMI specification limits are plotted in the MATLAB tool.

2. MEASUREMENT SETUP

The measurement setup consists of power converters called Boost and Buck converters, which are considered the equipment for testing the two-stage LISN circuit. DC power supply to run the equipment. The noise generated by this power converter is separated using a noise separator, which produces CM and DM noise. The elimination of these noises is done by using an EMI filter.

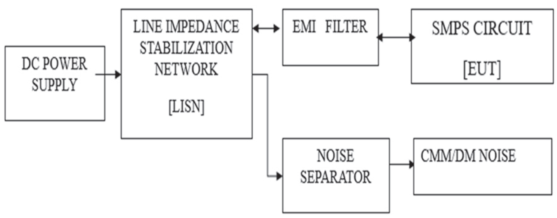

Fig.1. Block Diagram for total Measurement Setup

2.1. LINE IMPEDANCE STABILIZATION NETWORK

The LISN is placed between the power supply and the power converter [equipment] to maintain the known impedance. The LISN has an output impedance of 50 ohms; it acts as a low-pass filter.

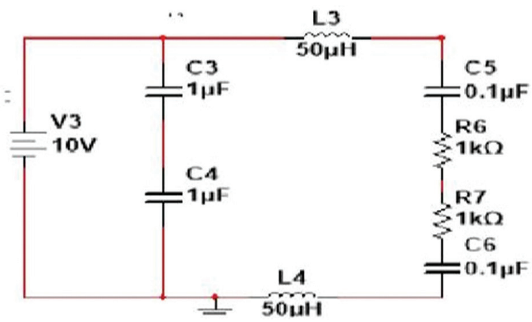

Fig. 2. LISN circuit

2. 2. POWER CONVERTERS

The converters used as equipment for the generation of noise inside the circuit are the Boost converter and the Buck converter; these are DC-DC converters. The noise generation is due to the switching action of diodes and transistors; the Boost circuit acts as a step-up converter, and the Buck circuit acts as a step-down converter. The selection of components for the power converter is calculated by considering the input voltage and frequency of operation. The conducted signal has a frequency range of 150 kHz to 3 MHz.

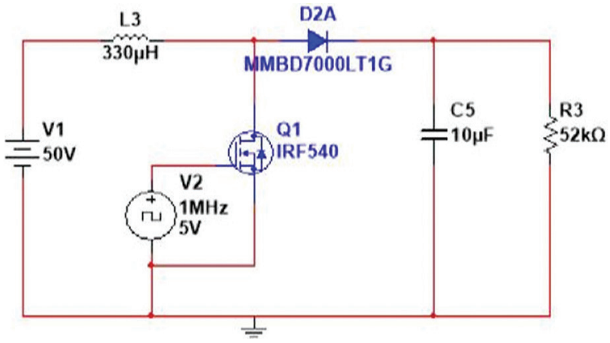

Fig. 3. Boost circuit

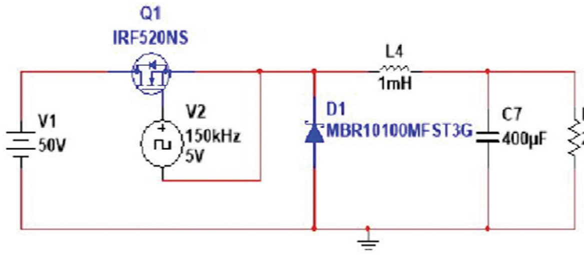

Fig. 4. Buck circuit

2. 3. NOISE SEPARATOR

The calculation of total noise inside the equipment is measured by using the noise separator; there are different types of noise separators. In this paper, the DM noise separator is considered. The total noise is obtained at the output of the LISN when it is connected to the equipment, and the CM noise and DM noise are calculated using the below formulae

$$V_{CM} = \frac{V_2+V_1}{2} \tag{2}$$

$$V_{DM} = \frac{V_2-V_1}{2} \tag{3}$$

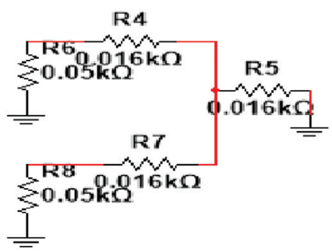

Fig. 5. DM noise separator

2. 4. EMI FILTER

The EMI filters are used to protect the electronic devices from high-power signals generated by other electronic devices. The design of filter characteristics depends upon the noise generated by the devices. Active and passive EMI filters are used for the reduction of noise in electronic devices. The LC inductor filter and PI filter are designed in this paper for the elimination of noise generated by the devices. The PI filter is considered because it gives a high output voltage and a very good ripple factor. The LC inductor has better voltage regulation and a very low ripple factor.

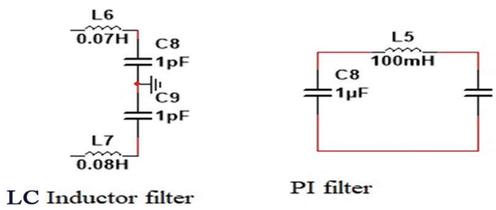

Fig. 6. Filters used in measurement setup

3. NOISE MEASUREMENT FOR BOOST CIRCUIT

The measurement of CM noise from EUT using LISN is shown in Fig. 2. The EUT is supplied by DC voltage of 50V through LISN circuit. The noise generated due to diodes and switches in the EUT, the noise is measured at the output of the noise separator by connecting through LISN, and the CM noise is obtained at the end of the noise separator by eliminating the DM noise [10]. The design process and noise calculation are done in Multisim software. The output graphs for CM noise with and without filter are plotted in the MATLAB simulation tool.

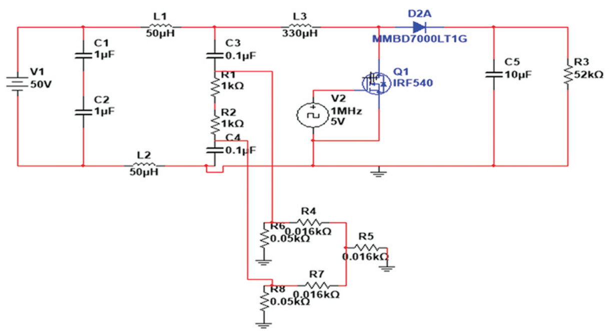

Fig. 7. Noise Measurement Setup for Boost circuit

The conducted emission ranges from 150 kHz to 3 MHz, so the filters are designed to satisfy the EMI regulation limits. For conducted emissions, the CISPR 22 standard is used as a limit line for EMI regulation. This standard deals with the conducted emissions range for different devices, like class A and class B devices.

The measurement of EMI in conducted mode requires a line impedance stabilisation network of 50 mH to be placed between the EUT and DC power supply to find impedance for noise measurement. The EUT used is an SMPS circuit of a boost converter that acts as a noise source due to diodes, transistors, and switching elements [11-13]. The noise separator is placed across the output of the LISN when EUT is connected to the LISN circuit. DM and CM noises are separated at the output of the noise separator. The noise separator used is a DM noise separator, which eliminates DM noise and produces CM noise.

Table 1. The limits for class A device in conducted mode as per CISPR standard

FREQUENCY [MHz]	µV	dB[µV]
0.15-0.5	8912.5	68
0.5-30	4467	62

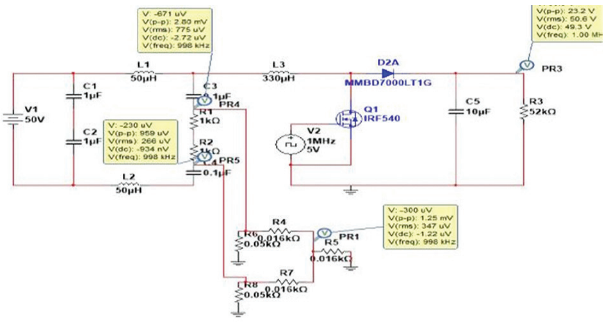

Fig. 8. CM noise obtained at the output of the Noise Separator

The noise obtained at the output of the noise separator is CM noise with a value of 266 mV, so it is converted to check whether the circuit meets the EMI specification limit [14]. By using equation 4, it is converted into a value of 108. So, it does not satisfy the CISPR standard limits shown in Table 1.

$$1\mathrm{dB}_{\mu\mathrm{V}} = 20\log_{10}[\mu\mathrm{V}] \tag{4}$$

So, the design of an EMI filter is necessary for the reduction of noise in the circuit. The insertion loss required for the design of an EMI filter depends upon how much the amount of noise increases as per the EMI limit. In order to get better performance out of the circuit, the filter should satisfy these conditions: the CM noise obtained at the output of the noise separator, in dBµV, is the noise limit as per the CISPR standard.

$$IL_{CM} >= V_{CM}(\mathrm{dB\mu V}) - \mathrm{V}_{\mathrm{LIMIT}}(\mathrm{dB\mu V}) \tag{4}$$

3. 1. EMI FILTER DESIGN FOR BOOST CIRCUIT

The passive EMI filter was designed after measuring insertion loss; the filter used for elimination of CM noise is the LC inductor filter. This filter is placed between LISN and EUT. The noise measurement is done at the output of the noise separator, and in the MULTISIM software, it is observed that 296 is obtained when a filter is added to the equipment. The obtained noise is converted into dB with a value of 49 dB by using equation 4, and graphs are plotted in the MATLAB simulation tool. From the simulations, it is observed that the output noise is decreased and is within the CISPR limit after placing the LC inductor filter.

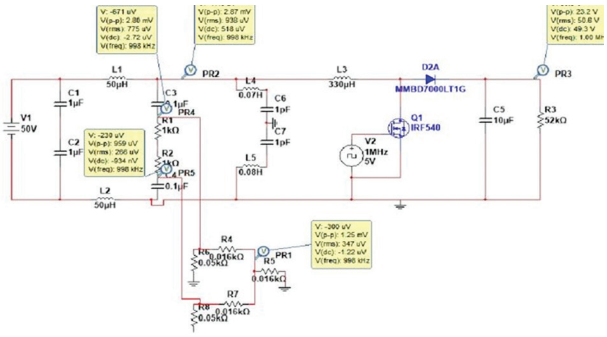

Fig. 9. CM noise obtained at the output of the Noise Separator when LC Inductor filter is connected

The PI filter is considered for the measurement of CM noise, and it is placed in between EUT and LISN. The design is done in Multisim software. The noise measurement is done at the output of the noise separator in the MULTISIM software, and it is observed that 62 is obtained when filtering is added to the equipment. So, it is converted into dBµV by using the equation 4, and the value obtained is 35 dBµV. Graphs are plotted in the MATLAB simulation tool.

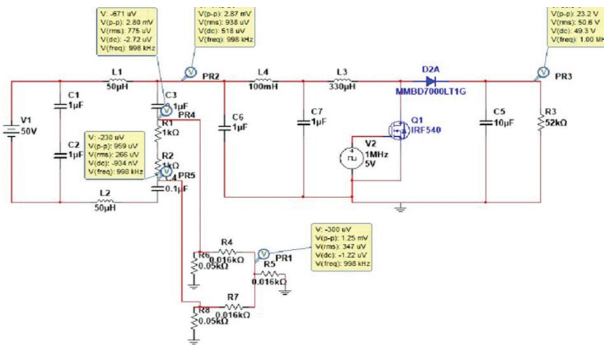

Fig. 10. CM noise obtained at the output of the Noise Separator when PI filter is connected

In Fig. 11. Shows the graph for CM noise measurement with filter and without filters. As per CISPR standards, it is observed that the PI filter has better performance characteristics when compared to the LC inductor filter.

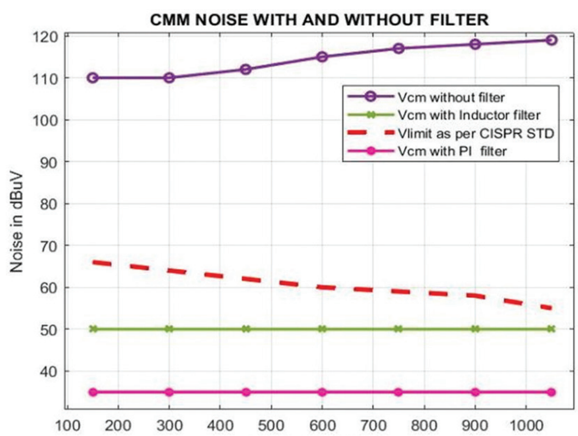

Fig. 11. Noise measurement as per CISPR standard with and without EMI filter

The filters designed for the elimination of noise are the PI filter and the inductor filter, which generate an insertion loss greater than the insertion loss without a filter.

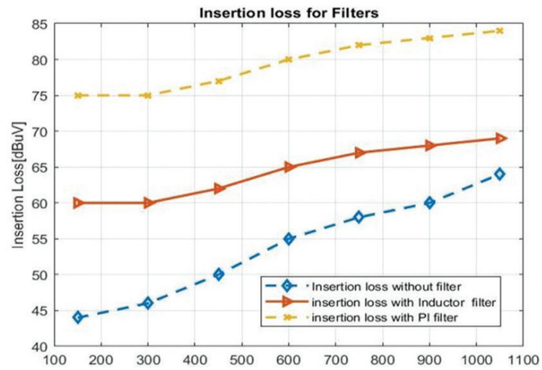

Fig.12. Insertion loss for LC Inductor filter, PI filter and without filter

4. NOISE MEASUREMENT SETUP FOR BUCK CIRCUIT

The noise is measured from the buck circuit by placing the noise separator between EUT and LISN. The total measurement is done with software simulation tools. The buck converter acts as a noise source in this setup. The noise separator used in the circuit is a DM noise separator. The EUT is supplied by DC voltage of 50V through LISN circuit. The CM noise is obtained at the end of the noise separator by eliminating the DM noise. The design process and noise calculation are done in Multisim software. The output graphs for CM noise with and without filter are plotted in the MATLAB simulation tool.

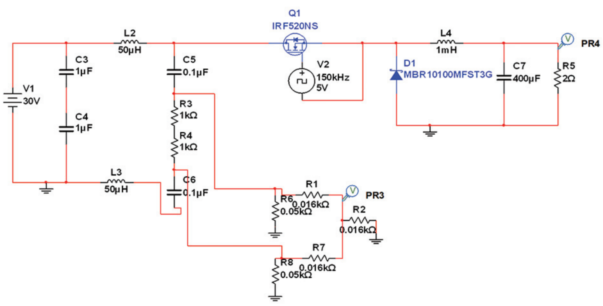

Fig.13. Noise Measurement Setup for Buck circuit

The EUT used is an SMPS circuit of a Buck converter, which acts as a noise source due to diodes, transistors, and switching elements. The noise separator is placed across the output of the LISN. The CM noise is generated at the output of the noise separator.

The noise obtained at the output of the noise separator is CM noise at 421 mV, so it is converted into dBµV by using equation 4, to check whether the circuit meets the EMI specification limit. The noise obtained is 112 dBµV at the output, so it does not satisfy the CISPR standard limits shown in table 1. So, the design of an EMI filter is necessary for the reduction of noise in the circuit. The insertion loss required for the design of an EMI filter depends upon how much the amount of noise increases as per the EMI limit. In order to get better performance out of the circuit, the filter should satisfy these conditions, is the CM noise obtained at the output of the noise separator, in dBμV, is the noise limit as per the CISPR standard.

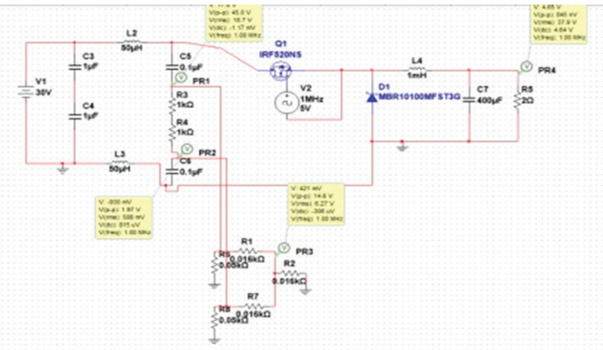

Fig.14. CM noise obtained at the output of the Noise Separator for Buck circuit

4.1. EMI FILTER DESIGN FOR BUCK CIRCUIT

The passive EMI filter was designed after measuring insertion loss, the filter used for elimination of CM noise is the LC inductor filter. This filter is placed between LISN and EUT. This filter is placed between LISN and EUT. The noise measurement is done at the output of the noise separator in the MULTISIM software. It is observed that this is obtained when a filter is added to the equipment. The obtained noise is converted into dB with a value of 56 dB by using equation 4, and graphs are plotted in the MATLAB simulation tool. From the simulations, it is observed that the output noise is decreased and is within the CISPR limit after placing the LC inductor filter.

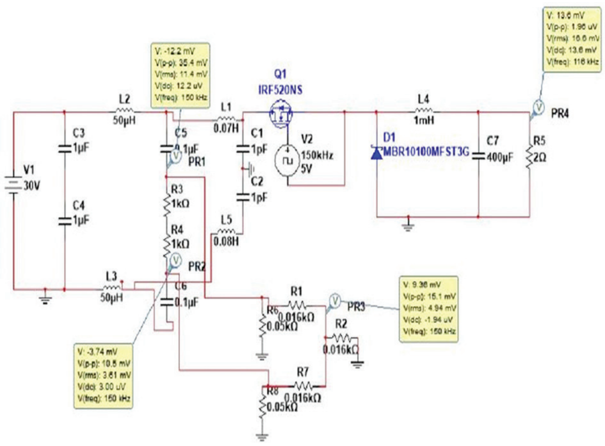

Fig.15. CM noise obtained at the output of the Noise Separator when LC Inductor filter is connected

The PI filter is considered for the measurement of CM noise, and it is placed in between EUT and LISN. This filter is placed between LISN and EUT. The noise measurement is done at the output of the noise separator, and in the MULTISIM software, it is observed that 59 is obtained when filtering is added to the equipment. The obtained noise is converted into dB with a value of 38 dB by using equation 4, and graphs are plotted in the MATLAB simulation tool. From the simulations, it is observed that the output noise is decreased and is within the CISPR limit after placing the PI filter.

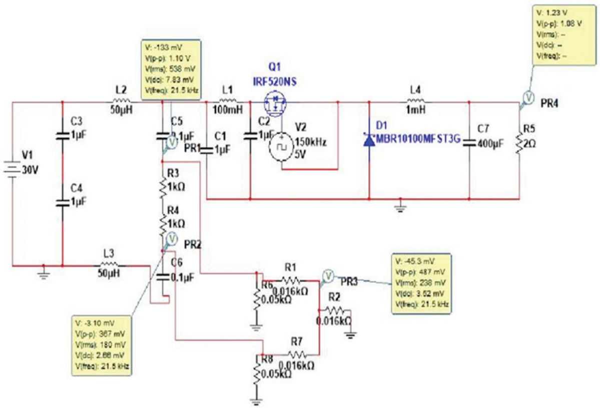

Fig.16. CM noise obtained at the output of the Noise Separator when PI Inductor filter is connected

In Fig. 17, which shows the graph for CM noise measurement with and without filters as per CISPR standards, it is observed that the PI filter has better performance characteristics when compared to the LC inductor filter.

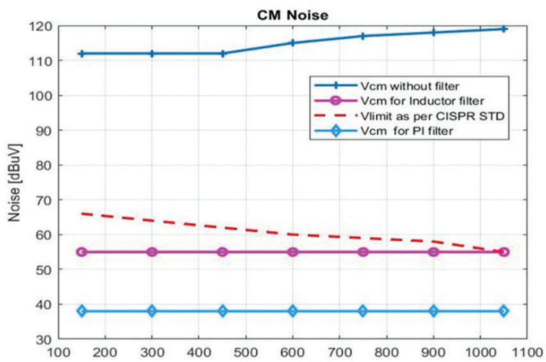

Fig.17. Noise measurement as per CISPR standard with and without EMI filter

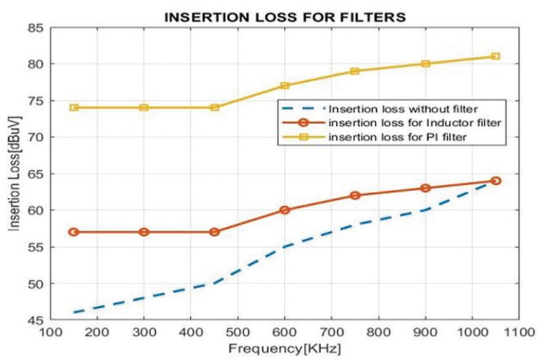

Fig.18. Insertion loss for LC Inductor filter, PI filter and without filter

5. RESULTS

The conducted signal radiates in the frequency range of 150 kHz to 30 MHz. The measurement setup consists of Boost and Buck power converters treated as equipment with LISN, and the noise generated by these power converters without filter is shown in the below table. The insertion loss without a filter is around 40-45dBμV for a frequency range of 150–1100 kHz for both power converters. The insertion loss for the designed filters, the PI filter and the inductor filter, is higher than the insertion loss for the setup with no filter. The inductor filter for the boost and buck converters produces an insertion loss of around 55–60 dBμV in the 150KHz–1MHz range for both the SMPS circuits. The PI filter produced an insertion loss of 75 dBμV for 150 KHz–1 MHz. The use of Multisim software made easier for the design and calculation of noise. The graphs are plotted in the MATLAB tool. The results obtained for SMPS circuits are given below. The measured noise and filters used for elimination of noise with their values are mentioned in Table 2.

Table 2. Noise levels in the measurement setup

Specifications	Boost circuit	Buck circuit
NOISE measured without filter	108 dBμV	112 dBμV
NOISE at LC filter	49 dBμV	56 dBμV
NOISE at PI filter	35 dBμV	38 dBμV

From the table, it was observed that the buck circuit generates more noise than the boost circuit, and the filter used for noise elimination is designed as per the CISPR standard. The PI filter has better performance than the LC inductor filter

6. CONCLUSION

The conductive emission ranges from 150 KHz to 30 MHz, the measurement setup generates noise inside the equipment, and the elimination of noise is done by designing the appropriate EMI filter, which depends upon the frequency of operation and insertion loss. By measuring the insertion loss, the filter was designed. The LC inductor filter and PI filter generate more insertion loss than a measurement setup without filters. The noise generated by the boost circuit is 108 dBμV and by the buck circuit is 112 dBμV.

The filter design should meet the EMI standards. The CISPR 22 standard is considered for the filter design, and the designed filter satisfied the CISPR STD with these values. The noise at the output of the LC inductor filter for the boost converter is 49 dBμV. The noise at the PI filter output for the Boost converter is 35 dBμV. The noise at the output of the LC inductor filter for the Buck converter is 56 dBμV. The noise at the PI filter output for the Buck converter is 38 dBμV. Hence, PI filters meet good EMI standards in the conducted emissions range of 150 kHz–1 MHz

7. REFERENCES

[1] C. R. Paul, "Introduction to Electromagnetic Compatibility", 2nd Edition, Hoboken, Wiley, New Jersey, 2006.

[2] V. S. C. Pathala, P. V. Y. Jayasree, "Design of a Shielded Room against EMP Signal as per MIL-STD 461", Engineering, Technology & Applied Science Research, Vol. 13, No. 1, 2023, pp. 9837-9842.

[3] P. V. Y. Jayasree, V. Baba, P. Rao, P. Lakshman, "Analysis of Shielding Effectiveness of Single, Double and Laminated Shields for Oblique Incidence of EM Waves", Progress in Electromagnetics Research B, Vol. 22, 2010, pp. 187-202.

[4] A. Rabat, P. Bonnet, K. E. K. Drissi, S. Girard, "Analytical Formulation for Shielding Effectiveness of a Lossy Enclosure Containing Apertures", IEEE Transactions on Electromagnetic Compatibility, Vol. 60, No. 5, 2017, pp. 1384-1392.

[5] X. Chang, W. Chen, Y. Yang, K. Wang, X. Yang, "Research and realization of a novel active common-mode EMI filter", Proceedings of the IEEE Applied Power Electronics Conference and Exposition, Charlotte, NC, USA, 15-19 March 2015, pp. 1941-1945.

[6] K. Mainali, R. Oruganti, "Conducted EMI Mitigation Techniques for Switch-Mode Power Converters: A Survey", IEEE Transactions on Power Electronics, Vol. 25, No. 9, 2010, pp. 2344-2356.

[7] D. Hamza, M. Sawan, P. K. Jain, "Suppression of common-mode input electromagnetic interference noise in DC-DC converters using the active filtering method", IET Trans. Power Electron., Vol. 4, No. 7, 2011, pp. 776-784.

[8] S. Wang, Y. Y. Maillet, F. Wang, D. Boroyevich, and R. Burgos, "Investigation of hybrid EMI filters for common-mode EMI suppression in a motor drive system", IEEE Transactions on Power Electronics, Vol. 25, No. 4, 2010, pp. 1034-1045.

[9] D. Shin et al. "Analysis and design guide of active EMI filter in a compact package for reduction of common-mode conducted emissions", IEEE Transactions on Electromagnetic Compatibility, Vol. 57, No. 4, 2015, pp. 660-671.

[10] V K. Prasad, "Engineering Electromagnetic Compatibility", Wiley-IEEE Press, 2001.

[11] S. Banerjee, A. Bandyopadhyay, A. Mukherjee, A. Das, R. Bag, “Random Valued Impulse Noise Removal Using Region Based Detection Approach”, Engineering, Technology & Applied Science Research, Vol. 7, No. 6, 2017, pp. 2288-2292.

[12] M. C. Caponet, F. Profumo, L. Ferraris, A. Bertoz, D. Marzella, "Common and DMnoise separation: comparison of two different approaches", Proceedings of the IEEE 32nd Annual Power Electronics Specialists Conference, 2001, pp. 1383-1388.

[13] Wenjie Chen, Xu Yang, Zhaoan Wang, “An active EMI Filtering Technique for Improving Passive Filter LowFrequency Performance”, IEEE Transactions on Electromagnetic Compatibility, Vol. 48, No. 1, 2006.

[14] K. Raggl, T. Nussbaumer, J. W. Kolar, “Guideline for a Simplified Differential-Mode EMI Filter Design”, IEEE Transactions on Industrial Electronics, Vol. 48, No. 7, 2009, pp. 1865-1872.