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Estimation of Common Mode noise and Differential Mode noise generated by DC-DC Power Converters

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ABSTRACT- The study contains a review of the body of knowledge regarding differential mode (DM) and common mode (CM)noise and how they affect power converter performance. With an emphasis on practical application, this work seeks to give an estimation of differential mode (DM) and common mode (CM) noise for cutting-edge DC-DC power converters such as Zeta converters, Single Ended Primary Inductance Converters (SEPIC), and Cuk converters. Active noise separators and Differential mode noise separators are used as a measurement technique to quantify DM and CM noise, considering a number of variables including input voltage, output voltage, load current, and switching frequency. By using filtering techniques, DM and CM noise can be reduced. Both CM noise and DM noise are created by the Zeta converter at 114 dBµV and 108 dBµV, respectively. CM noise from the SEPIC converter is 119 dBµV, and DM noise is 114 dBµV. With values of CM noise 98 dBµV and DM noise 106 dBµV, Cuk converter produces less noise when compared to Zeta and SEPIC converter. The results show that power converters can generate DM and CM noise, and that this noise is over the Comité International Special des Perturbations Radioélectriques [CISPR] limit line. The conducted emission range for various electronic devices is provided by this standard. This study provides useful insights for power converter designers and engineers to optimize the performance of their systems in practical applications.

Keywords: Differential Mode noise, Common Mode noise, Zeta converter, Single Ended Primary Inductance Converter (SEPIC), Cuk converter, Active noise separators, Differential mode noise separator.

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1. INTRODUCTION

The phenomenon of electromagnetic waves interfering with the normal operation of electronic equipment or devices is known as electromagnetic interference (EMI) [1-3]. Power lines, radio and television transmitters, cell phones, and other electronic gadgets are just a few of the sources that might produce EMI. An electronic device that has been exposed to EMI may suffer from undesirable side effects such signal distortion, data corruption, or even total failure. Numerous factors can cause this interference, including radiation from neighboring sources, transmission lines, electrical wiring, and magnetic fields.

Shielding, filtering, grounding, as well as proper cable positioning and wire routing, are some of the strategies used to reduce EMI [4]. The ability of electronic devices to function in their intended environment without being impacted by EMI is known as electromagnetic compatibility (EMC) [5], [6]. An electronic device called a power converter is used to transform electrical power from one form to another. It is a crucial part of numerous electrical gadgets, from modest home appliances to substantial industrial machinery. A power converter's main job is to adjust the voltage, current, or frequency of an electrical signal to meet the needs of a particular application. Power converters come in a wide variety of forms, each with a special layout and set of capabilities. DC-DC, AC-DC, and DC-AC converters are a few examples of common power converter types [7-11]. Common-mode noise and differential-mode noise are both known to be produced by power converters. Electrical interference in electronic circuits can take two basic forms: differential mode noise and common mode noise [12,13]. Unwanted signals may manifest in a circuit as a result of either sort of noise, which may worsen performance or result in other issues [14]. Differential-mode noise appears between the power supply lines, whereas common-mode noise appears between the supply and the earth [15].

When two or more circuit components are exposed to the same external disturbance, common mode noise results [16]. On the other hand, differential mode noise happens when the interference only affects one wire in a circuit. Because differential mode noise only impacts one wire in the circuit, it may be simpler to filter out than common mode noise [17]. Electronic circuits use a noise separator to monitor common-mode and differential-mode noise. It allows for the independent measurement of the common-mode noise and differential-mode noise components by separating them from one another. On both signal lines of a differential pair with respect to ground, common-mode noise can be seen [18]. On the other hand, differential-mode noise is a sort of noise that only manifests on

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one signal line relative to the other [19]. A noise separator is utilized to measure these two types of noise independently. Engineers can better understand the causes of noise in their electronic circuits and act to eliminate it by measuring the common-mode and differential-mode noise independently [20]. Numerous electronic applications, such as those involving audio equipment, power supply, and data transfer systems, frequently employ noise separators [21].

2. MEASUREMENT SETUP

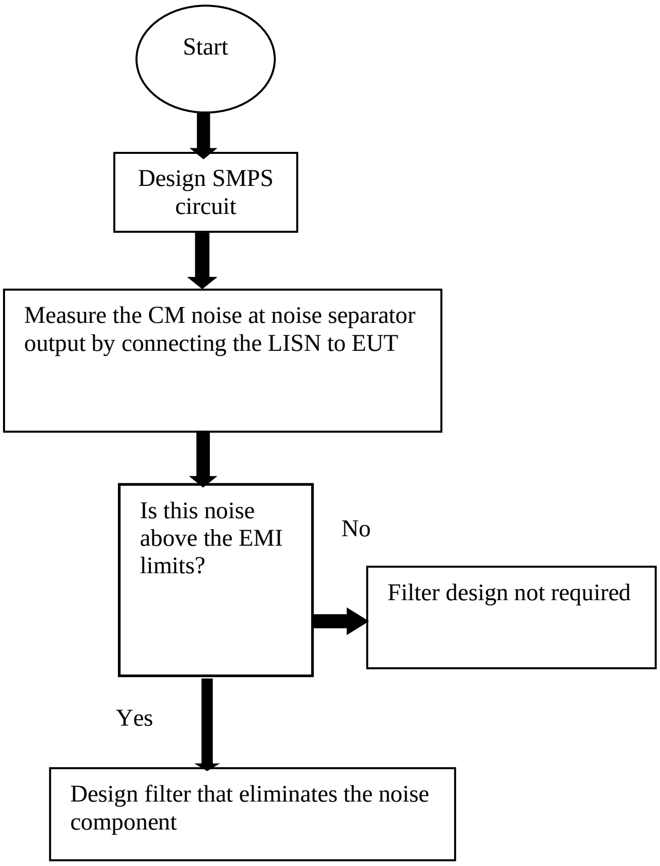

Fig.1. Flow chart of the proposed system

The measurement set-up consists of a LISN, a power supply connected to LISN, a power converter connected to LISN, and a noise separator used to measure the noise produced by the power converter. Both common mode noise and differential mode noise are produced by power converters.

2.1 Line Impedance Stabilization Network (LISN)

It is a tool for measuring conducted emissions, electrical disturbances that travel along power lines and may interfere with other electronic devices. It is used in electromagnetic compatibility testing. In order to assure precise measurements of the device under test's conducted emissions, a LISN is used to provide a consistent impedance for the DUT.

The LISN, which is connected between the power source and the DUT, filters out undesirable harmonics and high frequency noise. A low-pass filter, a series impedance that mimics the power line impedance, and a decoupling capacitor that blocks DC signals make up a conventional LISN. International standards like CISPR (International Special Committee on Radio Interference) and ANSI are used to specify the LISN, which is created to have a consistent impedance over a range of frequencies, typically from 9 kHz to 30 MHz (American National Standards Institute).

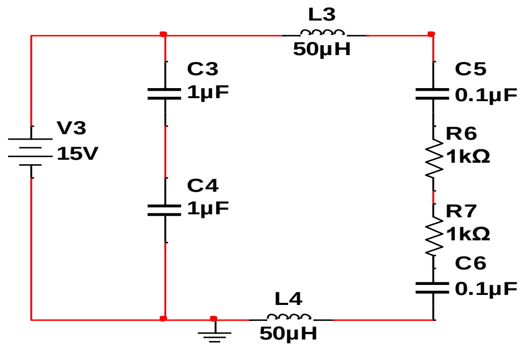

Fig.2. LISN circuit

2.2 Power Converter

Electrical circuits known as power converters can change one type of electrical energy into another. These converters are frequently found in power supply, electrical gadgets, and renewable energy sources. Power converters like the Zeta, Cuk, and SEPIC (Single-Ended Primary Inductance Converter) are all DC-DC converters, able to change one DC voltage level into another.

2.2.1 Zeta converter

A Zeta converter can step up or step down the input voltage and is a version of the well-known Buck-Boost converter design. A DC-DC converter known as the Zeta converter combines the benefits of SEPIC and buck-boost converters. Zeta converter can outperform the conventional Buck-Boost converter by adding an additional inductor and a diode to produce a two-stage process. In low-power applications like LED lights and battery-operated gadgets, the Zeta converter is frequently employed. When the input voltage is 5V, the converter in this article behaves as a step-up converter and produces an output value of 7.5V.

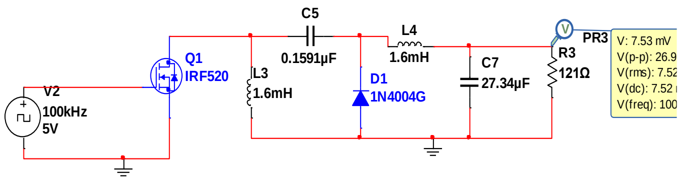

Fig.3. Zeta converter acts as a Boost converter

2.2.2 CUK Converter

Another form of DC-DC converter that may increase or decrease the input voltage and deliver a voltage with the opposite polarity is the Cuk converter. It utilizes a special topology that combines an inductor and a capacitor to produce high efficiency and low noise performance. Electric cars, photovoltaic systems, and portable electronic devices are just a few examples of the many uses for the Cuk converter. The converter functions as a negative polarity step-up converter. The output voltage of -30V is produced when the input voltage

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is 10V.Another form of DC-DC converter that may increase or decrease the input voltage and deliver a voltage with the opposite polarity is the Cuk converter. It utilizes a special topology that combines an inductor and a capacitor to produce high efficiency and low noise performance. Electric cars, photovoltaic systems, and portable electronic devices are just a few examples of the many uses for the Cuk converter. The converter functions as a negative polarity step-up converter. The output voltage of -30V is produced when the input voltage is 10V.

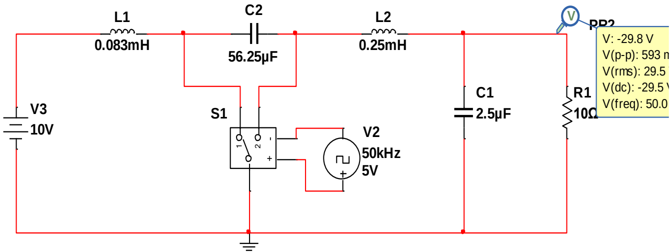

Fig.4. Cuk converter circuits acts as a step-up converter.

2.2.3 SEPIC converter

A form of DC-DC converter called a Single-Ended Primary-Inductance Converter (SEPIC) can be used to step up or step down the voltage. Although it utilizes a different architecture, it is comparable to the Zeta converter. It is renowned for its capacity to maintain a consistent output voltage despite variations in the input voltage.

When the input voltage fluctuates between 5V and 15V, an output voltage of 75.5V is produced with an increasing efficiency of 50%. A Boost converter is what the SEPIC converter does.

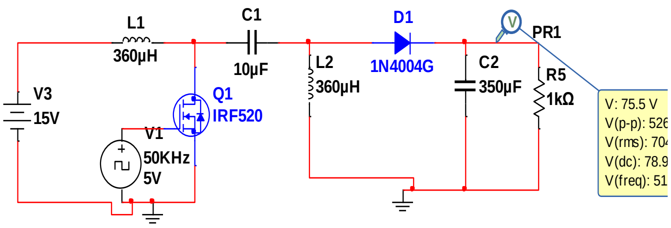

Fig.5. SEPIC converter circuits act as a step-up converter

2.3 Noise Separator

An approach to signal processing called a "noise separator" is used to isolate useful signals from undesired noise. To separate differential mode noise from a signal, utilize a differential mode noise separator. To operate, the differential mode noise signal must first be found and subtracted from the original signal. On the other hand, an active noise separator is a tool for removing common mode noise from a signal. To cancel out the common mode noise signal, it first detects it and then produces the opposite signal. Active and differential mode noise separators are both used to lower noise in electronic signals to enhance their quality. However, they operate on different types of noise and use different techniques to remove it from the signal.

The noises from the equipment called power converter is measured at the output of the LISN when it is connected to the equipment. The CM voltage (VCM) and DM voltage (VDM)is measured by using the formulae given below.

$$V_{CM} = \frac{V_2+V_1}{2} \quad (1)$$

$$V_{DM} = \frac{V_2-V_1}{2} \quad (2)$$

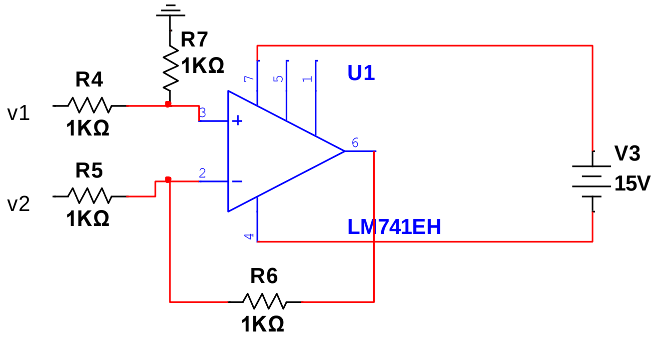

Fig.6. Active noise separator (adder) for measurement of CM noise

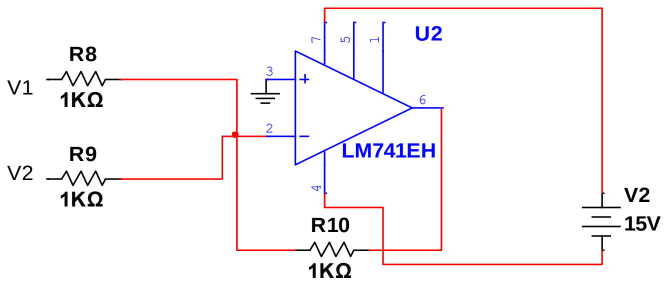

Fig.7. Active noise separator (Subtractor) for measurement of DM noise

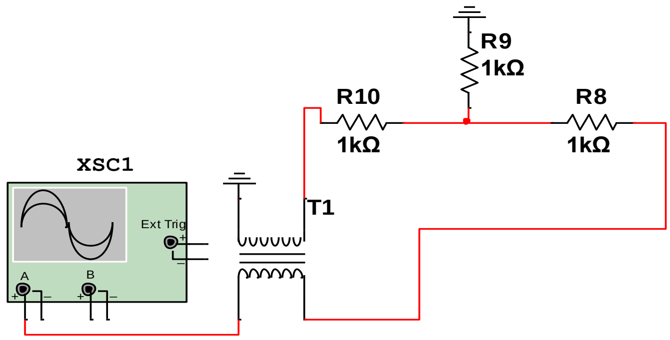

Fig.8.Differential mode noise separator for measurement of DM noise

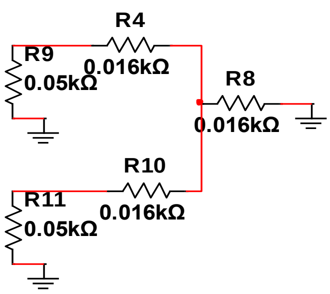

Fig.9. Differential mode noise separator

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3. NOISE ANALYSIS FOR ZETA CONVERTER

The graph below uses LISN to estimate the CM and DM noise coming from the power converter. ZETA converters employing LISN are supplied with an input voltage of 30V. The converter serves as a step-down converter, the switching components in the zeta converter are what cause noise to be produced, and the noise separator is used to measure CM and DM noise. Active noise separators are used to estimate CM mode noise, whereas differential mode noise separators are used to estimate DM mode noise. In Multisim software, the design process and noise computation are completed.

The graph shows that noises generated by the Zeta converter, the CM noise obtained without filter at the output of active noise separator is 114dBµV, the DM noise obtained without filter across the differential mode noise separator is 108 dBµV. the limit line for conducted emission as per the CISPR STD is 68 dBµV, from this graph it is observed that the noises generated is above the limit line, so the filter is inserted to decrease the noise in Zeta converter.

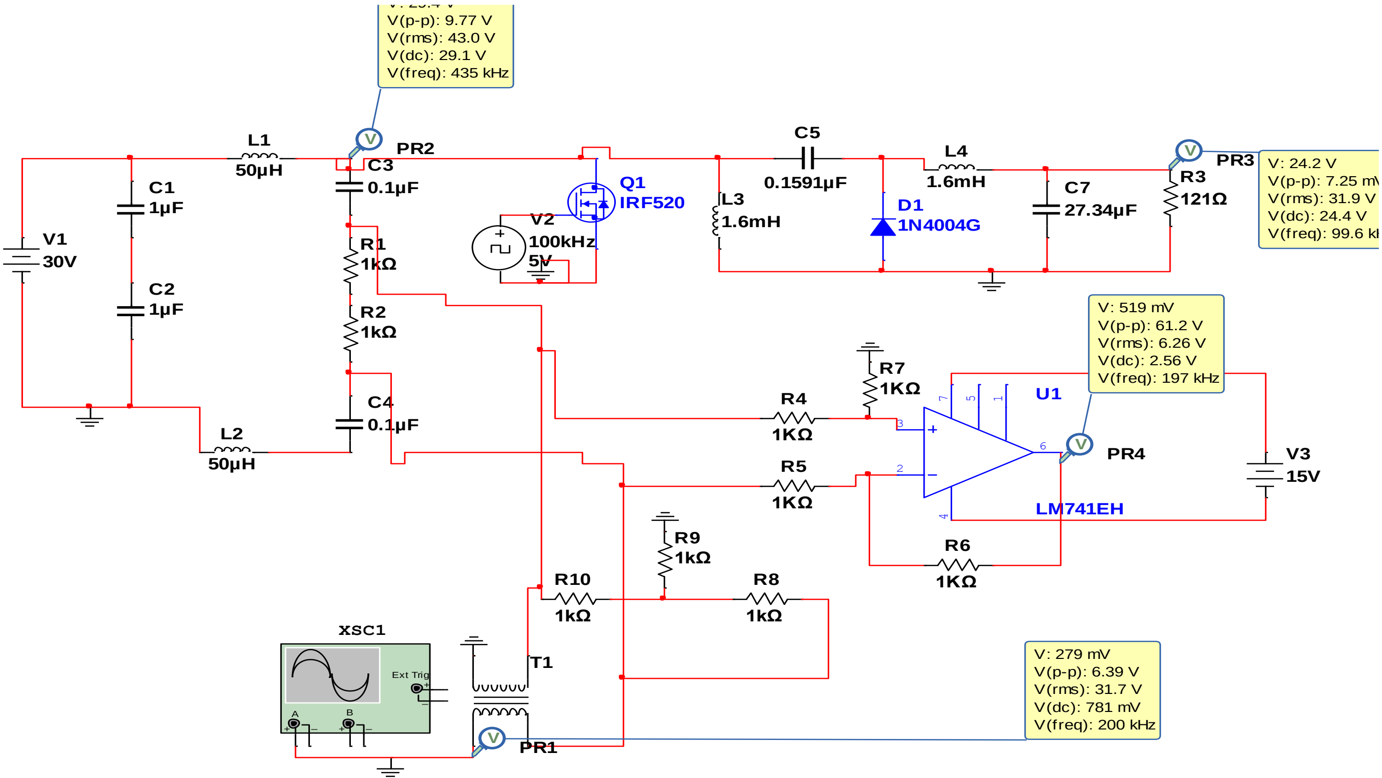

Fig.10. Noise measurement setup for Zeta power converter for both CM and DM noises

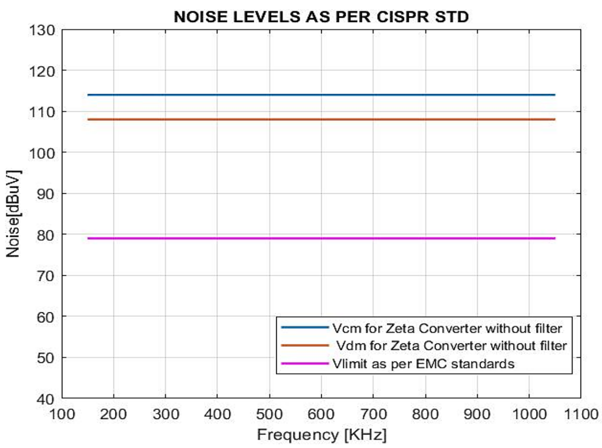

Fig.11. CM and DM noises with limit line as per CISPR std for Zeta power converter

To find the impedance for noise measurement when measuring EMI in conducted mode, a LISN with output impedance of 50mH must be installed between the equipment (power converter) and DC power source. Zeta converter, the equipment (power converter) that is being utilized, generates noise because of diodes, transistors, and switching components. When equipment (power converter) is linked to the LISN circuit, the noise separator is positioned across the LISN's output. At the noise separator's output, DM and CM noises are separated.

Active noise separator output noise is CM noise with a value of 519 mV, whereas differential mode noise separator output noise is DM noise with a value of 279 mV. To determine whether the circuit complies with the EMI standard limit, it is transformed. Between 150 kHz and 3 MHz, there is conducted emission. The CISPR 22 standard is used as a limit line for EMI regulation for conducted emissions. The conducted emissions range for various devices, including *class A* and *class B* devices, is covered by this standard. *Equation 3* is used to convert voltage into, dBµV.

$$dB_{\mu V} = 20\log_{10}[\mu V] \quad (3)$$

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Table 1: The Conducted emissions range for CISPR standard

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

4. NOISE ANALYSIS FOR SEPIC CONVERTER

By coupling the LISN with the power converter, the noise evolution for the SEPIC power converter is accomplished. The noise separators are used to measure the CM and DM noise. 15V is the input value for the SEPIC power converter when using LISN. It functions as a step-up converter; transistors produce the noise, while a diode serves as a noise source. A LISN with output impedance of 50 mH must be installed between the equipment and the DC power source in order to measure the impedance necessary for noise measurement when measuring EMI in the conducted mode. When equipment is connected to the LISN circuit, the noise separator is placed across the LISN's output. At the noise separator's output, DM and CM noises are separated.

Active noise separator output noise is CM noise with a value of 899 mV, while differential mode noise separator output noise is DM noise with a value of 547 mV. In order to determine whether the circuit complies with the EMI standard limit, it is transformed into dBμV.

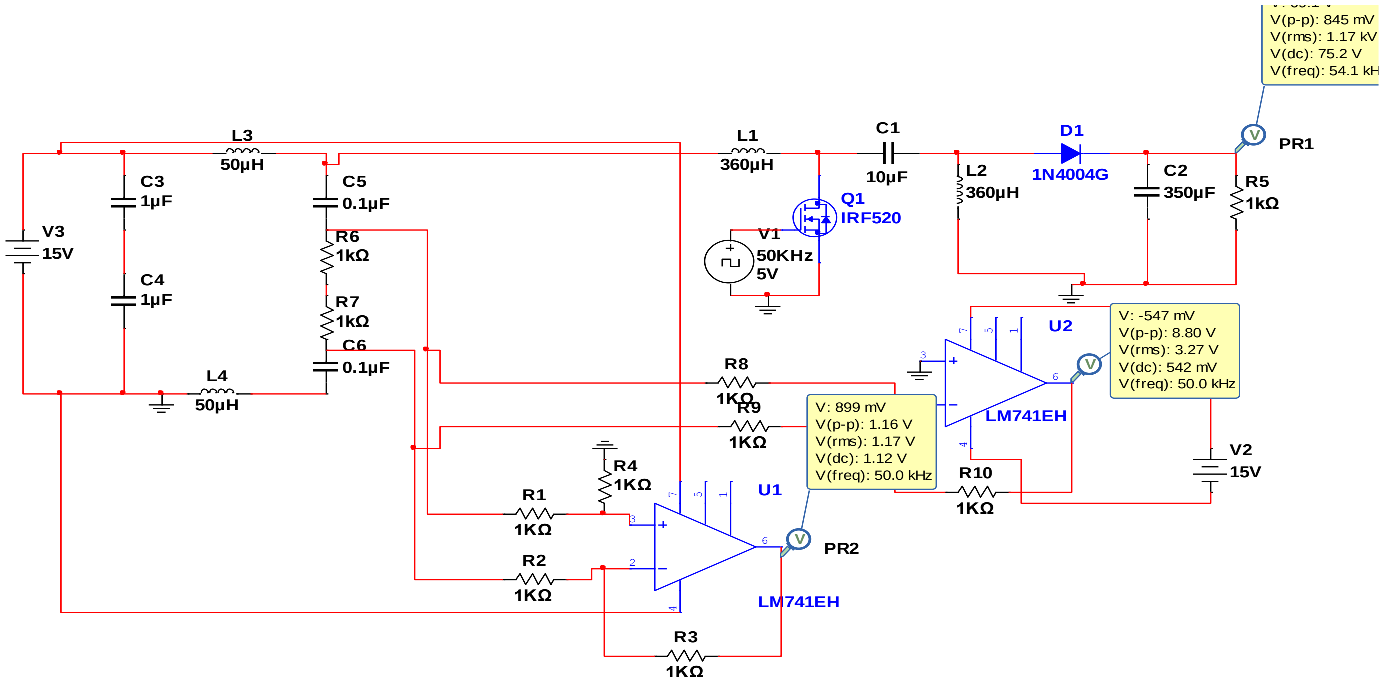

Fig.12. Noise measurement setup for SEPIC power converter for both CM and DM noises

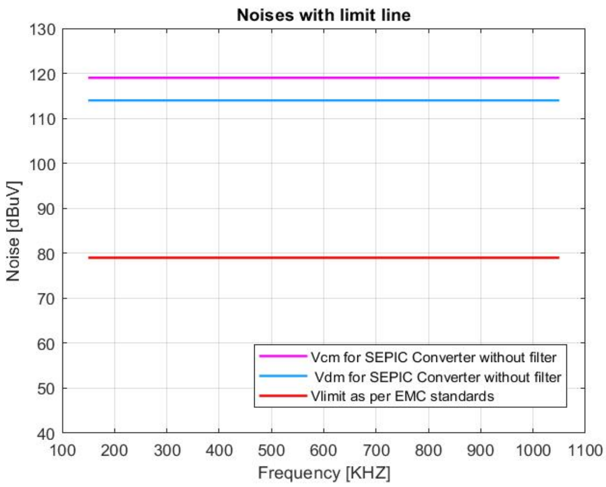

Fig.13.CM and DM noises with limit line as per CISPR std for SEPIC power converter

Based on the given graph, it is evident that the noise generated by the SEPIC converter exceeds the limit line specified by the CISPR STD for conducted emission. The CM noise, measured without a filter at the output of the active noise separator, is recorded at 119 dBμV, while the DM noise, measured without a filter across the differential mode noise separator, is measured at 114 dBμV. Comparatively, the limit line for conducted emission according to the CISPR STD is set at 68 dBμV. Consequently, the insertion of a filter is required to reduce the noise produced by the Zeta converter and bring it within the acceptable range defined by the CISPR STD.

5. NOISE ANALYSIS FOR CUK CONVERTER

By coupling the LISN with the power converter, the noise evolution for the Cuk power converter is accomplished. The noise separators are used to measure the CM and DM noise. 10V serves as the Cuk power converter's input voltage through

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LISN. It functions as a step-up converter; transistors produce the noise, while a diode serves as a noise source. Active noise separator output noise is CM noise with a value of 81.1 mV, whereas differential mode noise separator output noise is DM noise with a value of 213 mV. In order to determine whether the circuit complies with the EMI standard limit, it is transformed into dBµV.

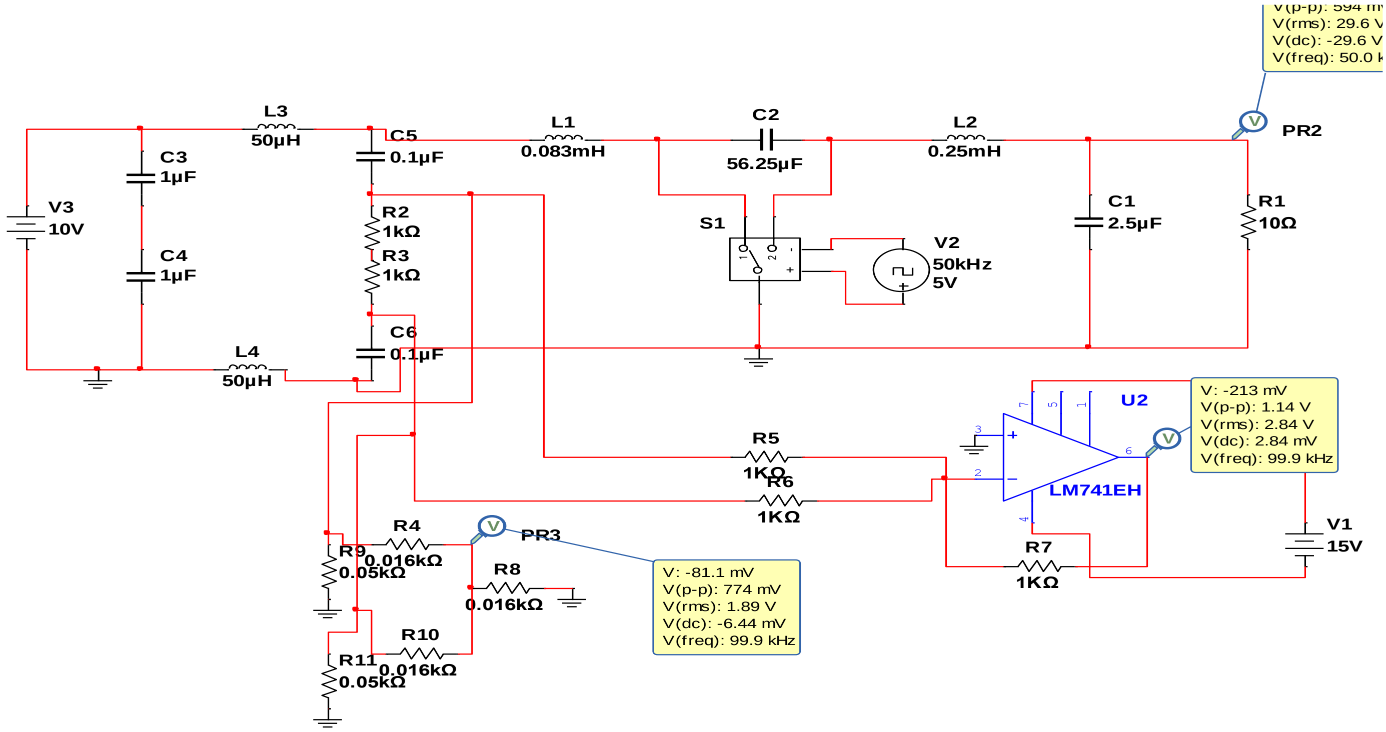

Fig.14. Noise measurement setup for Cuk power converter for both CM and DM noises

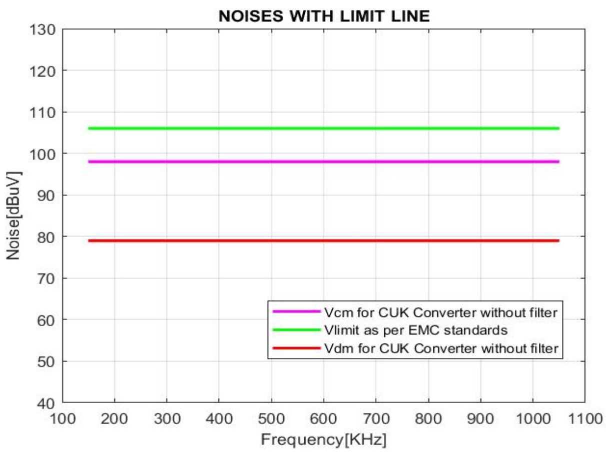

Fig.15.CM and DM noises with limit line as per CISPR std for Cuk power converter

Based on the provided graph, it is apparent that the noise generated by the Cuk converter exceeds the conducted emission limit line as defined by the CISPR STD. The CM noise, obtained without a filter at the active noise separator output, measures at 106 dBµV, while the DM noise, measured without a filter across the differential mode noise separator, is recorded at 98.2 dBµV. Comparing these values to the CISPR STD limit line of 68 dBµV, it is evident that the noise levels are significantly higher. Therefore, the installation of a filter is necessary to reduce the noise originating from the Zeta converter.

6. RESULTS

Power converters play a pivotal role in the world of electronic devices, facilitating the seamless transformation of DC voltages across various levels. Nonetheless, the substantial amounts of common-mode and differential-mode noise that these converters can generate pose significant challenges to the optimal performance of other electrical components. Thus, it becomes imperative to meticulously evaluate the common-mode and differential-mode noise produced by DC-DC power converters to ensure the development of innovative and reliable electronic systems. extensive research has revealed intriguing insights into the noise characteristics of these converters. It has been observed that DC-DC converters predominantly generate higher levels of common-mode noise, compared to differential-mode noise. Furthermore, specific converter types, such as the Zeta, SEPIC, and Cuk converters, exhibit distinct noise generation patterns. Among them, the Cuk converter stands out by producing relatively lower levels of noise, showcasing its potential for enhanced noise reduction. To provide a comprehensive overview, the accompanying table presents detailed information regarding the common-mode and differential-mode noises associated with the Zeta, SEPIC, and Cuk converters. This knowledge empowers engineers and designers to make informed decisions and implement efficient noise mitigation strategies in their electronic systems, fostering innovation and ensuring optimal performance. DC-DC power converters are often used in electronic devices to transform the DC voltage from one level to another. However, the high amounts of common-mode and differential-mode noise that these converters can generate may make it difficult for other electrical components to function properly. The evaluation of common-mode and differential-mode noise produced by DC-DC power converters is essential for the development of reliable electronic systems. It has been found that the differential-mode noise generated by DC-DC converters is typically substantially lower than the common-mode noise. The findings indicate that the power converters generate more CM noise than DM noise, and that the Cuk power converter generates less noise than the Zeta converter and SEPIC converter. The CM and DM noises for the Zeta converter, SEPIC converter, and Cuk converter are given in the table below.

Table 2: The CM and DM noises for DC-DC power converters

Power converter	CM (mV)	DM (mV)	Limit line (dBμ V)	CM (dBμ V)	DM (dBμ V)
ZETA	519	279	79	114	108
SEPIC	899	547	79	119	114
CUK	213	81.3	79	106	98.2

Table 3: Comparison of results with existing and proposed model for CM and DM noises for DC-DC power converters

Tittle of the Paper	Power Converter	Existing Model Results	Proposed Model Results
Research and Realization of A Novel Active Common-Mode EMI Filter	SMPS DC/DC Converter	Total Noise at The Output of Noise Separator is 78 dBμV.	Noise at the Output of Noise Separator CM=119 dBμV. DM=114 dBμV.

7. CONCLUSION

Electronic equipment typically uses DC-DC power converters to transform DC voltage from one level to another. The results have shown that the input voltage, load conditions, and converter design can all affect the noise level. It has been found that common-mode noise generated by DC-DC converters is generally more severe than differential-mode noise. The Cuk converter is quieter when compared to other DC-DC converters. The focus of future research will be on methods to reduce the noise that DC-DC converters generate and improve the dependability of electronic systems. estimating common-mode and differential-mode noise from DC-DC power converters is unique. A novel method for measuring common mode noise and differential mode noise from power converters such Zeta converters, Single Ended Primary Inductance Converters (SEPIC), and Cuk converters has been developed in this study. Instead of utilising a noise mixer and subsequently a splitter to measure CM and DM noises, active and differential noise separators are used to measure CM and DM noises separately. The noise produced by the power converters can exceed the Comité International Special des Perturbations Radioélectriques [CISPR] limit line for DM and CM noise. The noise level can be lowered to the CISPR limit line by utilising the filtering procedure. This standard provides the conducted emission range for different electrical equipment.

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