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A Comparison of SMD and Through-Hole Components on Conducted Noise Emission

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Abstract: Switched-mode DC-DC converter circuits create quite challenging electromagnetic compatibility problems. Additionally, the design preferences directly affect the EMC performance of the circuits. The study focuses on the conducted noise emissions of the same Boost converter circuits constructed with two different types of assembly technologies, Through-Hole and SMD. For this purpose, two Boost converter circuits using the same integrated circuit, LT1070, were designed by using Through-hole and SMD assembly technologies. The conducted emission measurements were taken according to Class B of EN 55032 standard requiring measuring the noise emission in the frequency range between 150 KHz and 30 MHz. The results obtained from measurements show that the emission amplitude at 160 kHz for Boost converter constructed with Through-Hole components is higher than the standard requirement while the converter constructed with SMD components meets the standard at the same frequency. The conducted emission amplitudes of both Boost converter at 200 KHz and 240 KHz cannot meet the requirements of the standard, but the peak values for SMD-based circuit are higher than the emission amplitudes of Boost converter constructed with Through-Hole components at the same frequencies. Because of failing both circuits on the tests of En 55032 standard, a low-pass π type filter was designed. After adding the π filter to the Boost converter circuits, the conducted emission values have met the standard requirements in all frequency range. The efficiency of the designed filter completely suppresses the noise all frequency range of EN 55032, from 150 KHz to 30 MHz.

Keywords Electromagnetic Compatibility (EMC), Electromagnetic Interference (EMI), EMI Filter Design, DC–DC Converters.

1. Introduction

Electromagnetic compatibility (EMC) is crucial for the smooth operation of electronic devices. While operating, electronic and electrical devices generate electromagnetic interferences (EMI) disturbing other devices. EMC refers to the ability of these devices to operate smoothly without being affected by EMI(Ott, 2009). There are two types of EMI: conducted electromagnetic noise and radiated electromagnetic noise (Paul, 2006). Conducted electromagnetic noise refers to the type of noise that devices transmit to other devices and the shared power grid via electrical cables or interconnects. Radiated electromagnetic noise is the type of electromagnetic noise that propagates via radio waves. From aviation to automotive or industrial products and home electronics, all electronic devices must meet EMC requirements. However, the EMC standards and limits of these standards vary depending on the usage area in which the relevant electronic devices are used. Electronic systems are tested not only on a circuit level but also as a final product consisting of multiple electronic circuits (Weston, 2017).

Electronic systems can operate at different voltage and power values. Therefore, they often need power converters. Therefore, DC-DC converters are indispensable components of electronic systems. DC-DC converter topologies require a switching element in terms of their operating principles. The ability of the switching element to drive the current at the desired speed and magnitude is the main factor that determines the efficiency of the converter. However, the fact that the switching element drives the current intermittently over time is the main cause of especially conducted EMI. In parallel with the developments in the field of power electronics, the switching frequencies of driver elements have increased recently. Additionally, EMC problems have increased in parallel with the switching frequency. EMC problems in DC-DC converters have been investigated and distortions in the power signal have been investigated in various studies in simulation environments or by implementing circuits (Karagöl, 2015; Yalçın, 2015; Roberts and Lametschwandtner, 2023; Tyagi et al. 2017). In this study, the Boost converter circuit using LT1070 integrated circuit as the switching element was designed and its conducted emission characteristics were investigated.

In the study, BOOST converter circuit was implemented by using Through-Hole and SMD (Surface Mount Device) components. The Conducted interferences of the BOOST converters fabricated with two different assembly technologies were tested individually because of observing how the conducted emission performances differed according to assembly technology and design. So, the aim of the study is to emerge the assembly technology and design effect on conducted emission performance. The measurements of the conducted interferences were performed in FARBA Automotive's Electromagnetic laboratories. The crucial component in the EMC test measurements is Line Impedance Stabilization Network (LISN) used to filter the source signal and match the line impedance to 50 Ω. The interference measurements are taken separately from both sides of LISN as LISN+(positive) and LISN-(negative). As mentioned above, the EMC standards vary depending on usage area of the electronic device. In the study, the conducted emission measurements were taken according to Class B of EN 55032 standard describing the limit of residential, commercial and light industrial electronic devices (EN 55032). The study investigates the effect of the SMD and Through-Hole components on the conducted noise values by presenting correspondingly conducted EMI measurements for both structures.

According to the measurement results, the conducted emissions of the BOOST circuit implemented with SMD components and Through-Hole components did not meet the conducted noise limits identified by the EN 55032 standard. Hence, a low-pass π (pi) type filter was designed and implemented to reduce the conducted noises below the limit values specified by the standard. The frequency interval of the EN 55032 standard for the conducted emission is between 150 kHz and 30 MHz. The filter was designed to subpress the noise within the frequency range specified by the standard. For this reason, no effort was made to filter noise values below 150 kHz and above 30 MHz. The measurements for filter added BOOST converter circuits with SMD components were repeated in the laboratories and the efficiency of designed filter was presented. The conducted emission values of the BOOST converter with SMD components reduced below the limit values specified by the EN 55032 standard after adding the designed filter. In the next section, the circuit schematic of the BOOST converter is given, and the operating principles of the circuit are explained. In the third section, the BOOST circuits constructed with SMD and Through-Hole assembly technologies, conducted emission results obtained from laboratories measurements for both circuits are presented. The study ends with conclusions.

2. BOOST Converter

The operating principle of the BOOST circuit topology is to increase the DC input voltage to higher DC output voltage than the input. Figure 1 shows the circuit diagram of the BOOST circuit topology.

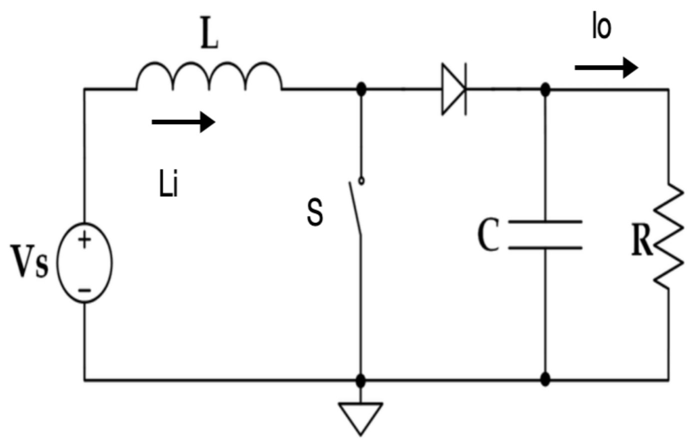

Figure 1 BOOST converter

The BOOST converter circuit was designed based on the datasheet published by Linear Technology, the manufacturer of the LT1070 integrated circuit. The circuit was implemented in accordance with the datasheet. As shown in Figure 1, there is a coil in the input of boost converter circuits. When the switching element is closed, energy is stored in the coil. When the switching element is open, the accumulated energy in the coil and the energy on the source side feed the capacitor and load on the output side of the circuit. During this time, the capacitor charges. When the switch is closed again, a stable output voltage is achieved. As the switch is opened and closed, fluctuations occur in the current signal. These fluctuations in the current signal produce EMI and cause EMC problems. Current fluctuations are the main source of conducted noise emissions. In addition to EMI caused by switching elements in the DC-DC converter topologies, the types of materials used in electrical circuits can also affect magnitude and phase electromagnetic interference in the frequency spectrum. In the study, it is aimed to compare effect assembly technologies on conducted emissions.

The electromagnetic noise nature is too complex. There are two kinds of electromagnetic noises, common mode noise and differential mode noise. Common mode noise propagates in the same direction on both signal lines. The common mode noise is measured between signal line (positive or negative lines) and ground line. Common mode chokes and Y-type capacitors are used to filter the common mode noise component. On the other hand, differential mode noise is the noise propagating in opposite directions on positive line and negative line. Differential mode inductors and X-type capacitors are used to filter the differential mode noise(Su et al. 2019; Felic, 2011). Each one of these noise components is measured by using different measurement techniques. In the study, total noise of implemented BOOST converter was measured according to EN 55032 standard without considering which component, differential or common, is dominant.

In this study, A BOOST converter circuit is designed by using two different assembly technologies. One of the electrical circuits was designed and implemented with two different assembly technologies, SMD and Through-Hole. The conducted noise values of the circuits designed with the two different assembly technologies were measured separately because of determining the impact of material type on the conducted emission taken according to EN 55032 standard. The measurements were taken in a real laboratory environment in FARBA Automotive Corporation.

3. Measurements and Discussions

Fluctuations in voltage signals and noise emissions on signal or ground line occur because of the discontinuous current caused by the switching element used in DC-DC converters. These fluctuations trigger distortions in the DC source signal or the mains frequency of grid signal. As a result, these distortions cause conducted or radiated electromagnetic noises. Distortions in the mains signal may occur not only because of conducted noise but also due to radiated noise. Conducted and radiated electromagnetic noise limit values are also specified by standards. In this study, conducted emission characteristic for commercial BOOST converter was investigated and a filter design to suppress the conducted noise obtained end of the measurement was performed.

In general, there are four basic types and classifications of filters: low-pass filters, high-pass filters, band-pass filters, and band-stop filters(Tyagi et al.2017; Tarateeraseth, 2011; Tarateeraseth, 2012; Johannesson and Fransson, 2008). In this study, a low-pass pi-type filter was designed to filter the conducted noise of the converter. The BOOST converter circuit was designed as specified in the datasheet. Figure 2 shows the BOOST converter with the LT1070 integrated circuit schematic given in the datasheet document published by Linear Technology company.

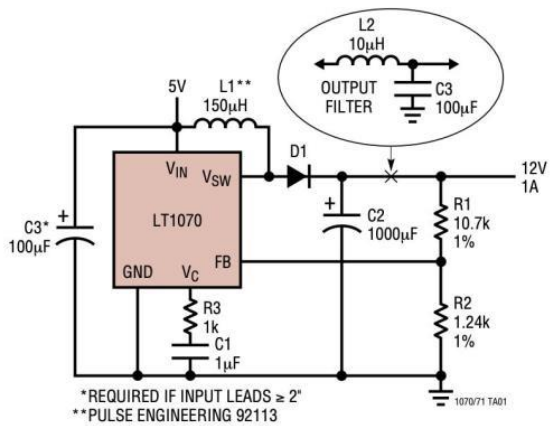

Figure 2 Application circuit in datasheet of LT1070

The LT1070 integrated circuit can be used in various DC-DC converter topologies. The BOOST topology converting 5V input voltage to 12V output voltage was used in this study. In the circuit, the LT1070 integrated circuit receives feedback from the FB pin and adjusts the output voltage through ratio of resistors R1 and R2. The top layer and bottom layer of the BOOST converter circuit implemented with through-hole materials and SMD materials is given in Figure 3 and Figure 4, respectively.

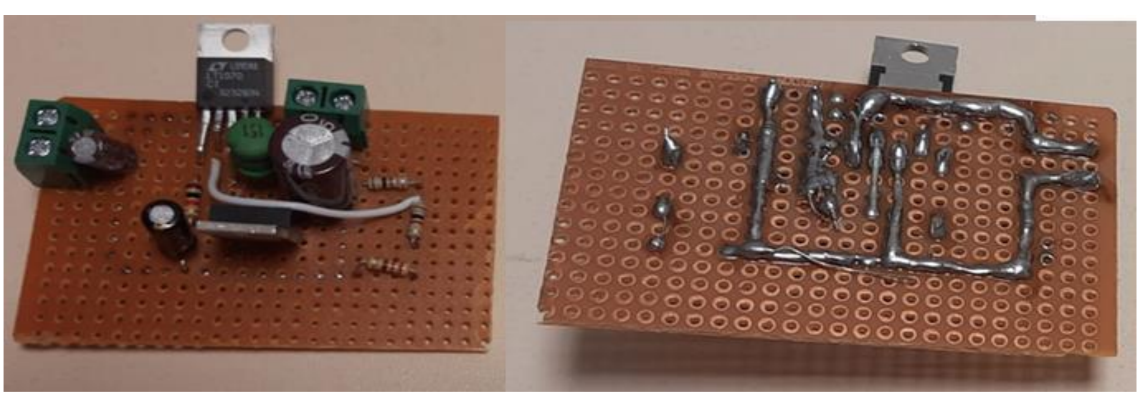

Figure 3 Top and bottom layer of the BOOST converter implemented with through-hole materials

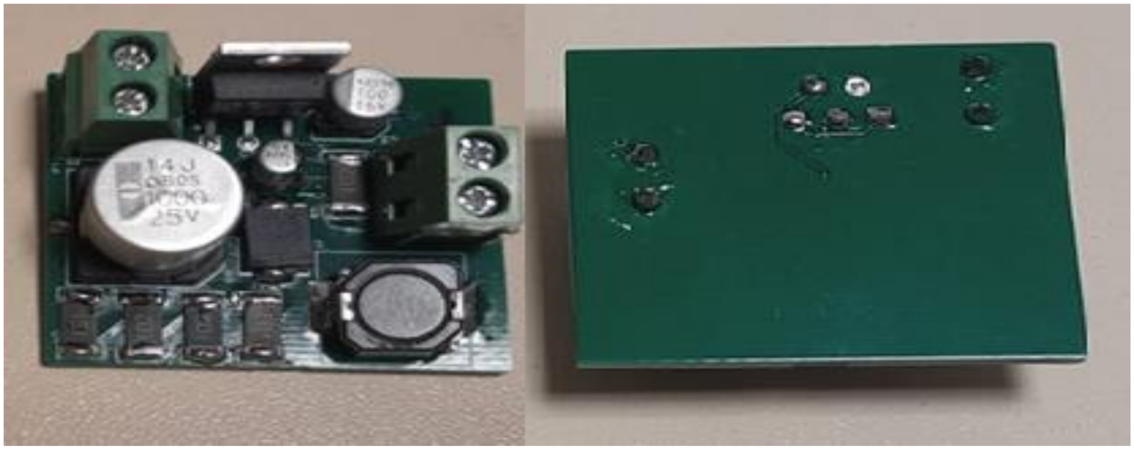

Figure 4 Top and bottom layer of the BOOST converter implemented with SMD materials

The component values of both BOOST converter circuits are identical. The only difference between the two identical circuits is their different assembly technologies. Because of different assembly technologies, the positions of the components on the circuits are different, as well. This study investigates the effect of assembly technologies differences on conducted emission values. The measurement graph of the conducted noise received by the LISN+ and LISN- for the BOOST circuit designed with SMD components is given in Figure 5. The conducted emission limits of the graph are determined according to Class B of the EN 55032 standard.

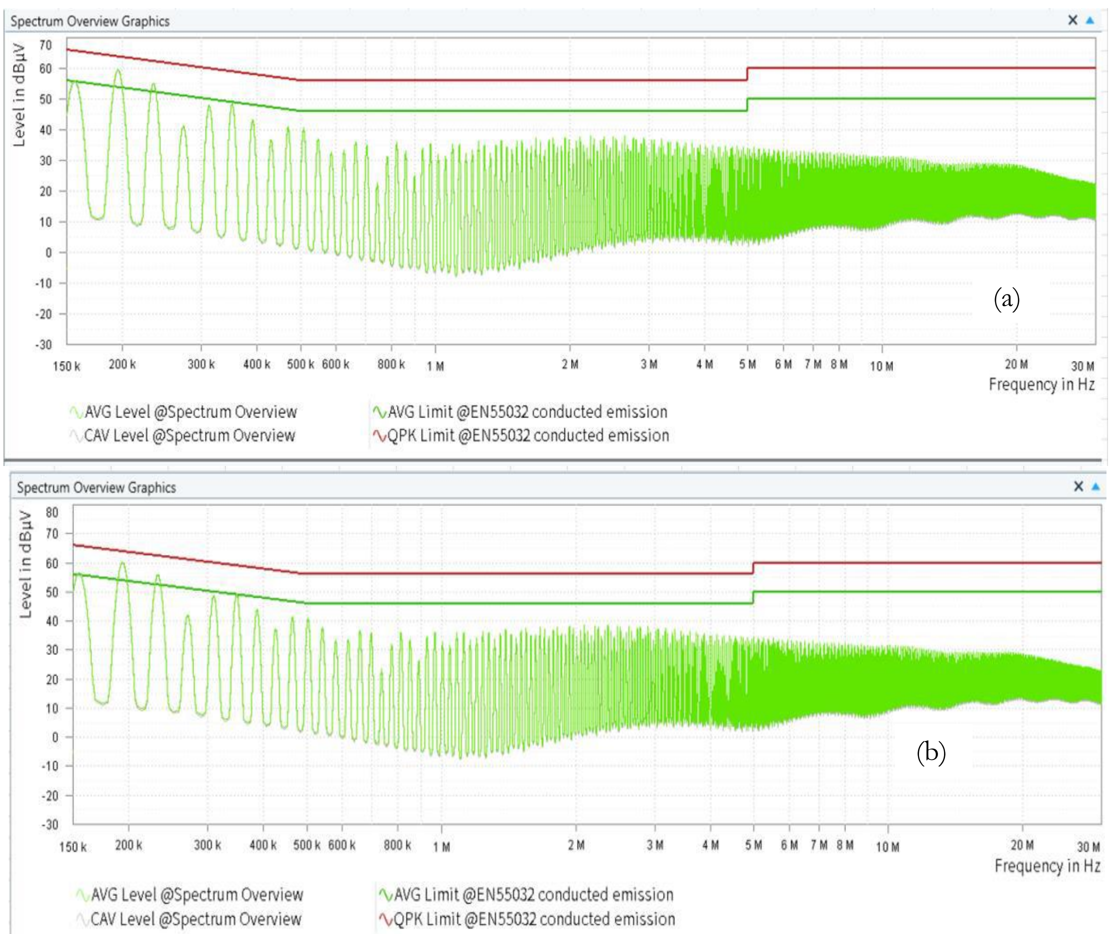

Figure 5 Conducted emission of the BOOST with SMD taken (a)LISN+ and (b)LISN-

As seen in the figures, the noise values of the conducted emission are similar on both side of the LISN. The noise values for conducted emission of the BOOST circuit implemented with SMD components exceed the noise limit specified by the EN 55032 standard around 200 KHz and 240 KHz. The study aims to compare conducted emission characteristics of BOOST converters implemented with two different assembly technologies, SMD and through-hole. The BOOST converter implemented with through-hole components was studied as second application. The conducted noise values of the BOOST circuit constructed with through-hole components were measured and presented in Figure 6.

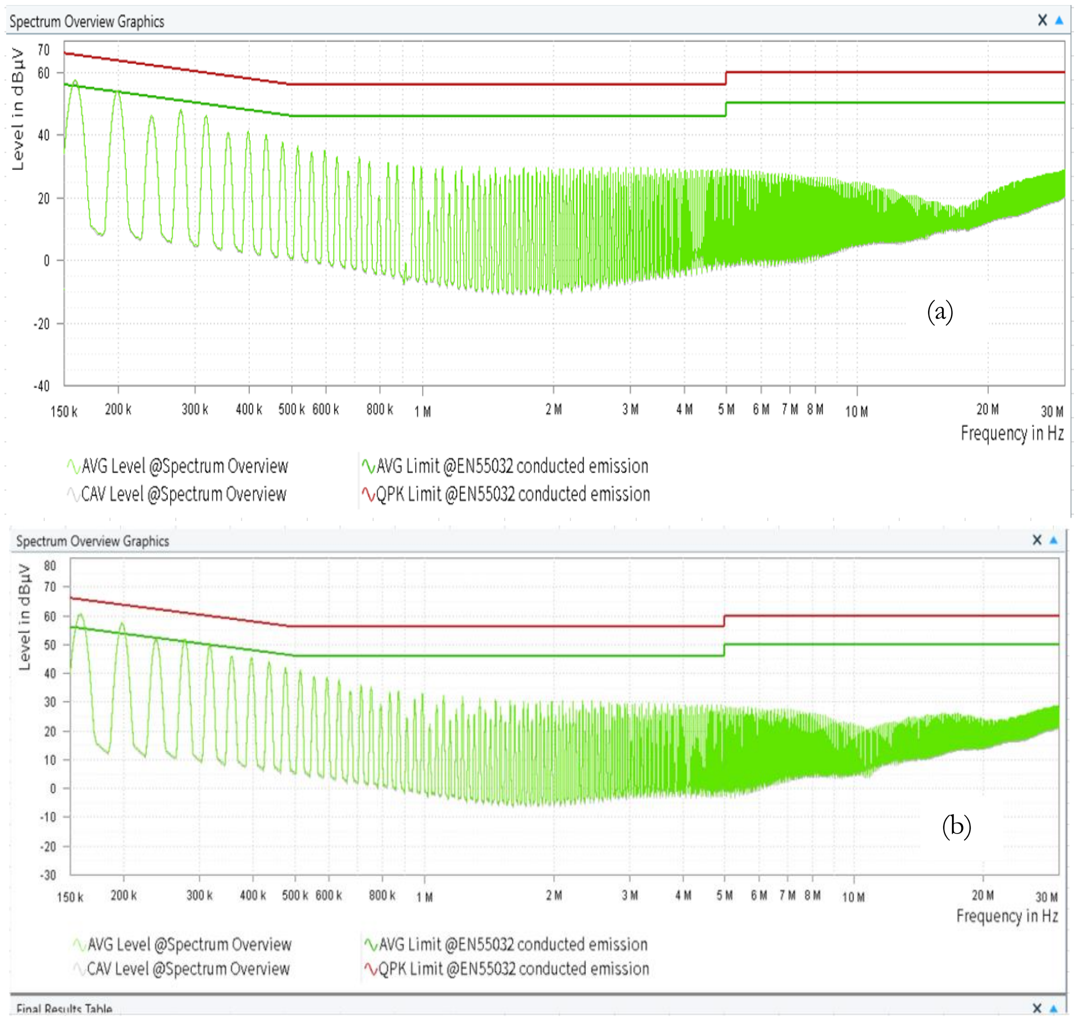

Figure 6 Conducted emission of the BOOST with through-hole components taken (a)LISN+ and (b) LISN-

As seen in the figure (a), noise values exceed the limits of standard in the vicinity of 160 KHz. The noise values taken LISN- for conducted emission of the BOOST circuit implemented with through-hole components exceed the noise limit specified by the EN 55032 standard around 160 KHz and 200 KHz. If the results obtained from both materials are analyzed comparatively, emission characteristics are similar between the LISN positive and negative side for same assembly technologies. On the other hand, the frequencies where the emission values are exceeding the limits shift from 160 KHz and 200 KHz for the through-hole component-based circuit to 200 KHz and 240 KHz for the SMD component-based circuit. As presented above, the conducted emission values of BOOST converter circuits constructed both type assembly technologies, Through-Hole and SMD, cannot meet the limits specified by the EN 55032 standard for the noise values received from the LISN+ and LISN- sides. However, the conducted noise values of the circuit constructed with Through-Hole components are considerably higher at a frequency of approximately 160 kHz than the noise values of the BOOST circuit constructed with SMD components at the same frequency. In both cases, the transmitted noise values exceed the limit values specified by the EN 55032 standard. To reduce the conducted noise values below the limit values specified by the standard, a filter design is required. There are different filter topologies such as low pass, high pass, band pass and band stop. The number of inductance and capacitance determines the order of the filter, and the location of the components defines input and output impedance of the filter. Additionally, the attenuation characteristic of a filter is presented insertion loss in decibels (dB). Insertion loss corresponds to the reduction in load voltage at a particular frequency due to the insertion of the filter into the circuit (Guler, 2025). In this study, a third order low-pass π (pi) type filter, including two capacitors and a inductor, was designed to suppress the conducted emission noise. The cutoff frequency was chosen as 40 kHz because the switching frequency of the LT1070 integrated circuit used in the BOOST circuit is 40 KHz and the noises exceeding the limits are observed the harmonics of the switching frequency. The formulas used to calculate the values of the elements for the third order low-pass π filter circuit are given in Equation (1) and Equation (2) (Tarateeraseth, 2011; Johannesson and Fransson, 2008; Chen, 1991; Yildiz, 2020).

$$L = \frac{R}{2\pi f_c} \tag{1}$$

$$R = \frac{1}{2\pi f_c C} \tag{2}$$

where, L is the inductance value of the π filter and C is the capacitance value of the filter. f_C is the cutoff frequency of the filter and R is the load resistance. Load resistance equals to 100**Ω** because it was used as load in all of measurements. For 100 ohms load resistance, the inductor value was calculated approximately 397 µH and the capacitor value was obtained 39 nF. However, it is hard or impossible to find the exact value of these components on the market. So closed values components were obtained as 470 µH for the inductor and 47 nF for the capacitor, and the circuit design was assembled with these values. The insertion loss, input and output impedance obtained using Würth Elektronik online software are presented for $C_1 = C_2 = 47\text{nF}$ and L=470 µH in Figure 7 (Würth Elektronik, 2026).

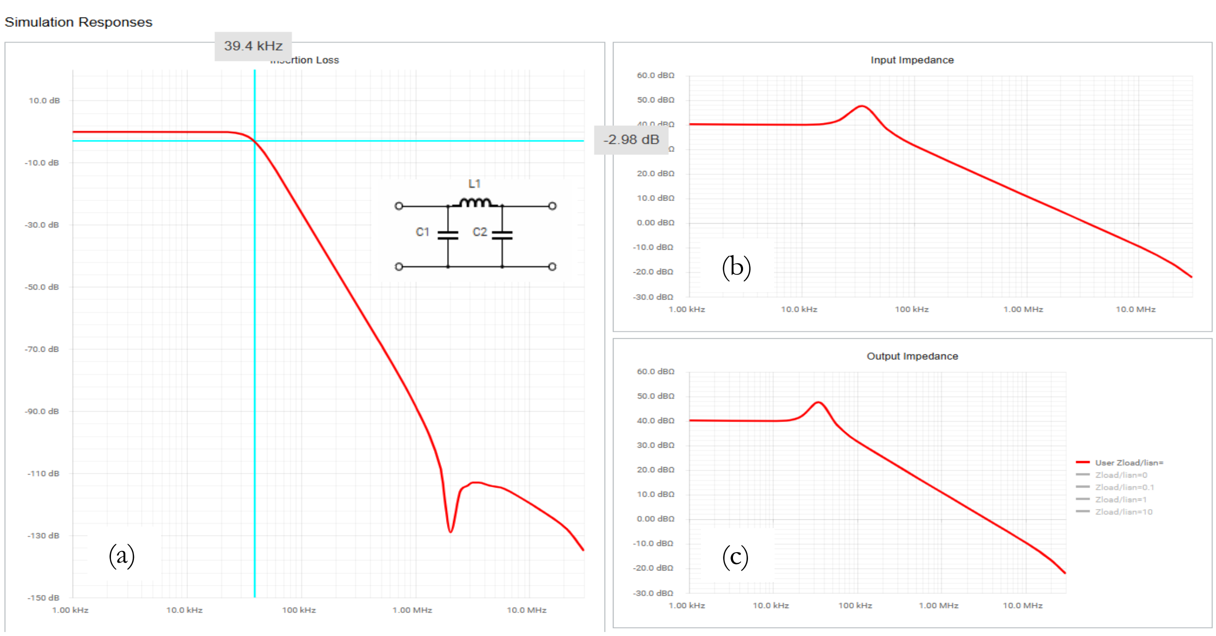

Figure 7 The simulation result obtained from Würth online software; (a)insertion loss, (b) input impedance, (c)output impedance

As seen in the figure, the insertion loss is about -3 dB around 40 KHz. Additionally, the filter shows high impedance in the vicinity of 40 KHz. The impedance characteristic of the designed filter obtained experimentally by using GW-Instek LCR-8110G impedance analyzer is presented in figure 8.

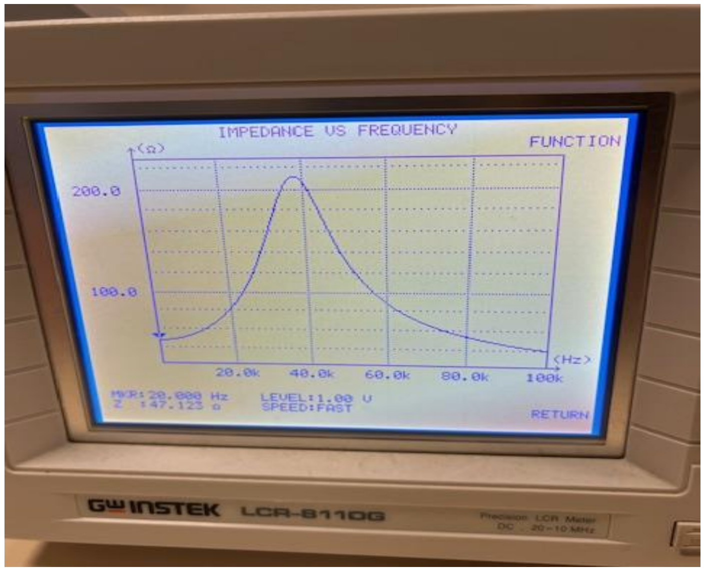

Figure 8 The impedance characteristic of the designed filter obtained from GW-Instek LCR-8110G

The experimental results are compatible with the results obtained from Würth Elektronik online software. In the next figure, a picture taken from measurement in the laboratory is given for low-pass π filter added BOOST converter.

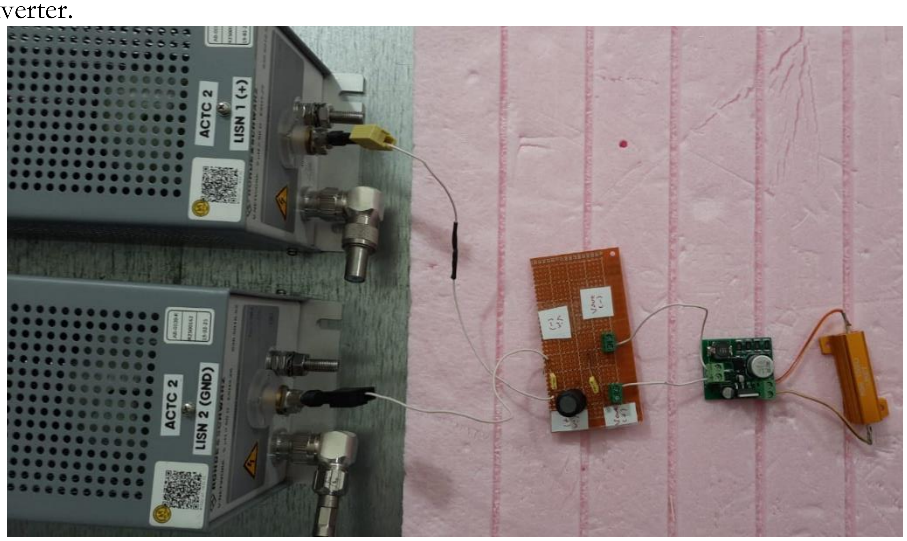

Figure 9 The measurement system for low-pass π filter added BOOST converter

The conducted emission values of the Boost converters constructed with Through-Hole and SMD components decreased below the limits of the EN 55032 standard by adding the low-pass π filter. The designed filter reduces the conducted emission values more than 30 dB at most of the frequency range. Figure 10 shows the conducted emission values of Boost converter with SMD components received form the LISN+ and LISN- after adding π type low-pass filter to the BOOST converter. The results obtained for Boost converter with π type filter show the conducted emission values fall below the limit values specified by the EN 55032 standard after adding the filter to the circuits constructed with Through-Hole or SMD components. It means the efficiency of the designed filter is greatly well for the frequency range of EN 55032, 150 KHz to 30 MHz.

Figure 10 Conducted noise of Boost converter with SMD material, taken from (a) LISN+ and (b) LISN-

4. Conclusions

The aim of this study is to compare material assembly technologies, through-hole and SMD, on conducted noise emission of a Boost converter. For this purpose, a Boost converter circuit was designed using the LT1070 integrated circuit. The Boost converter circuit was implemented with both SMD and through-hole components. In the study, the conducted emission measurements were taken according to Class B of EN 55032 standard. The standard describes the limit of residential, commercial and light industrial electronic devices. The standard requires to measure the noise emission in the frequency range between 150 KHz and 30 MHz. The conducted noise values of Boost converters constructed with two different assembly technologies were measured separately from the LISN+ and LISN- as required by EN 55032. The emission peaks reveal at the switching frequency harmonics as expected but the amplitudes of the peaks change depending on the circuit assembly technologies, SMD or Through-Hole. The results obtained from the Boost converter constructed with SMD components and Through-Hole components that the conducted emission amplitudes of SMD component-based Boost converter at 200 KHz and 240 KHz cannot meet the requirements of the standard, and they are higher than the emission amplitudes of Through-Hole component-based Boost constructed at the same frequencies. However, the emission amplitude at 160 kHz for Boost converter constructed with Through-Hole components is higher than the standard requirement while the converter constructed with SMD components meets the standard at the same frequency. The EMC emission characteristic of any system depends on numerous parameters such as trace loops, parasitic effects related to inductive or capacitive coupling, grounding, shielding, soldering techniques, PCB materials, assembly technologies, etc. The study aims only to compare the effect of the assembly techniques, through-hole and SMD, on the conducted emission. The results obtained from measurements show there is no dominant difference depending on assembly technology on conducted electromagnetic emission performance.

In both circuits, the conducted emission peaks are at multiples of 40 kHz, the operating frequency of the LT1070 integrated circuit. Both circuits, whether they are constructed with SMD or Through-hole components, cannot meet the requirements of En 55032 standard. Because of this cause, a low-pass π type filter was designed and added to the Boost converter circuits. The insertion loss, input impedance and output impedance of the designed filter obtained from Würth Elektronik online software, and the impedance characteristic obtained from impedance analyzer were included in the study. After adding the π filter to the Boost converter, the conducted emission values were taken again. The conducted emission values of the filter-added circuits can meet the standard requirements in all frequency range. The conducted emission results obtained from the SMD component-based Boost converter with filter has been given in the study to show performance of the designed filter. As presented in the previous section, the efficiency of the designed filter is greatly well for the frequency range of EN 55032, 150 KHz to 30 MHz. It can completely suppress the noise all frequency range of the standard.

Declaration of Ethical Standards

As the authors of this study, we declare that he complies with all ethical standards.

Credit Authorship Contribution Statement

D.Metin: Investigation, Resources, Validation, Formal analysis, Writing, Visualization,

E.Kelebekler: Methodology, Validation, Writing, Review & Editing, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declared that they have no conflict of interest.

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Data Availability

No datasets were generated or analyzed during the current study.

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