# Design and Implementation of EMI Filter for DC-DC Power Converter

**R Rakshith[1], H Suresh[2], Nachiketh G V[3], Syed Khaleel Ahmed[4], T J Shreyas[5]**

*[1]R Rakshith, Student, EEE Dept., BIT Bangalore, India*
*[2]H Suresh, Assistant Professor, EEE Dept., BIT Bangalore, India*
*[3] Nachiketh G V, Student, EEE Dept., BIT Bangalore, India*
*[4] Syed Khaleel Ahmed, Student, EEE Dept., BIT Bangalore, India*
*[5]T J Shreyas, Student, EEE Dept., BIT Bangalore, India*

---***---

**Abstract -** *A DC-DC converter is one of the simplest and widely used converters in controlled power applications like cell phones, laptops, communication systems and many more electronic devices. DC-DC converters are devices which convert one voltage level to other voltage level that may be higher in magnitude or lower in magnitude. Accordingly they are classified as boost and buck converters. We are working on the latter i.e., buck converter. They are used everywhere because of their high efficiency and single stage conversion. These converters are nothing but, high frequency switching devices operating on PWM principle. Almost all of the switching-mode power conversion systems generate conducted electromagnetic interference (EMI) noise. In this paper, we propose a design method of the EMI filter with DC-DC power converter and implement them to reduce the EMI noise generated, and thereby improve the overall efficiency of the power converter.*

***Key Words***: **DC power supplies, EMI Filter, EMI noise, Switch-Mode Power Supplies, Buck converter.**

## 1. INTRODUCTION

DC-DC converters are electronic devices that are used to change DC electrical power efficiently from one voltage level to another. The control of voltage is done by controlling the duty ratio of the switch. Switches used are MOSFETS, transistors, GTO's, IGBT's depending upon the circuit or the power transfer capability. The control of output voltage to a constant magnitude is achieved by the help of a feedback. The use of one or more switches for the purpose of power conversion can be regarded as a Switch-Mode Power Supplies (SMPS). Using a buck converter offers a much cheaper solution to supplying large systems comprised of smaller components.

We want to change the DC energy from one voltage level to another, while wasting as little as possible in the process. In other words, we want to perform the conversion with the highest possible efficiency. DC-DC Converters are needed because unlike AC, DC can't simply be stepped up or down using a transformer. In many ways a DC- DC converter is the DC equivalent of a transformer. DC to DC conversion of electronic manufactured components is always in demand as it saves money and many design constraints by allowing low rated components to be used in larger systems.

Electromagnetic interference (EMI) is harmful to sensitive electronic devices and is thus unwanted in electrical circuits. [1]EMI phenomenon requires three basic elements to be present and they are the "source", the "coupling path" and the "victim", as illustrated in Figure 1.

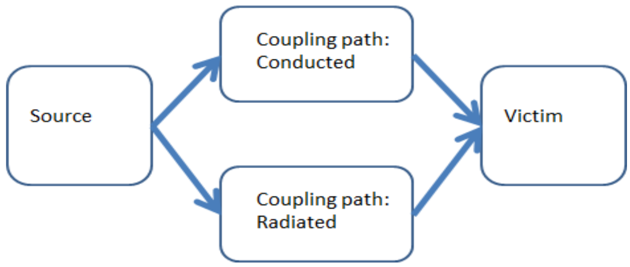


**Fig-1:** Condition for EMI occurrence

### 1.1 Source of EMI

In an electronic device, efficiencies are valued. A power converter is used to control the flow of electrical energy based on the demand by the requirement of the device. This allows the power converter to deliver power to a load with maximum efficiency. Power converter also serves the purpose of converting unregulated AC or DC input power into regulated DC output power that is suitable for the device to operate. For examples, computers, telecommunications systems and motor drives require regulated DC power supplies. However, power converters are also a major source of EMI. In most power converters, high frequency switching techniques are utilised. High frequency switching techniques can effectively reduce the size of the power converters, and also boost the efficiency of the power converter. In high frequency switching techniques, a transistor is switched on and off rapidly.

Just in a fraction of microsecond, the power transistor switch chops voltage of a few hundred volts. When the power transistor is being switched on and off rapidly, while generating the desired frequency, harmonics of that frequency is being produced at the same time. These higher harmonics produced by the rapid switching acts as noise to other devices in the same power grid. These conducted EMI at a much higher frequency as compared to frequencies adopted by the power transistors, up to several tens of MHz. The main sources of EMI in dc-dc converters are due to di/dt and dv/dt during a switching period. The conducted emissions are the major issue in most of the power electronic converters and it is caused by

• Stray inductance of current loops causing high di/dt can create over voltages in high power dc-dc converters.

• Stray capacitive coupling between windings and a frame resulting high dv/dt can create leakage current in magnetic elements and electric motors.

• AC/DC motors.

• Switch-mode power supplies (SMPS), due to high switching frequency and reverse recovery characteristics of diode.

## 2. BLOCK DIAGRAM

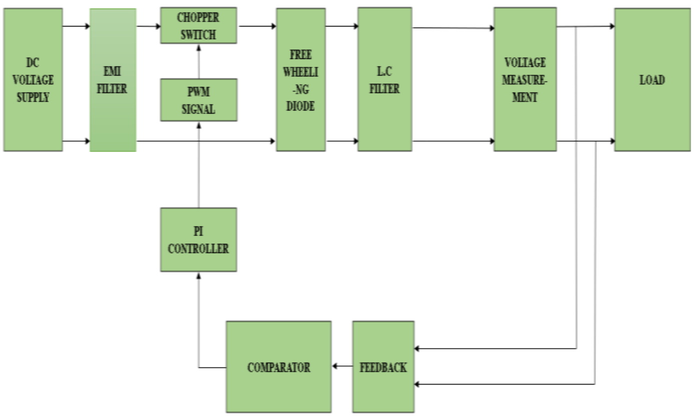


**Fig-2**: Block Diagram

The above figure shows the block diagram of the buck converter. The DC power supply is connected to the EMI filter which reduces the EMI noise, which is in turn connected to the drain of the MOSFET switch. The MOSFET switch is used as it operates for higher frequency (250 KHz). The schotkey diode is used as a freewheeling diode. Since the current in the inductor cannot change suddenly, a path must exist for the inductor current when the switch is off. This path is provided by the freewheeling diode. The purpose of this diode is not to rectify, but to direct current flow in the circuit and to ensure that there is always a path for the current to flow into the inductor. It is also necessary that this diode should be able to turn off relatively fast. Thus the diode enables the converter to convert stored energy in the inductor to the load. This is a reason why we have higher efficiency in a DC-DC converter as compared to a linear regulator. When the switch closes, the current rises linearly. When the switch opens, the freewheeling diode causes a linear decrease in current.

Inductor and capacitors are used to store the energy. The capacitor is used at input and output side in order to reduce the ripple. Capacitor provides the filtering action by providing a path for the harmonic currents away from the load. Output capacitance is required to minimise the voltage overshoot and ripple present at the output of a step down converter. The capacitor is large enough so that its voltage does not have any noticeable change during the time the switch is off. Large overshoots are caused by insufficient output capacitance, and large voltage ripple is caused by insufficient capacitance as well as high equivalent–series resistance in the output capacitor. The feedback is used in order to get the constant output voltage (5V). Voltage sensor is used to measure the voltage value at any given time interval.

### 2.1 EMI Filter

To effectively reduce EMI in a circuit, the coupling path connecting the victim to the source must be made as inefficient as possible. As aforementioned, EMI is at much higher frequencies as compared to normal signals. Hence, EMI can be suppressed by selectively blocking or shunting unwanted higher frequencies. Thus, the duty of an EMI filter is to make electrical signals of unwanted frequency unable to pass through it.

An EMI filter is inserted before the power converter to prevent EMI generated by the device from entering the power grid. The filter also prevents EMI present in the power grid to enter the device and interfere with its performance.

A passive EMI filter has two main components, the capacitor and the inductor. Both components attenuate the noise signals. A shunt capacitor is able to bypass the high frequency noise and a series inductor is able to block high frequency noise from passing through. Hence, these two components are commonly used to form an EMI filter. The goal of this project is to test the designed EMI filters and determine if they are capable of noise suppression.

## 3. BUCK CONVERTER OPERATION

**Mode 1:** The first state corresponds to the case when the switch is ON. In this state, the current through the inductor rises, and the energy stored in it increases, during this state the inductor acquires energy.

$$Vi=Lo*(di_L/dt)+Vo=Lo*(\Delta I/DT)+Vo$$

When the switch is closed, the diode is in the OFF state.

**Mode 2:** The second state is when the switch is OFF and the diode is ON. In this state, the inductor current free-wheels through the diode and the inductor supplies energy to the RC network at the output. The energy in the inductor falls in this state.

0= Vo +Lo*($di_L$/dt) = Vo- Lo*(ΔI/ (1-D) T)

When the switch is open, the inductor discharges its energy.

When all of its energy has discharged, the current falls to zero and tends to reverse, but the diode blocks conduction in the reverse direction. In the third state both the diode and the switch are OFF, in this state the capacitor discharges its energy and the inductor is at rest with no energy stored in it. There cannot be a net change in flux in the inductor or it would saturate over a number of cycles. The increase in current while the switch is on must exactly equal the decrease in current while the switch is open.

((Vi-Vo)/Lo)* DT= (Vo/Lo)* ((1-D)*T)

D=VO/Vi.

The conceptual model of the buck converter is best understood in terms of the relation between current and voltage of the inductor. Beginning with the switch open (in the "off' position), the current in the circuit is 0. When the switch is first closed, the current will begin to increase, and the inductor will produce an opposing voltage across its terminals in response to the changing current. This voltage drop counteracts the voltage of the source and therefore reduces the net-voltage across the load.

Over time, the rate of change of current decreases, and the voltage across the inductor also then decreases, increasing the voltage at the load. During this time, the inductor is storing energy in the form of a magnetic field. If the switch is opened while the current is still changing, then there will always be a voltage drop across the inductor, so the net voltage at the load will always be less than the input voltage source. When the switch is opened again, the voltage source will be removed from the circuit, and the current will decrease. The changing current will produce a change in voltage across the inductor, now aiding the source voltage. The stored energy in the inductor's magnetic field supports current flow through the load. During this time, the inductor is discharging its stored energy into the rest of the circuit. If the switch is closed again before the inductor fully discharges, the voltage at the load will always be greater than zero.[6-8]

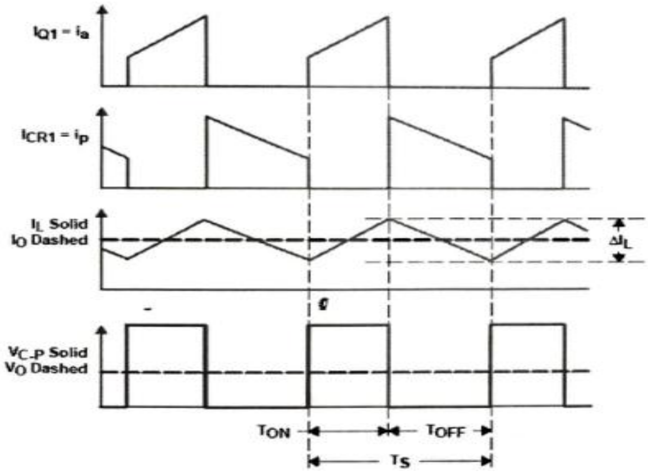


**Fig-3:** Waveform

## 4. DESIGN

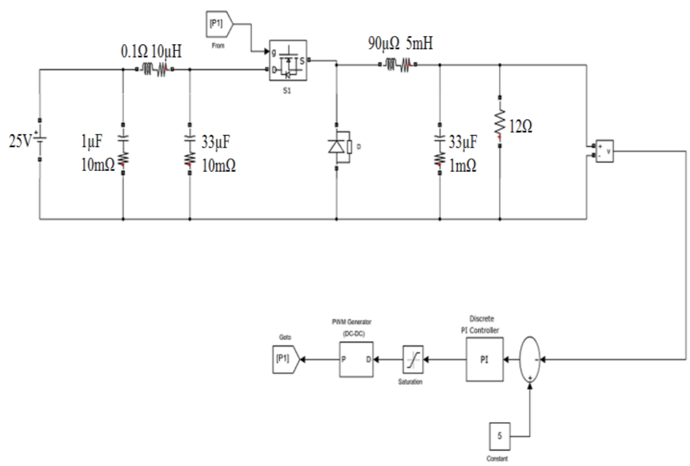


**Fig-4**: Circuit Diagram

Switching frequency, $f_{sw}$=50 KHz

Input voltage, $V_{in}$= 25 V

Output voltage, $V_{out}$= 5 V

Power rating, P= 2 W

Duty ratio, D= $V_{out}/V_{in}$ = 5/25 = 0.2

T=1/$f_{sw}$ = 1/50 KHz= 0.2µs

D= $I_{in}/I_{out}$

P= 2W, $V_o$= 5V

Therefore, $I_o$= P/$V_o$ = 2/5 = 0.4 A = 400mA

Substituting $I_o$ we get $I_{in}$

$I_{in}$ = D* $I_o$ =0.2*0.4= 0.0834A ~ 0.1A

If we consider the peak current as 15% above the load current $I_o$

Then,

I= 0.15*0.4= 0.06A

CALCULATION OF INDUCTANCE:

ΔT = $\Delta I_L$*L*$V_i$/($V_o$($V_i$/$V_o$))

L = 5mH

CALCULATION OF OUTPUT CAPACITANCE:

$T = D/f_{SW} = 0.2/50K$

$= 4\mu s$

Let ripple voltage be 100mV

$I_{ripple} = 1/2 * I_{load}$

$= 1/2 * 0.4$

$= 0.2A$

Output capacitance, $C_{out} = V_o(V_{in} - V_o)/8*L*V_{in}*f^2*\text{change in } V_o$

$C_{out} = 33\mu F$

PI CONTROLLER, Kp=5 , Ki= 500.

The EMI filter is designed by using chain parameters also known as ABCD parameters and stability analysis , these filters are designed to provide insertion loss (IL), but they also affect converter's dynamics and this should be considered during the design process[3].

The choice of the Emi filter configuration- T, LC or π depends on the source and load impedances. If dc voltage source is almost ideal, then there would be no difference between LC and π- filter, in other words, π-filter will perform as an LC- filter if the dc line impedance is negligible. In real operation, this is unlikely to occur due to cabling parasitic inductance will make it inductive therefore a π- filter will perform better.

## 5. APPLICATIONS

- DC to DC conversion is common in large manufactured products such as computers and motor vehicles.
- Cars radios are rated to 5V, so a buck converter is used to step down the voltage to supply the radio.
- Regulating voltage in computers for CPU chips.
- DC-DC converters are where 5V DC on a personal computer motherboard must be stepped down to 3V, 2V or less.
- In satellites.
- EMI filters block different frequencies of noise and to meet varying regulations in different industries.
- EMI filters suppress electromagnetic noise for a variety of home appliances from washing machines to treadmills.
- EMI filters for MRI rooms are purpose-built to create a secure test chamber free of EMI from lighting, intercoms and other sources of outside noise
- EMI filters are used in high-power applications such as industrial machinery and motors, medical equipment, test equipment and industrial tools.
- EMI filters are used in rockets, spacecrafts to mitigate noise for the power converter.
- EMI filters for military applications protect against damage to aerospace and military communication systems for secure operations.

## 6. SIMULATION AND RESULTS

The design of buck converter with EMI filter and the simulation for the same is executed successfully.

1. BUCK CONVERTER WITHOUT EMI FILTER

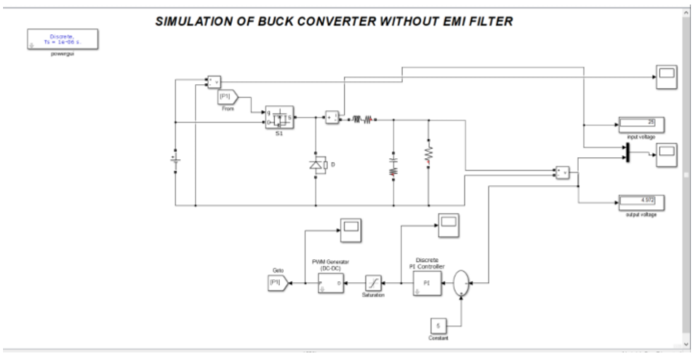


**Fig-5:** Simulation of Buck Converter without EMI filters.

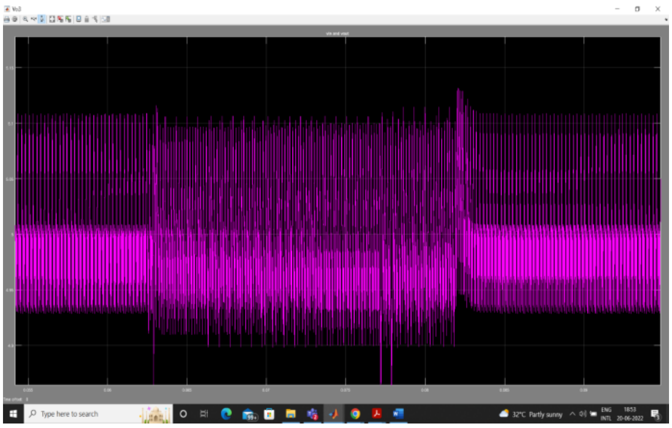

**Fig-6:** Simulation of Buck Converter without EMI filters

Without EMI filter in the buck converter, with an input voltage of 25V, you can see clearly the output voltage ripples ranging from ~5.1V to ~4.9V. Therefore there is a difference of +/-0.1V than the desired output.

2. BUCK CONVERTER WITH EMI FILTER

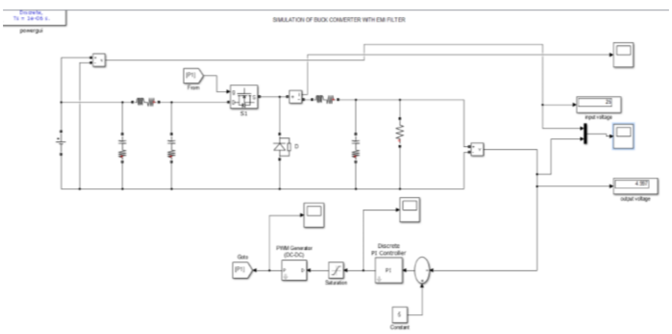

**Fig-7:** Simulation of Buck Converter with EMI filters.

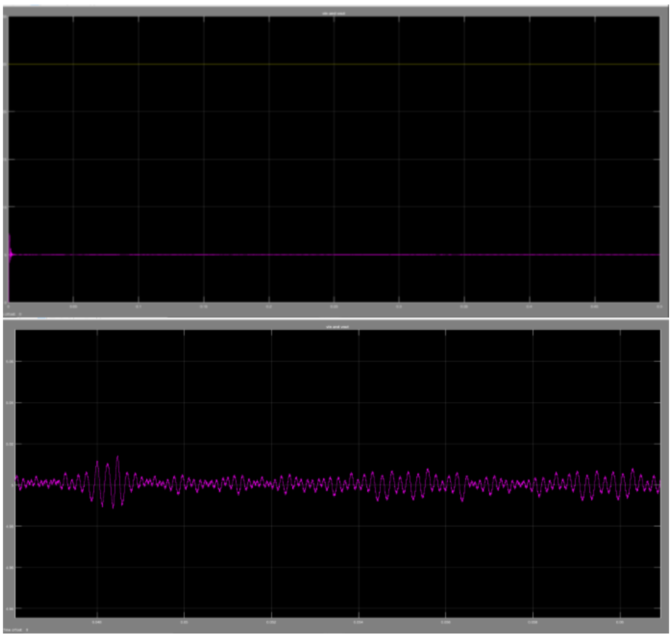

**Fig-8:** Simulation of Buck Converter with EMI filters.

With the addition of EMI filter to the buck converter circuit, for the same input voltage of 25V, you can see clearly the output voltage ripples is drastically reduced ranging from ~5.01V to ~4.99V. Therefore there is a difference of +/- 0.01V which is negligible than the desired output. Hence the desired outcome is observed.

## 3. CONCLUSION

For an EMI occurrence, there are always three basic components exist, the source, victim and coupling path. There are two types of conducted EMI, due to the difference in path undertaken, the CMN and the DMN. To suppress EMI effectively, the coupling path should be made as inefficient as possible, which can be achieved through the addition of EMI filters to the noise source.

Since the EMI generated are high frequency signals, to suppress the EMI, redirection and blockage of these signals are needed. To redirect and attenuate the noise signals, capacitors are used. Capacitors offer low impedance to high frequency and lining them parallel to the load will ensure the noise signals being bypassed instead of reaching the victim. To block the noise from reaching the victim, an inductor can be inserted in series with the victim. Inductors offer high impedance at high frequencies but low impedance at low frequency. Hence, high frequency signals, such as noise will experience high impedance and prevent it from entering the victim.

A step-down power converter has been successfully designed and based on the measurement that was performed, the step-down circuit was able to convert the higher DC input voltage (25V) to 5V DC output EMI free voltage.

## REFERENCES

[1] Liu Yitao, See Kye Yak, Electromagnetic Interference Filter Design, Nanyang Technological University, 28 July 2015.

[2] K.Manjula, B.E., S.Bhuvaneswari, M.E., (Ph.D)., A Review of Analysis and Design of EMI Filters for Power Electronic Converters, 08 Nov 2015.

[3] J. L. Kotny, T. Duquesne, N. Idir, Design of EMI filters for DC-DC converter, 02 June 2016.

[4] Konstantin Kostov, Jorma Kyyrä , Analysis and Design of EMI Filters for DC-DC Converters Using Chain Parameters, Teuvo Suntio Helsinki University of Technology, 24 September 2003.

[5] Magdy Saoudi, Ahmed El-Sayed, Hamid Metwally,Design and Implementation of Closed Loop Control System for Buck Converter Using Different Techniques Zagazig University. 22 June 2021.

[6] Rashid H. Muhammad, Power Electronics- Circuits, Devices and Applications, Prentice Hall India, 2004

[7] Bimbra P. S., Power Electronics, Khanna Publishers, 2007.

[8] http://en.wikipedia.org/wiki/Buckconverter