

An Application Study about SMPS Design and Reduction of Common Mode Noises

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Abstract

A switched-mode power supply (also called as switching-mode power supply, SMPS, or simply switcher) is an electronic power supply unit (PSU) that incorporates a switching regulator. This paper investigates SMPS design and a filter solution for common mode noises. At first, the design of an SMPS which has three outputs has been presented after that common mode noises have been determined and then these noises have been tried to be reduced by the filter. The experimental studies have shown that there is a considerable reduction in common mode noises thanks to designed filter.

1. Introduction

For many years the world of power supply design has seen a gradual movement away from the use of linear power supplies to the more practical switched mode power supply (SMPS) [1].

The main advantage of an SMPS is great efficiency because the switching transistor dissipates little power in the saturated state and the off state compared to the semiconducting state (active region). Other advantages include smaller size and lighter weight (from the elimination of low frequency transformers which have a high weight) and lower heat generation from the higher efficiency [2].

The increasing integration of power electronic circuit modules together with the continuing growth in power density, switching speed and operating frequency have resulted in a close interaction between electromagnetic, thermal and mechanical considerations and a significant increase in unwanted parasitic effects. The rapid switching capability of modern semiconductor devices (MOSFET, IGBT, etc) results in very fast voltage and current variations which act on structures such as heatsinks generating parasitic currents, voltage transients and radiated emissions [3].

The main disadvantages of SMPS are common mode and EMI noises. [2].

A common mode choke may be used to reduce a type of electrical noise known as common mode noise. Electro-magnetic interference (EMI) in the circuit's environment is one source of electrical noise. EMI induces or couples unwanted electrical signals into the circuit. It is desirable to filter out the unwanted noise signals without significantly affecting the desired signal. Environmental sources of EMI often create an independent return path (ground path) for the electrical noise signals. The return path of the desired signal is a different path. Because there are two different return paths, a common mode choke can be used to significantly block (hence reduce) the unwanted noise signal (at the load) without significant reduction in the desired signal [4].

Reducing the SMPS output noises which originates from high frequency switching is as important as suppressing the transmission of EMI noises into the SMPS circuits. Therefore this study aims to design a filter to reduce the common mode noises for the output of traditional SMPS which is applied in real time.

In this study, firstly a traditional SMPS will be designed then a filter will be proposed to suppress the noises that stated with reasons above which occurs in the SMPS output. The real time application studies shows that designed filter has considerable reduced the noises at the SMPS output.

2. Basic Switched Mode Supply Circuit and Its Working Principles

An SMPS can be a fairly complicated circuit, as can be seen from the block diagram shown in Fig. 1. (This configuration assumes a 50/60Hz mains input supply is used.) The ac supply is first rectified, and then filtered by the input reservoir capacitor to produce a rough dc input supply. This level can fluctuate widely due to variations in the mains. In addition the capacitance on the input has to be fairly large to hold up the supply in case of a severe droop in the mains [1].

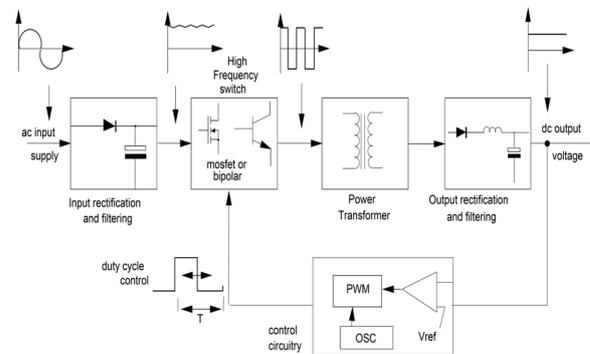


Fig. 1. Basic switched mode power supply block diagram [1]

In the SMPS first stage AC input is converted to DC. The inverter stage converts DC, whether directly from the input or from the rectifier stage described above, to AC by running it through a power oscillator, whose output transformer is very small with few windings at a frequency of tens or hundreds of kilohertz (kHz). If the output is required to be isolated from the input, as is usually the case in mains power supplies, the inverted AC is used to drive the primary winding of a high-frequency transformer. This converts the voltage up or down to the required output level on its secondary winding. The output

transformer in the block diagram serves this purpose. A feedback circuit monitors the output voltage and compares it with a reference voltage, which is set manually or electronically to the desired output. If there is an error in the output voltage, the feedback circuit compensates by adjusting the timing with which the MOSFETs are switched on and off. This part of the power supply is called the switching regulator [2].

2.1 SMPS Design

Required values for the SMPS that is to be designed in this study are shown in Table 1.

Table 1. Parameters of designed SMPS card.

Qualifications	Input: 85-265 V universal input
	Power: 34,87 W
	Outputs: 24V/1A, 8V/1.25A, 8V/0.1A

With the PI Expert Program [5], switched power supplies of various topologies can be designed. Also with the optimization add-on inside the program, optimum parameters can be found according to the design. Obviously, SMPS design steps are relatively difficult and complex. The most important advantage of this software is its own verification of SMPS designs [6]. Within the parameters, given in Table 1, required topology is created and the input-output elements (such as rectifier, capacity and filter elements...) are determined by PI Expert. Flyback is chosen for the designed topology and switching frequency is set to 132kHz. In the design, optimization and productivity are taken as the basis. Schematic of the designed SMPS and circuit form obtained via PI Expert are given in Fig. 2 and Fig. 3 respectively.

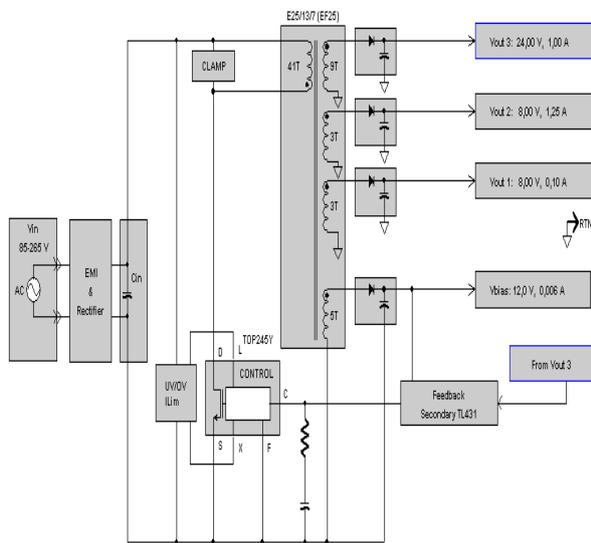


Fig. 2. Output visual of PI Expert Software

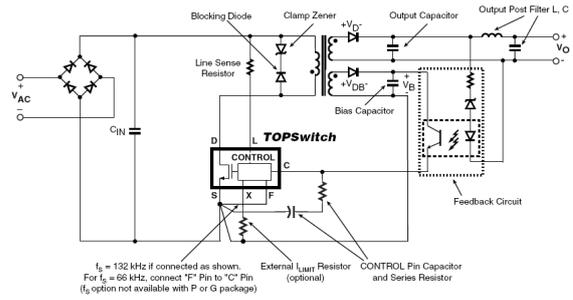


Fig. 3. SMPS equivalent circuit scheme [6]

Kelvin connection at S spot in Fig. 3 is used to prevent interference, that occurs through the high frequency switching of the transistor, from leaving the bias point and reach the output. A detailed view of the connection is shown in Fig. 4.

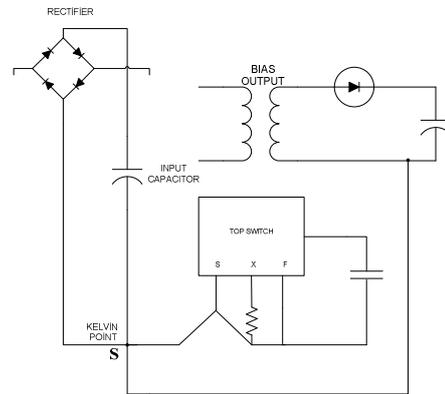
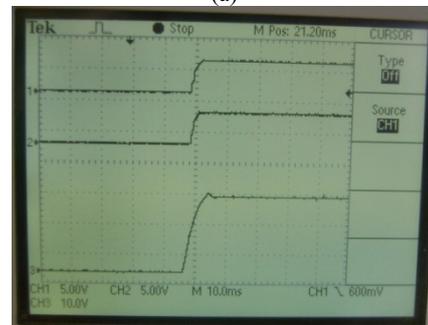


Fig. 4 Kelvin Connection [6]

The real time view of constructed SMPS, designed for experiment studies, is given in Figure 5 (a) and start-up profiles of its are shown in Figure 5 (b).



(a)



(b)

Fig. 5. (a) Picture of the designed circuit (b) Start-up profile of the circuit

3. Common Mode Choke and Common Mode Noise Problem

3.1 Common mode Choke

The common mode choke (Zorro or Balun) as shown in Fig. 6 is usually used to mitigate the common mode interference. In theoretical, the common mode choke has high impedance for common mode current and zero impedance for differential mode current. Although, in fact the common mode choke can reduce the common mode current, the leakage inductance of common mode choke also can reduce the differential-mode current. The leakage inductance is proportional to the gap between winding. The wide distance winding will get high leakage inductance and low differential mode current but the narrow distance winding is vice versa. Therefore, the common mode choke of EMI filter is wide distance winding [7].

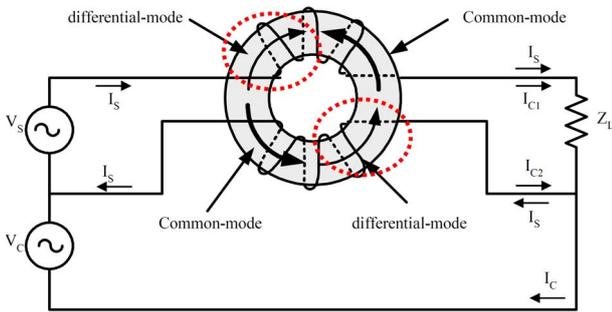


Fig. 6. The flux direction of common-mode chokes [7]

Fig. 7 shows the equivalent circuit of conventional common mode chokes (CM) [8]. The direction of common mode current that passing through the common mode choke will strengthen the magnetic field intensity which affects to increase the inductance but the direction of differential mode current will generate the opposite direction of magnetic field intensity that means the result of zero inductance [7].

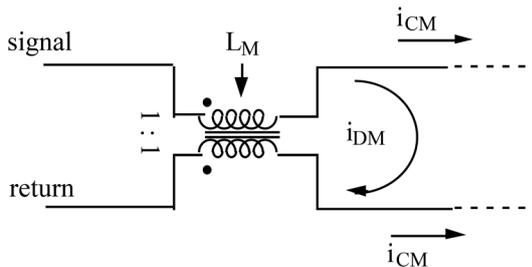


Fig. 7. Equivalent Circuit of Common mode choke [8]

3.2 Common Mode Filter

The second order common mode filter circuit scheme used for designed filter is given in Fig.8. A second order filter uses two reactive components and has two advantages over the first order filter: 1) ideally, a second order filter provides 12 dB per octave attenuation (four times that of a first order filter) after the cutoff point, and 2) it provides greater attenuation at frequencies above inductor self-resonance [9].

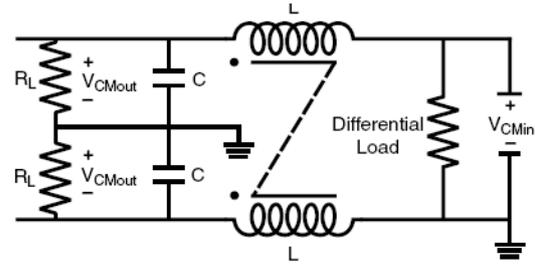


Fig. 8 Circuit Scheme of Second Order Common Mode Filter [9]

Conjugate circuit equations are given in Equation (1),(2),(3) and (4,5):

$$\frac{Vg}{V} = \frac{1}{1 + \frac{1}{R_L}s + LCs^2} \quad (1)$$

$$\frac{Vg}{V} = \frac{1}{1 - LCw^2 + jw\left(\frac{L}{R_L}\right)} \quad (2)$$

$$\frac{Vg}{V} = \frac{1}{1 + j2\zeta\frac{w}{w_n} - \left(\frac{w}{w_n}\right)^2} \quad (3)$$

w = radian frequency,
 R_L =the noise load resistance

$$w_n = \frac{1}{\sqrt{LC}}, \zeta = \frac{L}{2R_L\sqrt{LC}} \quad (4,5)$$

The load resistance at the cutoff frequency: Assumed $R_L = 50 \Omega$

3.3 Common mode Noise

The term “common-mode noise” is used in both ac power management and in circuit design considerations.

Common-mode noise in terms of ac power is the noise signal between the neutral and the ground conductor. This should not be confused with normal-mode noise, which is referenced between the line (hot) and the neutral conductor.

Common-mode noise impulses tend to be higher in frequency than the associated normal-mode noise signal.

This is to be expected since the majority of the common mode signals originate from capacitively coupled normal mode signals. The higher the frequency, the greater the coupling among the conductors, line, neutral, and ground. Electronic equipment is 10 to 100 times more sensitive to common-mode noise than to normal-mode noise [10].

Common-mode conducted noise in switching converters frequently causes radiated noise emission from their power cord, so it is important to reduce this noise to meet EMC. Because conventional switching converters are usually using unbalanced circuit topologies, parasitic capacitance between the drain of an MOSFET and the frame ground through its beat sink may generate the common-mode conducted noise [11].

A common-mode signal is a signal that appears common to either set of floating points. It can be either ac or dc [12].

The overall effect is that excessive common mode noise causes spurious results at the output, disrupting safe, precise measurements [12].

3.4 The origins of common mode noises

The transformer is made from concentric windings on top of each other for the primary and secondary windings, so there is quite a bit of capacitance from input to output on the transformer as shown in Fig. 9 [13].

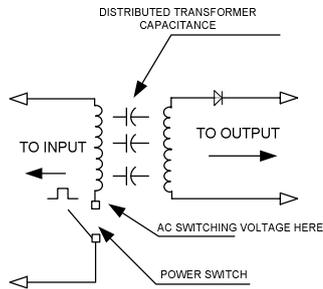


Fig. 9. The Distributed transformers capacitance [13]

The dV/dT caused by the power switch in turn causes a current to flow from the input to the output circuit through the distributed capacitance of the transformer. The trick is to keep this current out of design circuit.

Each time the input chopper switches, a large dV/dT is impressed by the input stage across the transformer I/O capacitance. This in turn, causes a current to want to flow from input to output through the transformer capacitance.

This current flows twice each switching cycle and it must find a path back to the input “source.” The current is commonly called the “Common Mode Current” since it can flow through any or all of the I/O pins individually or at the same time [13].

4. Proposed Common Mode Noise Reduction Filter and Experimental Results

The output voltage waveform of the designed SMPS is given in the Fig. 10 when DC output value is 8V. As clearly seen from Fig.10 common mode noise peak value reaches up to 280 mV that should be damped to allow the system, powered by SMPS, operates properly.

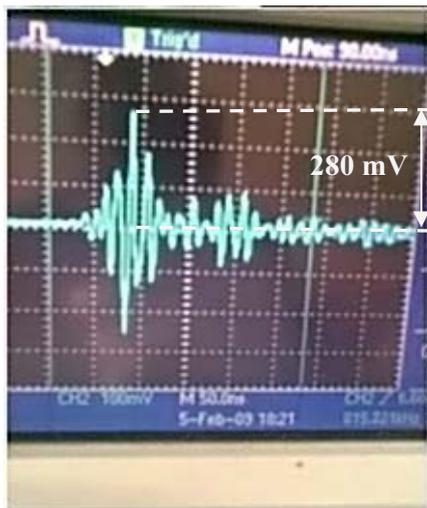


Fig. 10. Noise on the SMPS output (scale 100 mV)

The principle circuit scheme of the designed common mode filter to damp this noise is given in Fig 11 and the filter consisting of designed common mode coil and capacitors real time view are given in Fig. 12.

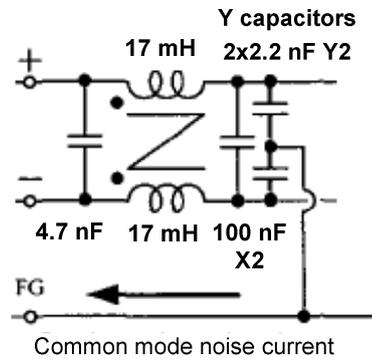


Fig. 11. Designed common Mode Filter basic equivalent circuit

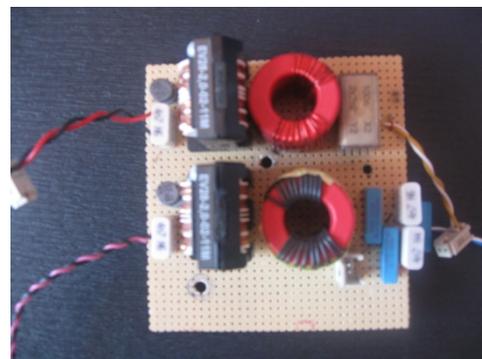


Fig 12. Common mode filter designed for SMPS 8v and 24v.

In order to prevent common mode noise, transient flux is returned to its source through the designed filter instead of the load by using common mode coil and capacitor on the secondary outputs of SMPS transformer. Circuit scheme and parasitic capacities are given in Fig. 13.

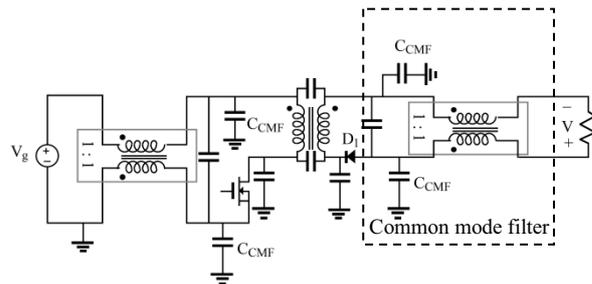


Fig. 13. Circuit scheme and parasitic capacities for common mode noise [8]

In Fig. 13, in the aspect of load, common mode coil and C_{CMF} capacitors are acting as filters. The real-time application and real-time view of the designed filter connected to SMPS are given in Fig. 14.

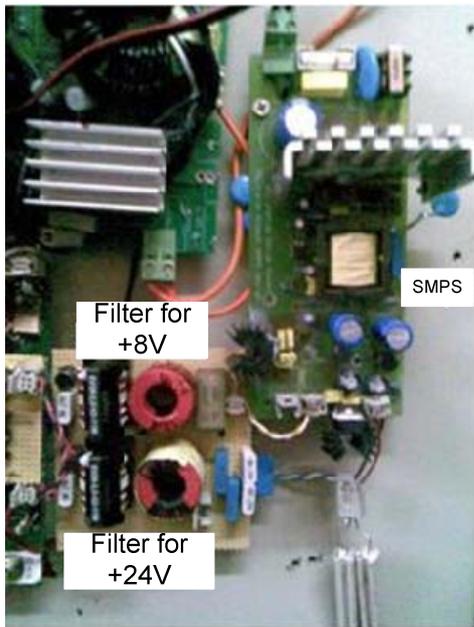


Fig. 14. Designed filters and SMPS.

When the designed filter is connected to SMPS output, the noise problem in +8V SMPS output is solved as shown in Fig. 15.



Fig. 15. SMPS +8V output after common mode filter (scale 2mV)

When Figs. 10 and 15 are compared, it could be clearly seen that the common mode noise occurs in SMPS output is significantly reduced with the designed filter.

5. Conclusion

This study consists of design and real time application of the filter to reduce common mode noise of SMPS. Common mode and EMI noises are two main problems that should be filtered on the input in SMPS's, but they also affect SMPS output because of the high switching. It is particularly inevitable to use filters for applications such as performing measurements on the output which are extremely sensitive to noise.

In this study, conventional noise reduction methods like EMI filters or Kelvin connection are used but their capability to reduce output noise was so limited. Therefore in this study a common mode noise filter is designed and realized in real time which reduces common mode noise on SMPS outputs. It is observed through the real-time application that designed filter significantly damp the common mode noise. Thus, this study brings a solution for the reduction of common mode noise that significantly affects measurement and system performance.

6. Acknowledge

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6. References

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