Global Journal of Researches in Engineering: F
Electrical and Electronics Engineering
Volume 17 Issue 2 Version 1.0 Year 2017
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Modeling and Mitigation on Conducted Emission for Switch Mode Power Supply

Li Lin, Qiu Dongmei , Yan Wei & Gao Xiang
Nanjing Normal University

Abstract- The switch mode power supply (SMPS) have been widely used in the electrical and electronics systems for AC-DC and DC-DC power conversion, which can generate a lot of electromagnetic interference (EMI), especially conducted emission (CE) from 9kHz to 30MHz. The traditional CE models and mechanisms have been present for three line systems, including live, neutral and ground lines, while a novel CE models and mechanisms have been proposed in the paper for two line SMPS. And the voltage division factor, isolation factor and impedance under SMPS side of artificial mains network have been studied based on high frequency parasitic parameters to analyze the CE measurement uncertainty. Moreover, three methods have been designed to reduce the CE of SMPS, such as the capacitor shunt between the source and drain electrodes of MOSFET, CM choke and crosstalk choke, and the capacitors matrix.

Keywords: electromagnetic interference (EMI); noise mechanism; noise mitigation; SMPS; conducted emission.

GJRE-F Classification: FOR Code: 290901

MODELINGANDMITIGATIONONCONDUCTEDEMISSIONFORSWITCHMODEPOWERSUPPLY

Modeling and Mitigation on Conducted Emission for Switch Mode Power Supply

Li Lin [α], Qiu Dongmei [α] , Yan Wei [σ] & Gao Xiang [ρ]

Abstract- The switch mode power supply (SMPS) have been widely used in the electrical and electronics systems for AC-DC and DC-DC power conversion, which can generate a lot of electromagnetic interference (EMI), especially conducted emission (CE) from 9kHz to 30MHz. The traditional CE models and mechanisms have been present for three line systems, including live, neutral and ground lines, while a novel CE models and mechanisms have been proposed in the paper for two line SMPS. And the voltage division factor, isolation factor and impedance under SMPS side of artificial mains network have been studied based on high frequency parasitic parameters to analyze the CE measurement uncertainty. Moreover, three methods have been designed to reduce the CE of SMPS, such as the capacitor shunt between the source and drain electrodes of MOSFET, CM choke and crosstalk choke, and the capacitors matrix. The experiment results show that the CE of the power concentrator and colonoscopy can be suppressed well and pass EN 55022 class B, thus realize the proposed approaches good validation.

Keywords: electromagnetic interference (EMI); noise mechanism; noise mitigation; SMPS; conducted emission.

I. Introduction

Switch mode power supply (SMPS) has been widely applied in the electrical and electronics devices, which can realize the AC-DC, DC-DC conversion and generate larger amount of electromagnetic interference (EMI), especially conducted emission (CE) from 9kHz and 30MHz [1-5]. The CE standards have been established by the most countries and areas, such as EN 55022 [6].

In recent years, the CE models and mechanisms for live, neutral and ground lines system have been proposed to analyze the noises paths, which contributes to noise suppression [7-11]. The CE models consist of common mode (CM) and differential mode (DM) noises. The CM noise path is from live/neutral line to ground line, and the DM path is from live line to neutral line. Four kinds of noise separation networks have been proposed to determine the CE mechanism by extracting CM and DM noises by Paul, See, Mardiguian and Guo [2, 12-14]. Paul network is composed of two radio frequency transformers with 1:1 and artificial switch, through which the high frequency (HF) noises are generated and coupled [2]. The core of See network is also two radio frequency transformers with 2:1, but the HF noises are generated through the parasitic capacitor between the primary and secondary coils [12]. To improve the topology of network, the network was designed with one radio frequency transformer with 2:1 by Mardiguian [13]. Moreover, the 0° and 180° power dividers have been used to constitute the noise separation network [14].

Based on the above models and mechanism, a lot of categories have been carried out to reduce the CE noises [15-19]. The EMI noises from DC-DC Buck conversion has been suppressed by employed MOSFET, decoupling capacitors and optimal design for PCB [15]. A frequency modulated (FM) source of conducted emission has an adverse effect on a DC power system and spread spectrum modulation is proposed to reduce EMI noises [16]. The Power Integrity problem for high speed systems is discussed in context of selection and placement of decoupling capacitors. The optimal capacitors and their locations on the board are found using the presented methodology, which can be used for similar power delivery networks in high speed systems [17]. A modified LLCL-filter topology is proposed to provide enough attenuation on the conducted EMI noise as well as to reduce the DC side leakage current [18]. A new method to reduce CM EMI at the DC input of variable-speed motor drives is analyzed. Unlike conventional passive or active filtering techniques that rely on impedance mismatch or active noise cancellation, the method uses a passive circuit with matched impedance to cancel the inverter CM current [19]. However, the above noise reduction methods can't obtain the EMI source and solve the EMI problem fundamentally in the economy and practical scale.

In view of above analysis and on basis of the acquired achievements about EMC of electronic equipments, the CE models and mechanisms for SMPS have been analyzed in the paper. And the CE measurement uncertainty was studies based on the voltage division factor, isolation factor and impedance under SMPS side of artificial mains network. Then, three methods have been proposed to reduce the CE, such as the capacitor shunt between the source and drain electrodes of MOSFET, CM choke and crosstalk choke, and the capacitors matrix. The experiment results show that the CE noises of the power concentrator and colonoscopy can be suppressed effectively and efficiently by using the present approaches, while can pass the EN 55022 and improve the safety and EMI performance.

Auhtor α: Jiangsu Institute of Metrology, Nanjing, 210023, China.
Auhtor σ: School of Electrical and Automation Engineering, Nanjing Normal University, Nanjing 210042, China. e-mail: 61197@njnu.edu.cn
Corresponding Author ρ: 61188@njnu.edu.cn.

II. SMPS Operation Description

SMPS can support direct current (DC) power to the load through four diodes and metal oxide semiconductor field effect transistor (MOSFET). Voltage dependent resistance (VDR) was employed to resist and suppress the external surges and interferences. Three capacitors and common mode (CM) choke were used to reduce the high frequency (HF) EMI noises. However, a large amount of EMI noises were generated by SMPS via four diodes and FET, which will go to power supply through power line and influence other electrical and electronics devices.

CM and differential mode (DM) models were established to analyze the noise mechanism and suppress the above EMI noises based on three line system including live, neutral and ground lines, as shown in Fig.1.

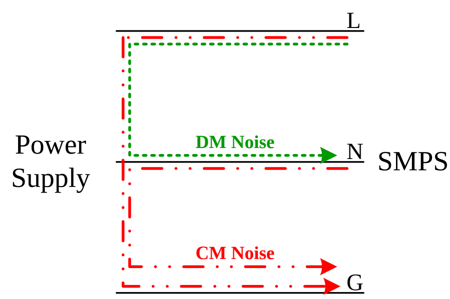


Fig. 1: CM and DM noise mechanism based on three line system

Due to the difference between the topology of SMPS (two line system without ground line) and traditional three line system, the conducted emission mechanism will be studied.

III. Uncertainty of Conducted Emission Measurement

According to EN 55022 and FCC Part 15, conducted emission can be detected by EMI receiver and artificial mains network (AMN), where quasi peak detector and average detector should be fixed on the EMI receiver.

To analyze the uncertainty of CE measurement, the topology structure and HF parasitic parameters of AMN will be investigated. According to CISPR 16, the topology structure is shown in Fig.2, where C_1 is 1μF, C_2 is 0.1μF, R_1 is 50Ω, R_2 is 1kΩ and L_1 is 50μH. The HF noise from 9kHz to 30MHz in power supply can be reduced by capacitor C_1 and inductance L_1, and the 50Hz current is also ordinary and functional. The CE from 9kHz to 30MHz in SMPS can be extracted through capacitor C_2. Resistance R_1 is used to bypass flow and resistance R_2 is designed to measure CE.

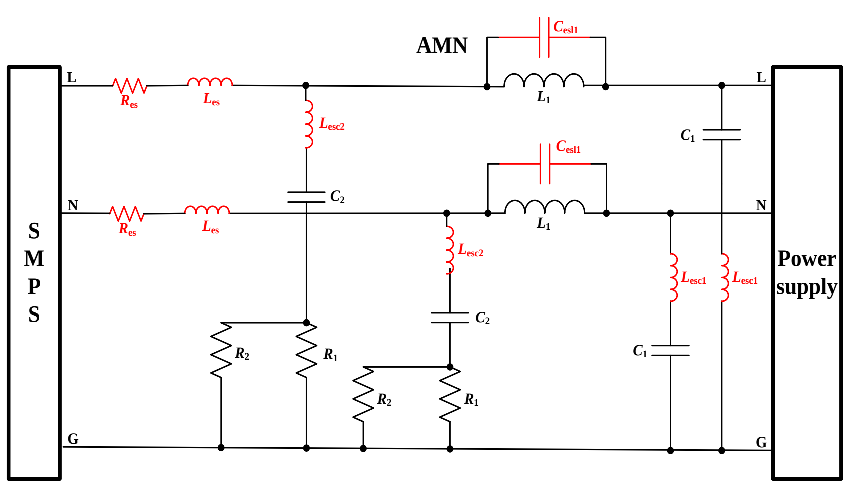


Fig. 2: Topology structure of AMN based on CISPR 16 (red characters are HF parasitic parameters)

Considering the HF parasitic parameters of the above capacitors, inductances and resistances, as shown in Fig.2, L_{esc1} and L_{esc2} are the parasitic inductance of C_1 and C_2, respectively. C_{esl1} is the parasitic capacitor of L_1. L_{es} and R_{es} are the parasitic inductance and resistance of the interface adapter. In the paper, R_{es} is neglected due to the adapter design and manufacturing technique.

To analyze the characteristic of AMN, the voltage division factor, isolation factor and impedance under SMPS side were defined as

$$\begin{array}{ll} VIF_L = 20\log\left|\dfrac{U_L}{U_{LG}}\right| & VIF_N = 20\log\left|\dfrac{U_N}{U_{NG}}\right| \\ IRR_L = 20\log\left|\dfrac{U_L}{U_{PLG}}\right| & IRR_N = 20\log\left|\dfrac{U_N}{U_{PNG}}\right| \end{array} \quad (1)$$

Where, VIF_L and VIF_N denote the live and neutral lines voltage division factor of AMN, IRR_L and IRR_N represent the live and neutral lines isolation factor of AMN, U_L and U_N express the total CE of live and neutral lines, U_{LG} and U_{NG} express the HF EMI noise between live/ neutral and ground lines.

a) The voltage division factor of AMN

To analyze the voltage division factor of AMN, the above parasitic parameters were considered lonely as shown in Tab.1 and the results were shown in Fig.3.

Table.1: Four Parasitic Parameters Assumption

L_{esc1}	1 nH
L_{esc2}	0.1 nH
C_{esl1}	40 pF
L_{es}	100 nH

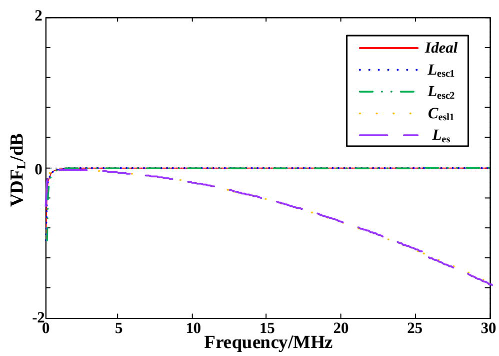


Fig. 3: The voltage division factor of AMN considering HF parasitic parameters

As shown in Fig.3, L_{esc2} and L_{es} have great influence on the voltage division factor of AMN.

b) The isolation factor of AMN

To analyze the isolation factor of AMN, the above parasitic parameters were considered lonely as shown in Tab.I and the results were shown in Fig.4, where the L_{es} can be neglected due to the measurement circuit.

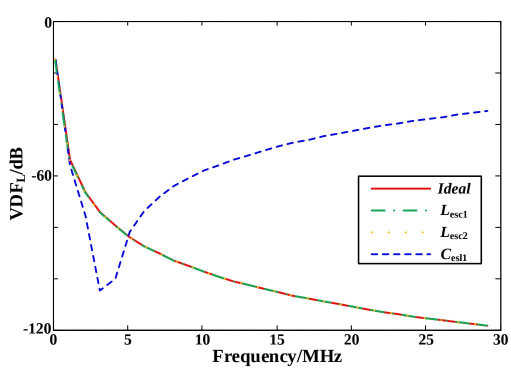


Fig.4: The isolation factor of AMN considering HF parasitic parameters

As shown in Fig.4, C_{esl1} have great influence on the isolation factor of AMN.

c) The impedance under SMPS side of AMN

To determine the impedance under SMPS side of AMN, L_{es} was considered as 10nH and 100nH, respectively, and the other parasitic parameters can be neglected due to the measurement circuit, as shown inFig.5.

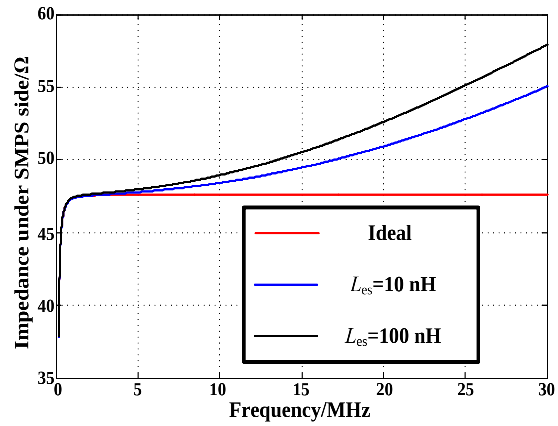


Fig.5: The impedance under SMPS side of AMN considering HF parasitic parameters

As shown in Fig.5, with the L_{es} and measurement frequency increasing, the impedance under SMPS side was increasing greatly.

Therefore, the proper AMN should be designed and employed to determine the CE and decrease the uncertainty of CE measurement through capacitor and inductance matching.

IV. CE Characteristic Mechanism Model

a) CM and DM models

Due to the difference between the two line SMPS system and three line system, the CE characteristic mechanism model should be established. Considered that SMPS have live and neutral lines but no ground line, the CM and DM noise transmission loop can't be formed and realized.

As shown in Fig.2, the two different results can be obtained based on EN 55022, as follows:

$$I_L = I_N \qquad I_L \neq I_N$$

Where, I_L and I_N denote the total CE current through live and neutral lines. Based on the formula (2), the unbalanced noise current can be defined as

$$I_L - I_{DM} = I_N + I_{DM} \tag{3}$$

Where, I_{DM} represents the unbalanced noise current and can be considered as DM noise current. Then,

$$\begin{cases} I_{CM} = I_L - I_{DM} \\ I_{CM} = I_N + I_{DM} \end{cases} \tag{4}$$

Where, I_{CM} signifies the balanced noise current and can be considered as CM noise current.

Based on Fig.2, the total live line noise have two bypass loops, such as live to ground noise I_{LG} and live to neutral noise I_{LN}. Similarly, the total neutral line noise also have two bypass loops, such as neutral to ground noise I_{NG} and neutral to live noise I_{NL}. Supposed that

$$\begin{aligned} I_L &= I_{LG} + I_{LN} \\ I_N &= I_{NG} + I_{NL} \end{aligned} \tag{5}$$

Moreover, the amplitude of the I_{LN} and I_{NL} were equal but the phases were opposite.

$$I_{NL} = -I_{LN} \tag{6}$$

By substituted to formula (5), it can be obtained

$$I_L = I_{LG} + I_{LN} \quad I_N = I_{NG} - I_{LN} \tag{7}$$

and,

$$I_{LG} = I_L - I_{LN} \quad I_{NG} = I_N + I_{LN} \tag{8}$$

Considered I_{LN} as I_{DM},

$$\begin{cases} I_{CM} = I_L - I_{DM} = I_L - I_{LN} = I_{LG} \\ I_{CM} = I_N + I_{DM} = I_N + I_{LN} = I_{NG} \end{cases} \tag{9}$$

Based on the formula (3) and (9), the CM noise can be defined as

$$U_{CM} = U_{LG} = U_{NG} \quad U_{CM} = \frac{U_L + U_N}{2} \tag{10}$$

The equivalent transmission circuit of CM noise was shown in Fig.6(a).

Where, U_{CM} and Z_{CM} represent the equivalent CM noise source and its impedance.

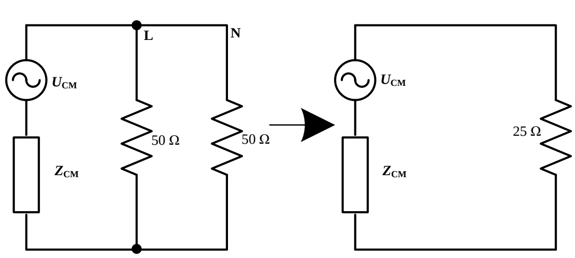
Based on the formula (3) and (8), the DM noise can be defined as

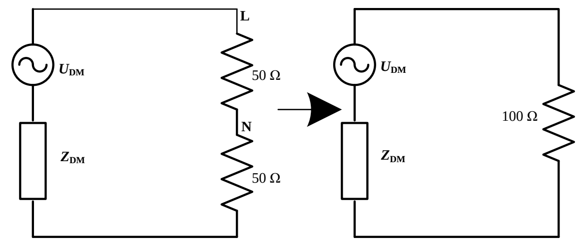
$$I_{DM} = \frac{I_L - I_N}{2} \quad U_{DM} = \frac{U_L - U_N}{2} \tag{11}$$

The equivalent transmission circuit of DM noise was shown in Fig.6(b).

Where, U_{DM} and Z_{DM} represent the equivalent DM noise source and its impedance.

Moreover, Z_{CM} and Z_{DM} can be determined by employing the insertion method, dual current probe method, single current probe current, scattering parameter method and the proposed dual resistance calibration method.





(a). *CM noises* (b). *DM noises*

Fig. 6: Noise equivalent transmission circuits

b) CE model for SMPS

Due to the two lines system, the parasitic capacitor to ground can be considered to analyze the equivalent bypass circuits of CM and DM noises, as shown in Fig.7.

The DM noise path was from live line to neutral line, the same as the three line system, as shown in Fig.1. However, the CM noise path was from live/neutral line to ground line, then to the SMPS through the parasitic capacitor C_{PG}.

Therefore, CE for SMPS still have CM and DM noises, but not the only DM noise, where noise suppression categories should be designed not only for DM noise but also for CM noise.

Moreover, the DM noise is much larger than CM noise in general because the parasitic capacitor is little, even ignored.

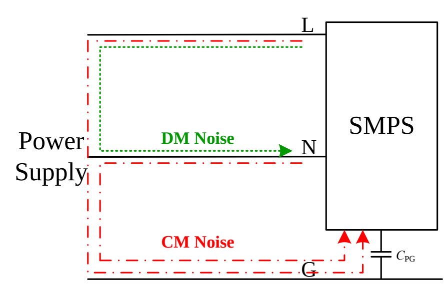


Fig. 7: CE model for SMPS

V. CE Mitigation Method for SMPS

a) The capacitor shunt between the source and drain electrodes of MOSFET

The switch frequency can be controlled through the grid electrode of MOSFET and the HF noise will generate and couple to the source and drain electrodes due to the MOSFET. The frequency of noises are based on the switch velocity, basically from 9kHz to 30MHz, which is the CE source.

The capacitor shunt between the source and drain electrodes can be used to reduce the above HF noises. Moreover, the value of the capacitor should be smaller than 0.1μF not only for the noise mitigation but also for the safety regulations & design, as shown in Fig.8, where, C_4 denotes the capacitor shunt between the source and drain electrodes of MOSFET.

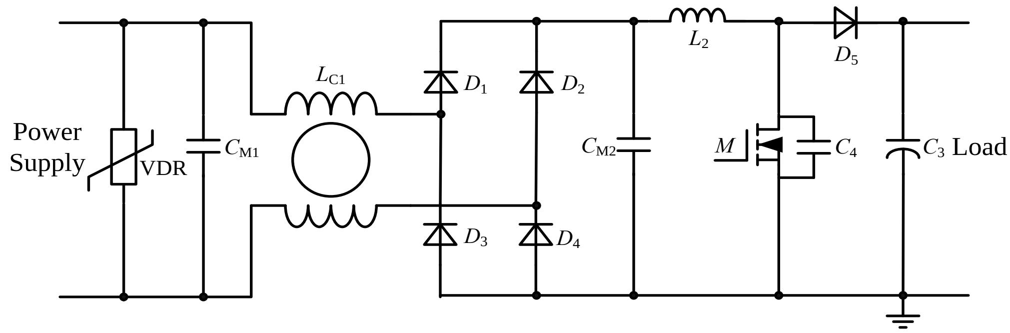
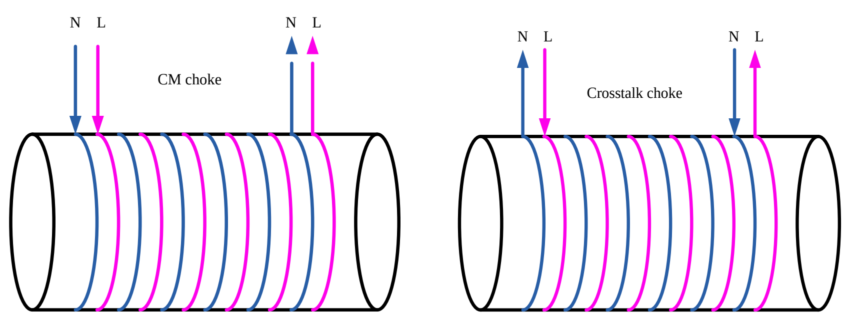


Fig. 8: Topology structure of SMPS

b) CM choke and crosstalk choke

The CM choke can be employed to suppress the CM noises, but can't solve the environmental electromagnetic field coupling. As shown in Fig.9(a), the live and neutral lines are in the same direction in the CM choke, which can well reduce the CM noise due to the electromagnetic field offset. Meanwhile, the CM choke can be considered as two electric dipoles which can receive the environmental electromagnetic field greatly and couple to the power lines. And the amplitude of the coupling noise is based on the length of dipoles and the noise frequency.

The crosstalk choke whose live and neutral lines are in the different orientation, can be used to solve the above problem. With different of CM choke, the crosstalk choke can be considered as the magnetic dipole, which can also obtain the environmental electromagnetic field. And the magnitude of the coupling noise resolves the area of dipole and the noise frequency. As shown in Fig.9(b), the area of the dipole is the area between the live and neutral lines, which is very little. As shown in Fig.12, the L_{C1} represents the CM choke and crosstalk choke.



(a). *CM choke* (b). *Crosstalk choke*

Fig. 9: CM choke and crosstalk choke

c) The capacitors matrix

The single capacitor with the fixed value can suppress the certain spectrum noise due to HF parasitic parameter of the capacitor, such as the parasitic inductance of the pins. The capacitors matrix can be employed to solve the problem, which consists of 100pF, 1nF, 10nF, 0.01μF and 0.1μF. The different frequency noise will be reduced by the capacitors with different values, as shown in Tab.2. As shown in Fig.8, the C_{M1} and C_{M2} denote the two capacitors matrix.

Tab. 2: Noise Mitigation Based on Different Capacitors

Capacitor's Value	Reduced noises frequency
100pF	20MHz and the above
1nF	10MHz-30MHz
10nF	5MHz-20MHz
0.01μF	500kHz-10MHz
0.1μF	9kHz-1MHz

VI. Experiment Verification

To verify the proposed methods, the SMPSs of the power concentrator and colonoscopy are studied in the paper. In the experiment, R&S EMI receiver ESL3 and R&S artificial mains network (AMN) ENV216 are used to determine the CE generated by the above devices.

a) SMPS of the power concentrator

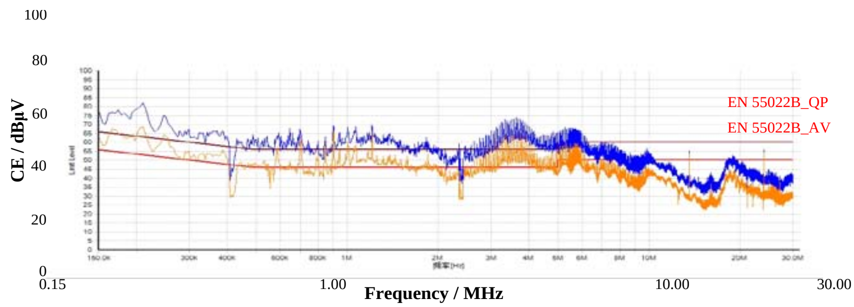
The original CE result of the power concentrator is shown in Fig.10(a),(b). According to EN 55022 Class B, the noise can't pass the standard from 150kHz to 10MHz. The average noises are 54dBμV@13.56MHz and 55dBμV@27.12MHz. And it exceeds 20dBμV from 3MHz to 5MHz, even critical.

Based on the proposed method, the mitigation approaches are designed as follows:

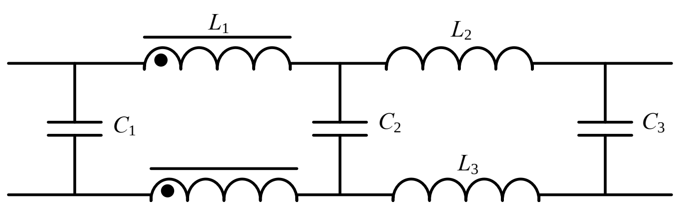
1. EMI filter for SMPS of the power concentrator is designed, as shown in Fig.10(c), where L_1 denotes 10mH CM choke, both L_2 and L_3 represent 1mH inductance, C_1, C_2 and C_3 signify 0.01μF, 10nF and 1nF, respectively.
2. 10nF capacitor is shunt between the power supply of the carrier module to HF noises.

Due to the above methods, the CE of the power concentrator can pass EN 55022 Class B, where the average noises are 35dBμV@13.56MHz and 41dBμV@27.12MHz. And the safety margin of the power concentrator can reach 10dBμV, as shown in Fig.10(d).

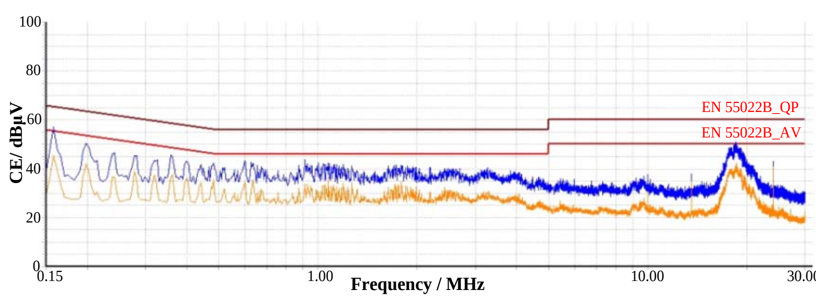
(a). *The power concentrator*



(b). *The original CE result*



(c). *EMI filter for the SMPS of the colonoscopy*



(d). *The final CE result based on the proposed method*

Fig.10: CE experiment of SMPS for the power concentrator

b) SMPS of the colonoscopy

The original CE result of the colonoscopy is shown in Fig.11(a),(b), and the noise can't pass EN 55022 Class B, as shown in Tab.3.

Tab. 3: The Original CE of the colonoscopy

Freuqency/MHz	Average/dBμV	Exceed/dBμV
0.16	66.42	1.42
0.18	67.02	3.02
0.22	68.01	5.03
0.24	65.01	3.01
0.26	65.02	4.11
0.30	64.96	5.04
0.32	65.04	6.16
0.34	63.95	5.82

Based on the present approach, the suppression methods are designed as follows:

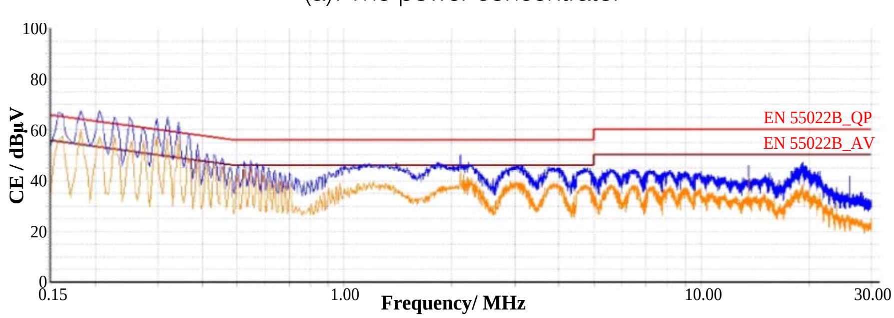
1. T model EMI filter is designed for SMPS of the colonoscopy, as shown in Fig.11(c), where L_1 and L_2 denote 35μH and 1.36μH crosstalk chokes, respectively, C represents 0.022μF capacitor.
2. L model EMI filter is also designed for the DC power conversion chip, where the inductance is 1.2μH and the capacitor is 0.15μF.

Due to the above methods, the CE of the colonoscopy can pass EN 55022 Class B, where the average noises are shown in Tab.4. And the safety margin of the colonoscopy can also reach 10dBμV, as shown in Fig.11(d).

Tab. 4: The Final CE of the colonoscopy

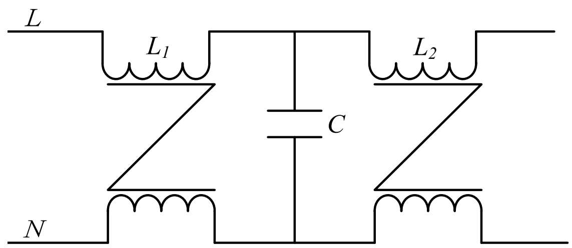
Freuqency/MHz	Average/dBμV	Decline/dBμV
0.16	50.20	16.22
0.18	49.96	17.06
0.22	42.62	25.39
0.24	44.88	20.13
0.26	42.16	22.86
0.30	39.92	25.04
0.32	43.81	21.23
0.34	40.68	23.27

(a). The power concentrator

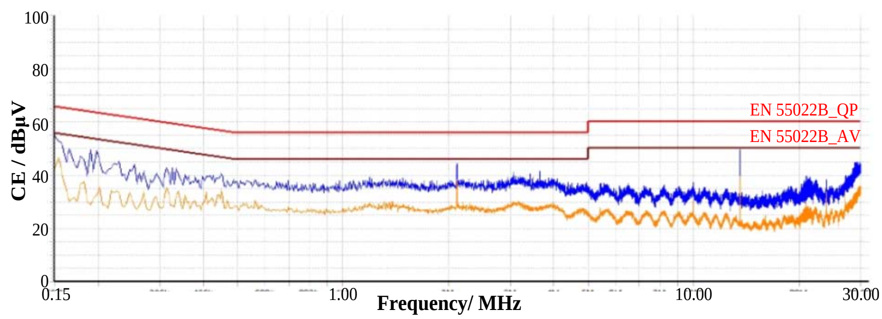


(b). The original CE result

Global Journal of Researches in Engineering (F) Volume XVII Issue II Version I Year 2017



(c). EMI filter for the SMPS of the colonoscopy



(d). The final CE result based on the proposed method

Fig.11: CE experiment of SMPS for the colonoscopy

VII. Conclusion

In this paper, CE mechanism generated from the special two line SMPS is analyzed to solve the safety and EMI problem of SMPS. Following conclusions are obtained.

1) The voltage division factor, isolation factor and impedance under SMPS side were analyzed based on the HF parasitic parameters, which can improve the CE measurement uncertainty.
2) The CM and DM models for the two line SMPS were established due to the balanced and unbalanced current.
3) Three CE noise mitigation methods were proposed in the paper, such as the capacitor shunt between the source and drain electrodes of MOSFET, CM choke and crosstalk choke, and the capacitors matrix, which can improve the safety and EMI performance of SMPS.

The experiment results show that the CE noises of the power concentrator and colonoscopy can be reduced very well by employing the present approaches.

VIII. Acknowledgment

This paper is supported by Project Supported by National Natural Science Foundation of China (51475246); National Natural Science Foundation of Jiangsu Province(BK20161019); University Science Research Project of Jiangsu Province (15KJB470011).

References Références Referencias

1. Clayton R. Paul, Introduction to Electromagnetic Compatibility (Second Edition), *Hoboken, U.S.A: John Wiley & Sons, Inc*, (2006), 326-343.
2. Henry W. Ott, Electromagnetic Compatibility Engineering, *Hoboken, U.S.A: John Wiley & Sons, Inc*, (2009), 6-42.
3. Attaianese C., Nardi V., Tomasso G., EMC of power converters: The self-compatibility approach, *IET Electric Power Applications*, **1**(6) (2007), 862-869.
4. Wei Yan, Qiang Tang, Enrong Wang, Radiated emission mechanism for semi-active control strategy of magneto-rheological damper, *International Journal of Applied Electromagnetics and Mechanics*, **51**(2) (2016), 185-198.
5. Wei Yan, Jing Yu, Qiang Tang, Analysis and mitigation on conducted electromagnetic interference of semi-active control strategy for magneto-rheological damper, *International Journal of Applied Electromagnetics and Mechanics*, **50**(2) (2016), 247-254.
6. European Committee for Electrotechnical Standardization, EN 55022-2010: Information technology equipment- Radio disturbance characteristics- Limits and methods of measurement, *Brussels, Belgium: The European Commission and the European Free Trade Association*, (2010).
7. Chang Y.H., Complex programmable logic device-based closed-loop implementation of switched-

capacitor step-down DC-DC converter for multiple output choices, *IET Electric Power Applications*, **1**(6) (2007), 926-936.
8. Xiaopeng Dong, Haixiao Weng, Beetner D.G., Hubing T.H., Approximation of Worst Case Crosstalk at High Frequencies, *Electromagnetic Compatibility, IEEE Transactions on*, **53**(1) (2011), 202-208.
9. Yan Wei, Zhao Yang, Wang Enrong, et a, Investigation and Reduction on Conducted Electromagnetic Interference Noise Mechanism for Complex Power Electronics Systems, *Proceedings of the CSEE*, **32**(30) (2012), 156-162.
10. L.H. Kim，J.S. Yu，W.C. Lee, et al, Conducted EMI reduction of PWM inverter for AC motor drive systems, *International Journal of Applied Electromagnetics and Mechanics*, **24**(3) (2006), 195-207.
11. X. Wang，Z. Liu，Z. Zhou, Rapid computation model for accurate evaluation of electromagnetic interference shielding effectiveness of fabric with hole based on equivalent coefficient, *International Journal of Applied Electromagnetics and Mechanics*, **47**(1) (2015), 177-185.
12. See Kye Yak, Network for conducted EMI diagnosis, *Electronic Letter*, **35**(17) (1999), 1446-1447.
13. Mardiguian M., An alternative method for characterizing EMI filter, *IEEE International Symposium on Electromagnetic Compatibility*, **2** (1999), 882-886.
14. Ting Guo, Chen D.Y., Separation of the common-mode and differential-mode conducted EMI noise, *IEEE Transaction on Power electronics*, **11**(3) (1996), 480-488.
15. Bhargava A., Pommerenke D., Kam K.W. et al, DC-DC Buck Converter EMI Reduction Using PCB Layout Modification, *Electromagnetic Compatibility, IEEE Transactions on*, **53**(3) (2011), 806-813.
16. Mukherjee R., Patra A., Banerjee S., Impact of a Frequency Modulated Pulsewidth Modulation (PWM) Switching Converter on the Input Power System Quality, *Power Electronics, IEEE Transactions on*, **25**(6) (2010), 1450-1459.
17. Tripathi J.N., Mukherjee J., Apte P.R., et al, Selection and placement of decoupling capacitors in high speed systems, *Electromagnetic Compatibility Magazine, IEEE*, **2**(4) (2013), 72-78.
18. Wu W., Sun Y., Lin Z. et al, A Modified LLCL Filter With the Reduced Conducted EMI Noise, *Power Electronics, IEEE Transactions on*, **29**(7) (2014), 3393-3402.
19. Lei Xing, Jian Sun, Conducted Common-Mode EMI Reduction by Impedance Balancing, *Power Electronics, IEEE Transactions on*, **27**(3) (2012), 1084-1089.

This page is intentionally left blank