Common-Mode Current Cancellation Scheme of Half-Bridge Switch-Mode Converter for DC Motor Drive

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Abstract: Due to the conventional half-bridge switch-mode converters for dc motor drive have been usually using unbalanced circuit topologies which generate common-mode currents through parasitic capacitors distributed between the ground and the dc motor frame such as the heat-sink of switching devices or the frame of the dc motor. This paper describes methods that cancel common-mode current generated in half-bridge switch-mode converters by using circuit balancing technique. The circuit balancing is to make the noise pickup or occurring in both conductor lines, signal and return pathes, is equal in amplitude and opposite in phase so that it will be canceled out in the ground plane. The common-mode current cancellation in the proposed converter is confirmed by experimental results.

Keywords: common-mode current cancellation, half-bridge switch-mode converter, electromagnetic interference, circuit balancing

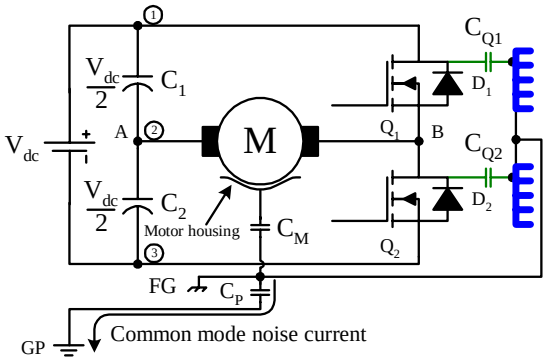
1. INTRODUCTION

Motor drive system using power converters composed of the PWM converter and inverter have been widely used for various kinds of applications such as incremental motion control systems, robotics, and transportation systems. Switching speeds of power devices used in power converters have become higher and higher due to requests for higher performance. This leads to increased problem of electromagnetic interference (EMI) noise [1], and then EMI noises easily diffuse through not only power transmission lines of power converters but also their converter into other electric equipment. Thus, motor drive systems have the potential of causing electromagnetic interference problems between electric equipment. Especially, because common mode noises are transmitted as common mode currents through stray capacitors distributed between the ground and the machine frame such as the cooling fin of power converters or the frame of the motor, they have the ability to make the influence of EMI noise. The methods proposed until now have suppressed EMI noise by inserting control means such as active cancellers [2] or EMI filters [3] between the power converter and the motor.

The common-mode current cancellation by passive elements for dc motor drive has not been intensively researched so far; therefore, we purpose the novel common-mode current cancellation by inserting passive elements in half-bridge switch-mode converter for bi-directional speed control of dc motor. Because of the half-bridge characteristics, there are two major advantages. First, with two voltage sources, it become easier for source balance. Second, the half-bridge circuit, comparing to the full-bridge circuit [4], contains has number of common-mode noise sources, parasitic capacitances. However, the conventional half-bridge switch-mode converter generally uses unbalanced circuit topologies switch generates high common-mode noise to ground, but our approach produces the balancing common-mode current in circuit as that it will be canceled out in the ground plane. The greatly common-mode noise reduction of this proposed half-bridge switch-mode converter is confirmed by experimental results.

2. CONCEPT OF CM NOISE CURRENT CANCELLATION SCHEME

Fig.1 shows the conventional unbalanced half-bridge switch-mode converter for dc motor driver. DC motor is

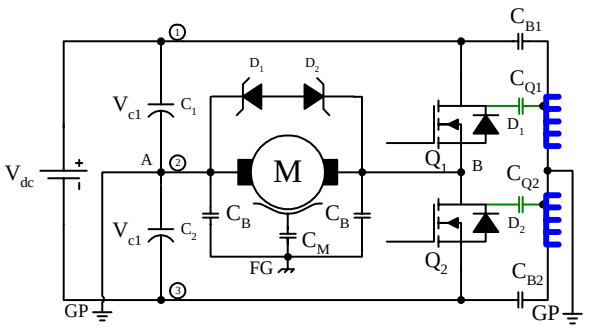


C_{Q1} and C_{Q2}: parasitic capacitance of Q_1 and Q_2
C_M: parasitic capacitance of dc motor
C_P: parasitic capacitance of frame ground

Fig.1 Conventional unbalanced half-bridge switch-mode converter for dc motor driver

connected to the junction of the capacitor C_1 and C_2 (electrical mid point A). The other end is connected to the junction of MOSFET, Q_1 and Q_2 which turn on and off on alternate half cycle. A heatsink is usually used with Q_1 and Q_2 so the parasitic capacitance, C_{Q1} and C_{Q2} are formed between the drain of the MOSFETs and heatsink of Q_1 and Q_2 respectively. The heatsink are usually fixed on the frame ground (FG). However dc motor housing and the frame ground also causes the parasitic capacitance, C_M as shown in Fig.1. At the high frequency the frame ground will have the capacitive coupling through the parasitic capacitance, C_P to the ground plane (GP). In unbalanced half-bridge converter for dc motor drive, when MOSFET Q_1 and Q_2 is turned off the drain voltage changed, (dv/dt) very rapidly in the switching time which causes to be common-mode noise current, ($i_{CM} = C_{Q1,\ 2}$ dv/dt) flows through the parasitic capacitor, C_{Q1} and C_{Q2}. And due to the switching voltage is applied to dc motor will also cause the common-mode noise current flows through the parasitic capacitor, C_M. Consequently this causes the large common-mode noise current flows through C_P to ground plane and lead to serious problems.

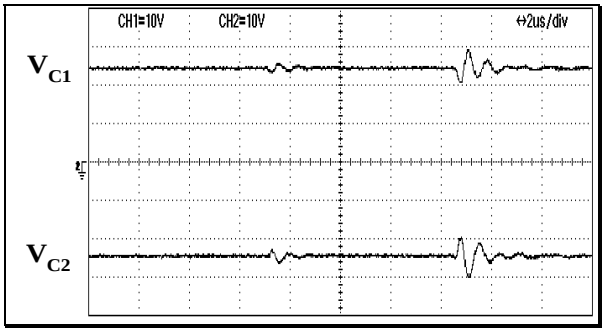
In order to solve this problem, we propose a balanced half-bridge switching-mode converter for dc motor drive which the common-mode noise current can be cancelled out in the ground plane as shown in Fig.2.



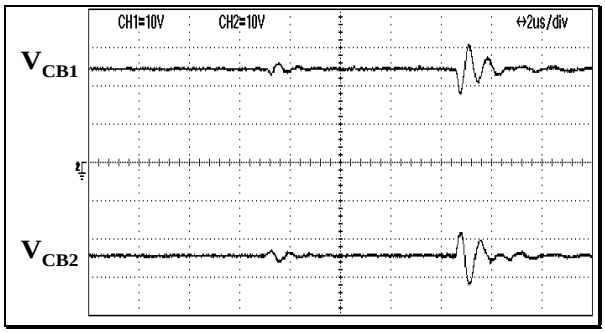
FG: Frame ground
G_P: Ground plane

Fig.2 Proposed balanced half-bridge switch-mode converter for dc motor drive.

Its basic circuit operation is essentially the same as that of the conventional unbalanced half-bridge converter. We take the advantage of the half-bridge converter configuration to make the circuit balancing easily within three parts. First, the source balance can provide by connection the electrical mid-point to the ground plane. According to the ground plane is the reference ground, we can get $V_{C1} = -V_{C2}$ as shown in Fig.3 (a). Second, we must balance the transmission line that means the conductor lines (Conductor No. 1, 3) between dc source and the load terminal must have same impedance, and twist them to getter. Third, the termination balance can be done by inserting auxiliary capacitors, C_{B1} and C_{B2} between terminal No. 1, 2, and the ground plane respectively, besides the parasitic capacitors C_{Q1} and C_{Q2} would be connected directly to ground plane as shown in Fig.2. The good termination balance can be achieved by adjusting the auxiliary capacitors C_{B1} and C_{B2} until we can get $V_{CB1} = -V_{CB2}$ as shown in Fig.3 (b). From Fig.3 (b), we can see that MOSFET Q_1 and Q_2 turn



(a) Shows the power balanced with $V_{C1} = -V_{C2}$



(b) Shows the termination balanced with $V_{CB1} = -V_{CB2}$

Fig.3 shows the voltage wave form of (a) source balance and (b) termination balance.

on and off on alternate half cycle which generate the common-mode noise currents flow through the auxiliary capacitors C_{B1} and C_{B2} with the same amplitude and opposite phase so that they will be canceled output in the ground plane. In case of dc motor or load must be separately balanced as shown in Fig.2.

3. EQUIVALENT CIRCUIT TO EXPLAIN THE COMMON-MODE NOISE REDUCTION

In order to explain the mechanism of occurring the common mode noise current in unbalance half-bridge switch-mode converter for dc motor drive by using the equivalent circuit as shown in Fig.4 (a). From Fig.4 (a), the common-mode noise current is generated by a rapid voltage change in the parasitic capacitances, C_{Q1} and C_{Q2}, C_M, and C_P. The total common-mode noise current can be obtained as follow;

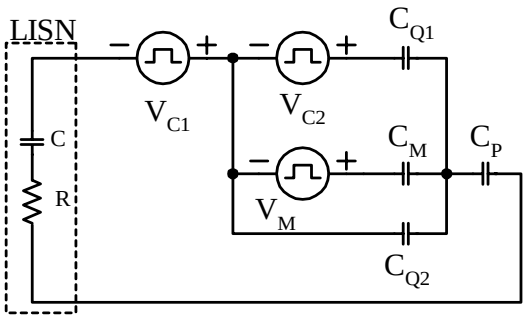
$$i_{CM1} = \left(\frac{C_P C_{Q1}}{C_P + C_{Q1}} \right) \frac{dV_{DS1}}{dt} \quad (1)$$

$$i_{CM2} = \left(\frac{C_P C_{Q2}}{C_P + C_{Q2}} \right) \frac{dV_{DS2}}{dt} \quad (2)$$

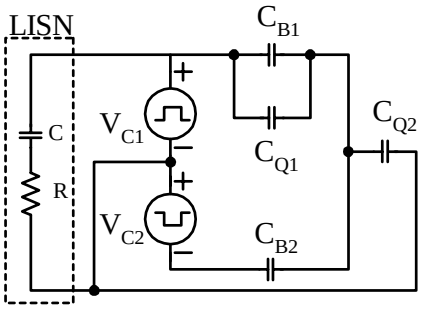
$$i_{CM3} = \left(\frac{C_P C_M}{C_P + C_M} \right) \frac{dV_M}{dt} \quad (3)$$

$$i_{CM} = i_{CM1} + i_{CM2} + i_{CM3} \quad (4)$$

The mechanism of common-mode noise current reduction can be explained by equivalent circuit of balanced half-bridge switch-mode converter for dc motor drive as shown in Fig.4 (b). From Fig.4 (b), due to source and termination balanced, the CM noise current through $C_{B1}//C_{Q2}$ is absorbed by C_{B2}.



(a) Conventional unbalanced half-bridge switch mode converter equivalent circuit



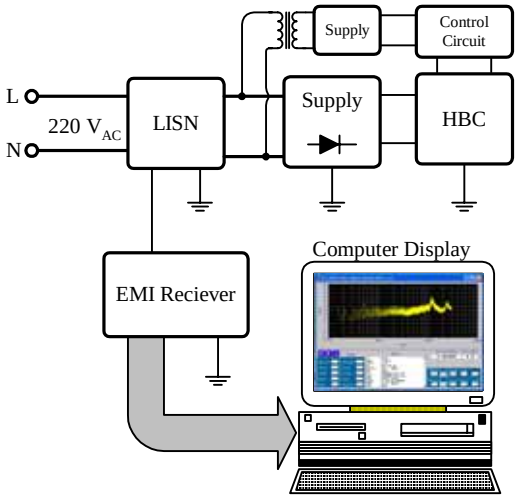
(b) Proposed balanced half-bridge switch-mode converter equivalent circuit which dc motor is separately balanced

Fig.4 Mechanism of common mode noise current cancellation in balanced half-bridge switch-mode converter

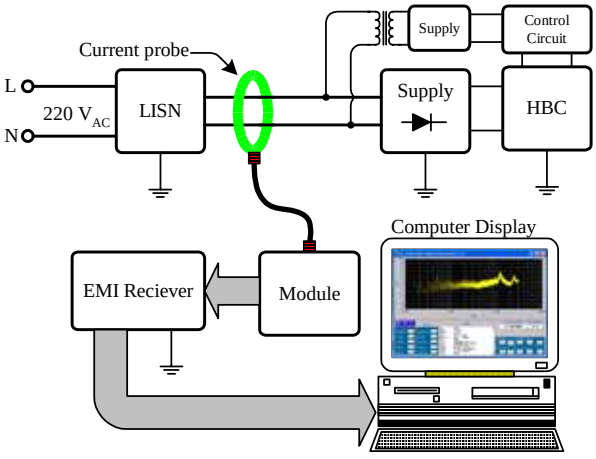
4. EXPERIMENTAL RESULTS

The are two experimental circuits used to investigate the effect of the conducted EMI and CM conducted noise. The conventional half-bridge switch-mode converter, and the proposed half-bridge switch-mode converter for dc motor drive as shown in Fig.1 and 2 respectively. For the experimental the basic circuit operation and each parameter of two circuits such as switching frequency, gate voltage control (duty cycle of PWM), voltage supply, and load of dc motor are setup with the same value.

We setup the two circuits for measuring the conducted EMI by using the line impedance stabilization network (LISN) connected to EMI receiver and display by computer as shown in Fig.5 (a). The common-mode conducted noise can be measured by using high-frequency current probe connected between output of LISN and input of EMI receiver as shown in Fig.5 (b).



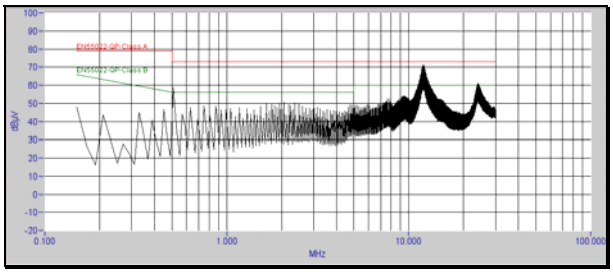
(a) Total noise measurement setup



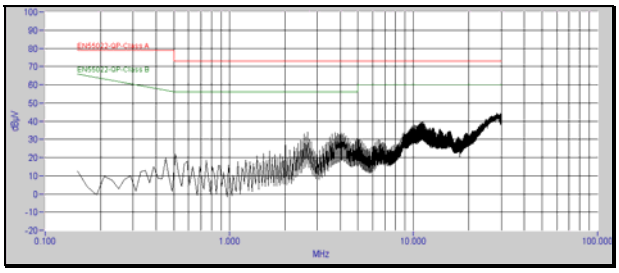
(b) Common mode noise measurement seup

Fig.5 Test setup for conducted EMI measurement

The measurement results of conducted EMI of two circuits are shown in Fig.6 (a) and (b) respectively.



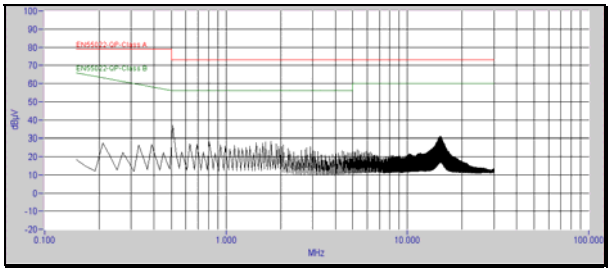
(a) Unbalanced circuit



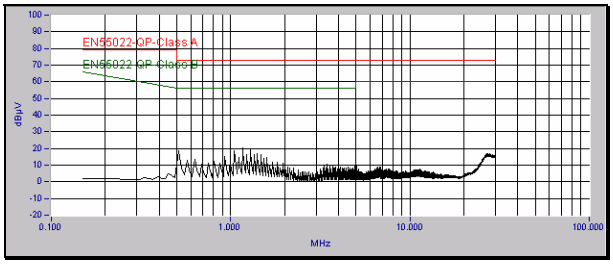
(b) Balanced circuit

Fig.6 Measurement results of the conducted EMI of two circuits.

Fig.7 (a) and (b) show the measurement results of the CM noise of two circuits.



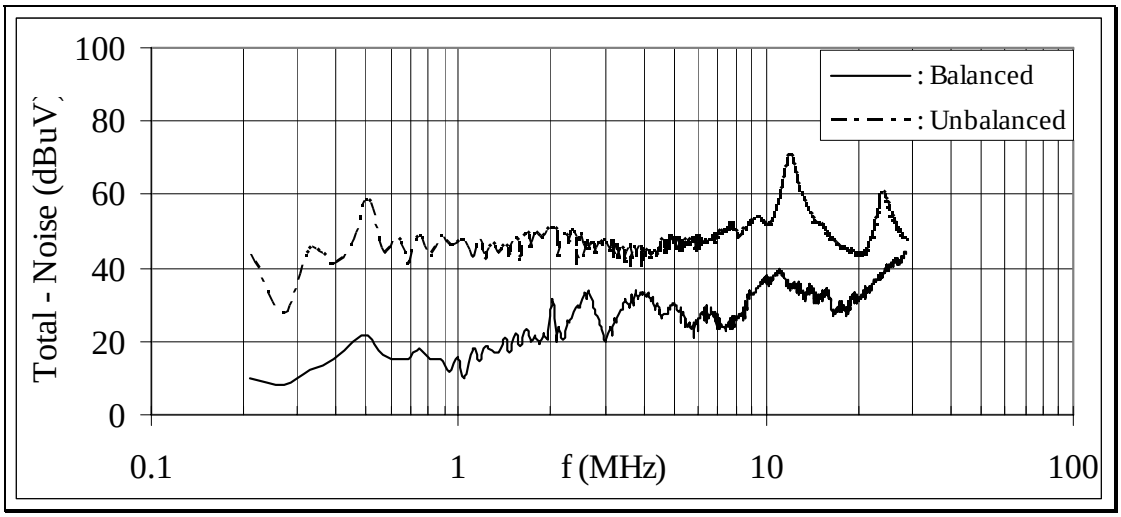
(a) Unbalanced circuit



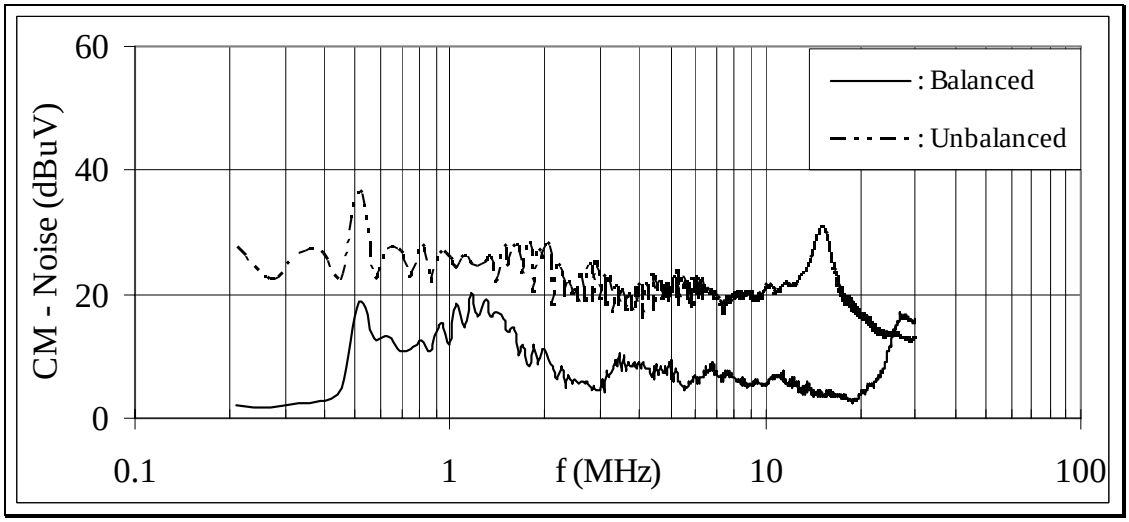
(b) Balanced circuit

Fig.7 shows the measured CM conducted noise of two circuits.

Fig.8 (a) and (b) show the greatly improved, conducted EMI, and CM noise performance, of the proposed half-bridge switch-mode converter for dc motor drive which used the CM noise cancellation topologies to make the CM noise significantly results.



(a) Comparing the conducted EMI of two circuits



(b) Comparing the CM noise of two circuits

Fig. 8 Shows the greatly reduction of conducted EMI and CM noise of the proposed circuit composes to the conventional circuit.

5. CONCLUSION

The balanced half-bridge switch-mode converter for dc motor drive has been proposed to reduce the common-mode noise by cancellation the common-mode noise currents in the ground plane. And noise of dc motor has been separately balanced. The greatly improved of common-mode noise was confirmed by experimental results. The concept of the balanced half-bridge switch-mode converter is the cost-effective for noise reduction technique without using of EMI filth and will a apply to the full-bridge converter for dc motor drive in further study.

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