DC Motor Drive with Circuit Balancing Technique to Reduce Common Mode Conducted Noise

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Abstract: In some requirements of dc motor drive circuit applications are high quality output with generation of low internal conducted EMI. However the conventional dc motor drive circuits have been usually using unbalanced circuit which generates the high conducted EMI to the frame ground. This paper presents a balanced dc motor drive circuit which is effective way to reduce the common-mode noise. The circuit balancing is to make the noise pick up or occurring in both conductor lines, signal path and return path is equal in amplitude and opposite phase so that it will cancel out in the frame ground. The common-mode conducted noise reduction of this proposed dc motor drive is confirmed by experimental results.

Keywords: dc motor drive, common mode noise, circuit balancing, common mode current cancellation, EMI.

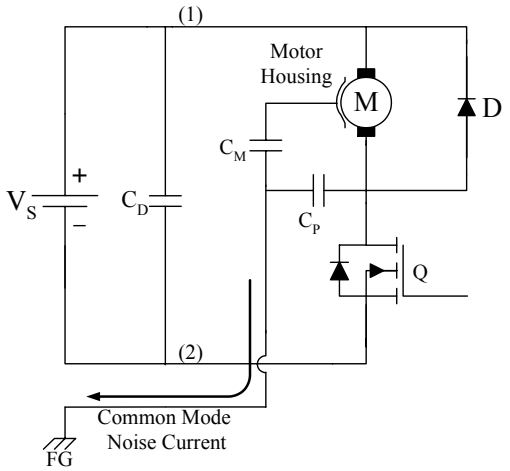
1. INTRODUCTION

In some requirements of dc motor drive circuit applications are high quality output with generation of low internal conducted EMI. It is well know that common-mode (CM) noise is caused by the common-mode current flowing through the parasitic capacitance of active devices or dc motors to ground in the power switching circuit and dc motor drive circuit. Because of the potential for interference with other systems it is necessary to attenuate this noise. Ordinarily this is accomplished by using a common-mode choke across the input power lines, resulting in penalties to the overall size and cost of the completed system. In order to lessen the requirement for this common-mode choke, these has been a recent years a desire to introduce noise cancellation technique to the area of EMI. Recently, there were articles dealing with cancellation of common-mode noise by using a fourth leg of transistors in a 3 phase inverter as shown in [1] [2]. Another articles describing a balanced switching converter circuit to reduce common-mode noise is shown in [3] [4].

This paper proposes a balanced dc motor drive circuit which is effective way to reduce the common-mode conducted noise. The circuit balancing technique [5];[6] has to balance the three parts of the dc motor drive circuit such that source balanced, transmission line balanced, and termination or load balanced. Such balanced of dc motor drive circuit is to make the noise pick up or occurring in both conductor lines, signal path and return path is equal in amplitude and phase is opposite so that it will cancel out in the frame ground. The common-mode conducted noise reduction of this proposed dc motor drive is confirmed by experimental results.

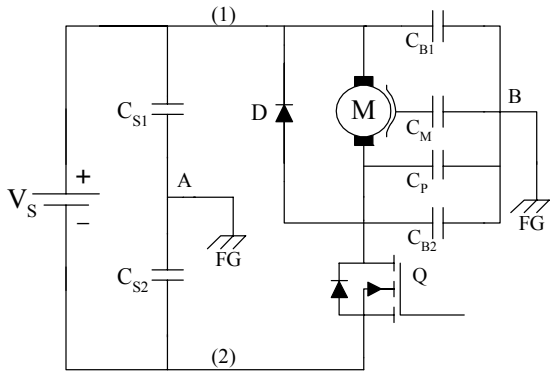
2. CONCEPT OF BALANCING TECHNIQUE

PWM-dc motor drives are widely used for many industrial applications of variable speed drive. Because of they provide smooth acceleration control, high efficiency and fast dynamic response. The conventional PWM-dc motor drives have been usually using unbalanced circuit which generates the high conducted EMI to the frame ground. A heat sink is usually used with the switching device MOS-FET, so the parasitic capacitance, C_P is formed between the drain of MOS-FET and heat sink. In addition the dc motor housing is usually attached to the metallic frame of the frame ground which acts as a heat sink. This produces a large capacitance, C_M between the motor housing and the frame ground.



C_P: Parasitic capacitance of Q.
C_M: Parasitic capacitance of dc motor.
FG: Frame ground.

Fig. 1 The conventional unbalanced dc motor drive.

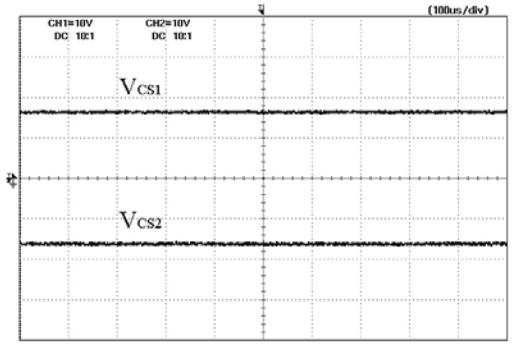


C_{B1} and C_{B2}: Addition capacitance.

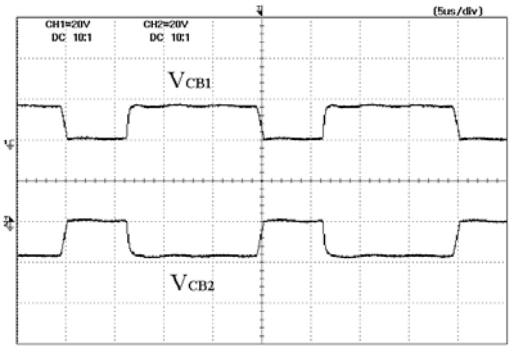
Fig. 2 The proposed balanced dc motor drive.

In unbalanced PWM-dc motor drive as shown in Fig. 1 when the MOS-FET, Q is turned off the drain voltage change (dv/dt) very rapidly in the switching time which cause to be a common-mode noise current (i_{CM}= C_P dv/dt) flow through the

parasitic capacitor, C_P. And due to the switching voltage is applied to the 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 and C_M to the frame ground and lead to be serious EMI problems. In order to solve this problem, this paper proposes a balanced dc motor drive as shown in Fig. 2. Its basic circuit operation is essentially the same as that of the conventional unbalanced PWM-dc motor drive. The purpose of circuit balancing is to make the noise pickup or occurring in both conductor lines, signal path and return path is equal in amplitude and phase is opposite so that it will cancel out in the frame ground. The circuit balancing concept has to balance the three parts of the dc motor drive circuit such that source balanced, transmission line balanced and termination or load balanced. The circuit balanced can perform as follow, first source balanced can provide by adding series capacitor C_{S1} and C_{S2} across the dc supply voltage (V_S) and connecting the electrical mid-point of C_{S1} and C_{S2} to the frame ground. According to the frame ground is the reference we can get V_{CS1}= -V_{CS2} as shown in Fig. 3(a). Next, we must balance the transmission line by twist the two conductors (conductor No.(1) and (2)) together, this can protect against both magnetic and electric field coupling. Third the termination balanced can be done by adding the capacitor C_{B1} parallel with C_M and C_{B2} parallel with C_P at which heat sink is connected to the frame ground as shown in Fig. 2. For good termination balanced we can get V_{CB1} = - V_{CB2}. As a result, the common-mode conducted noise is greatly reduced by this balanced circuit topology.



(a) Shows the source balanced with V_{CS1}= -V_{CS2}



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

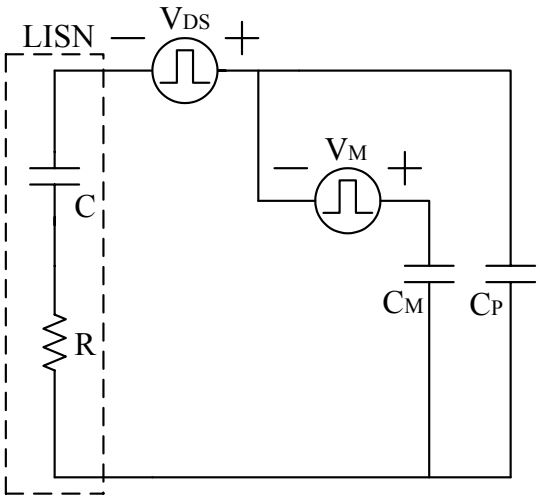
Fig. 3 Show the voltage waveform of (a) the source balanced and (b) the termination balanced.

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

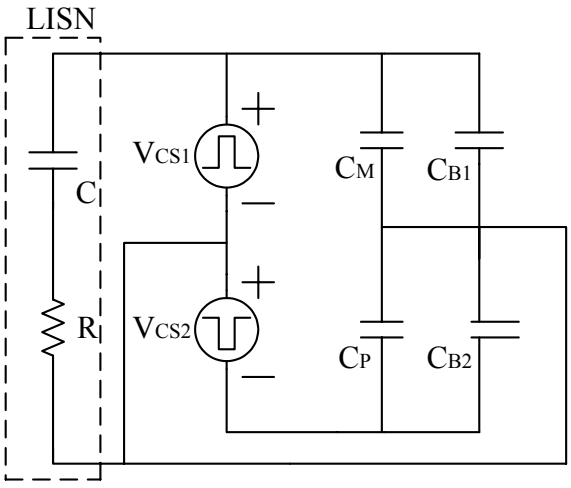
In order to explain the mechanism of occurring the common-mode noise current in the conventional unbalanced dc motor drive circuit by using the equivalent circuit as shown in Fig. 4(a). The common-mode conducted noise is generated by a rapid voltage change in the parasitic capacitance, C_M and C_P. The common-mode noise current flowed to the frame ground can be obtained in the Eq. (1).

$$i_{CM} = (C_P + C_M)\frac{dV_{DS}}{dt} \quad (1)$$

The mechanism of common-mode noise cancellation can be explained by equivalent circuit of balanced dc motor drive as shown in Fig. 4(b). From Fig. 4(b) due to source, transmission line and termination balanced, the common-mode noise current through C_{B1} is absorbed by C_{B2}//C_P//C_M. It results the common-mode noise is effectively reduced.



(a) Conventional unbalanced dc motor drive equivalent circuit.



(b) Proposed balanced dc motor drive equivalent circuit.

Fig. 4 Mechanism of common-mode noise reduction in the balanced dc motor drive circuit.

4. THE EXPERIMENTAL SETUP

There are two experimental circuits, the conventional unbalanced and balanced dc motor drive circuit used to investigate the effect of the conducted EMI. For the experimental each parameter of these two circuits is shown in Table 1.

The scheme utilized for conducted EMI measurement in this paper is shown in Fig. 5. LISN (Line Impedance Stabilizer Network) is placed at the input side of the circuit under test. A spectrum analyzer is used to record the EMI profiles, in the frequency range of 150 kHz to 30 MHz and display by computer. A high frequency current probe is used to sense the common-mode noise, which is measured by a spectrum analyzer. And the common-mode conducted noise measurement setup is shown in Fig. 6.

Table 1 Shows the details of conducted EMI measuring instruments and the parameters of the experimental.

LISN	EMCO MODEL 3825/2
EMI Receiver	AFJ ER55CR
High Frequency Current Probe	SCHAFFNER SMZ 11
DC Supply (Vs)	34V
Switching Device	MOSFET IRFP150N
Switching frequency	50 kHz, 60% Duty cycle
Gate resistance (R_G)	100 Ω
Diode	UF202
Load	DC Motor
Balancing elements - Source balanced - Termination balanced	 $C_{S1} = C_{S2} = 0.1$ uF $C_{B1} + C_M \approx 3$ nF $C_{B2} + C_P \approx 3$ nF

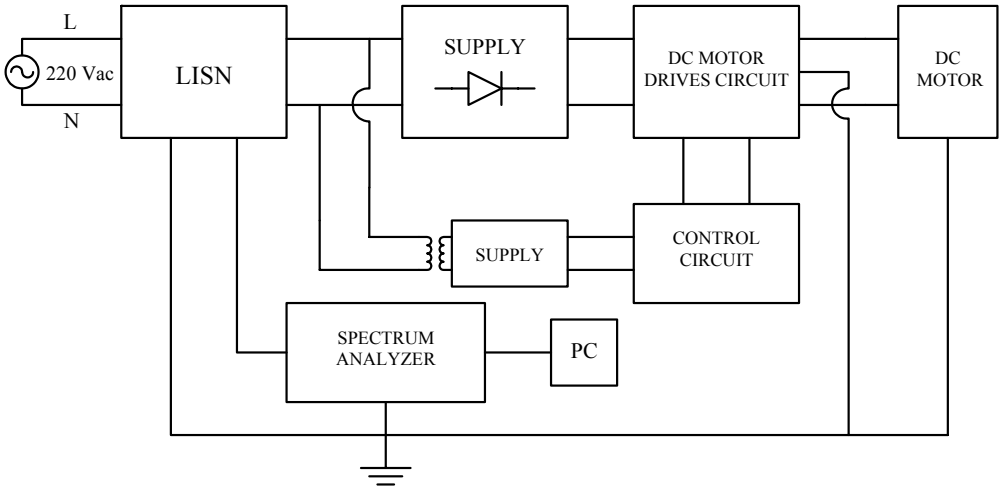


Fig. 5 The conducted EMI measurement setup.

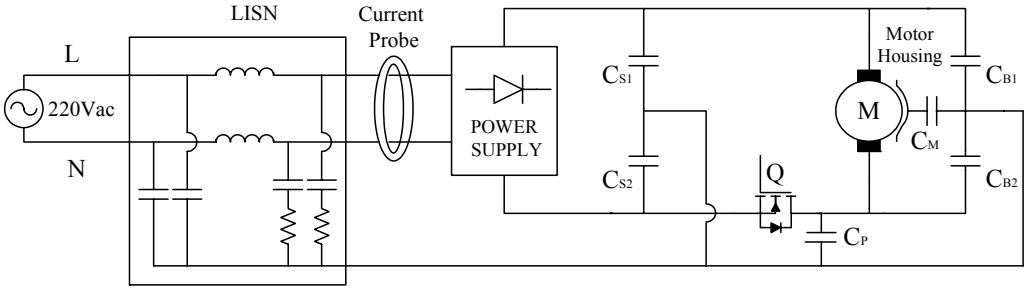
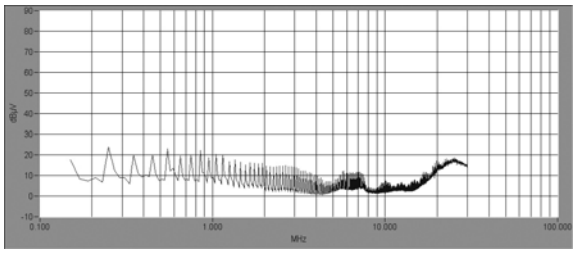


Fig. 6 The common-mode noise measurement setup.

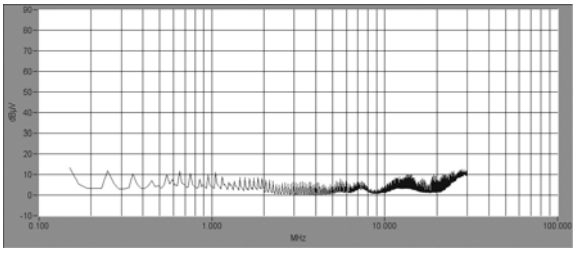
5. THE EXPERIMENTAL RESULTS

At first we would like to observe the balance condition of source and termination balanced giving what effect to the common-mode noise. Fig. 7(a) shows the effect of termination balanced by floating point A from the frame ground. And floating point B from the frame ground for investigate the effect of the source balanced is shown in Fig. 7(b). From Fig. 7(b) shows that, source balanced is more effective to reduce the common-mode noise than the termination balanced.

The conducted EMI test results of the conventional unbalanced dc motor drive compare to the proposed balanced dc motor drive are shown in Fig. 8(a) and (b) respectively. Fig. 8(b) shows that conducted EMI is greatly reduce about 20 dBμV by our approach. Fig. 9(a) and (b) show the common-mode noise measured result of the conventional unbalanced circuit and the proposed balanced circuit respectively. Fig. 9(b) shows that our approach can reduce the common-mode noise about 20 dBμV as well.

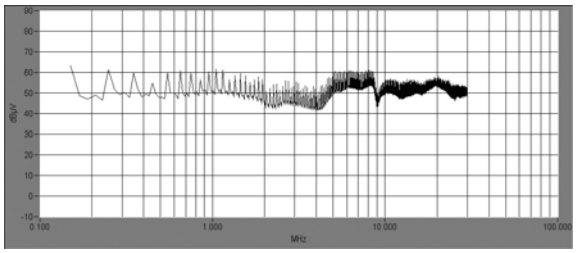


(a) Common-mode conducted noise of the balanced circuit without source balanced.

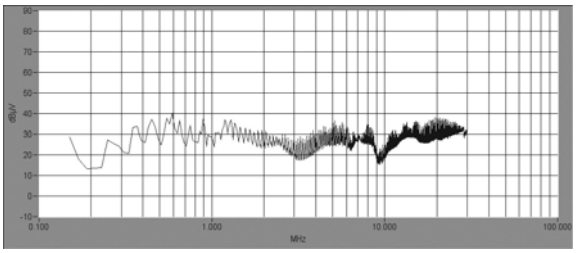


(b) Common-mode conducted noise of the balanced circuit without termination balanced.

Fig. 7 Common-mode conducted noise of balanced dc motor drive circuit in case of (a) without source balanced and (b) without termination balanced.

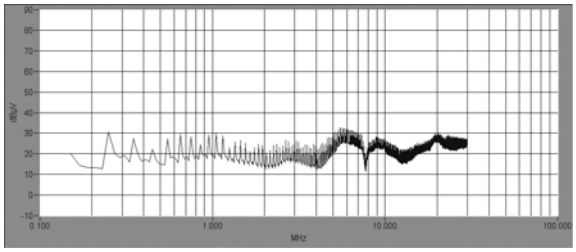


(a) Total conducted noise of conventional unbalanced dc motor drive circuit.

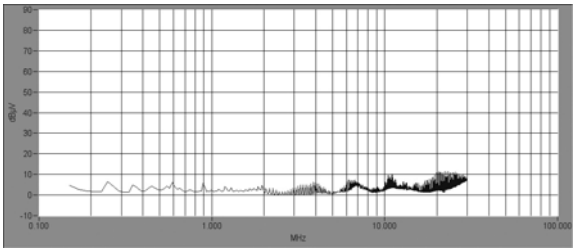


(b) Total conducted noise of the proposed balanced dc motor drive circuit.

Fig. 8 Total conducted noise of (a) conventional unbalanced circuit and (b) proposed balanced dc motor drive circuit.



(a) Common-mode conducted noise of the conventional unbalanced dc motor drive circuit.



(b) Common-mode conducted noise of the proposed balanced dc motor drive circuit.

Fig. 9 Common-mode conducted noise of (a) conventional unbalanced circuit and (b) proposed balanced dc motor drive circuit.

6. CONCLUSIONS

The balanced dc motor drive circuit has been proposed to reduce the common-mode conducted noise which generates from the unbalanced dc motor drive circuit. And the common-mode conducted noise affected from the dc motor is also suppressed by this balanced circuit. This good feature was confirmed by experimental results. The concept of this balanced is the cost-effective for noise reduction technique and can reduce the big feature of the EMI filter, and can be applied to other types of switching converter.

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