AN1103
APPLICATION NOTE

IMPROVED B-EMF DETECTION FOR LOW-SPEED AND LOW-VOLTAGE APPLICATIONS WITH ST72141

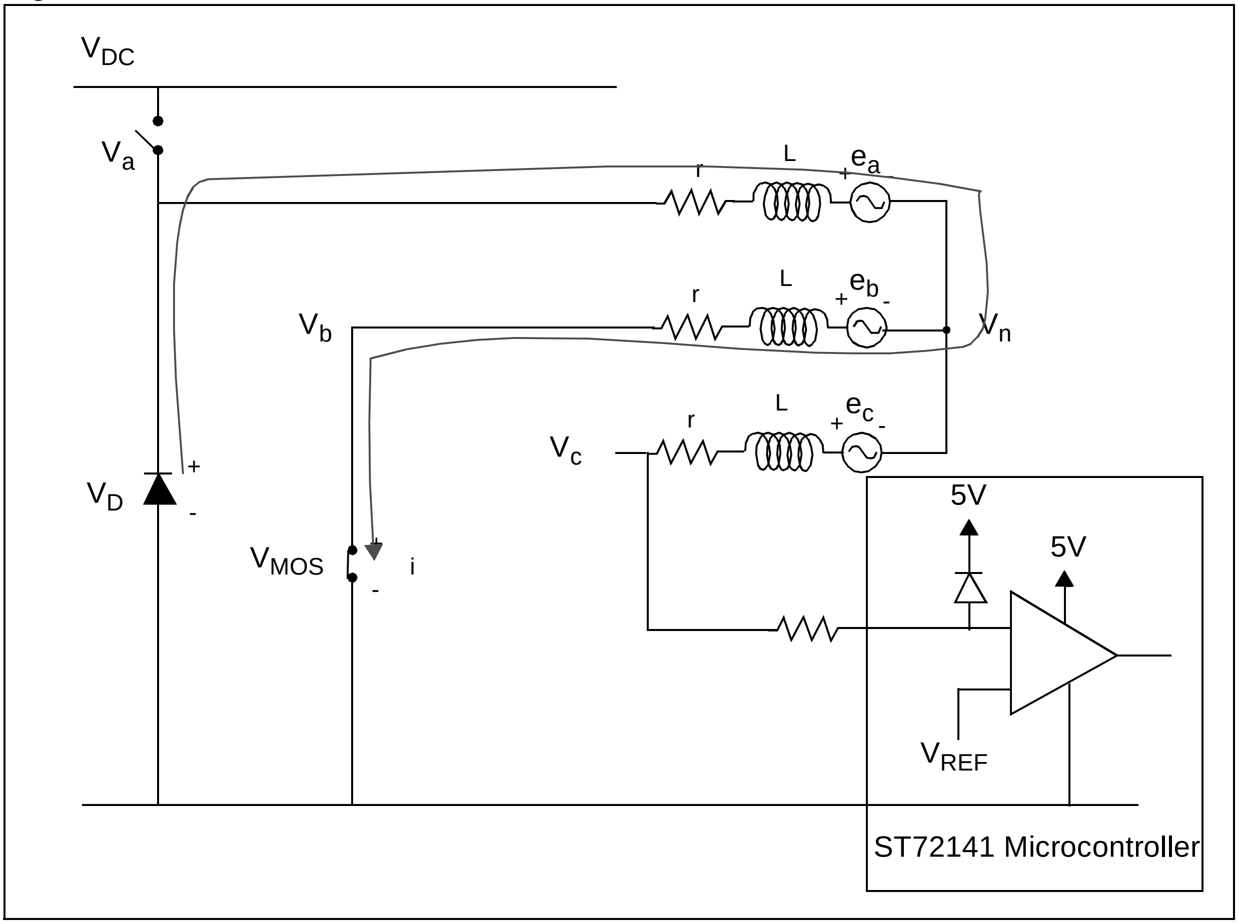
by Microcontroller Division Applications

The ST72141 Microcontroller has been designed by STMicroelectronics for BLDC motor drives. Optimized for sensorless motor control, based on back-EMF zero-crossing detection with four different voltage detection levels. The ST72141 provides a fully digital solution meaning that the motor phases can be directly connected to the microcontroller inputs through a simple resistor.

When the back-EMF signal is very low (low speed) or for low voltage applications, the back-EMF zero-crossing detection can become difficult due to the very weak signal. The purpose of this document is to develop a solution for improving the back-EMF zero-crossing detection at very low speeds or for low voltage applications.

1 THEORY OF OPERATION

Figure 1. Back-EMF Detection on Phase C



If phase A and B are conducting current, phase C is floating. The terminal voltage Vc is detected.

When the up transistor is turned off, the current is freewheeling through the diode D. During this freewheeling period, the terminal voltage Vc is detected as Phase C BEMF because there is no current in phase C.

In fact, $V_c = e_c + V_n$ .Only when Vn equals zero, Vc is the back-EMF. As matter of fact, Vn is always non zero.

From phase A, we have

$$V_n = 0 - v_D - ri - L\frac{di}{dt} - e_a \qquad (1)$$

From phase B, we have

$$V_n = V_{MOS} + ri + L\frac{di}{dt} - e_b \qquad (2)$$

Where Vd is the forward voltage drop of the diode, V_{MOS} is the voltage drop on MOSFET.

Adding (1) and (2), we get

$$2V_n = V_{MOS} - V_D - (e_a + e_b) \qquad (3)$$ and

$$V_n = \frac{V_{MOS} - V_D}{2} - \frac{e_a + e_b}{2} \qquad (4)$$

Also from the balance three-phase system, we have

$$e_a + e_b + e_c = 0 \qquad (5)$$

From (3) and (4),

$$V_n = \frac{V_{MOS} - V_D}{2} + \frac{e_c}{2} \qquad (6)$$

So, the terminal voltage Vc,

$$V_c = e_c + V_n = \frac{3}{2}e_c + \frac{V_{MOS} - V_D}{2} \qquad (7)$$

If we ignore the second term of (6), terminal voltage is the back-EMF. However, at low speed and low voltage, the back-EMF itself is very small, the second term will play a significant role here. For low voltage MOSFETs, Rd is very low, Vmos can be ignored, so (6) can be rewritten as,

$$V_c = e_c + V_n = \frac{3}{2}e_c - \frac{V_D}{2} \qquad (8)$$

2 PROBLEMS

(a). As mentioned before, the voltage drop on the diode will affect the back-EMF significantly when the back-EMF signal is weak. Theoretically, zero-crossing is distributed evenly each 60 electric degrees. But because of the diode voltage drop, this will cause the zero-crossing to be unsymmetrically distributed.

Figure 2 shows the simulation result.

Figure 2. Simulation result showing that the zero-crossing is unsymmetrical

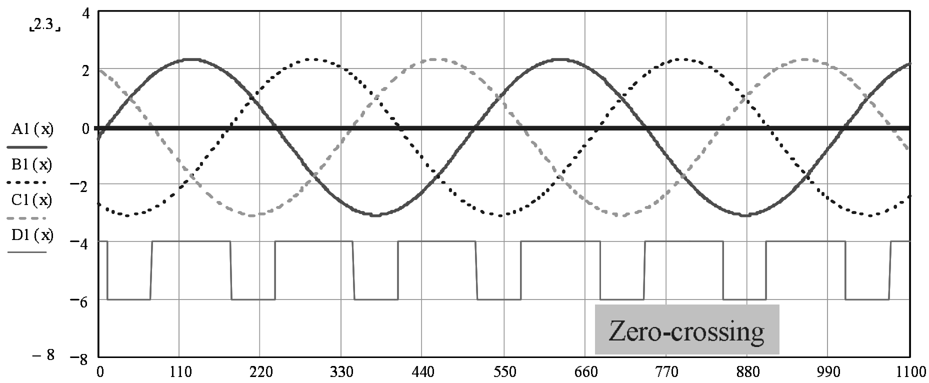
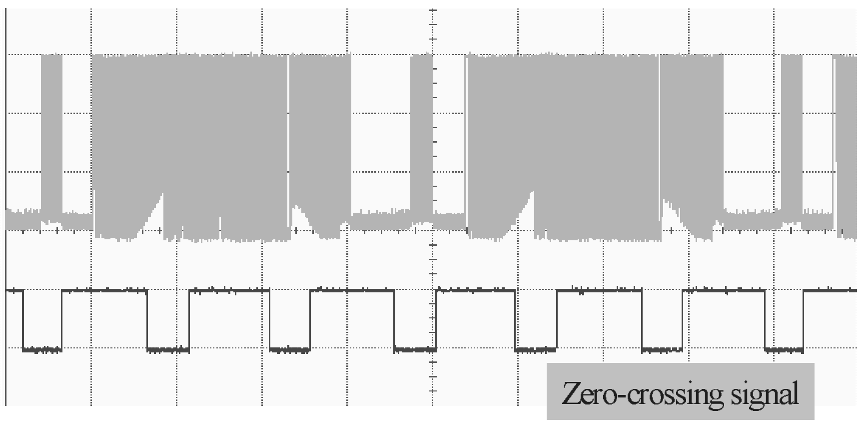


Figure 3 shows the test result.

Figure 3. Test result showing that the zero-crossing is unsymmetrical



The wrong zero detection will cause wrong commutation which probably will stall the motor. Also bad zero-crossing will cause bad speed regulation.

(b). At low voltage or low speed, the zero-crossing slope is very flat. The offset and the hysteresis loop of the comparator will cause the bad zero crossing detection. Meanwhile, because of the weak back-EMF, it is very susceptible to noise.

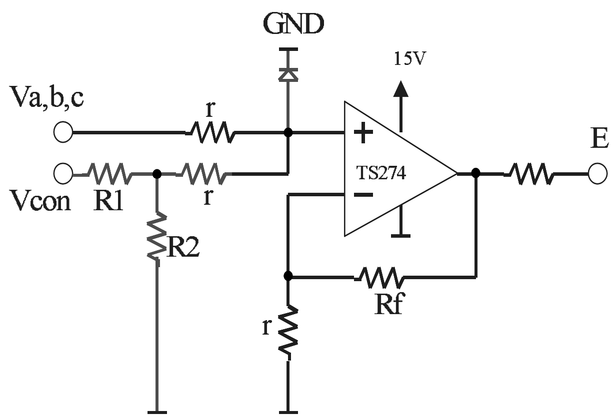
3 SOLUTION

To solve the first problem, we need to eliminate the effect of diode voltage drop. Adding another constant voltage before the voltage signal is sent to comparator can eliminate the effect of the diode.

To solve the second problem, we need to sharpen the slope of the back-EMF during the zero crossing period. We can use an amplifier to amplify the back-EMF signal only around zero crossing time because we are not interested in other time periods.

Figure 4 shows the solution.

Figure 4. Solution for improving back-EMF detection

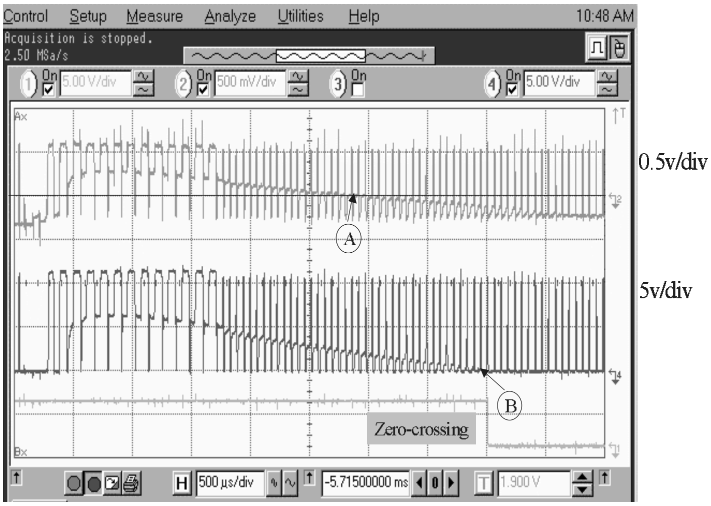


TS274 is a high speed Op-amp. Choose R1 and R2 such that VconR1/(R1+R2)=Vd/2.

The positive input of the Op-amp is clamped at 0.7v by a diode because we are only interested in the zero-crossing. So we only sharpen the slope of the back-EMF near the zero crossing.

4 RESULT

Figure 5. Back-EMF signal detection with and without amplification



In Figure 5, the green channel is the signal directly from the winding, the terminal voltage,0.5v/div. The back-EMF signal is very weak. Point A will be the zero crossing point.

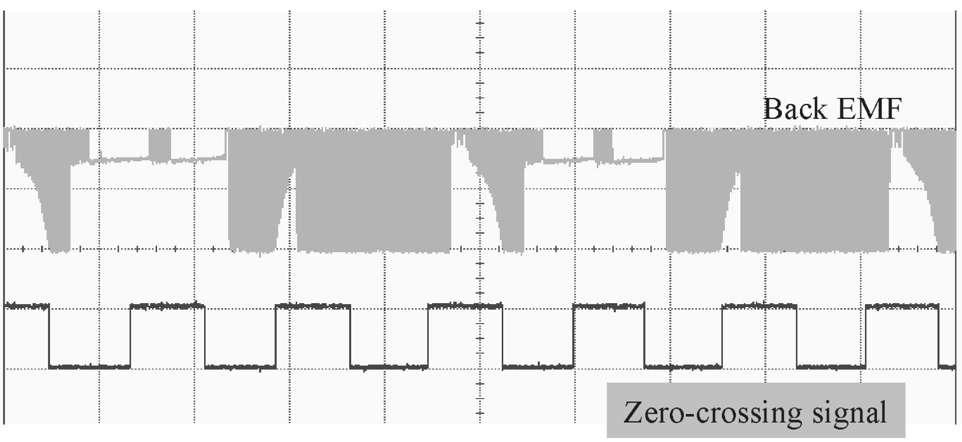
The pink channel is the output from the Op-amp, 5v/div. Point B is the zero crossing point.

Because of the diode forward drop, at the real zero crossing point, the terminal voltage is negative.

The amplification makes the slope very sharp.

Now, the zero crossing signal is in very good shape.

Figure 6. Back-EMF signal detection with amplification



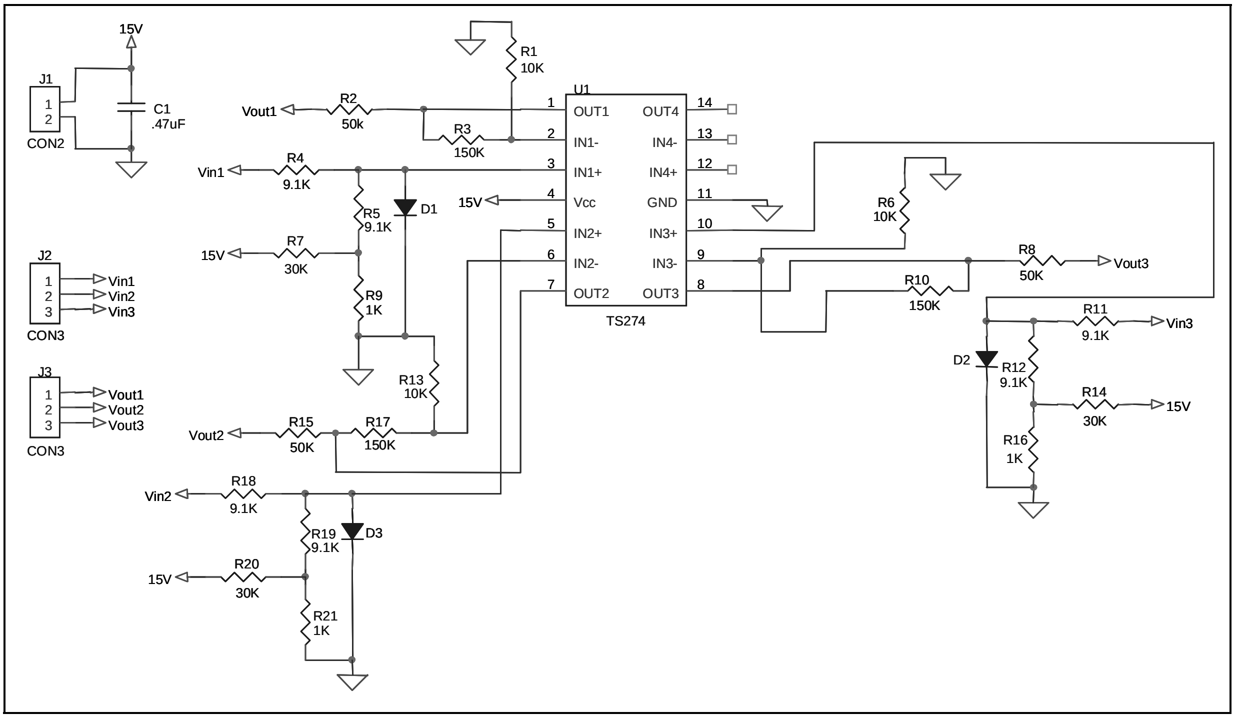
5 CONCLUSION

The theory clearly explains the mechanism of the back-EMF detection and shows the drawback of the original detection method.

The preconditioning circuit not only eliminates the effect of the diode forward voltage drop, but also sharpens the slope of the back-EMF during the zero crossing period.

This circuit can greatly improve the performance of sensorless BLDC drives in low voltage applications, especially for automotive applications. With this technique, the sensorless drive can be used in much wider speed range. As an example, using the original detection method, the speed range could only be 30-150 rpm in one application. By the improved method, the speed range can be 3-150 rpm.

Figure 7. Example Schematics



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