Level shifter/inverter for back-EMF sensing

Because N-channel Mosfets and NPN transistors generally have better performance compared to equivalent P-channel Mosfets and PNP transistors, it's tempting to control motor speed by connecting the motor positive terminal permanently to the positive supply and then switching the negative terminal to ground. This can also simplify the control circuitry, as it will normally have its ground rail connected to the power supply negative rail.

However there's a disadvantage to this approach: if you want to sense the motor's back-EMF for speed regulation, when the transistor switch is off, the negative terminal of the motor tends to sit near the positive supply rail and back-EMF causes a reduction in this voltage. This makes sensing the back-EMF tricky, especially if there's a lot of supply noise or ripple overlaid on it.

You can easily use an op amp configured as a differential amplifier to invert the back-EMF signal and shift it to be relative to the negative rail, so it can be filtered and fed to an analog-to-digital converter or analog circuit, for speed regulation. However, typical op amps will only operate to about 40V. So if you're dealing with a 48V (or higher voltage) motor, you would need an expensive and difficult-to-get high-voltage op amp, or a tricky supply arrangement.

This circuit provides an alternative. It uses just four transistors and a handful of passive components to invert and level-shift the back-EMF signal, giving you a positive-going, ground-referred output. While its accuracy and performance are compromised somewhat by its simplicity, it's more than adequate for speed regulation feedback. In this form, it will operate with a motor supply of up to 80V and switching speeds of at least several kilohertz.

It works as follows. NPN transistors Q1 and Q2 form a differential pair, with the base of Q1 acting as

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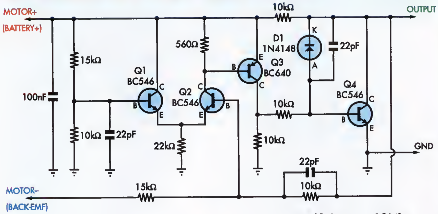

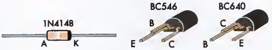

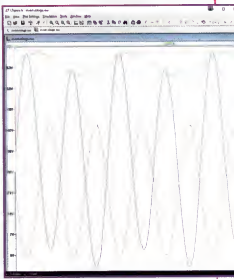

Fig.1: a simulation of the circuit. The motor+ terminal voltage is the green trace, the motor- terminal is the blue trace and the output voltage is the red trace.

Level shifter/inverter for back-EMF sensing – continued

the non-inverting input and the base of Q2, the inverting input. The non-inverting input is connected to a voltage divider across the motor supply, with a 22pF capacitor to reduce the effect of high-frequency hash. The inverting input is connected to a similar divider between the circuit's output and the motor's negative terminal, which serves as the motor back-EMF signal source when the motor is not being driven (ie, when the low-side switch transistor(s) are off).

The difference in voltage between the two inputs changes the current through Q2's 560Ω collector resistor and the resultant voltage controls PNP transistor Q3. Its base current is amplified and converted into a voltage relative to the negative rail (ground) by its 10kΩ collector resistor. The voltage across this resistor then controls NPN transistor Q4, which acts as an inverter, in combination with another 10kΩ collector pull-up resistor.

A 22pF capacitor between Q4's base and collector reduces the bandwidth of the circuit to around 20kHz, to prevent oscillation, while diode D1 stops this capacitor from charging to more than about -0.5V at times when the output is near 0V, which greatly improves recovery from this condition and also improves stability.

To better understand how the circuit works, consider what happens if the motor's negative terminal starts at a voltage similar to its positive terminal and then drops. Assume that the circuit output is initially 0V. In this condition, the bases of both Q1 and Q2 are initially at 40% of the supply voltage but the voltage at the base of Q2 then begins to drop.

This reduces the current through Q2's collector and hence the voltage across its collector resistor, increasing the voltage at Q3's base. This reduces Q3's base bias, thus reducing the current flowing to the base of Q4. This in turn causes it to start to switch off, allowing the output voltage to rise, so the feedback voltage at the base of Q2 starts to rise. This cancels out the drop in that voltage due to the lower back-EMF voltage.

Hence, the bases of Q1 and Q2 are held at essentially the same voltage, with the output voltage rising when the back-EMF voltage falls and vice versa.

The overall gain is set to around 67% because the output at Q4's collector can't swing all the way up to the positive rail. Normally, the back-EMF signal needs to be attenuated to be sensed anyway, so you can simply compensate by reducing the attenuation ratio. The ratios of the pairs of 10kΩ and 15kΩ resistors can be changed to adjust the overall gain of the circuit; for unity gain, use identical value resistors (eg, change the two 15kΩ resistors to 10kΩ). For lower gain, increase the value of the 15kΩ resistors.

Fig.1 shows a simulation of this circuit, with the motor + terminal voltage shown in green (with 10kHz ripple), the negative terminal varying in a 20kHz sinewave at greater than the full supply amplitude (blue waveform) and the output voltage in red.

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