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Precision DC motor speed control via pot or DAC

OCTOBER 4, 2022 < HTTPS://WWW.EDN.COM/PRECISION-DC-MOTOR-SPEED-CONTROL-VIA-POT-OR-DAC/> BY STEPHEN WOODWARD < HTTPS://WWW.EDN.COM/AUTHOR/STEPHEN-WOODWARD/>

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Ideally (in that magical land where theory and practice are the same thing), the speed of a permanent magnet DC motor is exactly proportional to the input voltage: **Speed = K_SV**, where constant **K_S** is specific to the motor in question. But since real motors exist alongside us in the practical world, their behavior differs from this theoretical ideal, mostly because real motors include resistance: Mechanical resistance (friction), and electrical (winding resistance = **R_W**). To produce the torque needed to overcome the former, motors must draw current (**I**) and when they do, current passing through **R_W** decreases the effective driving voltage (**-**

$\mathbf{IR_W}$). Therefore, when a motor is loaded by internal and/or external friction, current draw increases and effective voltage decreases. So, it slows down, as predicted by:

$$\mathbf{Speed = K_S(V - IR_W)}$$

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One way to reduce (or eliminate) this effect and make motor speed constant, despite varying frictional loading, is to actively cancel $\mathbf{R_W}$ by sensing current **I** and adding a proportional compensating term to **V**, thereby forcing:

$$\mathbf{Speed = K_S(V - IR_W + IR_W) = K_S V}$$

Figure 1 presents a simple, versatile circuit that does exactly that, plus the convenience of grounding one of the motor connections. Here's how it works.

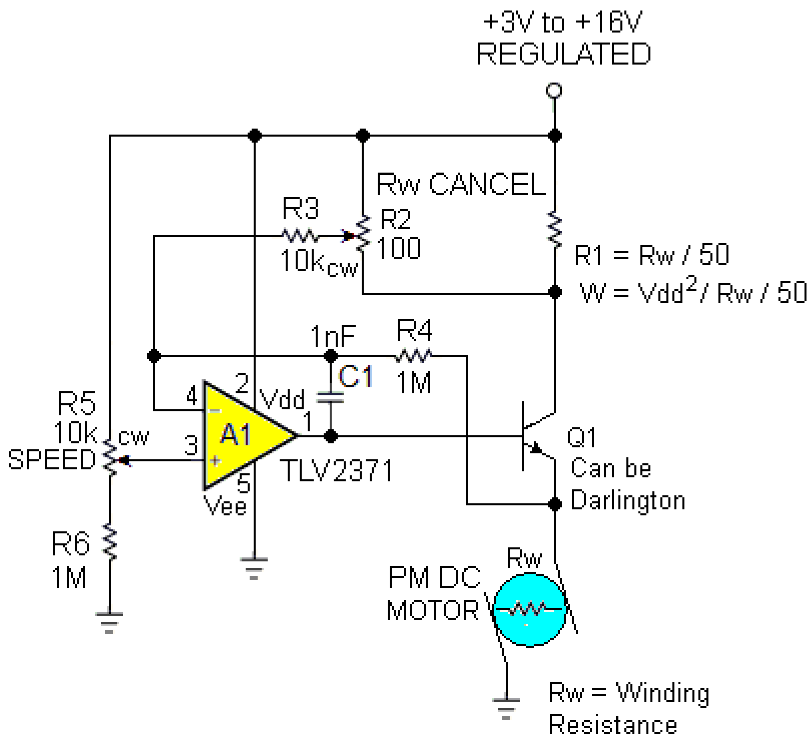

Figure 1 The R_W-cancelling motor drive.

Rail-to-rail op-amp A1 compares the speed setpoint from potentiometer R5, variable from (0.99)V_{dd} to V_{dd}, to the motor drive voltage $\mathbf{V_s}$ that is output by Q1 *via* the 100:1 R4/R3 voltage divider feedback loop, and servos Q1 base current accordingly. $\mathbf{V_s}$ is thereby settable from a minimum of zero (R5 fully CCW), to a maximum of V_{dd} minus the sum of the saturation voltages of A1 and Q1 (fully CW). The usable limits of V_{dd} are 3V to 16V, corresponding with A1's TLV2371 datasheet ratings. The V_{dd} and Q1 should be chosen for compatibility with motor drive ($\mathbf{V_s}$ and current) requirements.

But what about R_W cancellation?

Motor current **I**, as reflected in Q1's collector current, is sensed by R1. An adequately accurate estimate for R1, given that cancellation is ultimately fine-tuned with R2, can be based on a simple multimeter measurement of R_W while the motor shaft is held stationary. Typical R1 resistances (R1 = R_W / 50) will lie in the milliohm range, making implementation of R1 with a simple circuit-board-trace meander feasible. This is a good thing because a circuit board trace, being copper, will have a temperature coefficient similar to the (likewise copper) motor wiring: ~ 3930ppm/^{o}C, which will improve the stability of R_W cancellation versus temperature, provided that motor and R1 are in similar thermal environments. Note that R1's voltage drop due to its connection to Q1's collector isn't subtracted from max motor drive, but instead makes due with the (otherwise wasted) difference between Q1's base and collector saturation voltages. Note that the wattage rating needed for $\mathbf{R1 = V_{dd}^2/R_W/50}$ and a multiple of the **IR1** voltage developed (as set by R2) is added to $\mathbf{V_s}$ *via* the +40dB R4/R3 feedback loop.

Proper adjustment of R2 for Rw cancellation and constant speed independent of friction will thereby result in the (magical?):

$$\mathbf{K_S(V - IR_W + IR_W) = K_SV}$$

R2 adjustment can be accomplished in a variety of ways. For example, motor speed can be quantitatively measured (e.g., with an inexpensive optical tachometer) where R2 is adjusted for a constant speed while frictional load is varied. Or it can be done subjectively (by ear, listening to the pitch of the spinning motor's whine) for a similarly accurate result—if you can read music.

The Figure 1 circuit can thus generate a dialed-in motor drive voltage and compensate it for winding resistance, thereby achieving, and holding an accurate and stable set speed. But that speed is manually set by a pot wiper position. What if we need a more automated source of motor control?

Figure 2 answers this question with a variant of Figure 1 that replaces potentiometer R5 with an inexpensive ripple-canceled PWM-DAC.

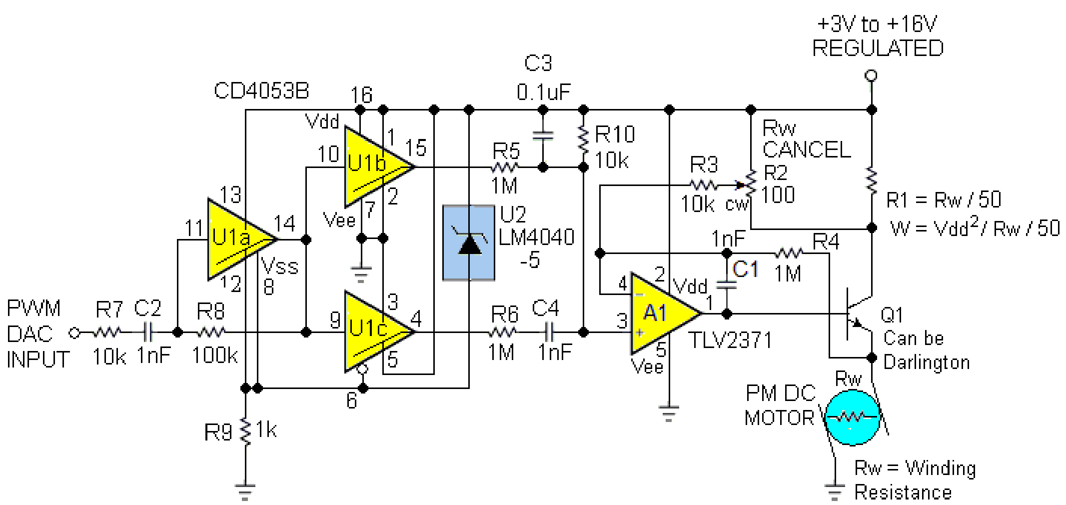

Figure 2 PWM DAC control of R_W-cancelling motor drive.

Gate U1a of triple-switch U1 regeneratively translates the logic level PWM input at R7 into a square wave output for gates U1b and U1c. V_{dd} voltages between 3 and 5V pass directly to U1 pin 8 (V_{SS}) *via* R9, while V_{dd} > 5V causes shunt regulator U2 to kick in, limiting U1's V_{dd} -V_{SS} to a logic compatible 5V.

U1b generates an uninverted PWM waveform for low-pass averaging by the R5, C3, and R10 network and output of $\mathbf{V_S}$, while U1c cranks out an AC-coupled inverted version suitable for analog subtraction ripple cancelation *via* R6C4 per the scheme described in this **design idea < https://www.edn.com/cancel-pwm-dac-ripple-with-analog-subtraction/>** .

Stephen Woodward < https://www.edn.com/author/stephen-woodward/> *'s relationship with* EDN's *DI column goes back quite a ways. In all, a total of 64 submissions have been accepted since his first contribution was published in 1974.*

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11 COMMENTS ON "PRECISION DC MOTOR SPEED CONTROL VIA POT OR DAC"

Konstantin Kim

October 6, 2022

Why C3 and C4 have not same value in this case ?
I guess that design may be simplified a bit by low side driving with PNP (or Sziklai) and ungrounded motor.
BTW: Your ripple cancelation idea is genius.

↪ **Log in to Reply**

Konstantin Kim

October 6, 2022

I'm a bit confused by the dead zone at the top of the input voltage.
TLV271 Common-mode input voltage is 0 .. VDD −1.35

↪ Log in to Reply

WStephenWoodward

October 6, 2022

Oops! I think I misread the TLV271 datasheet as being rail-to-rail output AND input. I was looking for a cost-effective alternative to the OPA2156 dual. Thanks for the correction.

↪ Log in to Reply

WStephenWoodward

October 6, 2022

The TLV2371 is RRIO and therefore should work. Sorry for the typo and losing that "3" in the part number.

Thanks again for the correction.

↪ Log in to Reply

WStephenWoodward

October 6, 2022

C3 and C4 have different values to achieve the same ripple-subtraction timeconstant.
R10C3 = R6C4.
= 1ms.

And thanks!

↪ Log in to Reply

Konstantin Kim

October 7, 2022

I would love to try low side sensing with LM358 for 24V supply.

↪ Log in to Reply

WStephenWoodward

October 7, 2022

If we're going with classics, why not stick with high-side sensing and pop in an LM301?

↪ Log in to Reply

WStephenWoodward

October 7, 2022

…or for something not (quite) as archaic, how 'bout a TL071?

Konstantin Kim

October 7, 2022

Let say LM301 is a bit too classic. 1967!!! ;). LM358(321) is actually just good cheap working horse.
LM301 will limit minimum supply by 10V. It may require output pulldown because LM301 not RRO.
Price of high-side sensing also is: input AC coupling + floating Vss of 4053, which is a bit annoying ;). I would prefer to ground 4053 instead of motor.

On the other hand, choosing something from the modern, I would pay attention to those with less offset. like TLV9151 instead of TLV2371 or TLV07 instead of 358.
Vos of TLV2371 (or 358) is 5mV which is 10% of input control range. But this is just little polishing details…

This is not a call to action. just reflections. Idea is clear and amusing. Thanks 🙂

BTW: decoupling caps for U2 and A1 are expected.

Konstantin Kim

October 7, 2022

+ low side sensing may not require 4053 . Most of the time, a PWM source can provide you with an inverted signal for free.

WStephenWoodward

October 7, 2022

Many aspects of this DI would become easier if the requirement of using only a single, variable PS and making motor drive proportional to it, were abandoned.

Sidebar: I'm pretty sure the high-side-sensing LM301 is rated for 30V, as is its internally compensated kissing cousin, the 307. Ditto for the TL071. True that none is RRO, but then neither is the LM358 — for sinking current greater than a few 10s of uA.

But thanks for a stimulating discussion!

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