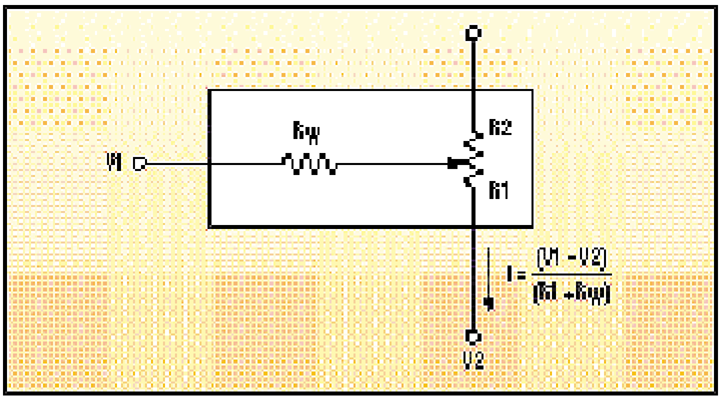
Active cancellation of a pot's wiper resistance

Contributing Author
ED Online ID #6209
June 14, 1999

Although we almost always call them "potentiometers," many (if not most) adjustable resistance devices actually end up being used as two-terminal variable resistors (rheostats). In actuality, the term "potentiometer" means a three-terminal variable voltage divider.

Unfortunately, when used as variable resistors, pots (whether electromechanical or electronic) suffer from a number of non-idealities that can thoroughly bust an error budget. Chief culprits among these parasites is the "wiper resistance."

Wiper resistance arises in electromechanical pots because they consist of a stationary resistance element over which a sliding contact (wiper) moves to set the desired resistance. Perversely, the contact point between wiper and resistance element itself inevitably makes an undesired non-zero contribution (RW in figure 1) to the total resistance (R1 + RW). The effective resistance of the pot can therefore never be adjusted all the way to zero but instead has a minimum value directly related to RW. What's worse, RW is strongly influenced by surface phenomena lurking in the mechanical interface between wiper and resistance element. This makes it seriously unstable against time, temperature, and life-cycle wearout mechanisms.

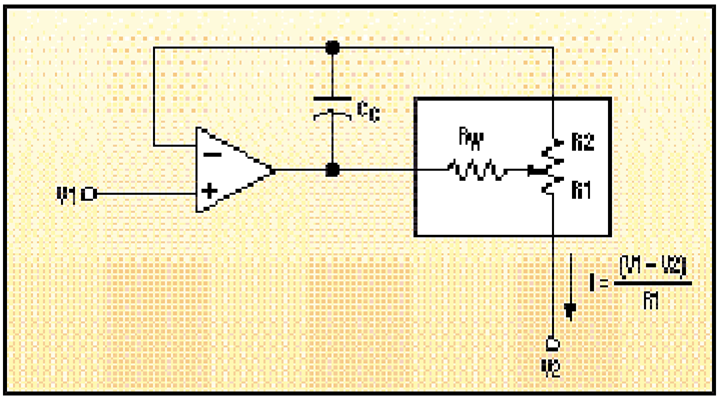


1. Uncompensated wiper resistance can cause serious instabilities due to time, temperature, and life-cycle wearout mechanisms.

Electronic (digitally controlled) potentiometers (DCPs), on the other hand, escape the contact resistance problems of the mechanical pot. However, they must contend instead with the relatively large RON resistances (usually tens of ohms) of the FET switches that implement the multiplexer, which substitutes for the mechanical pot's wiper.

While FETs don't wear out and get noisy like mechanical wipers, the FETs' RON temperature coefficients approach 3000 ppm/°C-five to ten times worse than typical resistance elements. Therefore, even relatively small RW contributions to total circuit resistance may significantly degrade circuit stability. Take, for example, the Xicor XC102 digitally controlled pot. Its 1k resistance element has a tempco of ±600 ppm/°C max, and the setting resolution is 10 Ω. RWis typically 40 Ω. For resistance settings of 200 Ω or less, the overall resistance tempco is dominated by RW. In addition, because RW can range as high as 100 Ω, the resistance setting accuracy is at the mercy of RW for settings below 500 Ω. Not a pretty picture.

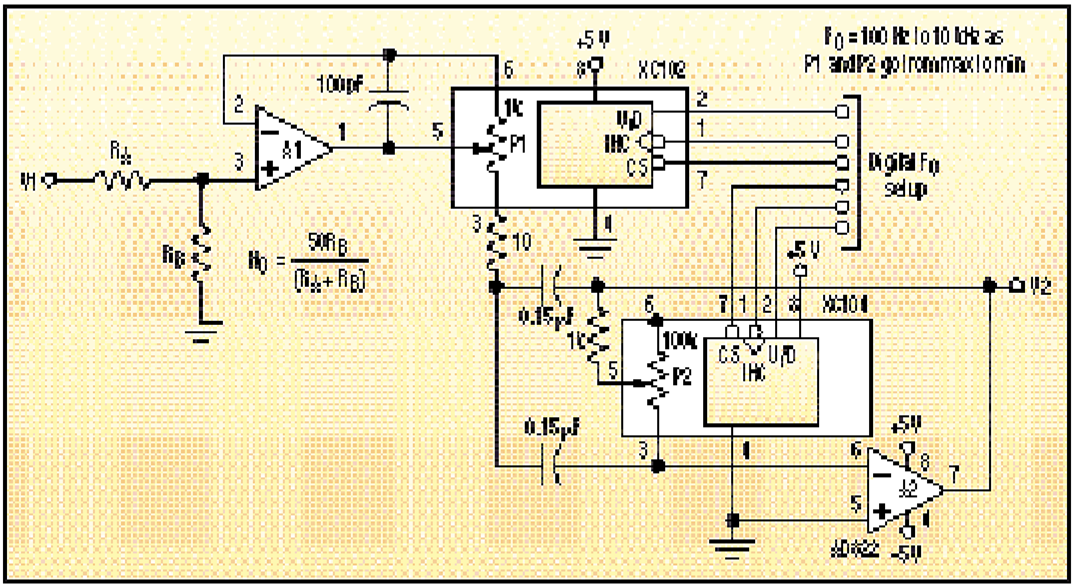
Figure 2 illustrates a way to effectively blot out these RW-related difficulties. It relies on the fact that, since the resistance component R2 conducts only negligible (op amp bias) currents, the voltage at the amplifiers (–) input is essentially the same as the voltage at the R1-R2 node and therefore equal to (I * R1 + V2) independent of RW. Consequently, when the op amp forces the R1-R2 node to V1 (as it must to maintain input balance), I is forced to accurately equal (V1 – V2)/R1, and thus the RWeffects vanish. Optional frequency compensation in the form of CC will sometimes be needed to avoid op-amp feedback instability resulting from phase shift in R2.



2. This arrangement effectively blots out wiper-resistance-related difficulties.

Figure 3 shows the new topology put to good use in a widerange (f_O = 100 Hz to 10 kHz) Qof-5, digitally tunable bandpass filter. DCP P2 (100k) isn't bothered much by RWeffects, due to RWeffects, its typical 2500:1 RW-to-element resistance ratio. Therefore, it wouldn't benefit from Figure 2's trickery. But DCP P1's performance would be compromised significantly (due to its 25:1 ratio) at low-resistance (high-frequency) settings if nothing were done to cancel its RW. A1 does that while simultaneously buffering the RA–RB voltage divider, the adjustment of which can set passband gain anywhere from 0 to 50.

The incremental (up/down) digital interface of P1 and P2 makes this filter ideal for frequency-tracking applications. Such applications have a phasesensitive quadrature detector/comparator combination that can be used to generate the up/down direction control signal for both DCPs. As a result, it's possible to implement a feedback loop that will automatically converge on optimum tuning.



3. The new topology is put to good use in a wide-range (f_0 = 100 Hz to 10 kHz) Q-of-5, digitally tunable bandpass filter application.