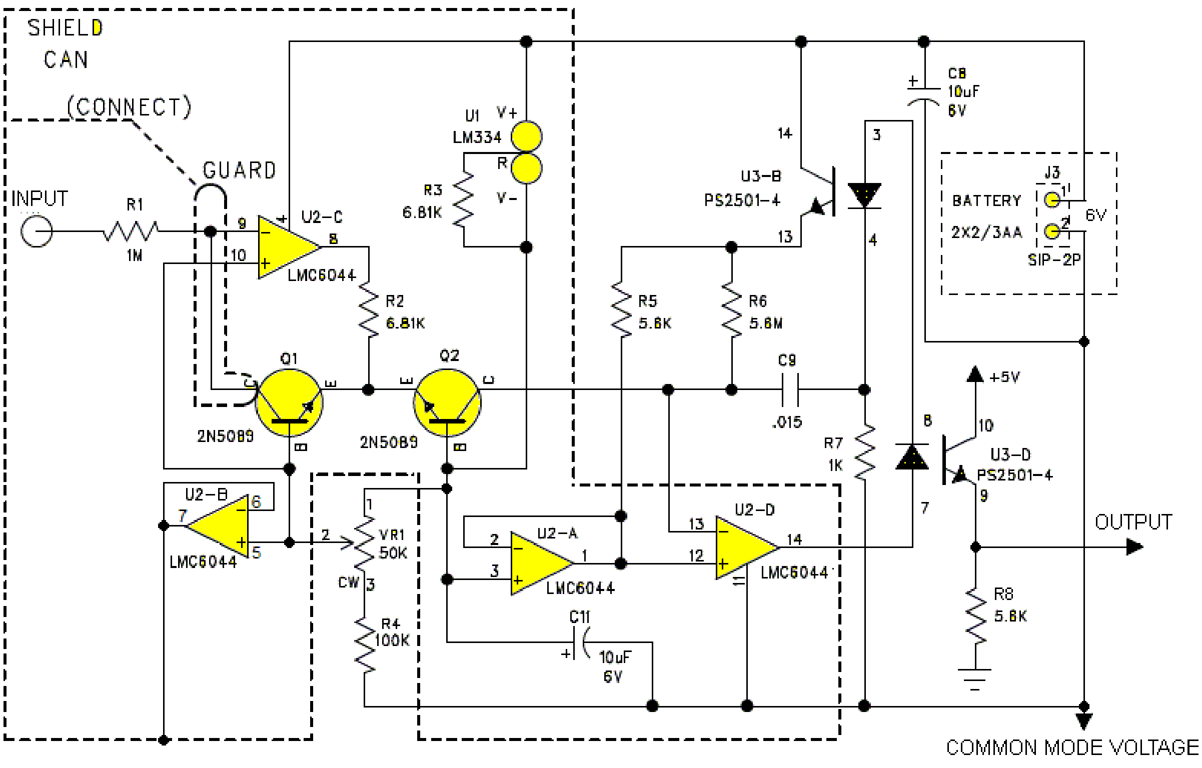
[FemtoAmp offers extreme gain range & isolation]

[Stephen Woodward] - April 16, 2018

Amplification of sub-picoamp signal currents is always a design challenge, especially when gain adjustment is required that spans multiple decades. A straightforward approach to the design task would normally involve potentiometers and teraohm feedback resistors, which are neither easily miniaturized nor temperature stable. This **Design Idea** takes a different path, utilizing bipolar transistors, the diode junction equation, and a temperature-tracking bias current source, and offering a 160 dB (100,000,000:1), temperature-compensated, linear-in-dB gain adjustment range, plus linear optical isolation for good CMR with low-level signals.



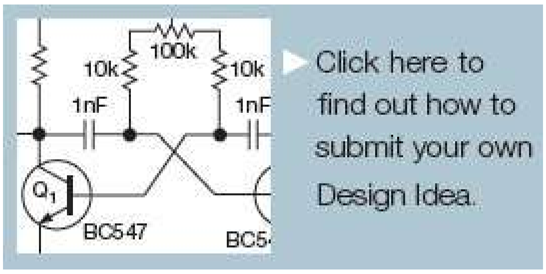
FemtoAmp has eight decades of gain range.

The core of the design is U2-C's feedback network centered around current steering pair Q1 & Q2. Gain adjustment VR1 establishes a bias differential V_b (0 - 500 mV) between the transistors that in turn establishes a ratio between their emitter currents according to the usual *Diode Equation*:

$$I_2/I_1 = 10^{V_b/(2E\text{-}4 \cdot T_a)} \qquad [1]$$

Where T_a = ambient temperature in kelvins.

Thus, for T_a = 300 K (27 °C), a gain range of 0 – 166 dB is accessible via adjustment of trimpot VR1 (From the classic transistor equation, a differential of 60 mV at 300 K equates to a factor of 10 in current. Hence the gain control voltage adjustability of 500 mV translates to a gain range of $10^{500/60}$).



Meanwhile, temperature compensation is provided by current source U1's PTAT (proportional to absolute temperature) output (10 µA at 300 K). U1, Q1, and Q2 should be thermally intimate. Being under the shield together may be enough, but actual bonding is even better, as gain will vary by about 5% for every degree difference between the transistors.

Q2's output current is further amplified by U2-D by the 1000:1 (60 dB) ratio specified by R6/R5, and coupled by LED/phototransistor pair U3-D. Putting U3-B inside U2-D's feedback loop, and operating the two coupled photo-pairs at similar bias voltages and current levels, provides good linearity and calibration stability against time and temperature.

The original application of the *FemtoAmp* was in instrumentation for uniquely high performance detection of the 1.6×10^{-15} coulomb pulses produced by the radioactive decay of radon (^{222}Rn) in air. Most radon detectors are incapable of direct detection and counting of primary Rn decay, and depend instead on electrostatic precipitation of the "daughter atom" byproducts of the primary decay. Due to the slow "grow-in" times of the daughter atoms, assays that depend upon them require hours to produce an accurate measurement of radon concentrations. In contrast, instrumentation based on this **Design Idea** includes post-processing of the acquired history of detected pulse rates…

$$R_n = P_n - D_{n-1}R_{n-1} - D_{n-2}R_{n-2} - \ldots \qquad [2]$$

…where the array of D_i comprises constants calculated from the decay rates of the radon daughter isotopes, which computationally deconvolves and removes the contribution of the daughter atoms, producing an accurate assay of radon activity in minutes instead of hours.

Related articles:

- **Design femtoampere circuits with low leakage, part one**
- **Achieve femtoampere leakage in surface-mount op-amp layouts**
- **Gain control**
- **My Geiger counter doesn't count (sob sob)**
- **Femtoamp (fA) measurements**

—*W. Stephen Woodward is one of EDN's most prolific and innovative Design Ideas authors, with dozens of contributions to his credit.*