Op amps multiply RC time constants

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Unusually long time constants can be generated with considerable accuracy by combining readily available low-value resistors and capacitors with a couple of general-purpose operational amplifiers. Besides being physically smaller than their higher-value counterparts, low-value components offer tighter value tolerances and do not have leakage or polarity problems. Furthermore, when high-value resistors are used, field-effect-transistor-input op amps must be employed. They are more expensive than general-purpose op amps and do not provide as good input offset and temperature drift specifications.

A number of instrumentation applications require time constants in the order of seconds or minutes. Circuit (a), for instance, can be used to stretch one-shot output pulses, or as a low-pass insertion filter for monitoring slowly changing meteorological, oceanographic, or other geoscientific phenomena where low-frequency noise is undesirable. This network can multiply a basic RC time constant by a factor as large as 10,000. (For example, a 100-second time constant can be realized with $R = 100$ kilohms and $C = 0.1$ microfarad.)

When V_i is a step input, output voltages E_1 and E_2 rise exponentially to final values $-V_i$ and $+V_i$, respectively, with a time constant (taken at 63% of the final level) of $(N+2)RC$.

$$E_2 = -E_1 = V_i[1 - \exp(-t/(N+2)RC)]$$

The actual values of resistors R_1 and R_2 are not critical because the time constant is determined by ratio N and the values chosen for R and C. The components indicated provide a time constant of 50 seconds.

The drift and noise of either output referred to the original input V_i will be the same as that obtained when amplifier A_1 is operated at a closed-loop gain of $N+1$, modified of course, by the filtering effect of the time constant generated. After capacitor C is removed, the circuit can be seen to be an op amp (A_1) connected for a closed-loop gain of $N+1$, since amplifier A_2 is simply a unity-gain inverter.

The offset null trimmer permits the E_1 output to be set initially to zero for a zero input. Generally, the trimmer can be omitted for values of N less than 50. To avoid a tedious time lag in circuit output response when making this adjustment, one end of the capacitor should be disconnected temporarily.

Gains other than plus or minus unity can be obtained at outputs E_1 and E_2 by making the input attenuation and feedback ratios unequal; they are both $1/(N+1)$ for circuit (a). Also, the inverting gain of amplifier A_2 can be other than unity. As shown in circuit (b), input attenuation can be controlled by ratio α, feedback by ratio γ, and inverting gain by ratio β. The two outputs become:

$$E_1 = -V_i(\gamma+1)[1 - \exp(-t\beta/(\beta+\gamma+1)RC)]/(\alpha+1)\beta$$
$$E_2 = V_i(\gamma+1)[1 - \exp(-t\beta/(\beta+\gamma+1)RC)]/(\alpha+1)$$

In applications where desired drift and noise specifications cannot be met by a 747-type op amp, amplifier A_1 can be stabilized with a temperature-controlled differential preamplifier, such as Fairchild's μA727B. This integrated circuit has an on-chip proportional temperature regulator, affording tight control of chip temperature at about 100°C. The 727-plus-747 combination provides excellent dc stability at high closed-loop gains and can be treated circuitwise as a single op amp. If a preamplifier is added, the null offset trimmer is no longer effective. □

Extending RC time constants. Low-value resistors and capacitors and two op amps can generate time constants that are several minutes long. Output voltages E_1 and E_2 exponentially approach level of step input V_i. Time constant, which is 50 seconds for circuit (a), primarily depends on R, C, and ratio N. For circuit (b), there are three controlling ratios: α for input attenuation, γ for feedback, and β for gain.