Letters to the Editor

MISUSE OF EXACT GAIN FORMULA

Dear Sir:

Somewhat over a year ago I noticed a continuing increase in the misuse of the exact gain formula in operational amplifiers. Attempts to bring this to the readers' attention were met with indifference.

In your June issue of ANALOG DIALOGUE the error has again been repeated. I refer on page 13 to the example using data from Figure 11. The author computes an amplification of -99, or 1% from ideal. Actually if he had taken into account the 90 degree phase lag, Θ, of A at the selected frequency of 100 Hz on the 6 dB slope in figure 11, the true G is $-100/\sqrt{1+(0.0101)^2}$ or 0.005% from ideal rather than 1%. Naturally, the effect of quadrature is less for departures of phase angle from 90 degrees. The standard formula (1) in the enclosed letter article can be modified into a working formula such as

$$G = -\frac{Z_f}{Z_i}\left[\frac{1}{1+\frac{1}{A}\cdot(\cos\Theta - i\sin\Theta)\cdot(1+Z_f/Z_i)}\right]$$

I should like to see the enclosed letter article published in your journal. It has been approved for publication by the National Bureau of Standards.

Louis A. Marzetta

(Letter referenced above)

INCORRECT USAGE OF EXACT CLOSED-LOOP VOLTAGE GAIN FORMULA IN OPERATIONAL AMPLIFIERS

No one who has been interested in operational amplifiers during the past year could avoid acquiring a voluminous folder of articles, booklets and reports on the subject. Most of the promotional literature contains tutorial material that is, for the most part, helpful. But a serious error in the application of a basic formula seems to have crept into so much of it that I submit this letter in the hope of bringing it to the reader's attention.

The usual format is to introduce the reader to the principles of operation by writing input and output loop expressions for the amplifier and its external impedances. Considering an ideal amplifier with infinite gain and bandwidth, the expression for closed-loop voltage amplification is given, as $\frac{V\,out}{V\,in} = -\frac{Z\,feedback}{Z\,input}$. The next step is to define an operational amplifier with special emphasis on the 6 dB octave roll-off characteristic of amplification. Unfortunately, most of the authors did not keep this slope in mind when they copied the following expression, the exact closed-loop voltage amplification formula.

$$\frac{V\,out}{V\,in} = -\left(\frac{Z_f}{Z_i}\right)\frac{1}{1+\frac{1}{A}\left(1+\frac{Z_f}{Z_i}\right)} \quad (1)$$

A is identified as the open-loop amplification, while Z_i and Z_f are the input and feedback impedances. The second bracketed group of terms is generally called the error factor. It expresses the degree of departure of the actual amplification from the ideal simple ratio of Z_f and Z_i. In a number of articles this formula has been augmented with numerical examples, convenient monograms and tables — almost all of which are in error for exact gain computation.

The formula is explicit for flat frequency response situations but it can lead to serious errors in calculating the precise amplification for operational amplifiers, the reason being that associated with an amplitude roll-off is a phase shift of 90 degrees for a 6 dB slope. At first glance one might underestimate the importance of the phase angle of A in the formula and expect to compute a sizeable error factor in the region of reduced amplification. In reality such an error factor involves a quadrature expression; therefore, the actual magnitude error may be very small. For example, calculate the error factor at the point where A has dropped to 100 on a 6 dB slope, in an operational amplifier with equal values for Z_f and Z_i. Neglecting the phase of A in the formula, the device would be thought to have an error factor of 2%. However, using the same formula, but treating A as a phasor quantity, the true error factor amounts to only 0.02%.

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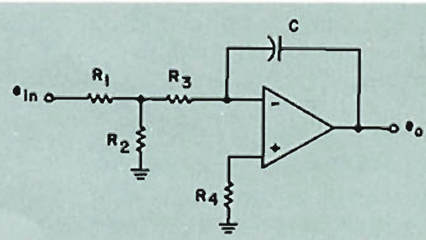
INDIRECT METHOD OF ACHIEVING LARGE RC PRODUCT

Dear Sir:

Ray Stata's article on Operational Integrators was timely and welcome. I wish, however, to extend his analysis to large time constant integrators. Because it is physically or economically impossible to achieve a large RC product directly, a Tee is commonly used to obtain the desired RC product.

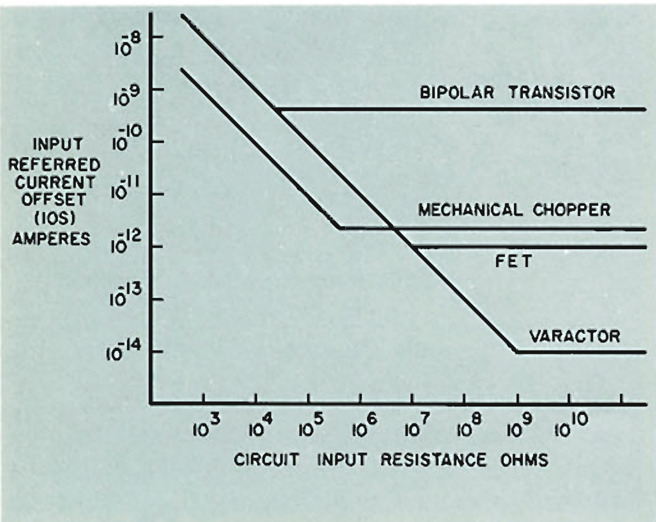


$$\frac{de_o}{dt} = \frac{e_{in}}{\left(R_1+R_3+\frac{R_1R_3}{R_2}\right)C} + \frac{e_{os}}{\left(R_3+\frac{R_1R_2}{R_1+R_2}\right)C} + \frac{I_{os}}{C}$$

$$R_{4\,OPT} = R_3 + \frac{R_1R_2}{R_1+R_2} \approx R_3$$

FIGURE 1.

As in the earlier analysis, C should be as large as possible. Assuming R_3 cannot then be made large enough to achieve the necessary RC product, it is wise to choose R_3 as large as possible, in order to reduce voltage offset errors. No particular advantage is gained by making R_1 and R_2 large, as their parallel value will generally be much smaller than R_3 anyway.
Selection of a suitable amplifier can be made from the log-log plot of input referred current offset (Ios) as a function of circuit input resistance. This plot is based on short term stability (½ hour). Longer term stability (day) is about five times worse and temperature stability (per °C) is about two times worse.



Notice that for integrator input resistance values of ten megohms or less, about equal performance can be expected from either a FET or a varactor amplifier. For input resistance values less than several megohms, best performance is offered by mechanical chopper amplifiers.
In a laboratory environment only the time dependent offsets are important. At input resistances below the "break point" the voltage offset is the limiting offset, and above, the current offset. It is apparent that an open input integrator is the most practical means of measuring current offset.
A similar such graph can be made in terms of input referred voltage offset vs. circuit input resistance this form being especially suited to selection of scaling amplifiers or of scaling impedance levels.

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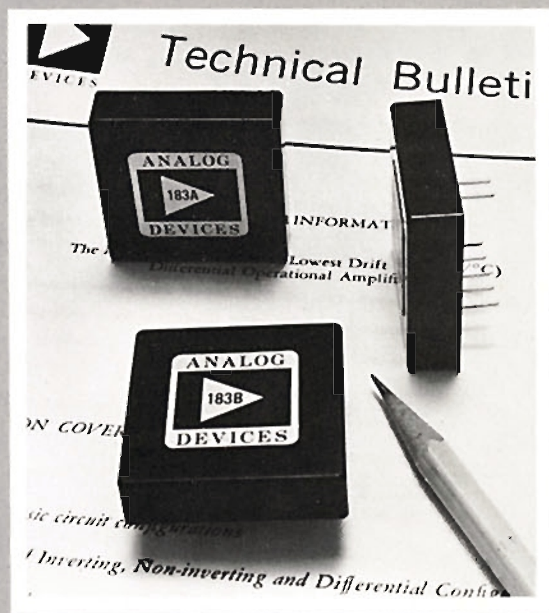
Editors Note: One should be aware that the voltage offset error using this method will be approximately $1 + \frac{R_1}{R_2}$ times as large as it would be with the equivalent single resistor connected to e_{in}.

NEW PRODUCT

the New Model 183 *CHOPPERLESS* Operational Amplifier

1.5uV/°C $65
3uV/°C $45
5uV/°C $35



SPECIFICATIONS

Open Loop Gain	200,000 min.
Rated Output	±10V @ 5mA
Unity Gain Response	0.5MHz
Full Power Response	5kHz
Current Drift (Differential)	0.05nA/°C max.*
CMRR (±10V)	100,000
Warm Up Drift	20μV (20 minutes)
Noise (dc to 1Hz)	1μV, peak to peak

Offset Voltage	Model J	Model K	Model L
@ 25°C, max.	3mV	.5mV	.5mV
vs. temp., max.*	5μV/°C	3μV/°C	1.5μV/°C
Price (1-9)	$35	$45	$65

***temperature range 10—60°C; for —25 —85°C add $5 and specify 183A/B/C**