Exclusive Technology Feature

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Average Value Extractor Is More Precise Than Low Pass Filters

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When designing switching power supplies and their associated filters, it is often necessary to know average values of acting voltages and currents. This is reflected in the many formulas used in switching power supply design that employ values of the duty-cycle that define the average value of acting voltage or current.

Furthermore, when measuring voltage or current, we may want to obtain the average value to avoid the error that may be introduced by a duty-cycle instability that produces a dc fluctuation, which in turn could affect measurement accuracy. This is the case when designing ac current sensors, where we use the current's average value to create a voltage that mitigates the error due to dc offset in the system of integrator and amplifiers.[1]

While it's possible to obtain the average value of an analyzed signal through usage of a low-pass filter, the filter significantly narrows the signal's operating frequency range, which is not always acceptable. However, we find another option if we recall that operational amplifiers perform a function of subtraction of signals at their inputs.

With an op amp, we can subtract an ac component from a signal composed of this ac component and a dc offset delivered by the high-gain amplifiers employed in the system. Then, further usage of the extracted and amplified dc offset (dc = (ac + dc - ac)) in the feedback loop can significantly reduce the dc error at the output of the measuring system thus improving its accuracy.

In this article, we'll derive the equations for an average value extractor circuit built from an op amp-based circuit—specifically a differential amplifier. Then we'll demonstrate how this average value extractor can be used to perform dc stabilization of a Rogowski integrator circuit. Now, for those who read my recently published article, "Integrator Feedback Resistor—Adverse Or Friendly?..."[2] you may be wondering, "didn't we already accomplish that goal using the servo feedback technique?

The answer is yes, but there are differences. In the previous publication, no differential amplifier was used. The schematic was based on low-pass filtering of the feedback signal, which also delivers an average value but within a narrower frequency bandwidth as noted above. In the method described in this article, we have a differential amplifier-based low-pass filter that uses a high-pass filter. This ensures a very low cutoff frequency due to the procedure of signal subtraction performed by the op amp. The result is a more accurate measurement.

The Differential Amplifier Should Have Well Matched Inputs

The schematic shown in Fig. 1 performs the mathematical operation of subtraction of the ac components from the dc + ac mixture thus providing an output signal proportional to the dc offset. This dc signal can be used in a negative feedback loop for removal of the adverse dc offset.

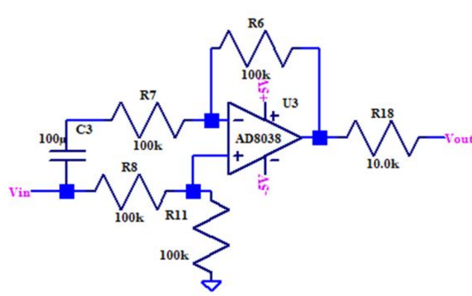

Fig. 1. A high-frequency differential amplifier based on a >85-MHz bandwidth operational amplifier can be used to build an average value extractor. Its performance depends on how well resistors' R6, R7, R8 and R11 values are matched and the operating frequency range. Unfortunately, integrated "ideal" differential amplifiers have too low a frequency range.

When the available low-cost conventional operational amplifiers are configured as a differential amplifier they should have same impedances for inverting and non-inverting inputs: R7 + R6 and R8 + R11 correspondingly. However, we have to have the inputs balanced (inverting and non-inverting gains the same) to obtain the lowest error. Abstracting from the resistors' values in Fig. 1, we can define the resistor values required to ensure the same input impedance as shown in the following analysis.

The inverting channel gain is (assuming C3 capacitance is too high to affect the negative channel gain since C3*R7 = 10 s and the maximum operating pulse duration is assumed to be 10 ms):

$$G_{inv} = \frac{R6}{R7} \quad (1)$$

The non-inverting channel gain as seen from the connection of R8 and R11 is

$$G_{ninv} = 1 + \frac{R6}{R7} \quad (2)$$

Since $G_{ninv} > G_{inv}$ we have to add to the non-inverting input a divider having a gain k to equalize both channels' gains:

$$G_{ninv} \cdot k = G_{inv} \quad (3)$$

Now, the value for k can be found from (1), (2) and (3):

$$\left(1 + \frac{R6}{R7}\right) \cdot k = \frac{R6}{R7} \quad (4)$$

which yields for k:

$$k = \frac{R6}{R6+R7} \quad (5)$$

At the same time, from Fig. 1

$$k = \frac{R11}{R8+R11} \quad (6)$$

Denote

$$a = \frac{R6}{R7} \quad (7)$$

This allows us to re-write (5) as

$$k = \frac{R6}{R6+R7} = \frac{\frac{R6}{R7}}{1+\frac{R6}{R7}} = \frac{a}{1+a} = \frac{R11}{\frac{R8}{1+\frac{R11}{R8}}} \quad (8)$$

Then, if we denote

$$n = \frac{R11}{R8} \quad (9)$$

this yields

$$k = \frac{n}{1+n} \quad (10)$$

Thus, (4) becomes

$$(1+a)\cdot\frac{n}{1+n}=a \quad (11)$$

which yields

$$a=n$$

or

$$\frac{R6}{R7}=\frac{R11}{R8} \quad (12)$$

Next, we will determine an expression for the output voltage Vout. Note that the input voltage is a combination of the useful waveform, describing the input signal $V_f(t)$ and a dc offset V_{off}:

$$V_{in}(t)=V_f(t)+\ V_{off} \quad (13)$$

Therefore, the inverting-channel output voltage would be

$$V_{inv\_out}(t)=V_f(t)\cdot\frac{R6}{R7} \quad (14)$$

And the non-inverting channel output would be

$$V_{noninv\_out}(t)=V_{in}(t)\cdot\frac{R11}{R8+R11}\cdot\left(1+\frac{R6}{R7}\right) \quad (15)$$

The resulting output voltage should be

$$V_{out}(t)=V_{noninv\_out}(t)-V_{inv\_out}(t)=V_{in}(t)\cdot\frac{R11}{R8+R11}\cdot\left(1+\frac{R6}{R7}\right)-V_f(t)\cdot\frac{R6}{R7}$$

$$=(V_f(t)+\ V_{off})\cdot\frac{R11}{R8+R11}\cdot\left(1+\frac{R6}{R7}\right)-V_f(t)\cdot\frac{R6}{R7} \quad (16)$$

After factoring the above expression, we get

$$V_{out}(t)=-\frac{R6\cdot R8\cdot V_f(t)-R7\cdot R11\cdot V_f(t)-R6\cdot R11\cdot V_{off}-R7\cdot R11\cdot V_{off}}{R7\cdot(R8+R11)}$$

Collecting V_{off} and $V_f(t)$ yields

$$V_{out}(t)=\left[\frac{R6\cdot R11+R7\cdot R11}{R7\cdot(R8+R11)}\right]\cdot V_{off}+\left[-\frac{R6\cdot R8-R7\cdot R11}{R7\cdot(R8+R11)}\right]\cdot V_f(t) \quad (17)$$

To remove the $V_f(t)$ from the output V_{out}, we should have

$$-\frac{R6\cdot R8-R7\cdot R11}{R7\cdot(R8+R11)}=0 \quad (18)$$

This expression requires

$$R7\cdot R11-R6\cdot R8=0 \quad (19)$$

or

$$\frac{R6}{R7}=\frac{R11}{R8}\ \text{(same as 12)} \quad (20)$$

The output offset dc voltage is

$$V_{out}(t) = \left[\frac{R6 \cdot R11 + R7 \cdot R11}{R7 \cdot (R8 + R11)}\right] \cdot V_{off} \tag{21}$$

If we apply the equivalence in (20) we obtain

$$V_{out}(t) = \left[\frac{R11^2}{R8 \cdot (R8 + R11)} + \frac{R11 \cdot R8}{R8 \cdot (R8 + R11)}\right] \cdot V_{off} \tag{22}$$

which simplifies to

$$V_{out}(t) = \left[\frac{R11 \cdot (R11 + R8)}{R8 \cdot (R8 + R11)}\right] \cdot V_{off} = \frac{R11}{R8} \cdot V_{off} = \frac{R6}{R7} \cdot V_{off} \tag{23}$$

For simplicity and to ensure maximum frequency range for the extractor, it is reasonable to make R6 = R7 and R11 = R8.

In this case $V_{out} = V_{off}$ —the output voltage is equal to the offset voltage.

As an example, we provide an LTspice schematic arrangement of the balanced integrator for the Rogowski sensor in Fig. 2

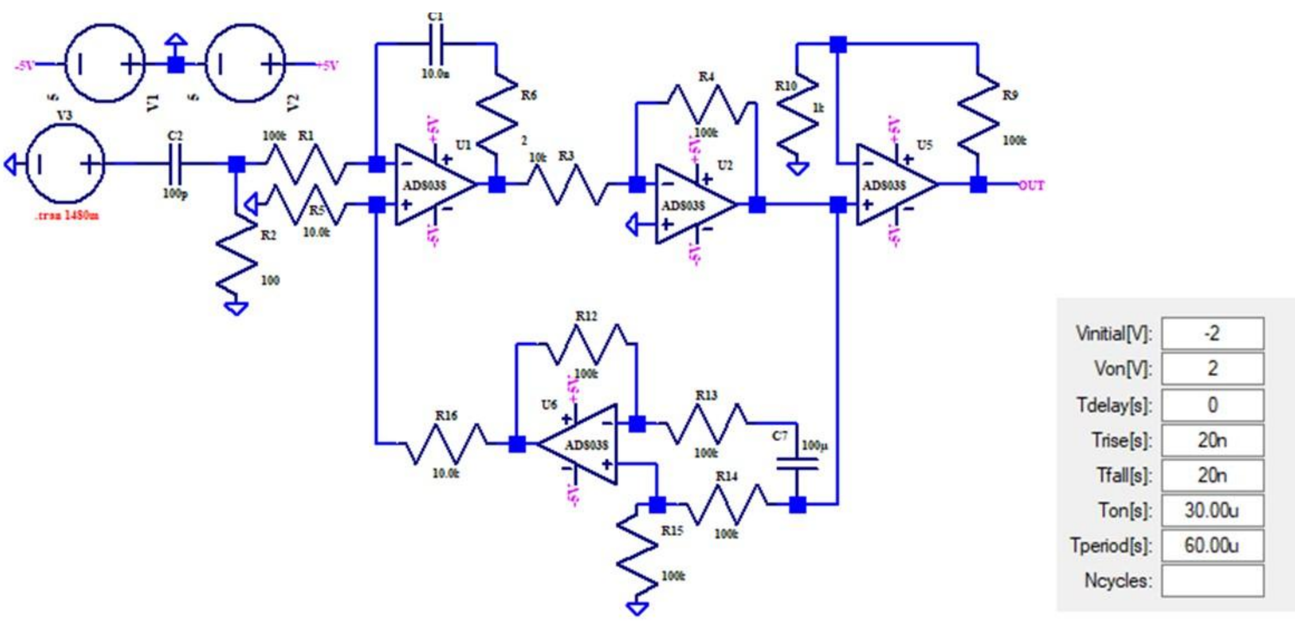

Fig. 2. Schematic of the Rogowski sensor integrator. V3 represents the current to be sensed, whose parameters are shown in the table above. Its plot is shown in Fig. 3.

Fig. 3. The integrator output voltage Vout is an exact replica of the pulses simulating the measured current per the table above.

Accuracy of this integrator is better than 2% within the frequency range of 30 Hz to 300 kHz.

The Takeaway

The proposed average value extractor can be successfully used in high-frequency devices requiring accurate dc stabilization over a wide frequency range.

Reference

1. "A Guide To Designing Your Own Rogowski Sensor (Part 2)" by Gregory Mirsky, How2Power Today, May 2024.
2. "Integrator Feedback Resistor—Adverse Or Friendly? How To DC Stabilize An Integrator Output" by Gregory Mirsky, How2Power Today, November 2025.

About The Author

Gregory Mirsky worked as a design engineer in Deer Park, Ill. He performed design verification on various projects, designed and implemented new methods of electronic circuit analysis, and ran workshops on MathCAD 15 usage for circuit design and verification. He obtained a Ph.D. degree in physics and mathematics from the Moscow State Pedagogical University, Russia. During his graduate work, Gregory designed hardware for the high-resolution spectrometer for research of highly compensated semiconductors and high-temperature superconductors. He also holds an MS degree from the Baltic State Technical University, St. Petersburg, Russia where he majored in missile and aircraft electronic systems.

Gregory holds numerous patents and publications in technical and scientific magazines in Great Britain, Russia and the United States. Outside of work, Gregory's hobby is traveling, which is associated with his wife's business as a tour operator, and he publishes movies and pictures about his travels online.