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Integrator Feedback Resistor—Adverse Or Friendly? How To DC Stabilize An Integrator Output

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In a recent article, we explored how the design of an inverting integrator can be tailored to achieve the desired bandwidth in a Rogowski sensor application.[1] However, that integrator design was incomplete as it did not correct for the "walkaway" of the integrator output caused by thermal and noise effects at the amplifier's inputs, which include input voltage offsets and leakage current. These stray parameters make the integrator inoperable if specific measures are not taken.

Very often designers use a feedback resistor of a few megohms, establishing negative feedback to eliminate the integrator output walkaway. But does this method work and if so, what effects might it have on integrator operation?

In this article, we analyze the impact of the dc feedback resistor on integrator design—both inverting and non-inverting. We also discuss another method of stabilizing integrator operation in the Rogowski sensor application with servo feedback. This article is a continuation of two previous series on designing Rogowski sensors[2,3,4] and integrator design.[5,6,7]

Integrator Transfer Functions

Let us obtain amplitude-frequency characteristics for both inverting and non-inverting integrators having negative feedback resistors R7, as shown in Fig. 1 below. First, we define transfer functions for the schematic arrangements of the integrators.

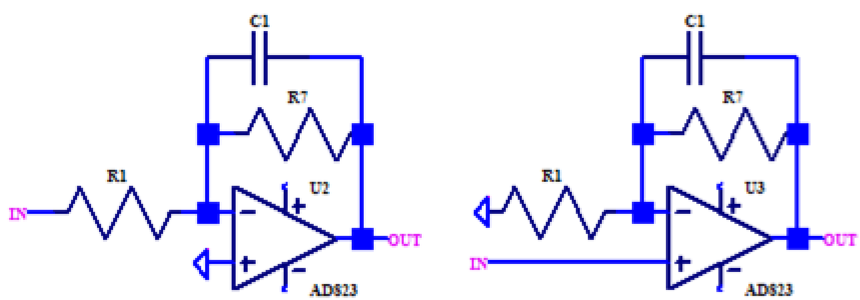

Fig. 1. Schematics for inverting (left) and non-inverting (right) integrators utilizing a feedback resistor R7 to eliminate the output dc walkaway.

The feedback impedance for both cases is

$$Z_{FB}(s) = \frac{1}{s \cdot C1 + \frac{1}{R7}}$$

which simplifies to

$$Z_{FB}(s) = \frac{R7}{C1 \cdot R7 \cdot s + 1}$$

Gain for the inverting integrator is

$$G_{in}(s) = \frac{Z_{FB}(s)}{R1} = \frac{\frac{R7}{C1 \cdot R7 \cdot s + 1}}{R1}$$

while gain for the non-inverting integrator is

$$G_{ni}(s) = 1 + \frac{Z_{FB}(s)}{R1} = 1 + \frac{\frac{R7}{C1 \cdot R7 \cdot s + 1}}{R1}$$

Simplifying we get the following for the inverting integrator,

$$G_{in}(s) = \frac{R7}{R1 + C1 \cdot R1 \cdot R7 \cdot s}$$

which can be rewritten as

$$G_{in}(s) = \frac{R7}{R1} \cdot \frac{1}{1 + C1 \cdot R7 \cdot s}$$ (1) Inverting Integrator

and for the non-inverting integrator

$$G_{ni}(s) = \left(1 + \frac{R7}{R1}\right) \cdot \left(\frac{1 + s \cdot C1 \cdot \frac{R1 \cdot R7}{R1 + R7}}{1 + s \cdot C1 \cdot R7}\right)$$ (2) Noninverting integrator

The transfer function for an inverting integrator schematic shows:

- The feedback resistor R7 transforms the inverting integrator into an amplifier with a limited frequency range, and this limitation is defined by the time constant τ = C1*R7. (In other words, instead of the circuit's response having a rolloff that begins at 0 Hz as it would for an integrator,[6] it would have a rolloff beginning at ω = 1/(R7*C1). This happens because C1 discharges through R7 and not R1.)
- The dc gain of this amplifier is just the ratio of the feedback resistance R7 and input resistance R1.
- The feedback resistor R7, although stabilizing the device output by removal of dc walkaway, removes its ability to serve as an integrator as explained above.

The transfer function for the non-inverting schematic shows:

- The feedback resistor R7 creates a zero of the transfer function, which is defined by the time constant $\tau = C1 \cdot \frac{R1 \cdot R7}{R1 + R7}$.
- The dc gain of this schematic arrangement is just the dc gain of a non-inverting amplifier.
- In this case, the feedback resistor R7 also eliminates the device's ability to serve as an integrator.

Applying Servo Feedback

While the feedback resistor is not usable in the integrator circuit, we still have to stabilize the integrator output dc wise.

If we cannot do that by applying negative feedback through a resistor *inside* the integrator, we should do that to the *whole* integrator by means of the feedback that encompasses the whole integrator. This is called a "servo feedback".

This servo feedback has a substantial gain within a very narrow frequency range close to dc and an extremely low gain beyond this range. This does not affect the integrator operation at any frequency within the integrator (Rogowski sensor) frequency range, but eliminates the dc walkaway.

The integrator schematic that performs with no dc walkaway is reviewed below in Fig. 2, while the sensor's input current (I1) and output voltage (V(out)) are shown in Fig. 2.

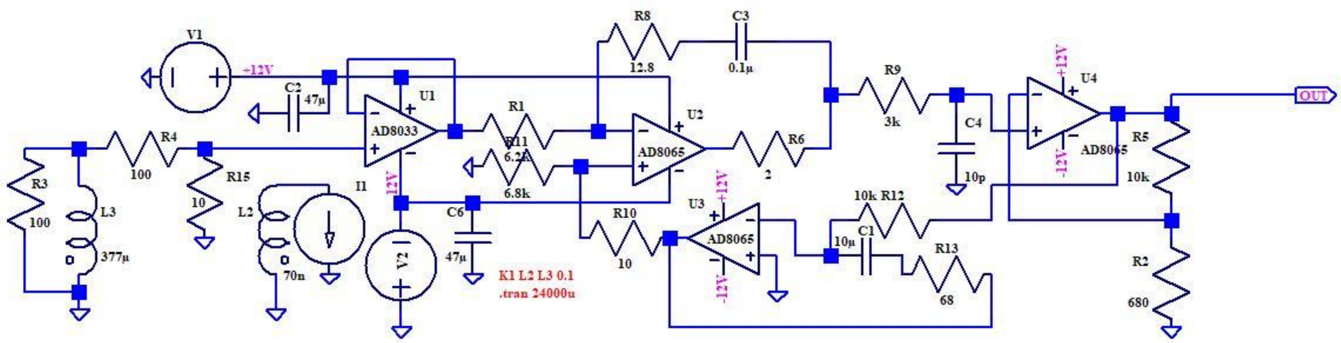

Fig. 2. Schematic of a Rogowski sensor utilizing integrator on IC U2 and servo feedback on U3 and U4.

Fig. 3. Timing diagram of the Rogowski sensor operation. Shown here are the measured current waveform (green trace) and the sensor output voltage (dark blue trace).

In Fig. 2, the current I1 that is to be measured, is sensed by the Rogowski coil L3 and pre-treated by resistors R3, R4 and R15. Buffer U1 converts the impedance at its input to a very low value, acceptable for matching the integrating resistor R1. This resistor along with the capacitor C3, IC U2, and a small phase-correcting R8, make up the sensor integrator. This integrator has no local negative feedback that would control its output offset.

Then, resistor R9 and capacitor C4 reduce the high-frequency noise before feeding the signal to U4. The amplifier built on U4, R5 and R2 amplifies the integrator output signal for proper further measurement and is a part of the servo feedback. The integrator based on U3, R12, C1 and R13 is the main part of the servo feedback. The output of U3 controls the non-inverting input of U2, the sensor integrator, thus removing the dc offset at U2 output.

The schematic described above employs two inverting integrators and provides very reliable performance.

The Takeaway

A feedback resistor in an integrator scheme destroys the integrator functionality and cannot be used to remove the integrator output walkaway. This happens because the feedback resistor R7 allows the integrating capacitor C1 to discharge through itself, not through the input resistor R1, which completely changes the integrator operation. The servo feedback is the only viable method of stabilizing the integrator output dc walkaway.

References

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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.