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WHITE PAPER

Preventing and Attacking Measurement Noise Problems

CAMPBELL SCIENTIFIC, INC.
815 W. 1800 N. • Logan, Utah 84321-1784 • (435) 753-2342 • FAX (435) 750-9540

Preventing and Attacking Measurement Noise Problems

This application note discusses some basic methods available for minimizing the effects of interference-type noise in voltage measurements. Campbell Scientific recommends these methods be used to reduce measurement noise.

Differential Versus Single-Ended

Differential voltage measurements use a High (H) and Low (L) input and measure the voltage (electrical potential difference) between these two inputs, usually by means of a high-impedance differential amplifier. In a multiplexed measurement system, the number of available measurement channels can be doubled by using single-ended instead of differential measurements. In this scheme the signal is multiplexed to one of the differential amplifier inputs, while the other amplifier input is connected to a low-impedance signal reference (ground). Small voltage differences between the signal reference and the actual sensor ground are often unavoidable, resulting in measurement errors. For example, currents flowing from a sensor to the signal reference (ground) cause a voltage drop, resulting in a single-ended measurement error. This error is eliminated with differential measurements because the high-impedance inputs permit only negligible current flow. Single-ended measurement errors are often small with respect to a 5 V signal, but noticeable with respect to a 10 mV signal.

Differential measurements also reject noise common to both inputs (common-mode noise rejection). For example, capacitively coupled (electric field) noise induced along a twisted-pair of wires results in noise common to both inputs when both wires have the same impedance. This is the case when both wires are connected to a high-impedance differential amplifier. For this situation, noise is converted to a common-mode signal that is rejected by the differential amplifier. **Differential measurements, rather than single-ended measurements, are recommended for low-level signals.**

Shielded Cable and Twisted Pair

Using shielded cable and/or twisted pair wire is a fairly simple and effective method of reducing measurement noise in low-level signals. Internal wires are shielded from external electric fields in a shielded cable when the shield is tied to a low-impedance potential, such as ground. When shielding low-frequency (≤1 MHz) analog signals, it is usually best to tie the cable shield to ground at only one end of the cable.[1] This prevents shield currents which occur due to ground differences between the ends of the cable, inducing noise on internal wires.

Higher level signals such as digital control and power connections are typically immune to noise induced by shield currents. As a result, its usually best to connect the shields to ground at both ends of the cables containing only digital control and/or power signals. **Shielded cable is relatively inexpensive and is recommended in all applications. Connect shields to ground at both ends of the cable if the cable does not contain any analog signals; connect the shield to only one end if the cable contains analog signals.**

Twisted pairs offer immunity to both electric and magnetic fields. Consider a differential sensor connected to a differential input with a twisted pair wire. As previously mentioned, external electrical fields exert similar influence into the close proximity wires of a twisted pair, resulting in common-mode noise if both wires have the same impedance. External magnetic fields induce voltages in loops proportional to the area of the loop[1]. Twisting the conductor pair between the source and load minimizes this loop area, but also helps cancel noise because induced voltages are of equal magnitude and opposite polarity in adjacent twists. Consequently, twisted pair provides better immunity to magnetic fields than two closely spaced parallel conductors.

Twisted pair wires also reduce the emission of magnetic fields. Consider a large dc current flowing on a twisted pair between a source and load. The current flow in the two close proximity wires is equal and opposite, with the resulting magnetic fields effectively cancelling each other within a few inches of the pair. **The close proximity of twisted pair wires results in common-mode noise from external electric fields and cancellation of voltages induced from magnetic fields. Differential measurements effectively reject common-mode noise. A twisted pair between a source and a load also reduces magnetic field emissions.**

Integration and Averaging

All Campbell Scientific dataloggers except the CR9000 offer signal integration in the form of an analog integrator. The output voltage for an analog integrator is

$$V_o(t) = \frac{-1}{RC}\int_o^{\tau} V_{in}(t)\,dt \ , \qquad \text{Eq. 1}$$

where R is the integrator resistor, C is the integration capacitor, V_{in} (t) is the input voltage to the integrator, and τ is the time duration of the integration. The magnitude of the resulting frequency response of the analog integrator is expressed as

$$\left|H_{INT}(f)\right| = \frac{\tau}{RC}\cdot\left|(\sin \pi f\tau)/\pi f\tau\right| \qquad \text{Eq. 2}$$

and is illustrated in Fig. 1 for τ/RC = 1. The frequency response of a simple RC low-pass filter with τ = RC = 1 is included for comparison.

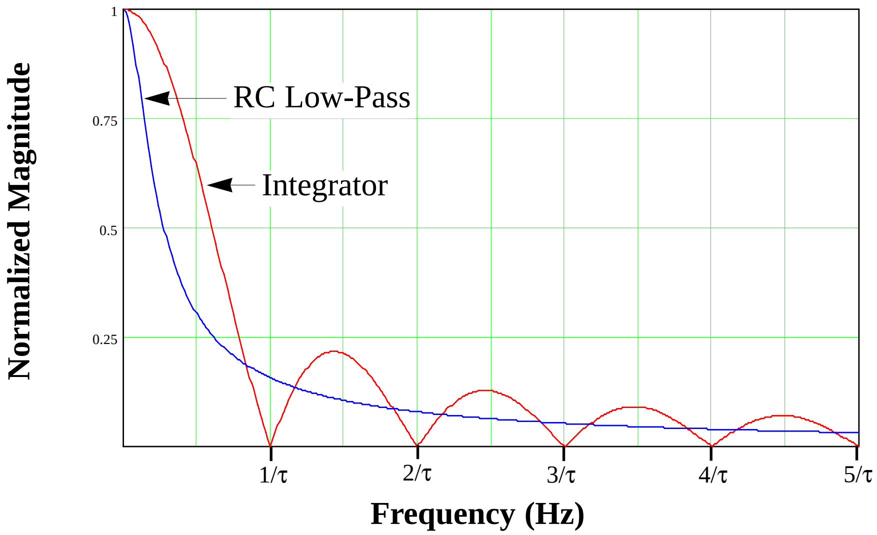

Figure 1. Magnitude of Frequency Response of Analog Integrator and Simple RC Low-Pass Filter

As can be seen from Fig. 1, the integrator is an effective low-pass filter with frequencies occurring at n/τ for n=1,2,3,... being totally rejected. For example, common 60 Hz noise can be rejected by integrating for τ = 1/(60 Hz) = 16.67 ms.

Similar results can be obtained using numerical (digital) integration as illustrated in Fig. 2.

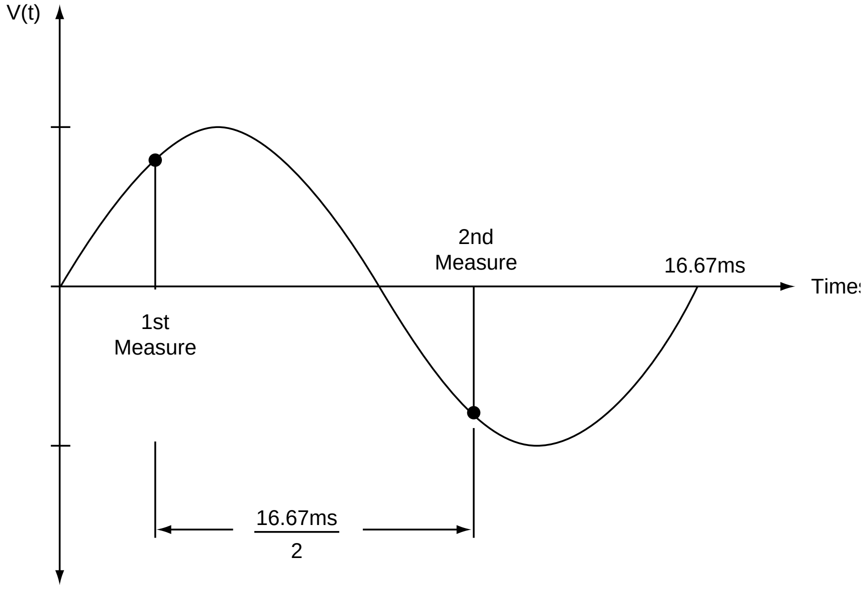

Figure 2. 60 Hz Noise Rejection

The numerical method averages two measurements separated in time by half the 16.67 ms period of the unwanted noise. Any 60 Hz noise is of opposite polarity during these two measurements and is canceled by averaging. This numerical method effectively rejects the 60 Hz noise in only half the time required for a full 16.67 ms line-cycle integration. Numerical integration, however, cannot reject noise that is in phase with the sample frequency. For example, the sample frequency illustrated in Fig. 2 is 1/(8.3 ms) = 120 Hz, therefore noise at 120, 240, 360 Hz,... will not be attenuated because it has the same polarity for both samples. Analog integration does not have this limitation.

CSI dataloggers provide programmable integration for 50/60 Hz noise rejection on voltage measurements. Numerical (digital) integration is provided in the CR5000 and CR9000 measurement instructions. **Analog or digital integration provide low-pass filtering and the ability to completely reject certain frequencies based on the integration duration or sample frequency.**

If previously mentioned methods do not reduce noise to an acceptable level, numerical averaging may be beneficial. Averaging individual measurements decreases **random** noise by

$1/\sqrt{N}$, where N is the number of samples in the average. Numerical averaging enhances resolution and reduces noise, but the individual measurements must vary (dither) about the true mean value for this technique to be effective.

Characterizing Noise

Measurement noise is characterized statistically. The root-mean-square (rms) noise of a system with a constant input can be determined using the standard deviation instruction available in CSI dataloggers[2]. The datalogger portion of the measurement noise can be determined by disconnecting the sensor and grounding the inputs at the datalogger terminal blocks. The mean of a group of measurements from this grounded system is the measured dc offset voltage. The programs provided below approximate the rms noise and offset voltage by computing the standard deviation and mean for a group of measurements in the CR23X and CR5000, respectively. These programs use 1000 samples and output the results in µV. **The standard deviation and mean of a group of measurements can be used to estimate the rms noise and dc offset, respectively.**

CR23X Measurement Noise and Offset Program

```
*Table 1 Program
  01:       0.02      Execution Interval (seconds)

1:  Volt (Diff) (P2)
  1:        1         Reps
  2:       11         10 mV, Fast Range
  3:        1         DIFF Channel
  4:        1         Loc [ smpl      ]
  5:     1000         Mult
  6:        0.0       Offset

2:  If time is (P92)
  1:     0000--       Minutes (Seconds --) into a
  2:       20         Interval (same units as above)
  3:       10         Set Output Flag High (Flag 0)

3:  Set Active Storage Area (P80)
  1:        3         Input Storage Area
  2:        2         Loc [ mean      ]
```

```
4:  Standard Deviation (P82)
  1:        1          Reps
  2:        1          Sample Loc [ smpl      ]

5:  Average (P71)
  1:        1          Reps
  2:        1          Loc [ smpl      ]

*Table 2 Program
  02:      0.0000   Execution Interval (seconds)

*Table 3 Subroutines

End Program
```

CR5000 Measurement Noise and Offset Program

```
Const Rep = 1
Public Smpl(Rep)

DataTable Table1,2,500
  DataInterval(0,2,sec,4)
    StdDev (Rep,Smpl(1),IEEE4,0)
   Average(Rep,Smpl(1),IEEE4,0)
  EndTable

BeginProg
  Scan(2,MSEC,10,0)
    VoltDiff(Smpl,Rep,mv20,1,1,0,0,1000,0)
    CallTable Table1
  NextScan
 EndProg
```

References

1. "Noise Reduction Techniques in Electronic Systems", Henry W. Ott, 1976, John Wiley and Sons, NY.

2. "Ditigal and Analog Communication Systems", Leon W. Couch II, 3rd Edition 1990, Macmillan Publishing Company, NY.

3. "Grounding and Shielding Techniques in Instrumentation", Ralph Morrison, 3rd Edition 1986, John Wiley and Sons, NY.

4. "Understanding Interference-Type Noise without Black Magic", Alan Rich, pp. 120-123, The Best of Analog Dialogue 1967 to 1991. (www.analog.com/publications/magazines/Dialogue/bestof/contents.html/) (verified Feb. 2001)

5. "Shielding and Guarding - How to Exclude Interference-Type Noise", Alan Rich, pp. 124-129, The Best of Analog Dialogue 1967 to 1991. (www.analog.com/publications/magazines/Dialogue/bestof/contents.html/) (verified Feb. 2001)