Analog modules specifications explained

TEC/NOT/082

Curtiss-Wright provides a wide range of analog modules, which offer a number of features and functionality. A lot of feature-specific terminology is used in the data sheets of these modules. This technical note explains some of the less common terminology used.

The following terms are discussed:

52.1 DC error: primary gain vs. secondary gain

Primary or analog gain can be defined as the analog amplification factor or *true hardware gain*. It is integrated in some, but not all, instrumentation amplifiers used on Curtiss-Wright analog modules. Because the analog gain amplifies the input signal in order to use the full scale range of the Analog-to-Digital Converter (ADC), it does not decrease the performance of the analog module (except for gain of 1000).

Secondary or digital gain is purely a software artifact that increases the overall performance of the module.

All Curtiss-Wright analog modules incorporate programmable digital gain, however only some modules incorporate programmable analog gain. For example, a KAD/ADC/105 provides both programmable analog and programmable digital gain; whereas a KAD/ADC/112/10V provides fixed analog gain and programmable digital gain.

Both analog and digital gain are programmed by software.

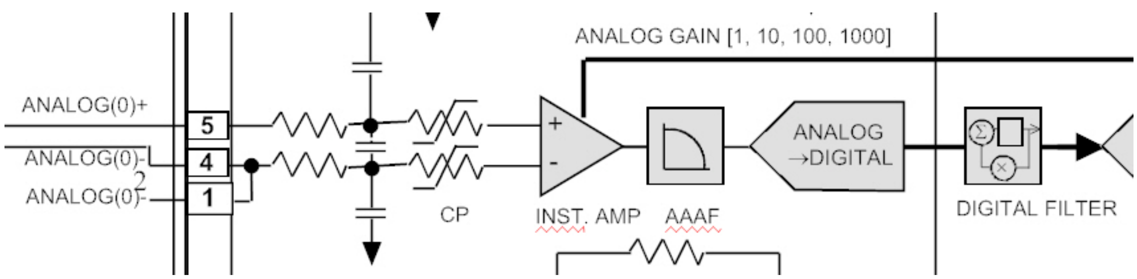

Figure 52-1: KAD/ADC/109 analog signal gain

The data sheet specifies the primary gains (analog gain) used on the module as shown in the following figure.

Input voltage					
operating range (G_p = 1)	-10	–	10	V	Primary gain = 1
operating range (G_p = 10)	-1	–	1	V	Primary gain = 10
operating range (G_p = 100)	-100	–	100	mV	Primary gain = 100
operating range (G_p = 1000)	-10	–	10	mV	Primary gain = 1000

Figure 52-2: KAD/ADC/109 input voltage as defined in the data sheet

The data sheet also specifies the DC error at different gains. These gains include the primary gain (analog gain) and the secondary gain (digital gain).

DC error				
gain = 1, 10, 100	–	–	0.08	%FSR
gain = 2, 20, 200	–	–	0.14	%FSR
gain = 4, 40, 400	–	–	0.25	%FSR
gain = 8, 80, 800	–	–	0.44	%FSR
gain = 1000	–	–	0.3	%FSR
gain = 2000	–	–	0.6	%FSR
gain = 4000	–	–	1.2	%FSR

Figure 52-3: KAD/ADC/109 DC error specification as defined in the data sheet

The gain stated in the data sheet is a combination of digital gain and analog gain; analog gains are: 1, 10, 100, and 1000. For example, a gain of 400 is composed of an analog gain of 100 and a digital gain of 4.

Curtiss-Wright recommends using a digital gain up to the maximum gain stated in the DC error specifications.

That is, for the above example, up to a digital gain of 8 for primary gain of 1, 10 and 100 and up to 4 for primary gain of 1000.

The KAD/ADC/109 can operate up to a digital gain of 16, for example, when only transmitting or analyzing the 12 most significant bits. However, at such a gain, the performance of the card is greatly decreased.

The digital gain is implemented by the FPGA on the module. Using a digital camera as an example: think of the camera's optical zoom as the primary gain (analog gain) on the module; while the camera's digital zoom is the secondary gain (digital gain) on the module.

As shown in the previous figure, the DC error stated on the KAD/ADC/109 does not linearly increase with digital gain.

If this was purely a software zoom, you would expect the DC error to be 8 times more when using a digital gain of 8, that is, 0.64%, wheras in fact it's 0.44%.

The digital gain is therefore not purely a software zoom because the module incorporates performance boosting techniques such as oversampling and decimation together with digital filtering that allows for more accurate signal digital processing.

Digital gain helps to increase the accuracy of DC signals but not AC signals. In other words, digital gain does not degrade or have any effect on AC signals, however too much digital gain can degrade DC signals due to offset errors.

A gain of 1,000 decreases the performance because it acts like a *natural* first order, low pass gain. An instrumentation amplifier with a bandwidth of 1 Mhz and a gain of 1000, effectively has a bandwidth with a cutoff frequency of 1,000 Mhz. This is common to all operational amplifiers.

Newer modules such as the KAD/ADC/136 have more primary gains, which occur from 1 to 256 in steps to the power of 2. This increased decimation between primary gains means the KAD/ADC/136 is more accurate.

For Gp = 32, the range is ±10 / 32 so ±0.3125 so 0.08 / 100 × (2 × 0.3125) = 0.5 mV max error.

For an KAD/ADC/109, using a range of ±0.3125, the primary gain is 100 and the digital gain is 3.125 so considering the maximum DC error is 0.14% for a gain of 2 and 0.25% for a gain of 4, maximum DC error for a digital gain of 3.125 can be approximately averaged as follow (3.125 × 0.14 / 2) + (3.125 × 0.25 / 4) = 0.21% so 0.21 / 100 × (2 × 0.3125) = 1.31 mV max error

Example of digital gain calculation

The primary gain is the sum of the operating range and the digital gain; it is calculated as follows:

(MaxOperatingRangeInput- MinOperatingRangeInput) / (MaxV-MinV)

The overall gain of a KAD/ADC/109 channel with min = -1.1V and max = 1.1V can be calculated as shown below:

Overall gain = analog gain × digital gain

Analog gain = 1 because the range of ±1.1V belongs to ±10V analog input range

Digital gain = (10- (-10)) / (1.1- (-1.1)) = 20 / 2.2 = 9.091

52.2 Common-Mode Rejection Ratio (CMRR)

The CMRR of a differential amplifier is a metric used to quantify the ability of the device to reject common-mode signals, that is, signals that appear simultaneously and in-phase on both inputs.

A high CMRR is required when a differential signal must be amplified in the presence of a possibly large common-mode input, such as strong electromagnetic interference (EMI).

The CMRR is calculated as CMRR = 20Log(Acm / Ameas) where Acm is the specified CMRR voltage range and Ameas is the measured amplitude in volts.

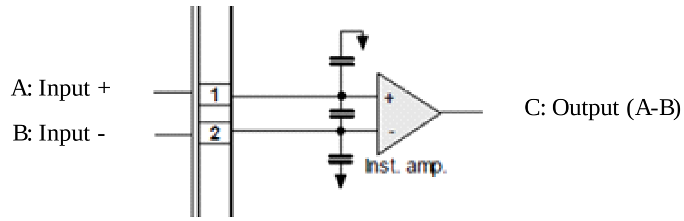

Figure 52-4: Instrumentation Amplifier with Input± and output

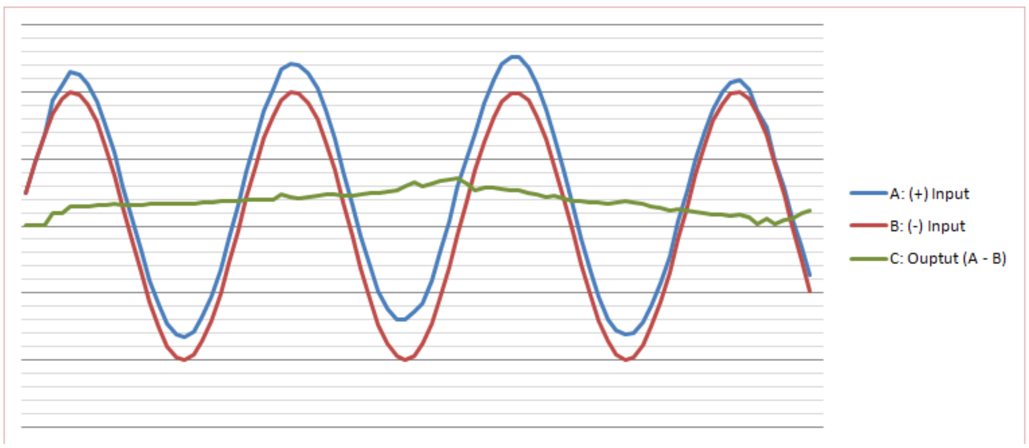

Figure 52-5: Input+ and Input- not in-phase signal and output result showing a poor CMRR

52.3 Effective Number of Bits (ENOB)

Effective Number Of Bits (ENOB) is a specification that helps to quantify dynamic performance.

ENOB states that a converter performs as though it were a theoretically perfect converter with a resolution of ENOB. The ideal (perfect) ADC has absolutely no distortion and the only noise it exhibits is quantization noise.

No instrument is ideal, so performance specifications show how close a device is to ideal. ENOB is calculated directly from SINAD using values for ideal ADC noise and spurs as shown in the following formula. This calculation shows how close to an ideal instrument the device is performing.

NOTE: In the following formula, SINAD is in dB and ENOB is in bits; otherwise the formula would not be valid.

ENOB [bits] = (SINAD [dB]-1.76) / 6.02

SINAD, also known as THD plus noise (THD + N), is the ratio of the RMS signal amplitude to the RMS sum of all other spectral components. All other spectral components include the harmonics but exclude DC. The most useful approximation of SINAD is the power of the fundamental signal frequency, plus the power of device spurs, plus the power of noise, divided by the power of noise, plus the power of distortion.

$$SINAD[dB] = 10Log_{10}\frac{Power_{Signal} + Power_{Noise} + Power_{Distortion}}{Power_{Noise} + Power_{Distortion}}$$

For the DC error, the results of the two sine waves in the following figure are very similar, however, the AC result is not the same; ENOB measures this distortion.

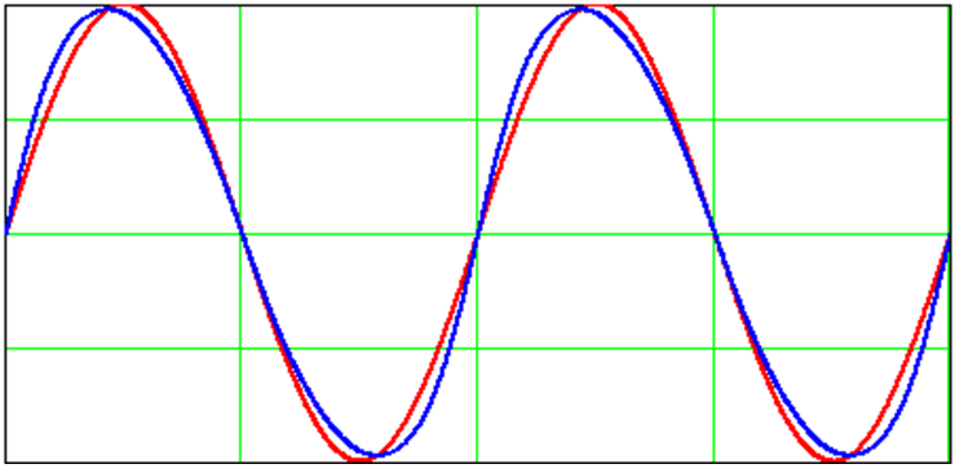

Figure 52-6: Comparison distorted sine (red) and undistorted sine (blue)

52.4 Crosstalk

Crosstalk has the potential to increase uncorrelated noise in ADCs, reducing signal-to-noise-ratio (SNR). Cross-coupled signals can create spurs (fraction of the coupled signal added on top of the considered channel), reducing spurious free dynamic range (SFDR).

Crosstalk can be expressed in dB as follows: 20 Log (V_{ppin} / V_{ppmeas}), where V_{ppmeas} is the amplitude of the signal measured by the channel under normal conditions (desired signal + crosstalk) and where V_{ppin} is the amplitude when the input of the channel is grounded (crosstalk alone).

52.5 Common mode range

The common mode range is the operational voltage range. For example, if the common mode voltage is ±10V, you cannot measure a signal from 27.5V to 28.5V even though the signal range of interest is only 1V. The common mode voltage of Curtiss-Wright modules is driven by the instrumentation amplifier voltage, which usually comes from the ±12V of the backplane.

52.6 Conclusion

DC error specification is important but it is not enough to select a device which is required to measure an AC signal. CMRR value for a differential device determines the level of noise which can be eliminated. ENOB value determines the level of distortion of the result.

NOTE: All specifications in Curtiss-Wright data sheets are valid within the operating temperature range (usually -40°C to 85°C) specified under “Environmental ratings” in the “General specifications” table of the respective data sheet.