

Data Acquisition Bridges the Analog and Digital Worlds

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In our solid state society today, daily advances in technology have set the standard in many applications to that of excellence when compared to only a few years ago. This new standard of living has benefited today's consumer in many ways that were only dreamt of years ago. Whether it is driver assistance controls that provide increased safety and convenience for your drive to work, or modern medical equipment that conduct Electrocardiograms (EKGs) to evaluate and monitor your loved one's heart. All of this is made practicable through a simple design practice known as data acquisition. Data acquisition creates a bridge from the analog world, where a measurement is taken, to the digital world, where the data from the measurement is manipulated. In these high-precision, life-saving data acquisition applications signal integrity is a priority.

Adaptive cruise control is a driver assistance feature available in many of today's automobiles and is a good example of data acquisition in action. Adaptive cruise control utilizes a type of radar to determine the distance of cars and adjusts the speed of the car accordingly. The radar in this application is a type of transducer that switches from emitting radar waves to detecting any radar wave "echoes" that bounce off of cars. A meaningful voltage signal is then generated from the echo by the radar sensor and is conditioned by amplifiers and filters then converted to a digital signal by an analog-to-digital converter (ADC). The digital representation of the

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voltage signal is then used to calculate the distance from the object based on the travel time of the radar signal. This information is used to maintain a safe distance between vehicles. In this example, data acquisition is the process from when the echo is received to when the digital signal is acquired. This process must be precise and provide reliable results in order to avoid scenarios that endanger the passengers of the vehicle.

The consumer's boom can sometimes be the designer's bane, especially when signal integrity in these high-precision, life-saving applications becomes a priority. Any source of random currents and voltages, fondly known as noise, can plague data acquisition just like any other electrical system. When dealing with noise, there are two types of noise that should be kept in mind, thermal noise (Johnson-Nyquist noise or white noise) and flicker noise ($1/f$ or pink noise). Thermal noise is present in any conductor (such as a resistor) and is due to the conductor's thermoelectric qualities in which heat causes electrons to become agitated and exhibit random motion.

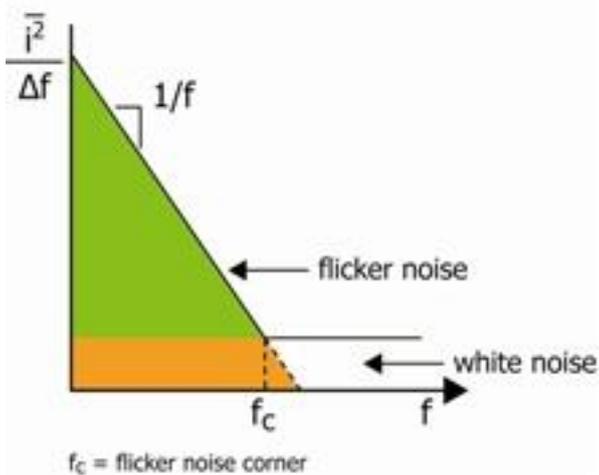


Figure 1. Flicker-White Noise
Power Spectral Density

One

way to look at thermal noise is for every 1k of resistance, there will be 4nV/ of

noise superimposed onto the signal. Flicker noise is the result of catch and release physical interactions of charge carriers in all active devices and carbon resistors. Flicker noise is inversely proportional to frequency, making it the dominate noise power spectral density at DC or low frequencies. At higher frequencies white noise is the dominate player. See Figure 1. MOSFET devices typically have higher flicker noise cutoff frequencies than JFET or BJT devices. To further reduce system noise use wire wound or metal resistors in place of carbon resistors.

It is best to begin a design knowing both the critical path components and the noise constraints. For instance, there's no reason to leave a circuit susceptible to high frequency noise in an EKG application. When the EKG sensor is measuring the human heart beat on average of 60 beats per minute (60Hz), it is safe to say that anything above 600Hz is safe to remove from the signal using a filter. This eliminates any noise introduced above 600Hz. Or, if the application includes a bandgap temperature sensor (a BJT for instance) with a poor signal to noise ratio (SNR), then that temperature sensor becomes the limiting factor in the signal path. There is no point in having a low-noise amplifier with an input referred voltage noise of 0.6nV/ when the temperature sensor injects 10nV/ into the signal path. In other words, using an ultra-low noise amplifier in this case won't hurt, but it certainly will not improve the noise level of the signal.

When designing a data acquisition application that relies on precision and accuracy, noise sources must be reduced. There are three areas in the data acquisition signal path that should be taken into account at the onset of design; the sensor/transducer, the signal

conditioning filter/amplifier, and the analog to digital converter. To fully understand the design issues in a low noise application, each piece of the puzzle in a data acquisition system (see Figure 2) must be considered.

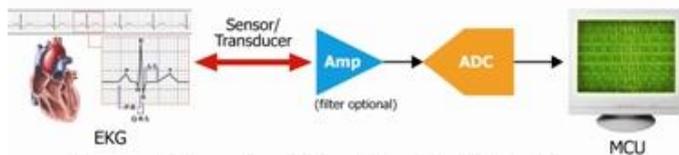


Figure 2. Data Acquisition Signal Path Blk Diag

The transducer, typically a sensor, can be the most difficult device to give design advice on as it truly depends on the application and what type of sensor is being used. When looking for a sensor, keep in mind the sensor's source resistance, SNR, and other noise qualities that may be specified. It will most likely be the SNR of the sensor that limits the noise performance of the rest of the circuit. The source impedance of the sensor will determine if a MOSFET or Bipolar (BJT) based device will be used.

The second piece of the puzzle is choosing the correct amplifier for a low noise application. In order to isolate the ADC's inputs from the sensor as well as provide signal conditioning and optional filtering, a low noise amplifier is used. If an amplifier is not used, the charge and discharge currents caused by the internal capacitors of the ADC will adulterate the precision of the sensor signal. Amplifiers whose inputs are MOSFET based provide the best performance when interfacing with a high impedance sensor. MOSFET amplifiers will typically have lower current noise than a BJT counterpart. Low current noise is crucial when using a high impedance sensor, as current noise is translated into voltage noise based directly on Ohm's law.

On the other hand, BJT based amplifiers typically have much lower voltage noise

and flicker noise. Thus providing much better performance for low frequency applications or when interfacing with a low impedance based sensor. Another thing to consider is the current driving capabilities of the amplifier that is conditioning the signal. To effectively minimize the overall noise contribution of any resistors, including the amplifier's feedback network and load, they must be sized as low as possible. However, if the chosen amplifier is unable to drive the desired signal level into the effective load, the signal becomes distorted and results in erroneous data. As an example, the CADEKA CLC1001 has an input referred noise of 0.6nV/, and an output current of $\pm 130\text{mA}$. The CLC1001 is designed to operate with minimal feedback and load resistances to reduce total system noise, the system designer can then take full advantage of the ultra-low noise offered by the CLC1001.

The final piece of the puzzle is selecting an ADC that compliments a low noise design. The resolution of an ADC indicates the number of discrete values it uses to represent an analog signal. The resolution is expressed in bits and is a way of declaring the precision level of the ADC. Typically, the parameter of most importance (neglecting sampling speed and prescribed bits) for a precision application is the signal to noise and distortion ratio (SINAD). SINAD will predict how much distortion and noise the converter will superimpose onto the signal and is also used in calculating the effective number of bits.

As an example, a 12-bit converter with a poor SINAD may only have 10 effective bits. Thus instead of expressing a voltage signal range with 212 codes, there are only 210 effective codes which is quite a large difference in precision and resolution. Finding a converter with good SINAD will offer the most resolution for

the prescribed number of bits. An additional parameter to consider is power dissipation. One caveat of minimizing the amplifier's feedback network, as described above, is increased power dissipation. A low power ADC can help compensate for the increased power dissipated yet allow for decreased total system noise. A 12-bit, 20MSPS ADC can consume as little as 19mW, such as CADEKA's CDK1307A.

The demand for design innovation will continue to grow as consumers expect more access to high-tech equipment and safety features that were once unavailable to them. Some of this can already be seen today. State of the art safety features are available on practically every new car, not just the elite luxury vehicles and military equipment. Large and expensive medical equipment of the past can now sit on night tables and bed stands. As this demand increases, data acquisition techniques and components will require higher precision, higher quality, and more accessibility. The bridge between analog and digital will always be crucial and will continue to be a focus for system designers.

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