Analog eBook

Microchip Analog Design eBook

Analog Design in the Digital Age

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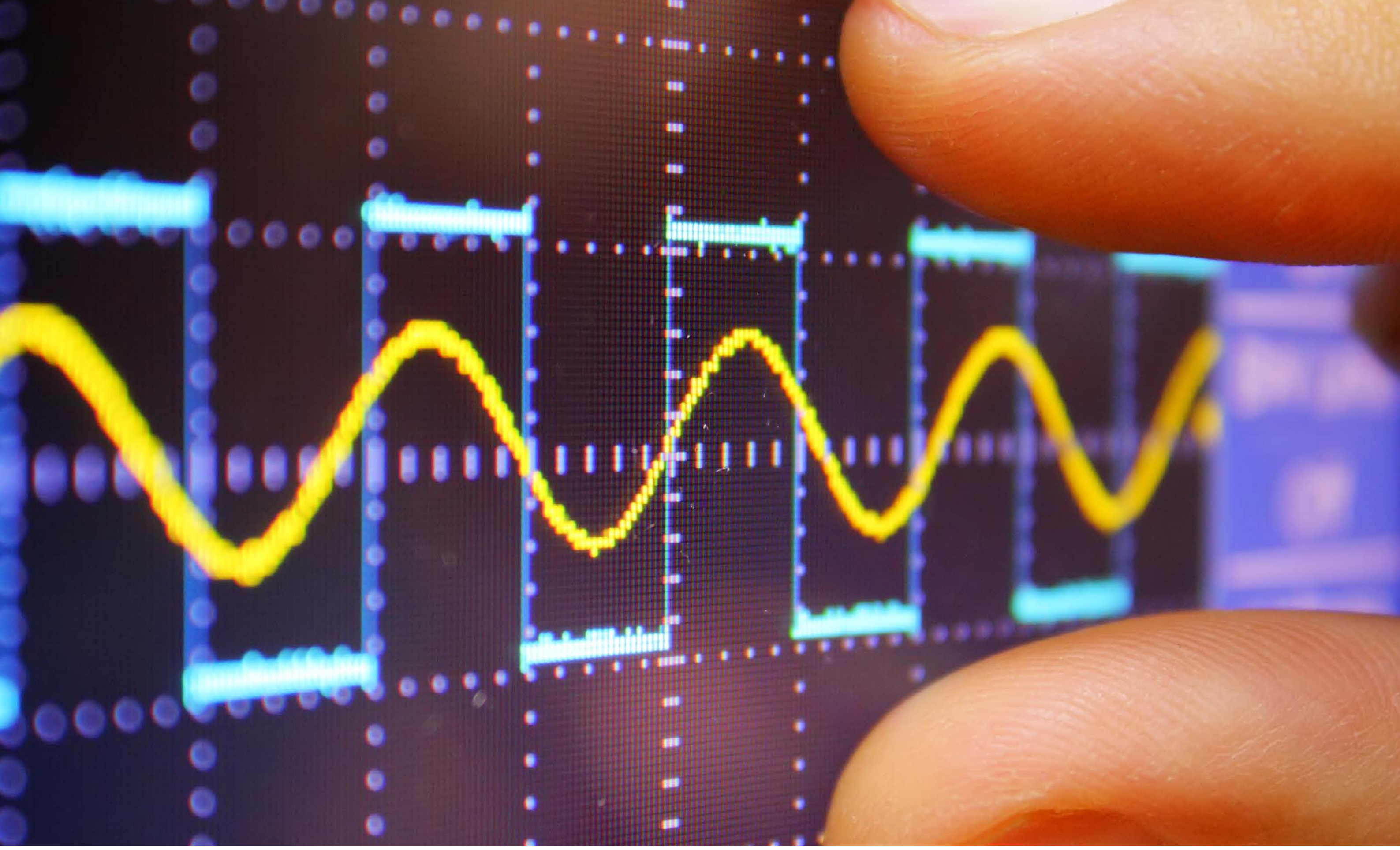

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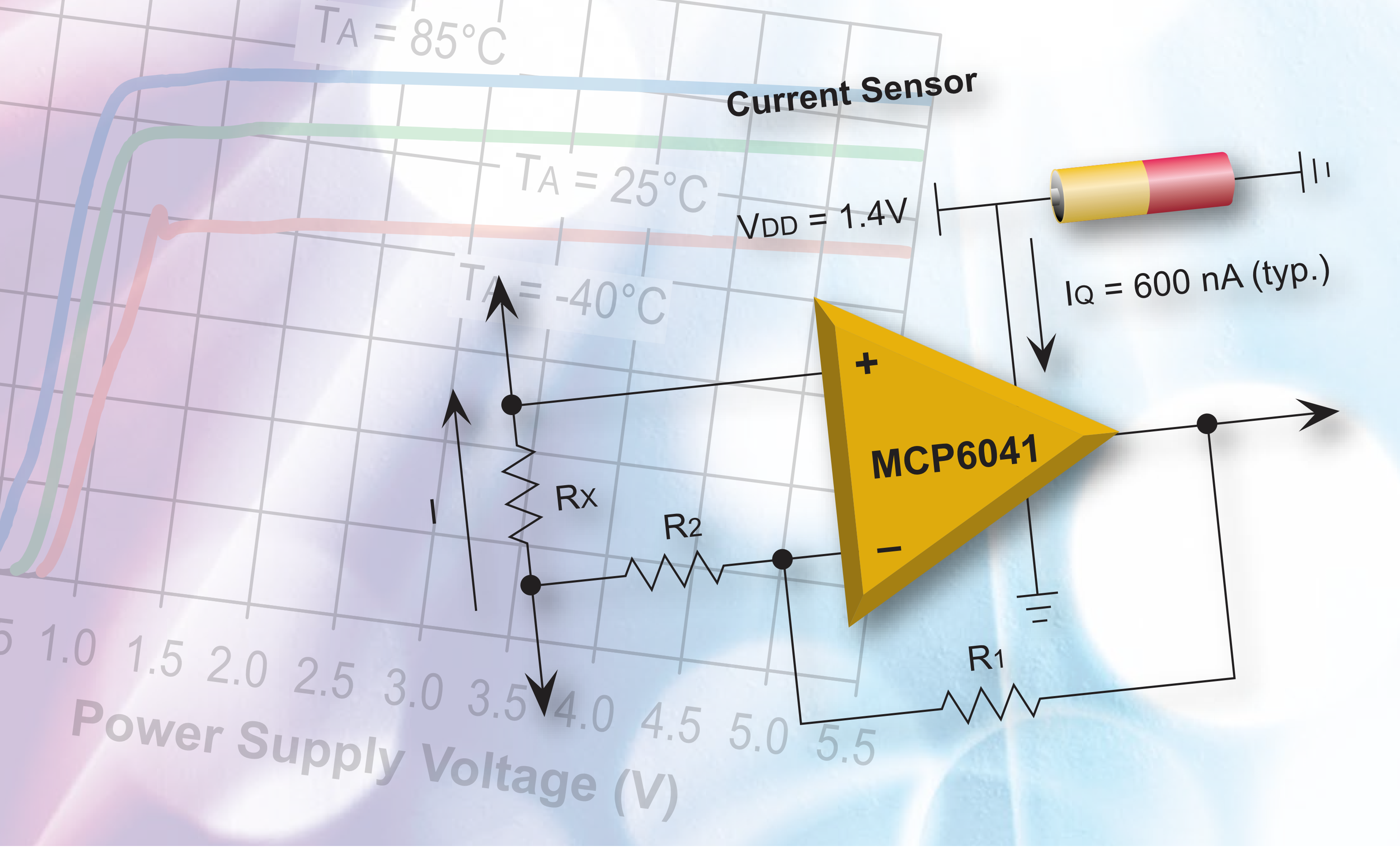


Technical article

CMOS vs. Bipolar Operational Amplifiers: Which is Best for My Application?

Author: Kevin Tretter, Senior Product Marketing Manager, MSLD

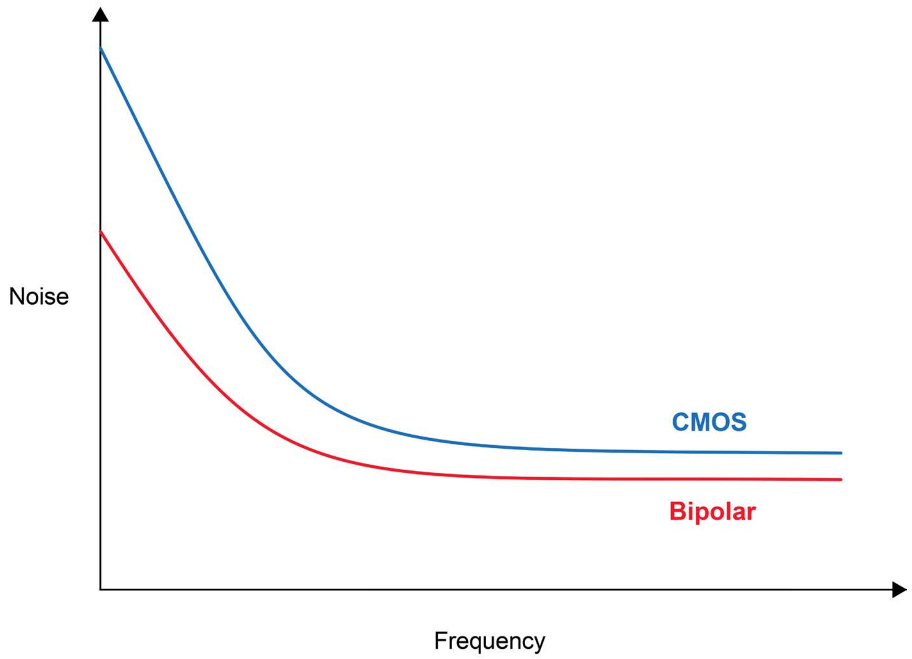
Today's system designer has many choices when it comes to selecting operational amplifiers (op amps). The three largest op amp manufacturers collectively have over sixteen hundred products from which to choose, and that doesn't include specialty amplifiers. How does one go about sorting through this overwhelming number of devices? One way to start narrowing down the options is to select the proper process technology. Most manufacturers clearly label an op amp as CMOS, bipolar or even BiCMOS, but what does this mean with regard to the actual application?

Power Consumption

CMOS is known for lower power consumption, as the transistors only draw current when switching states. However, this power advantage is only true for slower amplifiers. As the bandwidth increases, a CMOS amplifier's current increases dramatically, and soon draws more current then a comparable bipolar amplifier. Because of the exponentially increasing current in order for CMOS to achieve high speeds, bipolar op amps are typically better suited for high-bandwidth, high-slewing applications. For lower-bandwidth applications, CMOS amplifiers can still provide power advantages.

Noise Performance

In terms of flicker or 1/f noise, CMOS transistors have worse low-frequency noise than bipolar transistors. At low frequencies, this noise is dominated by irregularities in the conduction path and noise due to the bias currents within the transistors. In a bipolar transistor, the conduction path is buried down inside the silicon. On a CMOS transistor, the current flow is near the surface, making it susceptible to defects in the surface of the silicon, which increases the low-frequency noise. At higher frequencies, 1/f noise is negligible as the white noise from other sources begins to dominate. CMOS transistors have a lower transconductance relative to similarly sized bipolar transistors, which results in higher broadband noise. In general, bipolar op amps hold an inherent advantage over CMOS when it comes to noise performance.



Voltage Offset

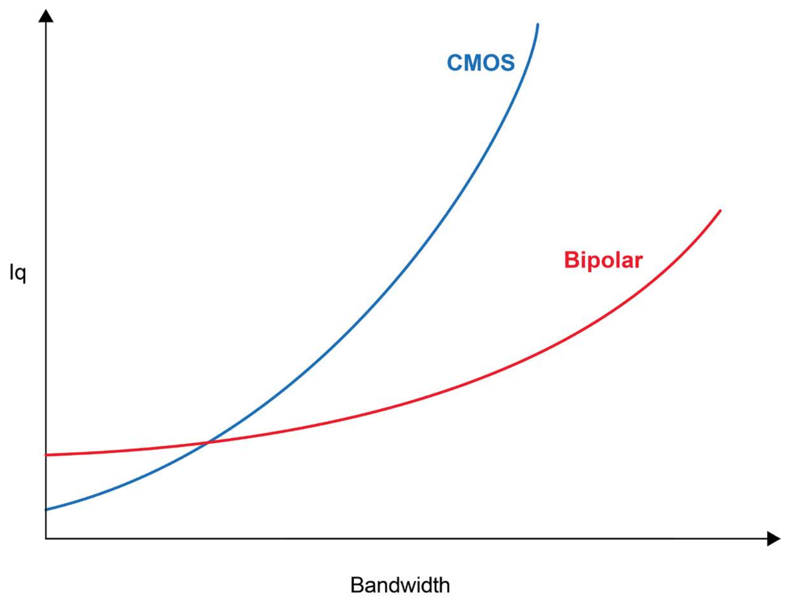
Another important amplifier specification is input offset voltage. This error voltage can vary from microvolts up to millivolts and is highly dependent upon how well-matched the input transistors are. Bipolar transistors inherently offer better matching, resulting in lower offset voltages for a given architecture. Some manufacturers compensate for this inherent mismatch by using laser trimming, fuses or even EPROM. These techniques can improve an amplifier's performance significantly, regardless of the process technology. Better matching also results in less voltage-offset drift over temperature, which is also an important consideration in many applications.

Price/Packaging

Historically, CMOS is known as a more cost-effective technology. This is mainly due to traditionally lower wafer costs, driven by the high volume of CMOS logic chips. Despite the lower wafer costs, for a given current capability, CMOS transistors take up more silicon area then bipolar transistors, resulting in a larger silicon dice. So, even though the wafer costs may be lower, there are less die per wafer, thus negating the cost benefit. In the end, the cost structure of these two process technologies is very similar. A larger silicon solution also limits a manufacturer's packaging options. This can be a significant limitation, as system designers are constantly tasked with placing more performance and functionality into smaller and smaller form factors. Several packages, such as those with Ball Grid Arrays (BGAs) and leadless packages, help address this situation.

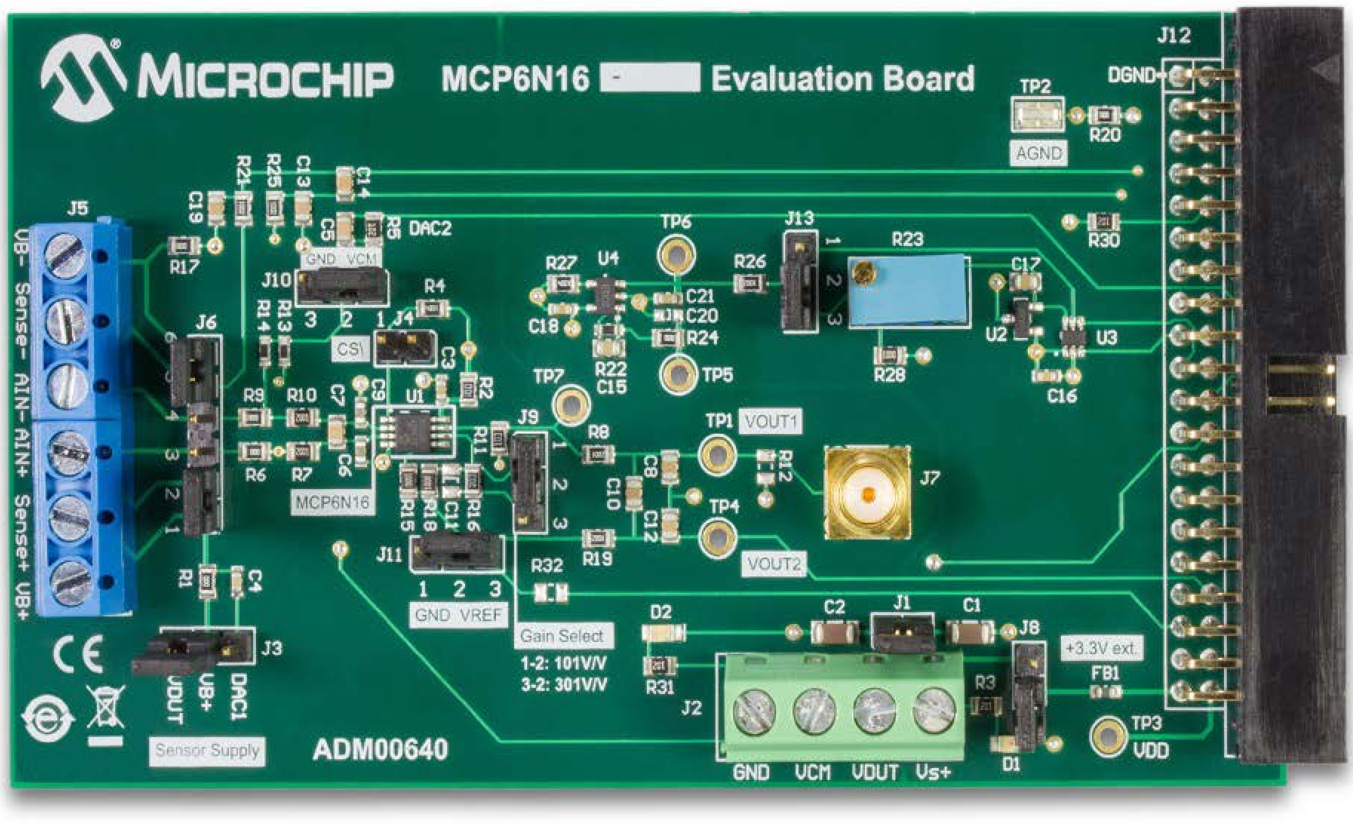
Input Bias Current

All amplifiers have a specification called input bias current. This is the amount of current flow into the inputs of an amplifier to bias the input transistors. This current can be thought of as leakage current, but is referred to as bias current when on the inputs of an amplifier. This bias current can range from picoamperes to hundreds of nanoamperes. Amplifiers with a CMOS input stage generally have less bias current when compared to an amplifier with bipolar input transistors, typically around 1 pA, while bipolar transistors can be orders of magnitude higher. This bias current is converted into a voltage through the input resistance of the circuitry and will end up resulting in an error voltage at the output of the amplifier. The less bias current the better, and in this regard CMOS has a distinct advantage.



Which Process is Best for Amplifiers?

This is a question that has been debated in the past and is expected to continue to be a point of discussion for years to come. Bipolar amplifiers are grounded in history, but CMOS amplifiers offer some inherent advantages. BiCMOS processes are the relative newcomers to the field, but this hybrid technology takes the best of both worlds and provides superior performance at a price point that is becoming more and more competitive. So in the end the answer to the question of which process is better for amplifiers is, "It depends." You need to evaluate the function of the amplifier in your system and then determine which specifications are most critical. There is no universal amplifier or process technology that addresses all of the many applications in which op amps are found. This is why manufacturers will continue to provide a multitude of amplifiers on a variety of process technologies. It is up to you to determine which one is best for the given application. Visit our Operational Amplifiers Design Center to learn about our portfolio of products.



Technical article

Evolution of the Instrumentation Amplifier

Written by: Greg Davis, Sr. Product Marketing Manager for Microchip Technology's Mixed Signal Linear Business Unit

Why we need instrumentation amplifiers

In the past, the term instrumentation amplifier (INA) was often misused, referring to the application rather than the architecture of the device. INAs are related to op amps, in that they are based on the same architecture, but an INA is a specialized version of an op amp. INAs are specifically designed and used for their high differential gain to amplify micro-volt level sensor signals while simultaneously rejecting high common-mode signals that can be several volts. This is important since some sensors produce a relatively small change in voltage or current, and this small change must be accurately captured.

Let's consider a few applications that benefit from INAs. For example, a medical instrument that uses sensors to align laser stepper motors for vision correction eye surgery. High accuracy is crucial and other equipment in the operating room cannot be allowed to compromise the sensor signals and cause unexpected results. Another example is a factory press. These machines apply thousands of pounds of force to bend metal into shapes. Using sensors, these machines are designed to stop if it detects a human hand. In this example, it is critical that electrical noise from other factory equipment does not cause interference that could lead to a malfunction.

In both cases above, the first step in the journey of the sensor signal is through an instrumentation amplifier. The tiny sensor signals must be accurately amplified in all environments. Instrumentation amplifiers are specially designed to do exactly that— to accurately amplify small signals resulting in high gain accuracy in an electrically noisy environment.

Other considerations

Other considerations further enhance the performance of an INA. Low power consumption is important to extend battery life. A low operating voltage allows the battery to be used over more of its depletion curve, extending battery life. A wide input voltage range allows compatibility with more sensors. Impedance matching at the input contributes to the seamless interface to sensors.

The evolution of INA designs

With an endless number of consumer, medical and industrial applications, designs have evolved over the years to take advantage of the performance benefits INAs offer. Let's look at the evolution of INA designs, from the original approaches to the instrumentation amplifiers offered today. By reviewing these architectures and their associated strengths and limitations, this article shows the performance improvements seen in present-day instrumentation amplifiers along with real-life applications.

Before delving into the different approaches, let's first look at what we are trying to accomplish using the diagram in Figure 1.

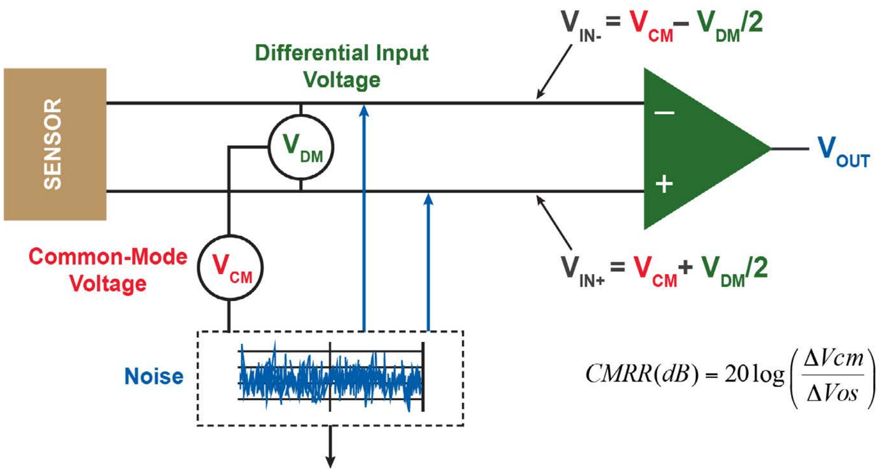
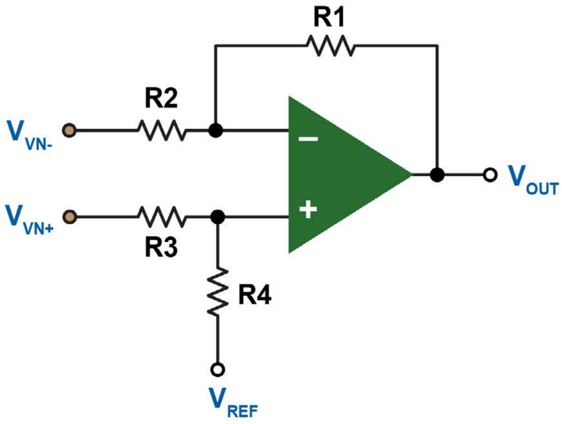


Figure 1: Sensor interface to INA block diagram

The sensor outputs are connected to the INA inputs that amplify the differential voltage. Noise comes from many sources, both radiated and conducted. Typical noise may come from switching power supplies, motors and wireless devices. This noise is reduced by shielding and good PCB layout practices, however some noise will get through. Fortunately, most of that noise shows up as an in-phase, common-mode voltage (V_{CM}) superimposed on the differential input sensor voltage (V_{DM}), and a properly designed instrumentation with good Common-Mode Rejection Ratio (CMRR) will greatly reduce this voltage to maintain gain accuracy. A minimum CMRR is typically specified at DC, while the AC CMRR performance is documented in performance curves.



R_1 = R_4 and R_2 = R_3

Figure 2: Discrete difference amplifier

If you want to amplify the voltage difference across the sensor output, a simple difference amplifier works, but it has a lot of downsides. In the simple implementation shown in Figure 2, V_{IN}+ is biased to V_{REF} (typically ½ the supply voltage) for single-supply applications. Designed to amplify differential voltages, the operational amplifier itself provides good CMRR, but this is overwhelmed by the circuit surrounding it. Any mismatch in the external resistors (including mismatch contributed by any divider network connected to V_{REF}) limits the ability of the op amp to reject common-mode signals, resulting in reduced CMRR. Resistor tolerances are simply not tight enough to maintain a good CMRR that would be expected from an INA. We can see how much the resistor mismatch affects CMRR using the equations below.

This equation uses a difference amplifier with G = 1V/V, and T_R is the resistor tolerance,

- If T_R = 1%, worst case DC $CMRR_{DIFF}$ will be 34 dB
- If T_R = 0.1%, worst case DC $CMRR_{DIFF}$ will be 54 dB

Where 'K' is the net matching tolerance of R_1/R_2 to R_3/R_4

K can be as high as $4T_R$ (worst case)

$$CMRR_{DIFF} \approx 20\log\left(\frac{1+\frac{R_1}{R_2}}{K}\right)$$

The amplifier amplifies the differential voltage at the input, and the gain of the amplifier is:

$V_{OUT} = G * V_{DM}$

$= (R_1/R_2) * (V_{IN+} - V_{IN-}) + V_{REF}$

The problem is that the differential voltage (V_{IN-} and V_{IN+}) includes superimposed noise, and any of that common-mode voltage that is not rejected (as a result of poor CMRR) will be amplified resulting in an output being corrupted by noise.

This simple approach also has other drawbacks. Typically the input impedance of an operational amplifier is high (MΩ to GΩ range), but due to the feedback path and reference, the impedance is both reduced and imbalanced, loading the sensor and adding to inaccuracies. While this circuit will amplify a small signal sensor, the poor gain accuracy in the presence of noise would not be useful for instrumentation purposes.

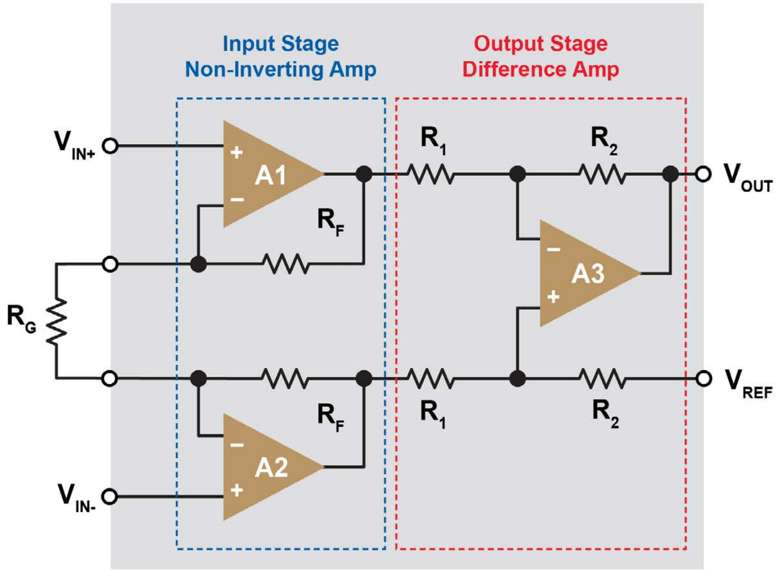


Figure 3: Three operational amplifier IC approach

This is a common INA packaged in a single integrated circuit (IC). The circuit is divided into two stages. The input stage has two inverting buffer amplifiers, and the output stage is a traditional difference amplifier. The internal resistors used throughout this design are matched to a very close tolerance only possible with trimmed resistor semiconductor designs. This results in a much higher CMRR. The input stage amplifiers also provide high impedance which minimizes loading of the sensors. The gain-setting resistor, RG, allows the designer to select any gain within the operating region of the device (typically 1 V/V to 1000 V/V). The output stage is a traditional difference amplifier. The ratio of internal resistors, R_2/R_1, sets the gain of the internal difference amplifier, which is typically G = 1 V/V for most instrumentation amplifiers (the overall gain is driven by the amplifier in the first stage). The balanced signal paths from the input to the output yield excellent CMRR. The design is simple to implement, has a small footprint and fewer components, resulting in lower system costs. The design is also compatible with single-source supplies using the V_{REF} pin. However, even with this design, there are limitations to consider. Three op amp INAs achieve high CMRR at DC by matching the on-chip resistors of the difference amplifier, but the feedback architecture can substantially degrade the AC CMRR. In addition, parasitic capacitances cannot be completely matched causing mismatches and reduced CMRR over frequency. The common-mode voltage input range is limited so that internal nodes do not saturate. The V_{REF} pin requires a buffer amplifier for optimal performance. Lastly, the temperature coefficient of the external and internal gain resistors are not matched which contributes to a decline in CMRR.

Mathematically the gain accuracy depends on resistor matching:

$$V_{OUT} = (G \times V_{DM}) + V_{REF}$$

Where

$$G = 1 + \frac{2\,RF}{R_G}\left(\frac{R_2}{R_1}\right)$$

$$V_{DM} = (V_{IN+} - V_{IN\_})$$

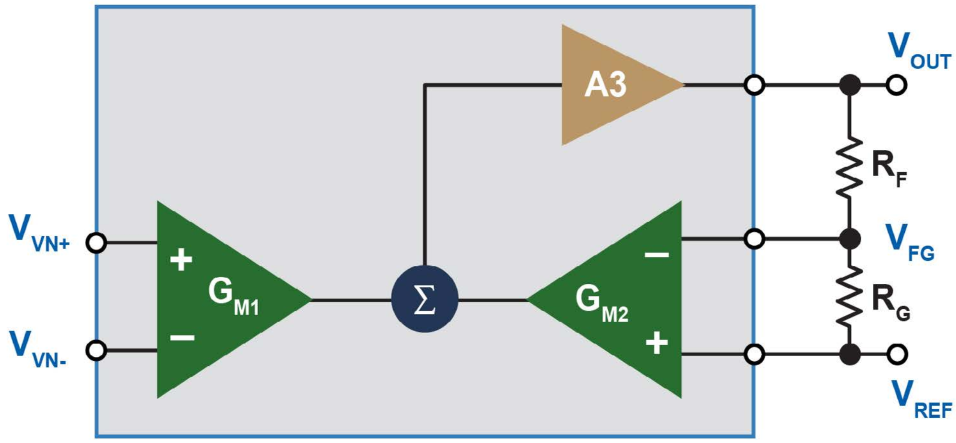


Figure 4: Indirect current feedback approach

The Indirect Current Feedback (ICF) INA uses a novel voltage to current conversion approach. It is comprised of two matched transconductance amplifiers, G_{M1} and G_{M2}, and a high-gain transimpedance amplifier (A3). The design does not rely on balanced resistors, so internally trimmed resistors are not required, thereby reducing manufacturing cost. Another advantage is that the external resistors do not need to match any on-chip resistors. Only the R_F and R_G external resistors temperature coefficients need to match as closely as possible for minimal gain drift.

DC CMRR is high since amplifier GM1 rejects common mode signals. AC CMRR also does not decrease significantly with increased frequency. It was mentioned that the three operational amplifier approach input range is limited to prevent internal node saturation. With an ICF, the output voltage swing is not coupled to the input common-mode voltage, resulting in an expanded range of operation not possible with the three operational amplifier architecture. The second stage (G_{M2} and A3) differentially amplifies the signal and further rejects common-mode noise on V_{FG} and V_{REF}. Single-supply operation can still be used by applying a bias to V_{REF}.

The ICF INA gain is:

$$V_{OUT} = (G \times V_{DM}) + V_{REF}$$

Where V_{DM} is the differential mode voltage

$$V_{DM} = (V_{IN+} - VIN\_)$$

$$= (V_{FG} - V_{REF})$$

Figure 5 shows a few typical applications for an INA. A variety of sensors are shown that are accurately amplified by an INA feeding a converter and microcontroller.

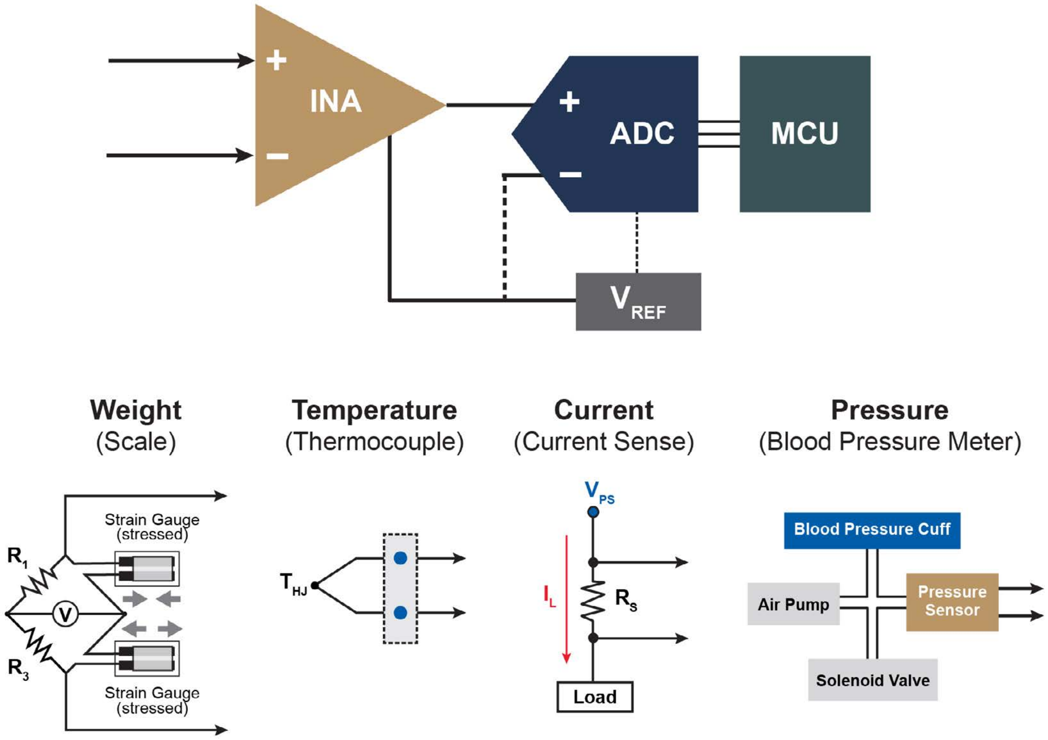


Figure 5: Examples of a typical circuit using an INA with a sensor

Summary

The need to amplify small signals in the presence of noise has gone through an evolution over the years. The simplest approach, the discrete operational amplifier, is not suitable as an INA. The integrated three operational amplifier approach has significant advantages including high DC CMRR, balanced and high input impedances with one gain resistor. However, there are common-mode voltage limitations and it is difficult to match internal versus external resistor temperature coefficients, resulting in gain drift. The impedance at the V_{REF} pin can also negatively impact CMRR unless a buffer is used. The ICF approach also has a high CMRR (even at higher frequencies), a wider common mode voltage range and no on-chip trimmed resistors resulting in lower cost and low temperature coefficient gain drift. INAs provide designers an excellent method to amplify micro-volt level sensor signals while simultaneously rejecting high common-mode signals found in noisy environments.

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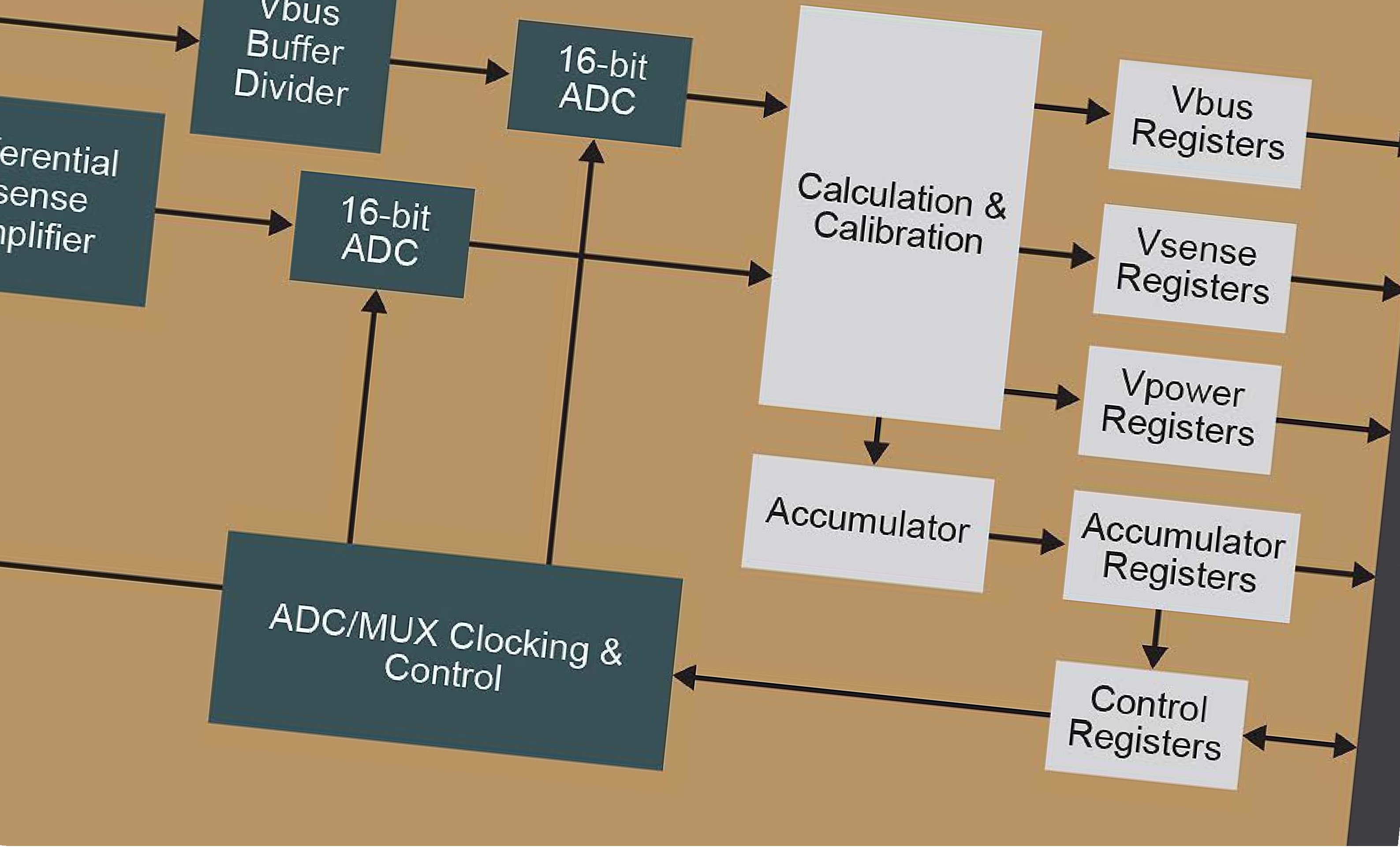


Technical article

The Role of Energy Monitoring in DC Systems

Written by: Adrian Lita – Microchip Technology Inc.

Introduction

Battery-powered devices have been present for a long time now. However, since cell phones launched, the number of rechargeable battery powered devices has increased exponentially over the past two decades. As of 2018, tens of thousands of models of phones, tablets, laptops and many other gadgets use lithium-based batteries.

A very important aspect for all portable devices is power consumption. Hardware developers tend to focus more and more on low-power implementations, while increasing capabilities and decreasing size and cost. Software developers also aim to lower power consumption by researching and developing new, power-aware approaches to older algorithms, both in operating systems field (i.e. through energy-aware scheduling) and newer topics, such as machine learning. Power is the instantaneous consumption of energy. As described in Equation 1, in electronics, power is the product between instantaneous voltage and current. Its measure is the Watt, which represents a Joule per second.

$$P = V \times I \quad [W = {}^{J}/_{s}]$$

Equation 1 - Power equation

Energy is the product between power and time. It is what circuits consume and what batteries store. Managing power usually means managing instantaneous currents and voltages to satisfy power transport capabilities and loading conditions. Energy monitoring generally gives information on energy consumption to help developers with battery management and overall power benchmarking. Active energy management occurs when energy is monitored by software specifically designed to take actions based on certain loads.

Active energy management can be done either automatically, based on predefined settings, or manually when the software starts, to give certain recommendations and suggestions to the user. For example, when most laptops run on battery instead of AC power, the processor performance may be automatically reduced and graphics may be switched to the integrated graphics processor that is lower power with less performance instead of the dedicated one. Some of the laptop peripherals can be switched off to achieve better battery life, or the user can receive notifications to reduce screen brightness or keyboard backlight. Most smartphones have energy-saving options which is suggested by the active energy management software when the battery drops below a certain level. This includes turning off some active internet connections, reducing screen brightness, and others.

However, the examples don't stop with battery-powered devices. Servers carefully monitor power consumption and load level to decide if certain services can be stopped or suspended. In the case of virtual servers where an application can scale up and down depending on the total current usage and usage predictions based on statistics, hypervisors can fully shutdown some of the virtual machines. Another usage of active energy management is in debugging. Monitoring energy can provide powerful information to whether overall systems, or parts of them perform within boundaries.

Electronic circuits used for measuring DC power and energy

As mentioned electric power is the product between voltage and current. Measuring precise power requires measuring both voltages and currents with high accuracy. Power measured and accumulated over a period of time results in energy. Because power consumption isn't constant in most cases, voltage and current measurements must be done with a selected bandwidth. A typical example of DC voltage measuring circuits is the simple voltage divider depicted in Figure 1 – on the left and the buffered voltage divider depicted on the right. While both circuits can offer high accuracy with proper calibration, the buffered voltage divider, while being more expensive than its unbuffered twin, usually consumes less power and is used especially when measuring very low DC signals.

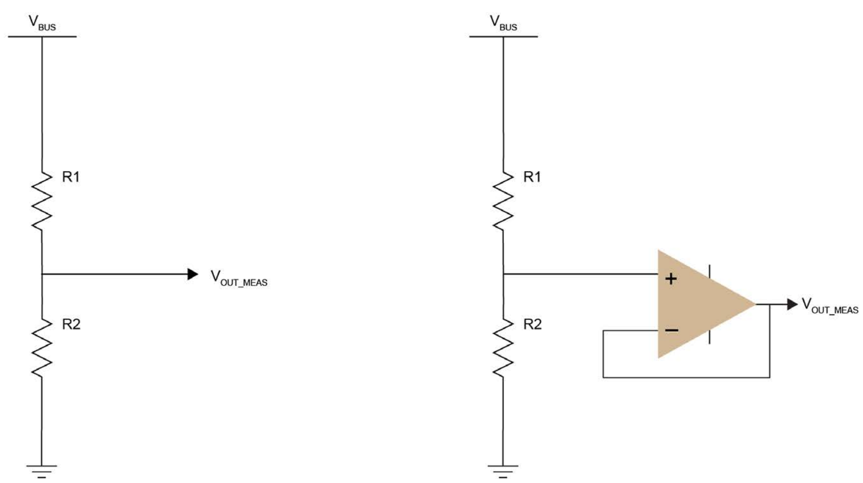


Figure 1 - Voltage divider circuits

While current (including DC) can also be measured with the help of the Hall effect, this article focuses on measuring DC current with shunt resistors, because they are more commonly used and less expensive. The shunt resistor is a low-valued resistor, which is connected in series with the circuit. When current flows through it, a small voltage drops across the shunt. The voltage drop is proportional to the current as in Equation 2 and is usually amplified with an op-amp.

$$V_{DROP} = R_{SHUNT} \times I$$

Equation 1 - Power equation

As the shunt resistor is in series with the rest of the circuit, it can be placed on two sides: high-side, where one of the shunt's terminals is directly connected to the bus voltage, or low-side, where it is connected to the ground, as depicted in Figure 2. In both cases, the small shunt voltage drop will be present, and the overall voltage applied to the circuit will be lower. However, the position of the shunt has several implications:

- If the shunt is placed on the low-side (Figure 2, on the right), the voltage across it is directly linked to ground. Since shunt resistors are usually small, voltage drops across them are small as well, making it very easy for the current measurement circuit to use a cheap, low-voltage op-amp to amplify the voltage drop. This is highly desired for cost reasons. However, the main downside of low-side shunts is the fact that the overall circuit is not connected directly to ground anymore, but to something higher than ground. Shunt voltage drops are usually in the range of millivolts.

- On the other hand, if the shunt is placed on the high-side (Figure 2, on the left), then the circuit is directly connected to ground, removing any ground bouncing effects. This is highly desired when the circuit does precise measurement or must provide precise outputs. The only downside of this method is that a higher-voltage differential op-amp circuit needs to be used, and, depending on the bandwidth of the op-amp, the price can increase.

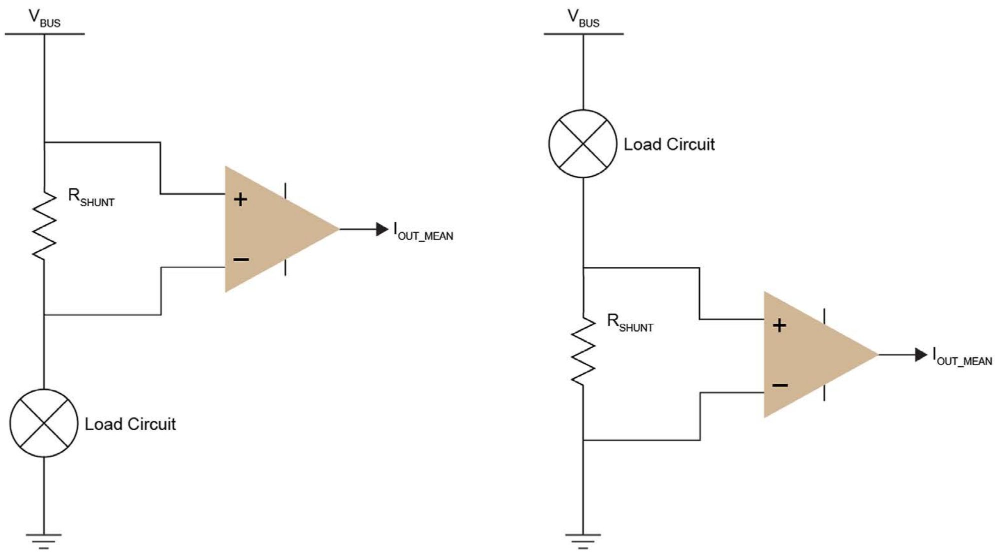


Figure 2 - Current measurement circuits

While voltage, current, and even power itself can be measured with analog circuits quite easily and at a low cost, energy requires a more complex circuitry. However, the classic approach to measure energy is to measure voltage and current using analog circuitry then convert the signals to digital using an Analog to Digital Converter (ADC), which outputs the data to a microcontroller. The microcontroller's responsibility is to sample the signal's accumulated power over time, which results in energy measurements. The typical circuit for measuring energy is illustrated in Figure 3. Adding a microcontroller to the measuring circuit has advantages and disadvantages. On one hand, it can offer lots of flexibility in computation algorithms, monitoring different behaviors, and doing more detailed reports – for example, hourly, daily, etc. One other advantage is that a microcontroller can do more than energy measurements. It can trigger events, run custom state machines or virtually anything the engineer needs it to do. The cost and Bill of Materials (BOM) increase aren't a problem if the system already needed a microcontroller. On the other hand, the disadvantages of monitoring energy with the microcontroller includes the increase in total power consumption of the measurement system, unwanted code development and overhead, and, depending on the accuracy, sometimes external ADCs may be needed.

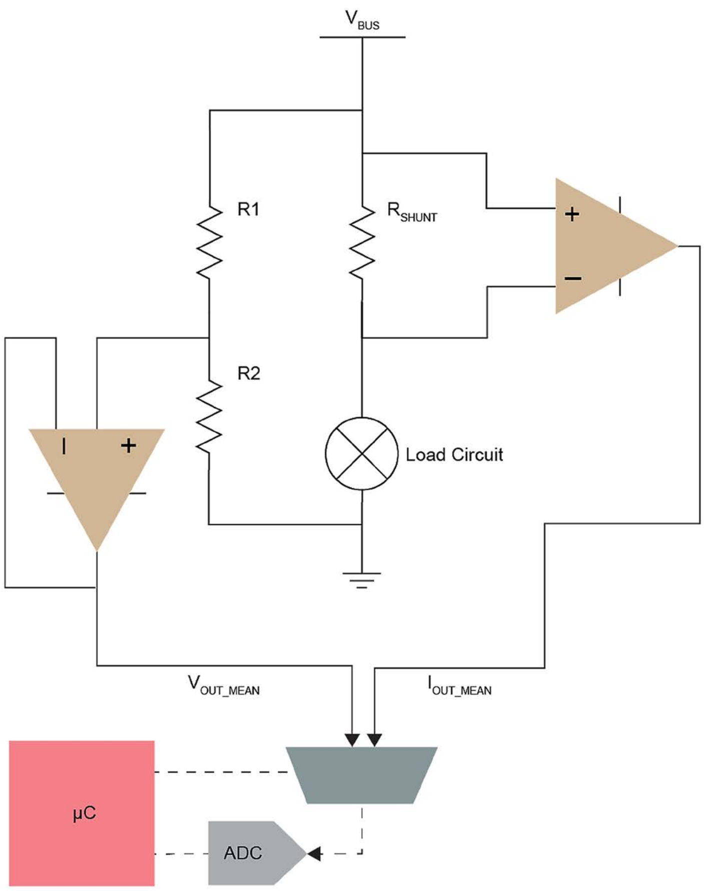


Figure 3 - Typical energy measurement circuit[1]

As the demand for DC energy monitoring features has grown over the course of years, several integrated circuits were developed for such applications. An example of such an IC is the PAC1934 from Microchip. Such an IC can easily sample up to 4 channels simultaneously,

the only required external component being the shunt resistor. The basic circuit diagram is presented in Figure 4. It integrates op-amps, ADCs, arithmetic calculation logic, memory and a standard interface in order to connect it to the system (usually I²C or SPI). The advantages of using an integrated circuit vs. the classic approach is immediately observed in cost, as the BOM reduces significantly, and of course in PCB size, as everything needed for energy measurement is already integrated into one IC.

[1] *Blue parts (Analog MUX and ADC) can be either external, as depicted, or internal to the microcontroller*

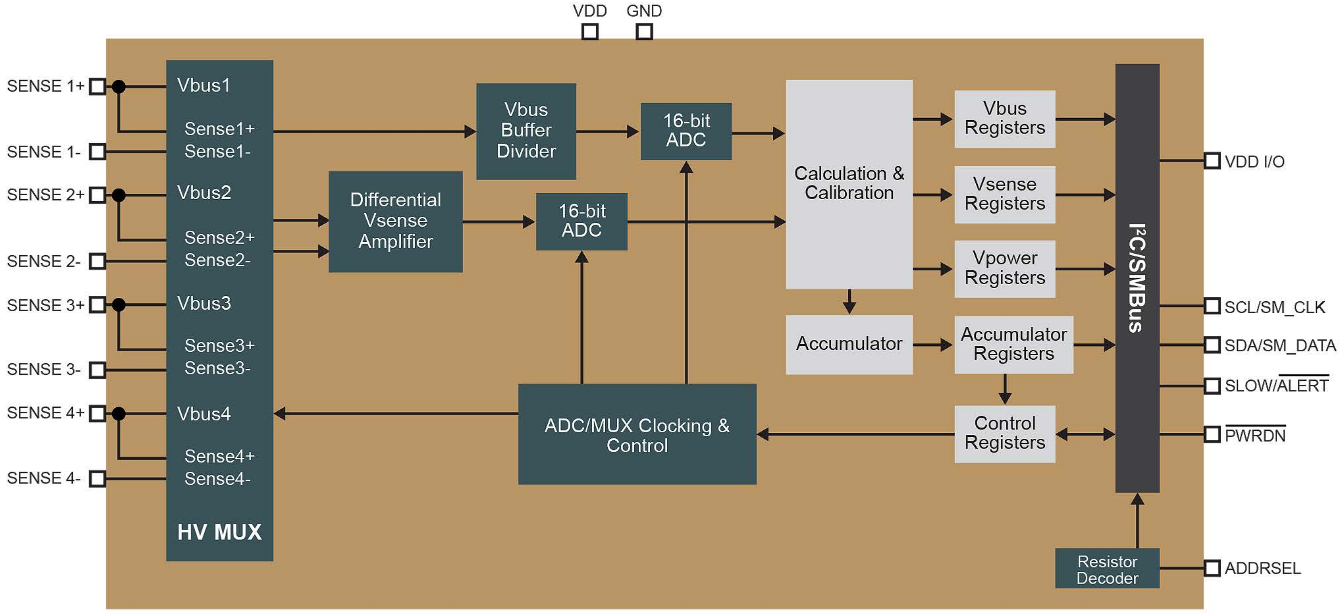


Figure 4 - Block diagram for Microchip's PAC1934, which can measure 4 channels simultaneously

Benefits of active energy monitoring

With a flexible configuration to fit most use cases, a specialized IC can accumulate power over large periods of time with very little power consumption. Usually, the power sampling rate varies from 8 samples per second up to more than 1 KSPS. PAC1934, for example, when running at 8 SPS, can accumulate power over more than 36 hours, with a current of less than 16 µA while all 4 channels are fully active and running at 16-bit resolution, without any intervention from the software. By allowing sampling rate changes on the fly, the use cases extend. An example use case is when the IC is used in a standard laptop to monitor power rails. The monitoring can be done at 1024 SPS while the laptop is running and active, and then the monitoring speed can drop to 8 SPS when the laptop is running in suspended state because the power usages won't fluctuate too much in the suspended state. Additionally, lowering the sampling rate reduces energy monitoring power consumption, without compromising performance.

One of the most popular use case of active energy monitoring is battery fuel gauging. A specialized IC monitors battery voltage and current and always knows how much energy the battery currently has. More advanced fuel gauges can also detect when the battery encounters certain issues. For example, it can track battery voltage versus energy, and when they don't correspond anymore, it means that the battery's overall capacity is shrinking due to age and other factors. Active energy monitoring is also the core of a standard battery management system (BMS). The BMS is a circuit used in multi-cell battery packs, and it is responsible for safely charging and discharging the pack, where it actively measures voltage and current to ensure each battery cell has the same parameters. BMS features also include detecting faulty cells, or disconnecting the pack when the voltage is either too high or too low.

Another popular use case of active energy monitoring is using it together with an operating system on smartphones and tablets, and Linux or Microsoft Windows on laptops, computers and servers. In the case of smartphones and tablets, the operating system monitors energy used by different services and applications through various methods. In its early stages, the energy was not directly measured, and the system estimated it based on CPU, GPU and screen usage, through the use of table data for power consumption in various operating points. The estimated power usage data was reported in a form of statistics for the user to decide on how they wanted to operate the device further.

On laptops and personal computers, Microsoft introduced the Energy Estimation Engine (E3) since Windows 8. In its early stages, E3 worked similar to the estimation algorithms in smartphones, with the ability to track every tasks' power consumption by estimating it based on various resource usage (processor, graphics, disk, memory, network, display and others). E3 also introduced the energy metering interface (EMI), which allows for system manufacturers to add and declare energy measurement sensors physically available to the system. When they are present, the E3 makes use of such sensors to accurately measure power and energy, instead of only doing estimations. Certain laptop manufacturers are already implementing these features into their laptops.

Additionally, in the past, several other initiatives were present (i.e. Sony monitoring power in the Vaio laptops), but there was no operating system support for this, and only proprietary applications could access the data. Linux does not have an equivalent for Microsoft's E3, but they are reportedly working on it. The Industrial I/O subsystem supports adding various sensors to the operating system, providing a very simple and powerful interface to the user space application (file-based interface). However, at the time when this article was written, the Industrial I/O subsystem is currently a Kernel extension, which is not part of the default Linux build. Linux also supports energy aware scheduling and intelligent power allocation, an algorithm designed to be used more in the embedded Linux area, allowing the system to decide how to schedule different tasks, while also having thermal considerations (power consumption results in CPU/GPU heating).

Another example of using energy measurement ICs worth noting is monitoring USB power and energy for various reasons and usage in server applications, as described in the first part of the article. Because servers are machines designed to continuously run without interruption, monitoring power consumption offers many benefits, from increasing overall power efficiency through active service control and meeting higher and higher power efficiency standards to allowing system administrators to perform predictive maintenance when certain parts of the server starts behaving differently in terms of power consumption (this might indicate future failure).

Summary

Depending on the need for energy monitoring, as well as other functions the system needs to perform, some approaches may be more suitable than others. The classic approach might be the winner in cases where an embedded system is built with its own purpose and it also needs to know its power consumption or have an energy estimation. It would also be recommended that the microcontroller has an internal ADC, so that the costs for energy monitoring features would be minimal. In this approach, only the external analog circuitry used for voltage and current sensing is needed. Other cases where the classic approach is more suitable than the integrated one is when very high accuracy is needed and BOM cost and power consumption are not an issue.

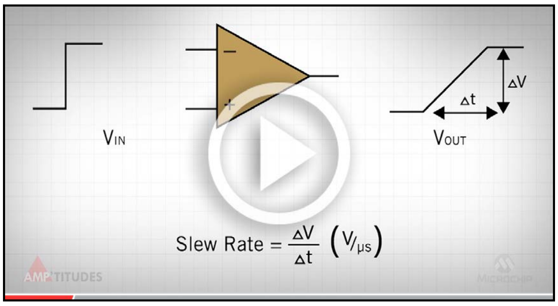
On the other hand, there are various cases when the integrated approach is more suitable. One example is when wanting to integrate energy measurement along with an operating system, because the integrated solution is already built for this, and with proper drivers the system automatically recognizes it and knows what to do. The integrated solution offers advantages when a lot of buses need to be monitored, because energy measurement ICs can usually measure more than one channel (thus, more than one bus)., Additionally, multiple ICs can be used on the same communication bus (such as I^2C or SPI). Another case where the integrated solution wins is when measuring energy over longer periods of time while having the system in a very low power sleep mode or completely shut down. This relies on the fact that the integrated energy monitoring chips draw very little power and can make calculations and energy accumulations over certain periods of time by themselves, without any system intervention whatsoever.

And of course, when size matters in highly integrated and dense PCBs, such as the mainboards of phones, tablets or laptops, an integrated circuit always occupies less area than its equivalent discrete components. For example, an integrated energy measurement circuit that can monitor four channels simultaneously can be found in WLCSP size chip, which is 2.225 x 2.17 mm.

Article "The Role of Energy Monitoring in DC Systems" First published on EDN

AMP'TITUDE Technical Video Library

Gain insights into improving amplifier and comparator development with the AMP'TITUDE series of videos. The videos help you to focus on specific design challenges and give you a quick overview of architectures used in Microchip's Op Amps and the design trade-offs. All videos feature Microchip analog experts covering topics they get asked about most frequently.



Watch the latest video to discover the differences between using Windowed and Non-Windowed Comparators, or select one of the other videos from the library.

Amplifier Bandwidth and Slew Rate

Input Bias and Offset Current

Rail to Rail Output Stage

EMI Rejection

Power Supply Filtering

Zero-Drift Terminology

Introduction to INAs

INA Gain Settings

Bipolar vs CMOS

Current vs Voltage Noise

Current Sensing

Gas Sensors

Application Notes

Anti-Aliasing, Analog Filters for Data Acquisition Systems

To simplify the development of a data acquisition system, this Application Note looks at the techniques used to implement the analog filter in an anti-aliasing filter.

The advantages of using analog or digital filters are outlined, and the Application Note covers key design parameters as well as the theory behind using an anti-aliasing filter. You will also find the best way to implement the design of the analog filter and an example design for an anti-aliasing filter.

Download the Analog Filters Application Note

Using Digital Potentiometers to Design Low-Pass Adjustable Filters

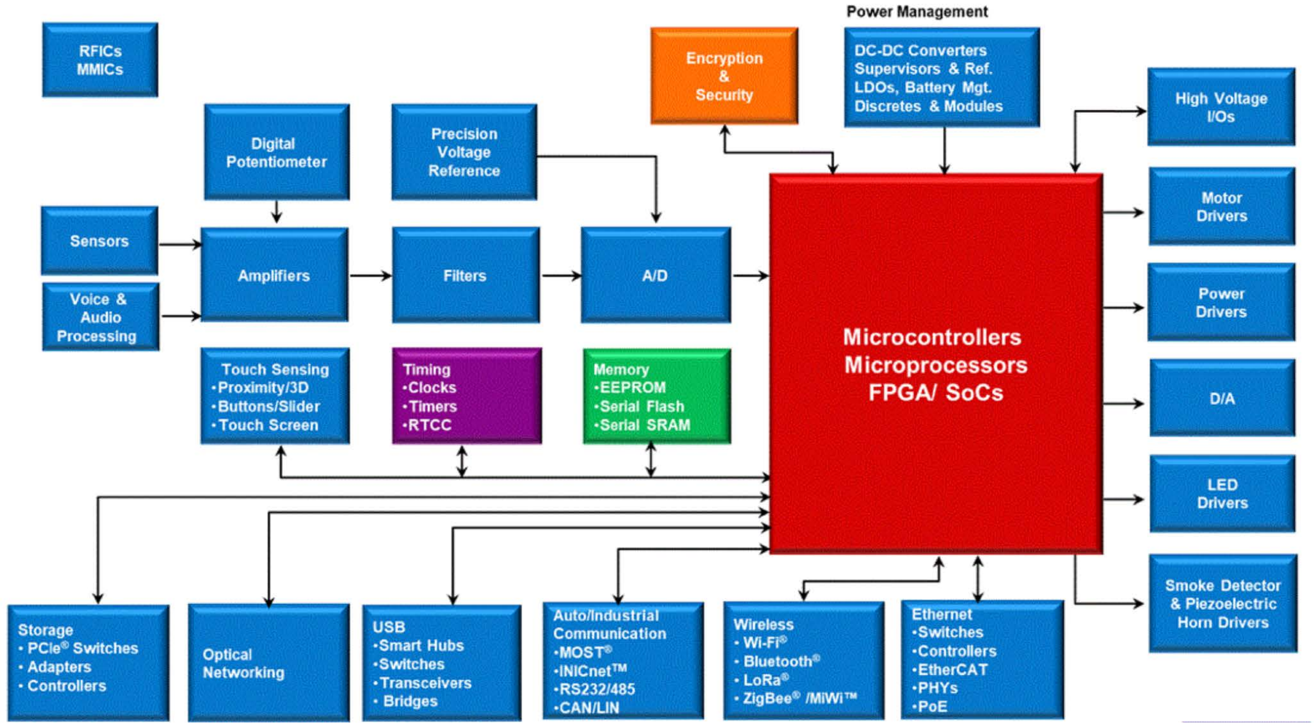
Discover how second-order, low-pass, programmable filters can be designed using one dual digital potentiometer, supported by an amplifier and two capacitors.

The Application Note considers Butterworth, Bessel and Chebyshev second-order low-pass filters and includes the idea of using a digital potentiometer to create a Butterworth filter and a programmable, second-order, Sallen-Key low-pass filter. Achieving absolute accuracy is discussed by using error analysis of the programmable filters.

Download the Digital Potentiometer Application Note

Microchip Analog Products Overview

To deliver breakthroughs in performance, size and precision, Microchip's analog and interface products combine advanced features with proven capability.



Amplifiers and Linear

With voltages down to 1.4V, the operational amplifiers deliver low power and high performance, as well as precision and zero-drift performance for high accuracy. The differential amplifiers feature low input offsets and low distortion.

Extend battery runtime with comparators which achieve ultra-low quiescent current and give you integrated references, multiple output configurations and windowed options.

View Full Range

Connectivity

Driving new levels of wired and wireless connectivity, this range increases performance in Automotive and Wired applications using CAN, LIN, INICnet™, CoaXpress®, USB and Ethernet communication.

Telecom applications can use the line Drivers and line circuits for connectivity, while wireless connectivity supports Wi-Fi®, Bluetooth®, LoRa®, IEEE 802.15.4 for mesh networking as well as sub-GHz and RF remote controls.

View Full Range

Data Converters

Manage signal-chain challenges with Analog-to-Digital Converters (ADCs) for high accuracy and low power and Digital-to-Analog Converters (DACs) which have one to four channels for precision-controlled conversion and low power consumption. The voltage references give you low noise and high precision with initial accuracy down to 0.1% and voltage from 1V to 4.096V.

View Full Range

Interface

For High-Voltage (HV) interfaces, level translation and amplification is provided by driver arrays, amplifier arrays and DMOS FETs which range from simple MOSFETs to multi-channel HV driver ICs. There are also innovative MEMS and piezo drivers for biasing, signal routing, level translation and amplification.

View Full Range

Power Management

For power management, the devices provide solutions based on industry-leading LDOs, as well as switching regulators, PMICs, Digitally Enhanced Power Analog (DEPA) controllers, DC-DC controllers, and MOSFET drivers. The highly integrated power modules improve power density with ultra-compact, rugged and thermally enhanced packages.

View Full Range

Sensors

Achieve system control and measurement of temperature or position with single- or multi-channel temperature sensors and inductive position sensors. The temperature sensors offer I^{2}C or SPI communication and the inductive sensors give you robust and accurate position measurement without magnets. There are also current sense amplifiers which combine high flexibility with high precision.

View Full Range

Silicon Carbide (SiC) Solutions

To reduce cost in power designs, the Silicon Carbide (SiC) devices improve system efficiency and support higher operating temperatures for high-voltage and high-power applications. The next-generation SiC MOSFETs and SiC Schottky Barrier Diodes (SBDs) feature high-repetitive Unclamped Inductive Switching (UIS) in addition to gate oxide shielding and channel integrity.

View Full Range

Timing Devices

Complex timing for low-jitter and low-power applications is supported by quartz- or MEMS-based oscillators and multiple-output clock generators. The range features buffers, oscillators and clock generators in addition to atomic clocks, real-time clocks and crystals. There are also devices to support SyncE and IEEE® 1588 and jitter attenuation as well as clock and data distribution.

View Full Range

Treelink Interactive Analog Product Selector

Treelink is your most flexible and comprehensive interactive discovery tool for selecting and developing with analog and interface components.

Bringing together over 3000 pages, this interactive tool lets you navigate through selectable links to download the datasheet for the right component, explore block diagrams for end applications and find the best development or evaluation board for your application.

This easy and complete guide also outlines the growth in the analog market and highlights the difference that analog can make to your application.

- Selectable Analog & Interface Product Tree
- Overview of Analog Market
- Links to over 300 Development and Evaluation Boards
- Block Diagrams for End Equipment
- Component Datasheets

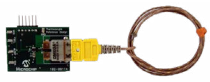
Download the interactive Treelink Analog Selector Guide

Development Tools

Thermal Management Products

MCP9600 Evaluation Board (ADM00665)

The MCP9600 Evaluation Board is used to digitize the Thermocouple EMF voltage to degree Celsius with ±1.5°C accuracy. You can easily evaluate all device features using a Type K thermocouple. The device also supports Types J, T, N, E, B, S and R. Each of these types are evaluated by replacing the Type K Thermocouple connector with the corresponding connectors (not included).



Thermocouple Reference Design (TMPSNSRD-TCPL1)

This reference design demonstrates how to instrument a thermocouple and accurately sense temperature over the entire thermocouple measurement range. This solution uses the MCP3421 18-bit Analog-to-Digital Converter (ADC) to measure voltage across the thermocouple.

Sensor Products

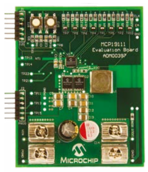
Linear Sensor Kit (LXK3301AL003)

This 100 mm linear position sensor evaluation kit comes with all you need to test out inductive technology for a linear sensor. The kit includes a 100 mm linear sensor evaluation board, a programmer that is run from our Integrated Programming and Calibration Environment (IPCE) GUI and applicable cables.

Rotary Sensor Kit (LXK3301AR001)

This 18 mm 120˚ rotary position sensor evaluation kit comes with all you need to test out inductive technology for a rotary sensor. The kit includes a rotary position sensor evaluation board, a programmer that is run from our Integrated Programming and Calibration Environment (IPCE) GUI and applicable cables.

Power Management Products



MCP19111 Evaluation Board (ADM00397)

The MCP19111 is a digitally-enhanced PWM controller. It combines a pure-analog PWM controller with a supervisory MCU making it a fast, cost-effective and configurable power conversion solution. The MCP19111 is ideal for standard power conversion, LED drivers and battery charging applications. This board demonstrates how the device operates in a synchronous buck topology over a wide input voltage and load range.

MCP16251 and MCP1640B Synchronous Boost Converters Evaluation Board (ADM00458)

This board demonstrates the MCP16251/MCP1640B in two boost-converter applications with multiple output voltages and was developed to help reduce product design cycle time. Three common output voltages can be selected: 2.0V, 3.3V and 5.0V.

For a complete list of development tools, please visit www.microchip.com/development tools.

Power Management Products (continued)

MIC33M650 6A Step Down Module Evaluation Board (DT100107)

The boards are intended to provide a platform allowing customers to easily evaluate the features of the new MIC33M650 6A Power Modules in a buck converter application with adjustable output voltage through pin-strapping using on board jumpers. These boards are ideal for powering core supply voltages and also high-power single-cell Li-ion battery powered applications.

MIC33M656 6A Step Down Module Evaluation Board (DT100108)

The boards are intended to provide a platform allowing customers to easily evaluate the features of the new MIC33M656 6A Power Modules in a buck converter application with output voltage and other settings via I2C. These boards are ideal for powering core supply voltages and also high power single-cell Li-ion battery-powered applications.

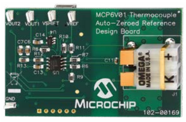
MIC23350 3A Synch Buck Regulator Evaluation Board (ADM00880)

The MIC23350 Evaluation Board is developed to evaluate and demonstrate Microchip Technology's MIC23350 product. The board features the MIC23350 in a typical Buck application supplied from an external source, between 2.4V–5.5V. Nine output voltage levels can be set via two Voltage Select pins. Test connectors allow probing, while the board can be loaded up to 3A.

MIC23650 6A Synch Buck Regulator Evaluation Board (ADM00885)

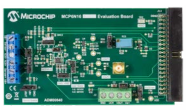
The MIC23650 Evaluation Board is developed to evaluate and demonstrate Microchip Technology's MIC23650 product. The board features the MIC23650 in a typical Buck application supplied from an external source, between 2.4V–5.5V. Nine output voltage levels can be set via two Voltage Select pins. Test connectors allow probing, while the board can be loaded up to 6A.

Linear Products



MCP6V01 Thermocouple Auto-Zeroed Reference Design Board (MCP6V01RD-TCPL)

The MCP6V01 design board demonstrates how to use a difference amplifier system to measure Electromotive Force (EMF) voltage at the cold junction of thermocouple to accurately measure temperature of the thermocouple bead. This can be done by using the MCP6V01 auto-zeroed op amp because of its ultra-low offset voltage (V_{OS}) and high Common Mode Rejection Ratio (CMRR).



MCP6N16 Evaluation Board (ADM00640)

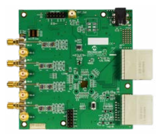
This board is designed to provide an easy and flexible platform when evaluating the MCP6N16, a zero-drift instrumentation amplifier designed for low-voltage operation featuring rail-to-rail input and output performance. The board is populated with the MCP6N16-100, which is optimized for gains for 100V/V or higher.

MCP6421 EMIRR Evaluation Board (ADM00443)

The MCP6421 EMIRR Evaluation Board is intended to support the Electromagnetic Interference Rejection Ratio (EMIRR) measurement and to show the Electromagnetic Interference (EMI) rejection capability of the MCP6421 op amp.

For a complete list of development tools, please visit www.microchip.com/development tools.

Mixed Signal Products



MCP37X3X-200 16-bit 200 Msps ADC VTLA Evaluation Board (ADM00505)

This board provides the opportunity to evaluate the performance of the MCP37X3X-200 device family. With the on-board MCP37D31-200 16-bit 200 Msps pipelined ADC, it allows you to evaluate the functionality of the 16-bit 200 Msps ADCs and the digital signal processing features. With the help of a compatible data capture card, the evaluation board can provide you with performance analysis features through the PC GUI.

PAC1921 High-Side Power and Current Monitor Evaluation Board (ADM00592)

The PAC1921 is a dedicated power monitoring device with a configurable analog output. This device is unique in that all power-related information is available on the 2-wire/ I^2C-compatible interface and power, current or voltage is available on the analog output. This evaluation board provides you with the means to exercise device functionality while connected either to target systems or while utilizing on-board sources.

MCP39F511 Power Monitor Demonstration Board (ARM00667)

The MCP39F511 Power Monitor Demonstration Board is a fully functional single-phase power monitor and energy monitoring system. The system calculates and displays active power, reactice power, RMS current, RMS voltage, active energy (both import and export) and four quadrant reactive energy. The Power Monitor Utility Software enables you to easily experiment with all system configuration settings such as zero-cross detection, PWM output frequencies, event configurations and calibration setup.

Interface Products

UCS81003 Evaluation Board (ADM00561)

This board provides the ability to evaluate the features of the UCS81003 Automotive USB Port Power Controller with Charger Emulation. It allows the UCS81003 to be tested in different configurations by populating jumpers on specific header locations. The Evaluation Board contains the MCP2221 USB to I^2C bridge, which allows communication via USB between the UCS81003 and the GUI running on the PC.

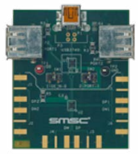
LAN9252 EtherCAT® Slave Controller Evaluation Kit with HBI PDI Interface (EVB-LAN9252-HBI)

This kit is a standalone platform to develop an EtherCAT slave device. It offers flexibility to explore different host bus interfaces such as 8-bit and 16-bit parallel bus, SPI and SQI™.

LAN874X 10/100 Ethernet Transceiver with EEE and Wake-On-LAN (EVB8740)

The EVB8740 is a PHY evaluation board for our LAN874X family, which integrates Energy Efficient Ethernet and Wake-on-LAN features. It interfaces to a MAC controller via a standard MII or RMII interface.

For a complete list of development tools, please visit www.microchip.com/development tools.

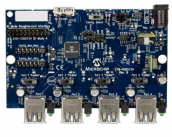


USB3740 Hi-Speed USB 2.0 2-Port Switch (EVB-USB3740)

The EVB-USB3740 is used to evaluate our USB3740 USB 2.0 compliant 2-port switch. Some applications require a single USB port to be shared with other functions. The USB3740 is a small and simple 2-port switch providing system design flexibility.

UTC2000 Basic USB Type-C™ Controller Evaluation Kit (EVK-UTC2000)

The EVK-UTC2000 is a complete kit to evaluate our UTC2000 basic USB-C controller. It includes a downstream-facing port dongle which can connect to any standard host, an upstream-facing port board to mimic a USB-C device, as well as a USB-C cable.

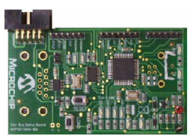


USB5734 USB 3.1 Gen1 Controller Hub Evaluation Board (EVB-USB5734)

This board is a demonstration and evaluation platform that provides the necessary requirements and interface options for evaluating the USB5734 Smart Hub on a 4-layer RoHS-compliant PCB. This will allow you to gain an understanding of the product and accelerate integration into your design.

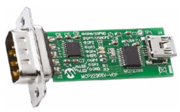
USB5926 USB 3.1 Gen1 Smart Hub with 2:1 USB-C MUX Evaluation Board (EVB-USB5926)

This board demonstrates implementation of USB Type-C ports using Microchip's UTC2000 CC pin interface controller and the USB5926's built-in 2:1 Muxes. The board supports two downstream facing USB Type-C ports along with an upstream facing USB Type-C port. The USB5926 also supports two additional downstream Type A ports for legacy purposes.



MCP2515 CAN Bus Monitor Demo Board (MCP2515DM-BM)

The MCP2515 CAN Bus Monitor Demo board kit contains two identical boards that can be connected together to create a simple two-node Controller Area Network (CAN) bus, which can be controlled and/or monitored via the included PC interface. The board(s) can also be connected to an existing CAN bus.



USB to UART Converter Evaluation Board (MCP2200EV-VCP)

The MCP2200EV-VCP is a USB-to-RS232 development and evaluation board for the MCP2200 USB-to-UART device. The board allows for easy demonstration and evaluation of the MCP2200. The accompanying software allows the special device features to be configured and controlled. The board is powered from USB and has a test point associated with each GPIO pin. In addition, two of these pins are connected to LEDs which can be used to indicate USB-to-UART traffic when the associated pins are configured as TxLED and RxLED pins respectively.

For a complete list of development tools, please visit www.microchip.com/development tools.

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