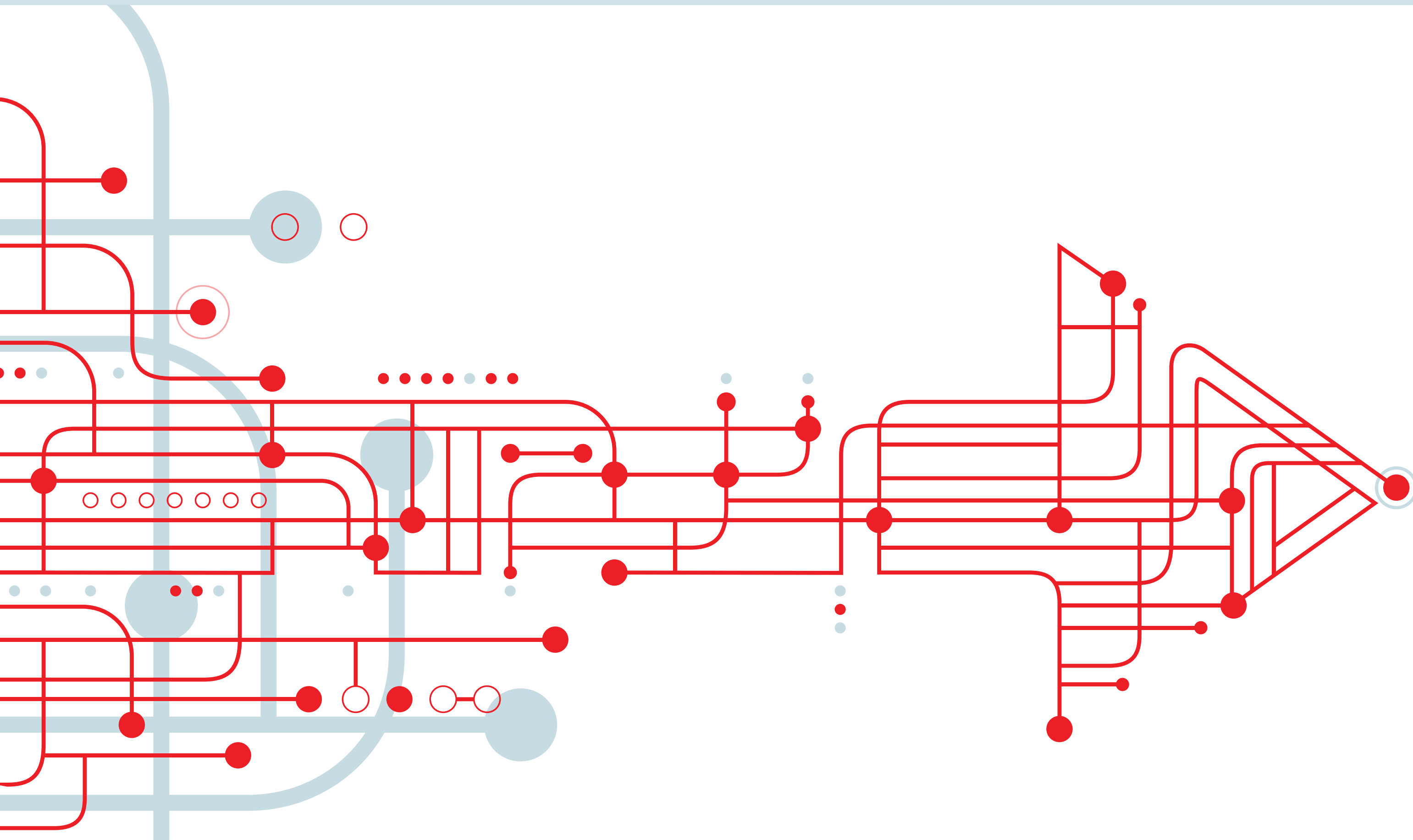
Texas Instruments

Amplifier Solutions that Answer a Range of Design Needs



Operational Amplifiers | Comparators | Instrumentation Amplifiers | Current Sense Amplifiers | Programmable/Variable Gain Amplifiers | Special Function Amplifiers

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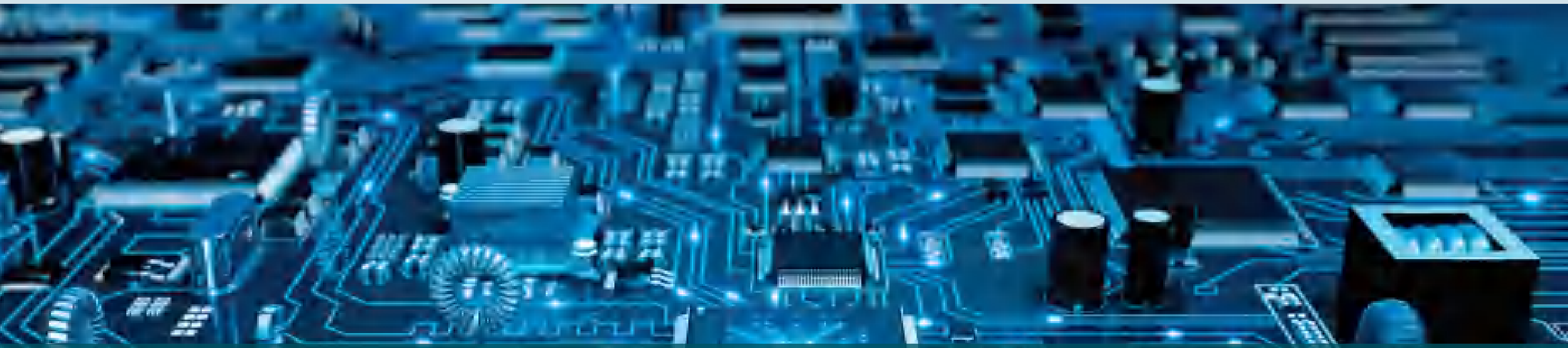

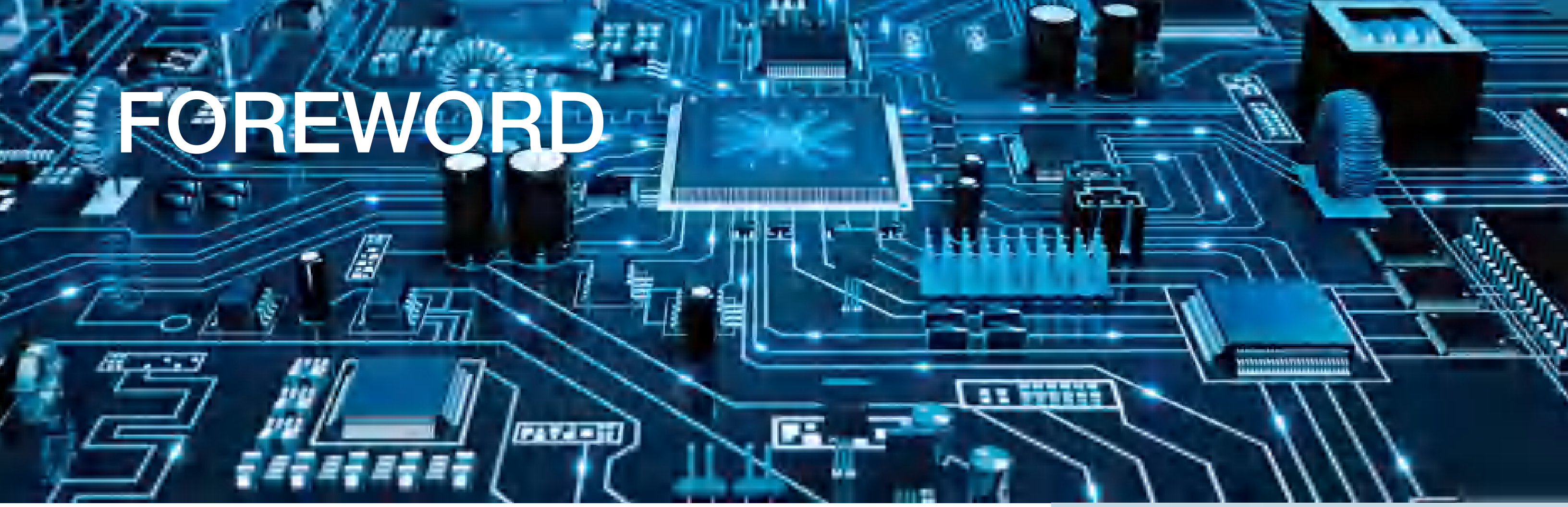

FOREWORD

Op Amps—Here Today… Gone Tomorrow?

About 10 years ago, the industry predicted that operational amplifiers (op amps) would become obsolete and replaced by the ever-increasing rise of microcontrollers. In actuality, the increased processing power, smaller size, and lower cost of the digital microcontroller have added opportunities for more accurate monitoring and control of real-world processes. The real world is not digital. Colors of the rainbow, temperature, pressure, flow, etc., are not a “1” or a “0.” This is why the op amp is key to an analog signal chain, which converts very small real-world analog signals into accurate voltages, which can be read by an analog-to-digital converter (ADC) and then further processed by the microcontroller for decision making and output process control.

Who will need an op amp? Op amps are needed in every major market segment ranging from industrial, personal electronics, and communications equipment to enterprise systems and automotive. Whether engineers are measuring temperature, pressure, flow, light, motion, gases, medical responses, moisture, voltages, current, power, or any other of the multitude of real-world monitor functions, the op amp will be required. When going back into the real world through actuators, valves, motors, speakers, laser diodes, etc., the control will almost always involve op amps.

Texas Instruments (TI) has been involved in op amps since TI engineer Jack Kilby co-invented the integrated circuit (IC) in 1958. To this day, TI continues to be a leading provider of analog ICs, including op amp solutions for every system design need. You can choose from precision op amps (<1mV input offset voltage), general purpose op amps (>1mV input offset voltage), and high-speed op amps (>50MHz to >8GHz). TI’s precision op amps input offset voltages have been designed down to 3uV maximum with a drift specification of 0.005uV/C. Among TI’s general purpose amps, the industry’s smallest op amp is available in a 0.8mm x 0.8mm package. TI’s high-speed op amps include the highest DC-precision, 150-MHz fully differential amplifier.

Op amps are alive, well, and thriving with ever-increasing performance and ever-decreasing size, power, and cost. So for today and the long foreseeable future, op amps will be needed in any type of control, monitoring, or interface to the real world. TI not only offers a full selection of op amps for conversion of small real-world signals into useable ranges for digitization but also offers the know-how and how-to for engineers to quickly get first pass designs to market. This eBook is a great starting point for any designer on the road to becoming an op amp expert.

By Tim Green
MGTS Applications
Manager-Op Amps
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Tim Green is the Member Group Technical Staff (MGTS) Applications Manager – Op Amps at Texas Instruments. Tim has over three decades of analog and mixed signal experience with seventeen years in board/system level design and seventeen years in analog/mixed signal semiconductors. Tim is also an expert in Op Amp stability & SPICE Op Amp macro-modeling and holds a BSEE from the University of Arizona.

Always ON Sensing: Nanopower Op Amps Deliver Precision That's Never Off

By Paul Golata, Mouser Electronics

Technology today is expected never to sleep, providing never-ending, round-the-clock, continual service. Amplifying analog-sensed signals precisely while consuming and utilizing low power levels are keys to a successful design. This article explores how low-power op-amps allow the successful deployment of always ON sensors in the field.

No Sleep

The city of New York has received the nickname "The City That Never Sleeps," as famously mentioned in the song New York, New York crooned by Frank Sinatra (1915–1998) in 1980. This musical number is an ode to the city and embraces it as the place to be.

I have been to New York, and it is certainly true. Within the United States, I cannot think of a city that is more Always ON. The city goes non-stop—a city of constant action, motion, and excitement.

Like the city of New York, the technology employed today never sleeps. Technology today is expected to be ON 24-hours-a-day, 7-days-a-week providing uninterrupted service. With the arrival of the Internet of Things (IoT) and other technologies, the world has seen a large increase in demand in the number of sensors and electronic components used in high-tech design. Amplifying analog-sensed signals precisely while consuming and utilizing low power levels are the keys to successful design.

Texas Instruments (TI) is a recognized world leader in electronic analog component sales with $9.9B in 2017 sales, more than double the market share of their closest competitor. TI provides amplifiers to answer any need or specific engineering requirement. TI's LPV811/LPV812 Precision Nanopower Op-Amps **Figure 1** and LPV821 Zero-Drift Precision Nanopower Op-Amps are an excellent choice for applications that require always ON sensing. This article explores how low power op-amps allow the successful deployment on always ON sensors in the field.

Figure 1: Texas Instruments LPV821 Zero-Drift Nanopower Operational Amplifier. (Source: Mouser Electronics)

Sensors Here, There, and Everywhere

Why are there so many sensors showing up in just about any application you can think of?

It is because as human beings we want more information so we can better control and manipulate things to our advantage, and flourish. Sensors provide a way for us to collect information about our external world in the form of an analog electronic signal. A variety of electronic sensors may be employed to collect analog information. These include:

- **Temperature sensors**
  Provide smart thermal monitoring with high-accuracy, low-power
- **mmWave sensors**
  Rapidly and accurately sense range, angle, and velocity
- **Magnetic sensors**
  Durable and reliable operation, simple, often used for position-sensing
- **Humidity sensors**
  Humidity and temperature monitoring
- **Specialty sensors**
  Ultrasonic, ambient light, time-of-flight (TOF)

Ideal sensors consume low power and are accurate in response to the items they are measuring and responding to.

Before the collected sensed analog signal might be sent on to be digitized and processed further, it is usually necessary to increase and make the collected signal stronger, making further discernment and screening of the analog signal easier. External conditions that are not desirable for further processing gets controlled through electronic filtering, a process whereby their signal strength may get degraded or ignored, while the desired signal gets boosted through amplification. Such a process improves the signal-to-noise ratio (SNR) of the analog information, allowing further steps in signal conditioning to be performed to shape the signal before manipulation into the digital domain whereby it undergoes processing.

Operational amplifiers are used to boost the sensor's signal level. Ideal op-amp performance is impossible. However, semiconductor companies like Texas Instruments invest a great deal of design effort to tailor their designs so that the greatest ideal op-amp performance for the application gets realized. Ideal op-amps characteristics generally include:

Gain	0–∞
Impedance, Input (ZIN)	∞
Impedance, Output (ZOUT)	0
Noise	0
Offset, Output (VO)	0VDC, when inputs grounded
Bandwidth (BW)	∞

High Precision

Earlier it was stated that two key characteristics of op-amps necessarily optimized for always ON sensing applications were (1) precision and (2) low power. Let's examine the first of these two characteristics—precision.

The International Organization for Standards in ISO: 5725-1:1994 entitled Accuracy (Trueness and Precision) of Measurement Methods and Results–Part 1: General Principle and Definitions defines precision as the repeatability or reproducibility of the measurement. It is a measure of how close the collected results agree with one another and is thus a measure of variability.

The LPV8xx series may be considered as precision op-amps because they achieve ongoing high DC accuracy and AC performance. They have been designed “Always ON” sensing applications in wireless and wired equipment where low input offset (VOS) is required. In addition to having low offset and ultra-low quiescent current (IQ), the LPV821 amplifier has pico-amp bias currents, which reduce errors commonly introduced in applications monitoring sensors with high output impedance and amplifier configurations with megaohm feedback resistors. The op-amp is well-suited for end equipment that monitor current consumption, temperature, gas, or strain gauges.

Zero-Drift

In the very hot days we have in these Texas summers, I recall summers spent in California. My friends and I would travel the Los Angeles area out to the eastern California border, where the state of Arizona and California would meet. We would arrive at the town of Blythe, CA. There in the Palo Verde Valley of the Lower Colorado River Valley, we would go drifting down the Colorado River through the Colorado Desert in about one meter of water. We would utilize large inner tubes from semi-trucks or tractors and take all day to float some 25km–50km, lazily refreshing ourselves with the cool river water and playing games. Idly meandering in the direction of the Gulf of California, the travel was slower than walking. However, after a full day in the tubes, you finally arrived at the destination spot. It was a day dedicated to slow drift.

Slow drifting may be a good way to keep cool in the hot summer, but optimal precision amplifiers should have no offset voltage drift (Vos). Offset drift is the differential voltage measured between the inputs of an op-amp. Due to manufacturing processes, statistically, the inputs of an op-amp may be very close to each other but not perfectly matched. Additionally, as temperature changes, the differential value can move as well.

The LPV821 nanopower op-amp employs a TI proprietary auto-calibration technique called zero-drift. This auto-calibration technique gets performed through an act of internal compensation. It saves engineering time and expense because the part corrects itself without the need for engineers to intervene. Zero-drift works to minimize input offset voltage drift that may be caused due to changes in temperature and does so without compounding 1/f noise (flicker noise, 3.9µVp-p). Low flicker noise provides for optimal performance for high-impedance sensor operation.

Zero-drift provides very low input offset voltages (VOS: ±10µV, max) and minimal drift over time and temperature (dVOS/dT, input offset voltage drift, TAmbient = –40°C to 125°C, VS=3.3VDC; ±0.02µV/°C, typ; ±0.096µV/°C, max). Due to its high DC precision, TI’s zero-drift finds utilization in high-precision applications, particularly involving instrumentation that is working with low-level input signals. Zero-drift enables the op-amp to more closely perform to the characteristics of an ideal op-amp. It allows design engineers to obtain high DC precision.

Nanopower

Nanopower helps provide maximum battery life with nanopower products consuming <1µA per channel. The LPV821 consumes a best-in-class IQ = 650nA, VS = 1.7VDC–3.6VDC, with an 8kHz bandwidth. The LPV821 amplifier also features an input stage with rail-to-rail input common mode range and an output stage that swings within 12mV of the rails, maintaining the widest dynamic range possible. The device is EMI hardened to reduce system sensitivity to unwanted RF signals from mobile phones, Wi-Fi, radio transmitters, and tag readers. Because the LPV821 zero-drift amplifier can operate with a single supply voltage as low as 1.7VDC, designers can count on continuous always ON sensing performance in low battery situations over its extended temperature range. The LPV821 (single-channel) is available in industry standard 5-pin SOT-23, providing a nominal footprint of 2.9mm × 1.6mm = 4.64mm2.

Nanopower means the LPV821 delivers an exceptional precision-to-power consumption ratio. This exceptional ratio means it is an ideal op-amp for applications that require the utilization of a limited-capacity power supply and battery current, but still must deliver high-performance amplification. Potential applications include battery voltage and current monitoring in portable applications, wireless sensing nodes, home and factory automation equipment, industrial sensors and detectors, field-deployed remote transmitters, battery packs, precision strain gauge and weigh scales, ongoing blood glucose monitoring, and other electrochemical cell applications. TI has extensive experience in designing systems covering analog and embedded processors. TI has reference designs available for supporting designs, including always ON low-power gas sensing with long battery life and micropower electrochemical gas sensors.

Current monitoring may happen by placing an op-amp across a low resistance shunt resistor (RShunt) that is in series with the battery. The op-amp needs to be both precise and low power to ensure the correct current measurement while maximizing the battery life. The LPV821 is a suitable op-amp for this type of application **Figure 2.** The figure shows the LPV821 employed as a differential amplifier. Employment as a differential op-amp helps to reduce errors caused by the resistance value of the shunt resistor (RShunt). The high common-mode-rejection-ratio (CMRR, 125dBB, typ) of the LPV821 ensures it performs this function well.

Like the always ON New York City, nanopower enables this part to support always-on applications. The low supply current decreases the external circuitry required to turn the amplifier on and off.

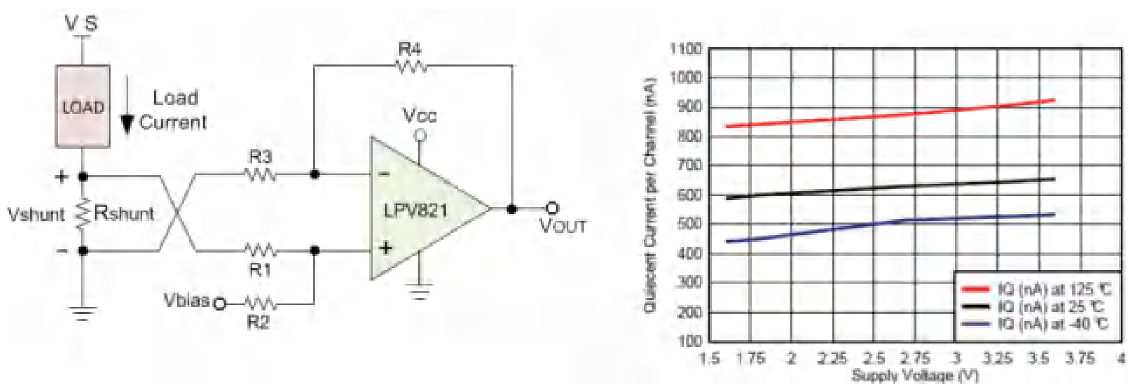
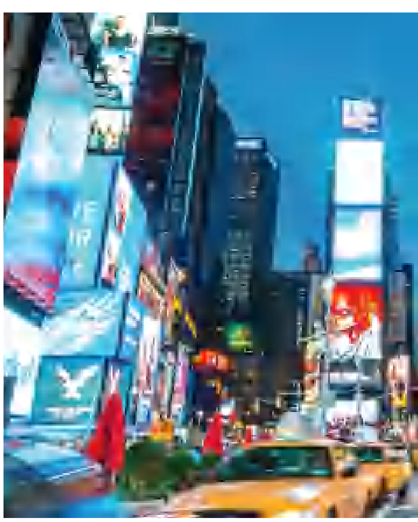


Figure 2: Low-Side, Always On Differential Current Sense employing Texas Instruments LPV821. (Source: Mouser Electronics)



Conclusion

Texas Instruments has a large portfolio spanning high-speed, precision, audio, and general purpose op-amps. Always ON sensing applications require high-precision nanopower op-amps. They help engineers extend their system's life with no battery change or recharging. Texas Instruments' LPV821 zero-drift nanopower op-amp allows designers to get some downtime and sleep knowing they have provided the perfect solution to any application that may require always ON sensing. Now, if only I can get Frank's song to stop playing on and on inside my head, maybe I can finally get a little sleep myself.

Zero-drift Amplifiers: Features and Benefits

By Errol Leon, Richard Barthel, Tamara Alani, Texas Instruments

Zero-drift amplifiers employ a unique, self-correcting technology which provides ultra-low input offset voltage (VOS) and near-zero input offset voltage drift over time and temperature (dVOS/dT) suitable for general and precision applications. TI's zero-drift topology also delivers other advantages including no 1/f noise, low broadband noise, and low distortion simplifying development complexity and reducing cost. This may be done 1 of 2 ways: Chopper or auto-zeroing. This tech note will explain the differences between standard continuous-time and zero-drift amplifiers.

Applications suitable for zero-drift amplifiers

Zero-drift amplifiers are suitable for a wide variety of general-purpose and precision applications that benefit from stability in the signal path. The excellent offset and drift performance of these amplifiers make it especially useful early in the signal path, where high gain configurations and interfacing with micro-volt signals are common. Common applications that benefit from this technology include precision strain gauge and weight scales, current shunt measurement, thermocouple-, thermopile-, and bridge-sensor interfaces.

Rail-to-rail zero-drift amplifiers

System performance can be optimized by using standard continuous-time amplifiers plus a system level auto-calibration mechanism. However, this additional auto-calibration requires complicated hardware and software which results in increased development time, cost, and board space. The alternative and more efficient solution is to use a zero-drift amplifier, such as the OPA388.

A traditional rail-to-rail input CMOS architecture has two differential pairs; one PMOS transistor pair (blue) and one NMOS transistor pair (red). Zero-drift amplifiers with rail-to-rail input operation use the same complementary p-channel (blue) and n-channel (red) input configuration shown below in **Figure 1.**

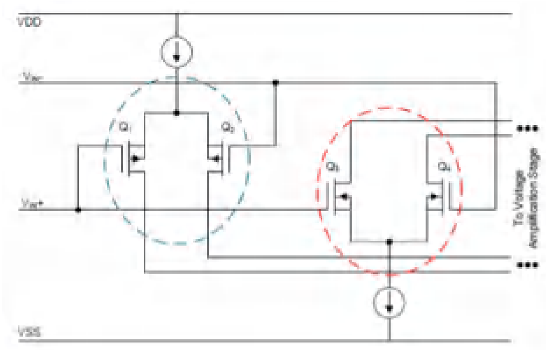


Figure 1: Simplified PMOS / NMOS Differential Pair

The result of this input architecture exhibits some degree of crossover distortion (for more information on crossover distortion, see Zero-crossover Amplifiers: Features and Benefits). However, the offset of the amplifier is corrected through internal periodic calibration, so the magnitude of the offset transition and the crossover distortion is greatly diminished. **Figure 2** shows a comparison of the offset between a standard CMOS rail-to-rail and a zero-drift amplifier.

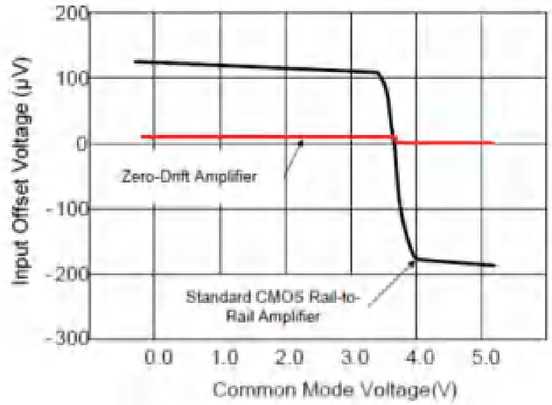


Figure 2: CMOS and Zero-drift Input Offset Voltage Comparison

How zero-drift works

Chopping zero-drift amplifiers' internal structure can have as many stages as continuous-time amplifiers the main difference is that the input and output of the first stage has a set of switches that inverts the input signal every calibration cycle. **Figure 3** shows the first half cycle. In the first half cycle, both sets of switches are configured to flip the input signal twice, but the offset flips once. This keeps the input signal in phase but the offset error polarity is reversed.

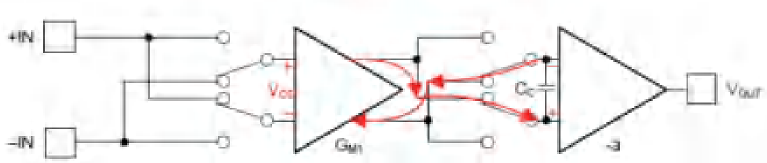


Figure 3: First Half-cycle of Internal Structure

Figure 4 shows the second half cycle. Here, both sets of switches are configured to pass the signal and offset error through unaltered. Effectively, the input signal is never out of phase, remaining unchanged from end to end. Since the offset error from the first clock phase and second clock phase are opposite in polarity, the error is averaged to zero.

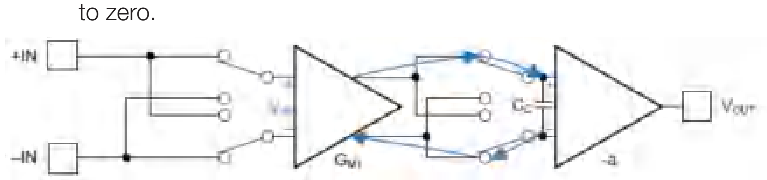


Figure 4: Second Half-cycle of Internal Structure

A synchronous notch filter is used at the same frequency of switching to attenuate any residual error. This principle continues to be in effect throughout the amplifier's operation across its input, output, and environment. In essence, TI's zero-drift technology delivers ultra-high performance and outstanding precision owing to this self-correcting mechanism.

Table 1: shows a comparison of VOS and dVOS/dT of a continuous-time and zero-drift amplifier. Notice that the VOS and dVOS/dT are three orders of magnitude smaller on the zero-drift amplifier.

Table 1: Input Offset Voltage and Drift Comparison

Device		V_{OS} (µV)	dV_{OS}/dT (µV/°C)
OPA388 (Zero-drift)	typ	0.25	0.005
	max	5	0.05
OPA316 (Continuous-time)	typ	500	2
	max	2500	10

Auto-zeroing requires a different topology but results in similar functionality. The auto-zeroing technique has less distortion at the output. Chopping results in lower broadband noise.

Noise in zero-drift amplifiers

In general, zero-drift amplifiers offer the lowest 1/f noise (0.1Hz–10Hz). 1/f noise (also referred to as flicker or pink noise) is the dominant noise source at low frequencies and can be detrimental in precision DC applications. Zero-drift technology effectively cancels slow varying offset errors (such as temperature drift and low frequency noise) using the periodic self-correcting mechanism.

Figure 5 shows the 1/f and broadband voltage noise spectral density for a zero-drift (red) and continuous-time (black) amplifier. Notice the zero-drift curve has no 1/f voltage noise.

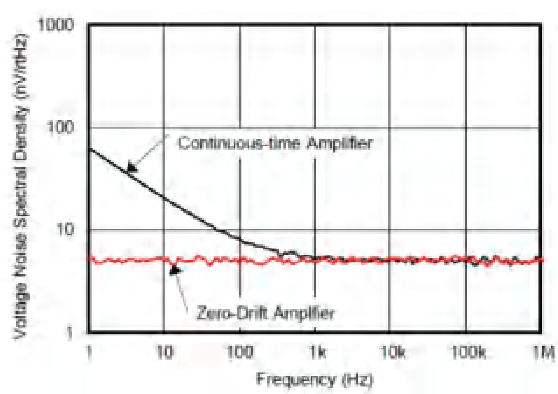


Figure 5: Voltage Noise Comparison

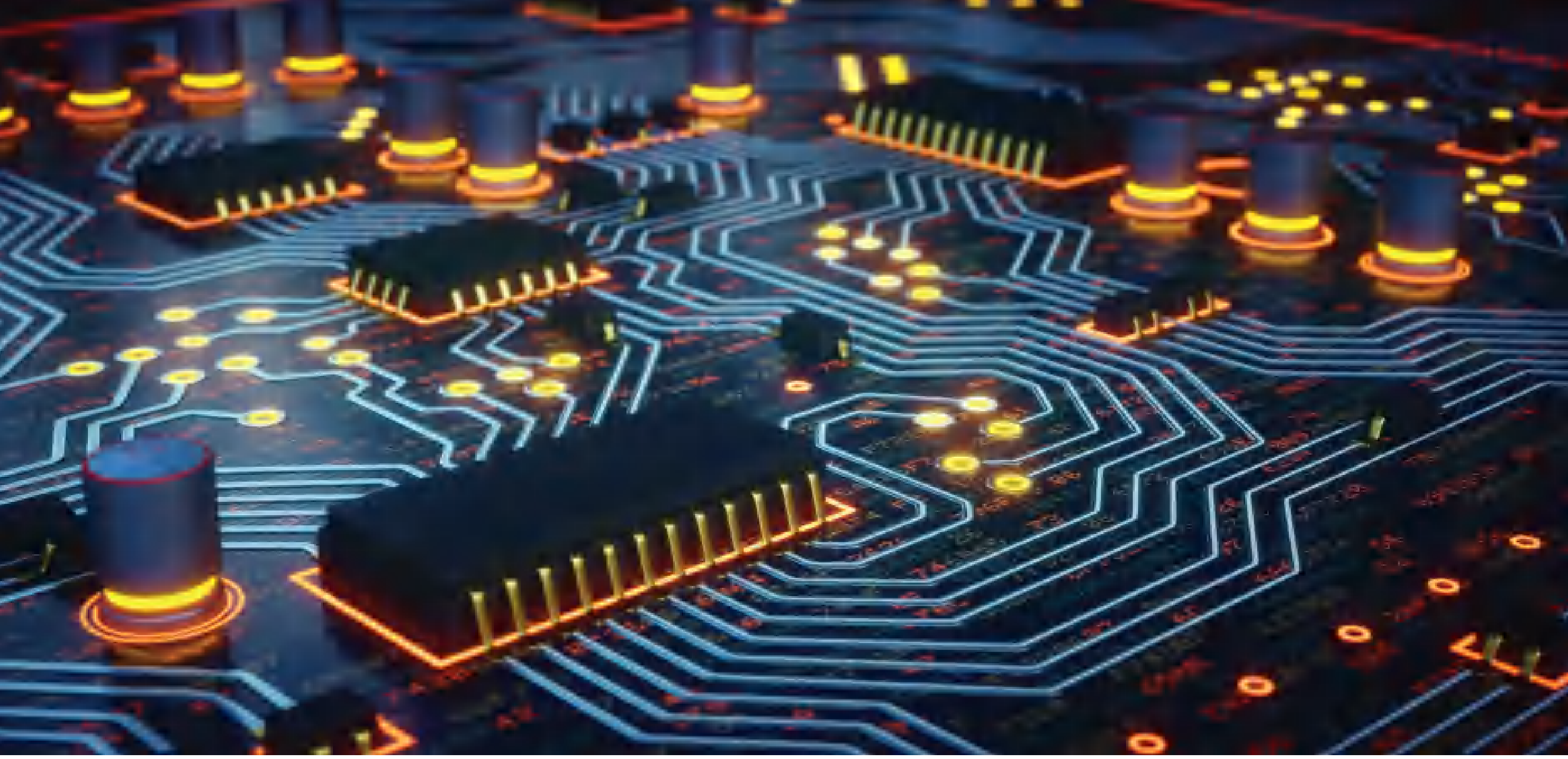
Again, why zero-drift?

Zero-drift amplifiers provide ultra-low input offset voltage, near-zero input offset voltage drift over temperature and time, and no 1/f voltage noise-design factors which are crucial to general purpose and precision applications.

Table 2 highlights some of TI's zero-drift amplifiers.

Table 2: TI's Zero-drift Amplifiers

Device	Optimized Parameters
OPA388	Zero-crossover, $V_{os(max)}$: 5μV, $dV_{os}/dT_{(max)}$: 0.05μV/°C, GBW: 10MHz, Noise: 7nV/√Hz, RRIO
OPA2333P	2mm x 2mm SON package, $V_{os(max)}$: 10μV, $dV_{os}/dT_{(max)}$: 0.05μV/°C, $I_{Q(max)}$: 25μA/Ch, 1.8V<Vs<5.5V, RRIO
OPA333	$V_{os(max)}$: 10μV, $dV_{os}/dT_{(max)}$: 0.05μV/°C, $I_{Q(max)}$ 25μA/Ch, 1.8V<Vs<5.5V, RRIO
OPA188	$V_{os(max)}$: 25μV, $dV_{os}/dT_{(max)}$: 0.085μV/°C, GBW: 2MHz, 4V<Vs<36V, Noise, 8.8nV/√Hz, RRO
OPA317	$V_{os(typ)}$: 20μV, $dV_{os}/dT_{(typ)}$: 0.05μV/°C, $I_{Q(max)}$: 35μA/Ch, 1.8V<Vs<5.5V, RRIO
OPA334 OPA335	$V_{os(max)}$: 5μV, $dV_{os}/dT_{(max)}$: 0.05μV/°C, RRO



Low-Quiescent Places Among Top Op-Amps

By Bill Schweber for Mouser Electronics

Basic analog components, such as op-amps and comparators with ultralow quiescent current, maximize battery life in IoT, automotive, and other applications, yet do not require unacceptable performance compromises.

The growth in applications related to the Internet of Things (IoT) is also creating more opportunities for classic analog components such as op-amps and comparators. This is primarily due to the many sensors (e.g., temperature, pressure, humidity, air quality, motor speed) that need signal interfacing and conditioning, as well as actuators that need drive circuitry, **Figure 1**. The critical functions provided by these analog components cannot be eliminated or avoided, while integrating them within mostly-digital ICs is often technically impractical.

Figure 1: The industrial environment is now laced with IoT sensors for many physical and operating parameters, many of which require analog signal-conditioning components for their front-end circuitry. (Source: Texas Instruments)

This IoT growth is also changing the nature of these analog components, while rearranging the top-tier parameters that vendors focus on providing and designers use to assess the available ICs. Traditional device priorities such as linearity, bandwidth, power dissipation, voltage offset, and bias current are still critical, but they have been joined by what was once a less-critical specification: Quiescent current.

What is quiescent current (usually designated as IQ), and why is it increasingly important? In simplest terms, quiescent current is the current that the component still draws with no load. In recent years, quiescent current has come to the forefront as the need to minimize current (and thus power) use has become a major issue. First, there's the environmental aspects, often driven by regulatory mandates, although in actual terms the milliamps used by most of these components is truly insignificant in the bigger "green" picture.

However, IoT systems often consist of self-powered modules that are not connected to an AC power line, but instead must operate using limited sources such as those from energy harvesting or a small battery, and that's where slashing quiescent current makes a big difference. This is especially the case as many IoT devices have very low operational duty cycles and are in sleep or idle mode a large percentage of the time. It's therefore wasteful of the limited energy resources to have components in active states when they are actually needed only for intermittent short bursts of data collection and connectivity.

Low Quiescent Current: For IoT and Cars, Too

How are today's ultralow quiescent current levels achieved? It's done via a combination of factors: Advanced process technicalities, innovative and clever IC topologies, and lower DC-rail supply voltages. Some op-amps and comparators also include a separate shutdown pin that the system processor controls and that forces the IC into an even lower quiescent current state rather than just relying on the inherent quiescent current level of an unloaded device. At the same time, these devices do not compromise on the other critical performance factors cited earlier.

Ironically, it's not just IoT applications that are increasingly concerned about quiescent-current drain: Automotive applications are as well (Figure 2 and Figure 3). This seems incongruous compared to IoT applications, as the auto has a substantial battery typically rated at 100A-hr or more and is recharged when the car is running. But today's cars are loaded with electronic subsystems for the power train, for infotainment, and for safety/security under the advanced driver assistance systems (ADAS) designation.

Figure 2: The automobile of today, and even more so of tomorrow, is a heavily sensored platform with unique requirements for low quiescent current despite the battery's capacity. (Source: Texas Instruments)

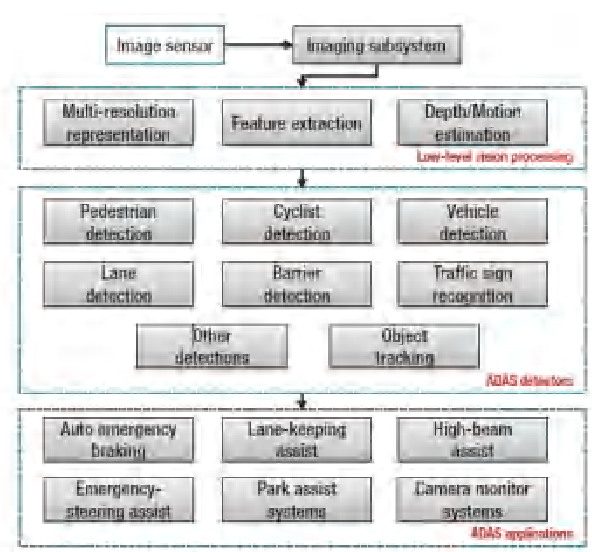


Figure 3: Power train, ADAS, and infotainment subsystems all have signal-conditioning circuitry to extract useful information from the wide array of diverse sensors embedded in the vehicle. (Source: Texas Instruments)

These functions are not physically disconnected from the battery when the car is presumably off. Instead, they remain connected but in a quiescent state, and the milliamps of current drain each of the many modules—the count easily reaches one hundred—which adds up to continual "vampire" drain on the car's battery. No one wants to find that the battery is drained after the car has not been started for a few weeks, especially in cold weather where its capacity is greatly reduced. Therefore, minimal quiescent current is not just an IoT concern, but an automotive one as well.

Data sheets for basic analog components such as op-amps and comparators have always seemed to be somewhat of a contradiction. On one hand, these are fairly simple analog functions, serving as basic building blocks, and there shouldn't be much to say about them, at least in principle. Yet the reality is that their data sheets are comprehensive, often running tens of pages, with many detailed specifications and numerous graphs defining their performance under nominal conditions as well as under variations in rail voltage, temperature, load characteristics, and other perspectives. For older op-amps and comparators, the quiescent current was often only a small note on the basic specification table. Now the quiescent current is usually listed in large type on the first page of the data sheet: It's that important.

Literally thousands of unique op-amp/comparator devices are available from dozens of reputable vendors, and each one has an array of specifications for top-, second-, and third-tier parameters. With the growth of IoT (and auto applications), there has been a rearrangement of which parameters go into which tier, and quiescent current has moved to the top in many cases.

It's About Priorities and Tradeoffs

Any assessment of IoT-focused op-amp/comparator parameters begins with the application specifics, of course. Temperature is the most measured physical variable and doesn't change quickly, due to the inherent thermal lag; similarly, factors such as rotational speed (rpm) and chemical-reaction results don't change instantaneously **Figure 4**. This is good news for the power-constrained IoT world, as high-speed operation generally requires more power to quickly source and sink current within the IC, for example. Similarly, applications such as automotive infotainment may demand high linearity, low distortion, and moderate bandwidth to ensure audio quality, but these may be of less concern in a modest IoT data-acquisition situation (although exceptions exist), and enhanced fidelity generally requires increased operating power.

The question that engineers attempt to answer is simple to state: Among the thousands of available op-amps/comparators, which one is best for the application? The answer is also simple: There is no best one, even after you

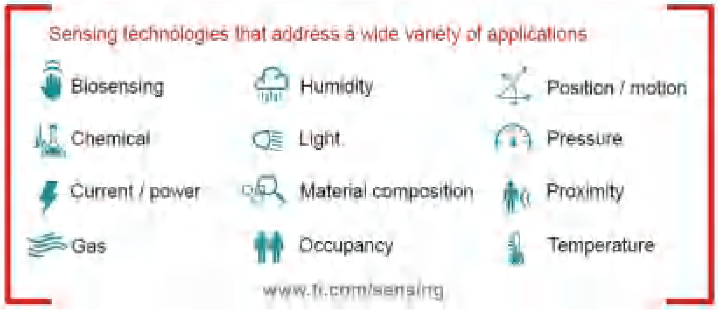


Figure 4: The range of physical variables with which an IoT design needs to interface is large and diverse; many of them have fairly low bandwidth and speeds. (Source: Texas Instruments)

eliminate those that are not a good fit or are optimized for other application classes. Instead, developing the answer requires understanding and then balancing the application priorities and tradeoffs.

The first step to do is obvious: Develop a list of the most important parameters and minimum acceptable specifications for each. The second step is harder, as it requires a definition of how much of parameter X you would give up for an improvement of a certain amount in parameter Y; for example, determining how much is worth paying in additional power dissipation to get a device that offers additional needed bandwidth.

A basic calculation demonstrates the impact of low quiescent current versus active operating current. Consider an IoT application using an op-amp with 1mA operating current and 1µA quiescent current, with a 1 percent duty cycle. The total current used by this op-amp is (99 × 1µA) + (1 × 1mA) or approximately 1.01mA. As the ratio between active and quiescent current-mode changes, or the duty cycle changes, the total current required will change as well. If the quiescent current drops by a factor of ten, down to 100nA, the total current needed will drop even closer to the operating current alone.

Why the emphasis on active and quiescent current as a measure rather than power? The reason is that the important capacity figure-of-merit for most sources, including batteries and supercapacitors, is measured in amp-hours (A-hrs) or milliamp-hours (mA-hours), and the integral of current versus time is what determines the length of time that the source is viable. Power, in contrast, defines the rate at which this energy is used, but being able to deliver the power at a high-enough rate from the energy source is rarely a constraining issue.

Of course, there's more to low-current design than using low-current, micropower components, although they do play a major role. Other design techniques are also used, such as choosing high-value pull-up resistors where possible, or using load switches to disable entire sub-circuits via load switches when they are not needed.

Also, components with low rail voltages usually offer low operating and quiescent currents, but this may compromise some other performance parameters. Using low voltages may be a challenge for analog circuits as these signals are by their nature sensitive to noise; low operating voltages often result in reduced signal-to-noise ratio (SNR) and thus require additional attention to both internal and external noise sources to minimize the impact. Further, modeling of the circuit performance at nominal-condition operation, as well as with temperature-related drift, maximum/minimum performance specifications, and tolerance of passive components is critical to design reliability and consistency.

So Many Very Good Options

The ideal op-amp or comparator with perfect performance specifications and requiring no power (other than what is being delivering to the load) doesn't exist. But many of today's devices come quite close, especially in the power area, with microamp active-mode current requirements as well as microamp and even nanoamp quiescent current ratings, as four examples demonstrate.

The LPV801 (single channel) and LPV802 (dual channel) nanopower CMOS op-amps are designed for long run-time applications that are powered by small batteries or even energy harvesting, such as carbon dioxide (CO) and oxygen (O2) gas detectors, passive infrared (PIR) motion detectors **Figure 5**, and ionization smoke alarms. They operate from a single supply down to 1.6V with rail-to-rail output that swings to within 3.5mV of the supply rail with a 100kΩ load.

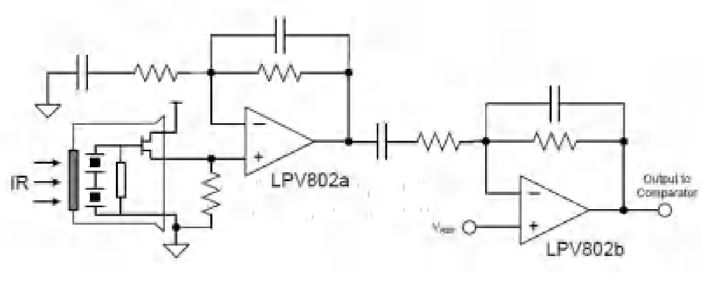


Figure 5: The LPV802 dual op-amp is well-suited for long-life battery operation in applications such as the widely used PIR detector. (Source: Texas Instruments)

However, those specifications don't tell the whole story, which includes the fact that their ultralow quiescent current of just 320nA/channel along with 8kHz of bandwidth—more than adequate for these applications—really stands out. Further, this quiescent current is fairly constant across the entire operating temperature range at a given supply voltage, **Figure 6;** this eases design-in worst-case calculations and simulation.

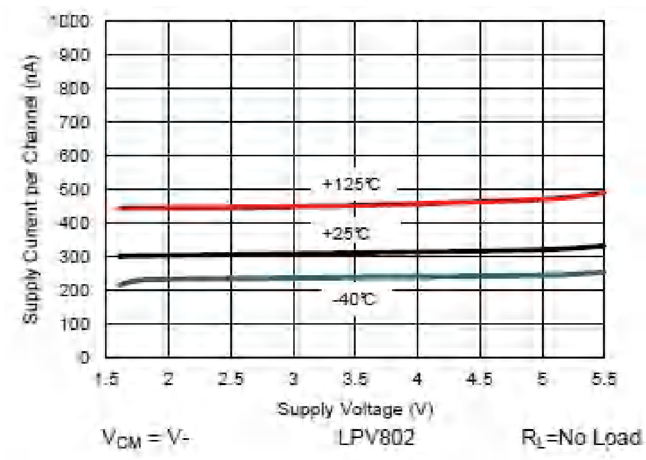


Figure 6: While the quiescent current of the LPV801 op-amp increases with increasing temperature, it remains fairly constant across the entire supply-voltage range, which eases design analysis and corner case concerns. (Source: Texas Instruments)

Some applications need an instrumentation amplifier, a specialized configuration of three op-amps that provides unique attributes with respect to gain, gain setting, bandwidth, stability, and common mode rejection. The INA828, **Figure 7**, features 50µV maximum offset, gain drift of 5ppm/°C (at gain G = 1) and 50ppm/°C (G > 1), extremely low noise of 7nV/√Hz, and wide bandwidth of 2MHz (G = 1) and 260kHz (G = 100). In addition, its maximum quiescent current is just 650µA at 25°C, rising to just 850µA at 125°C. It can be used in single-supply designs (5V) as well as those with dual supplies up to ±18V.

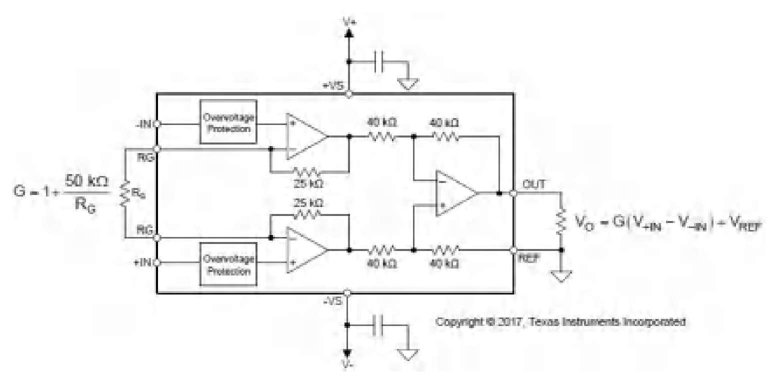


Figure 7: In instrumentation, amplifiers such as the INA828 greatly minimize many sensor-interface concerns due to its ease of gain setting, high common mode rejection, and overall performance stability. (Source: Texas Instruments)

Some op-amps even include a hardware shutdown control. The TLV906x series of wideband (10MHz) low voltage, single, dual, and quad op-amps offer this additional feature, denoted by versions with an "S" suffix. This is a discrete shutdown pin that can be invoked to individually disable each op-amp and so place it in a low-power standby mode, **Figure 8a** and **Figure 8b**. In this mode, the op-amp typically consumes less than 1µA, which is almost three orders of magnitude less than its 538µA quiescent current; enable time is 10µsec for full shutdown of all channels while disable time is 3µs.

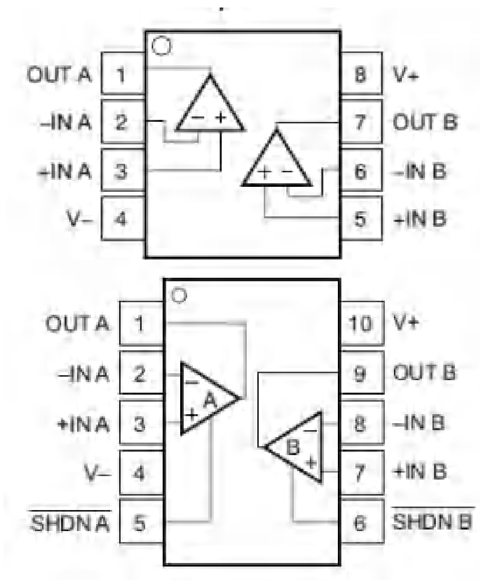


Figure 8a and **Figure 8b**: Each op-amp in the TLV906x series of single, dual, and quad op-amps comes in two versions: a) no separate shutdown-control input (here for the dual-channel devices) and b) an extended package with a control for each internal op-amp. (Source: Texas Instruments)

The comparator function is so basic and simple that it is easy to ignore its critical role in many system implementations, where it functions as a basic overvoltage/undervoltage detector for out-of-spec conditions, or as a zero-crossing detector. Comparators are often set up to operate independent of any software, thus providing an added level of operational integrity and confidence. The TLV3691 0.9V to 6.5V (or ±0.45V to ±3.25V) nanopower comparator with quiescent current of just 75nA at 25°C increasing to 150nA at 125°C. Its fast 24µsec response time makes it a good fit for critical alarm situations such as a bus undervoltage/overvoltage window circuit, **Figure 9**, with response shown in **Figure 10.**

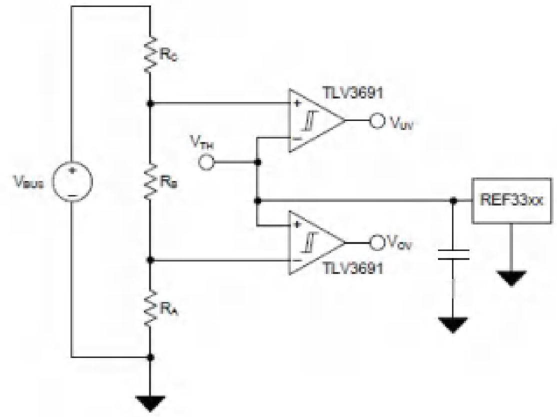


Figure 9: The simplicity of a comparator-based circuit is among its virtues, as shown by this bus undervoltage/overvoltage window-alarm configuration using two TLV3691 devices. Source: Texas Instruments

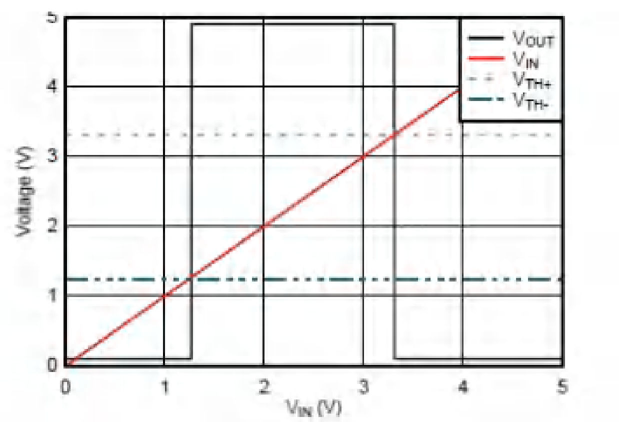


Figure 10: The basic window circuit generates an alert when the input signal falls below 1.25V or rises above 3.3V, yet requires less than 1µA from a 5V supply. (Source: Texas Instruments)

Conclusion

Basic analog components such as op-amps and comparators have a large yet sometimes unseen role in many applications such as IoT sensor interfaces as well as automotive designs. For these (and other) designs, it's important to select devices with low quiescent current—whether to maximize battery life or minimize vampire power drain—and stay within tight power budgets.

Fortunately, the newest of these components have miniscule quiescent current needs while also offering excellent performance for other parameters such as bandwidth, noise, offset, and drift, to cite a few of their many specifications.

Why You Should Use a Class-D Audio Amplifier in Your Automotive Infotainment System

By Texas Instruments

Have you seen all of the latest technology that is being integrated into today's new cars? Well, it is quite impressive and some of these technologies are even being offered in entry-level and economy vehicles:

- A forward-collision warning with emergency braking system that automatically brakes your car to avoid a rear-end collision in case the car in front of you stops too suddenly.
- An advanced parking guidance system that will automatically back your car perfectly into a parallel parking spot.
- Lane-keeping assist technology vibrates your seat to alert you that you are drifting across the lane; it can even automatically control the steering to ensure that your car remains within the white lines.

New infotainment systems **Figure 1** handle the navigation, music, radio, and streaming services inside today's vehicles. As customers buy more mid-range or entry-level cars, it is a natural expectation that their infotainment system have a large liquid crystal display (LCD) touchscreen, like on our smartphones and tablets. They also expect their cars to support Bluetooth® and/or Wi-Fi so that they can stream music, podcasts or news.

Figure 1: Automotive infotainment system

In this post, I will discuss several key design considerations for audio amplifiers in new automotive infotainment system.

Size

Some advanced features need their own dedicated processors and sensors, which are typically located in their own separate electronic control unit (ECU) box mounted behind the dashboard. Space behind the dashboard is very limited, so Tier-1 ECU suppliers are always looking for ways to shrink the footprint of these boxes, including the size of the infotainment head unit (where the radio and audio amplifiers are located) to allow more room for advanced features.

Heat

The addition of new features requires more and more processing power. Higher-performing system-on-chip (SoC) processors run a lot faster and typically consume more power and generate more heat. Likewise, the larger LCD touchscreens in infotainment systems can be affected by the heat generated inside the infotainment head unit box. Therefore, Tier-1 ECU suppliers are looking for ways to reduce the overall thermal load inside infotainment head units.

Tier-1 ECU suppliers have been using Class-AB audio amplifiers inside infotainment head units. However, Class-AB amplifiers are significantly less efficient than newer Class-D amplifier designs see **Figure 2**. This is important because the car's audio amplifier is the second-largest source of heat generation inside the head unit, just after the SoC. The more heat generated inside the head unit's box means that designers need to include a much larger passive radiated heat sink or a mechanical fan. Both options exacerbate the goal to reduce overall solution size.

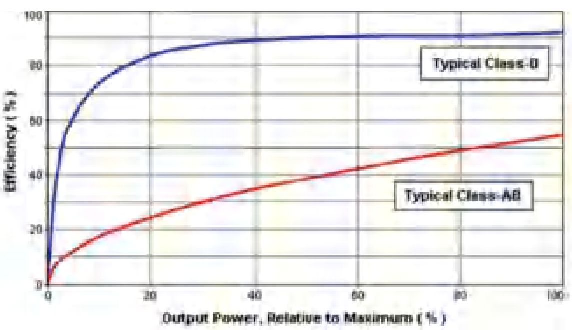


Figure 2: Class-AB vs. Class-D efficiency
(Courtesy of www.audioholics.com)

At the 2018 Consumer Electronics Show (CES), Texas Instruments will be demonstrating the industry's first 2.1MHz high switching frequency Class-D analog input automotive audio amplifier. We designed the TPA6404-Q1 to best address the issues related to infotainment head unit size and thermal load.

Class-D amplifiers typically switch the amplifier on and off at ~400kHz. A much higher 2.1MHz switching frequency in the TPA6404-Q1 Class-D amplifier design enables the use of a significantly lower inductance value for the output filter. You can see in **Figure 3** that a 2.1MHz design using a newer 3.3µH metal alloy-type inductor (as opposed to the much larger 10µH/8.2µH needed for a 400kHz amplifier) allows all eight inductors for a four-channel solution to fit into the same footprint as just one 8.2µH inductor.

Figure 3: Inductor size comparison

Another key feature of the TPA6404-Q1 that helps contribute to a small four-channel amplifier solution size is its "flow-through" audio signal design. **Figure 4** illustrates how the analog input signals come into the amplifier device on one side of the chip; then amplification of the audio signal takes place on the opposite side of the device where the signals flow into the external output filters.

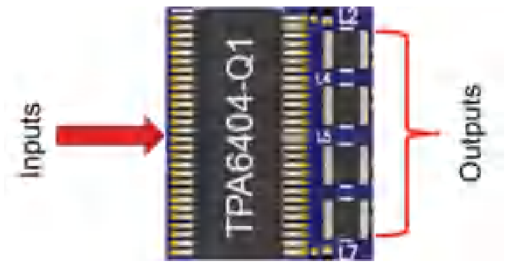
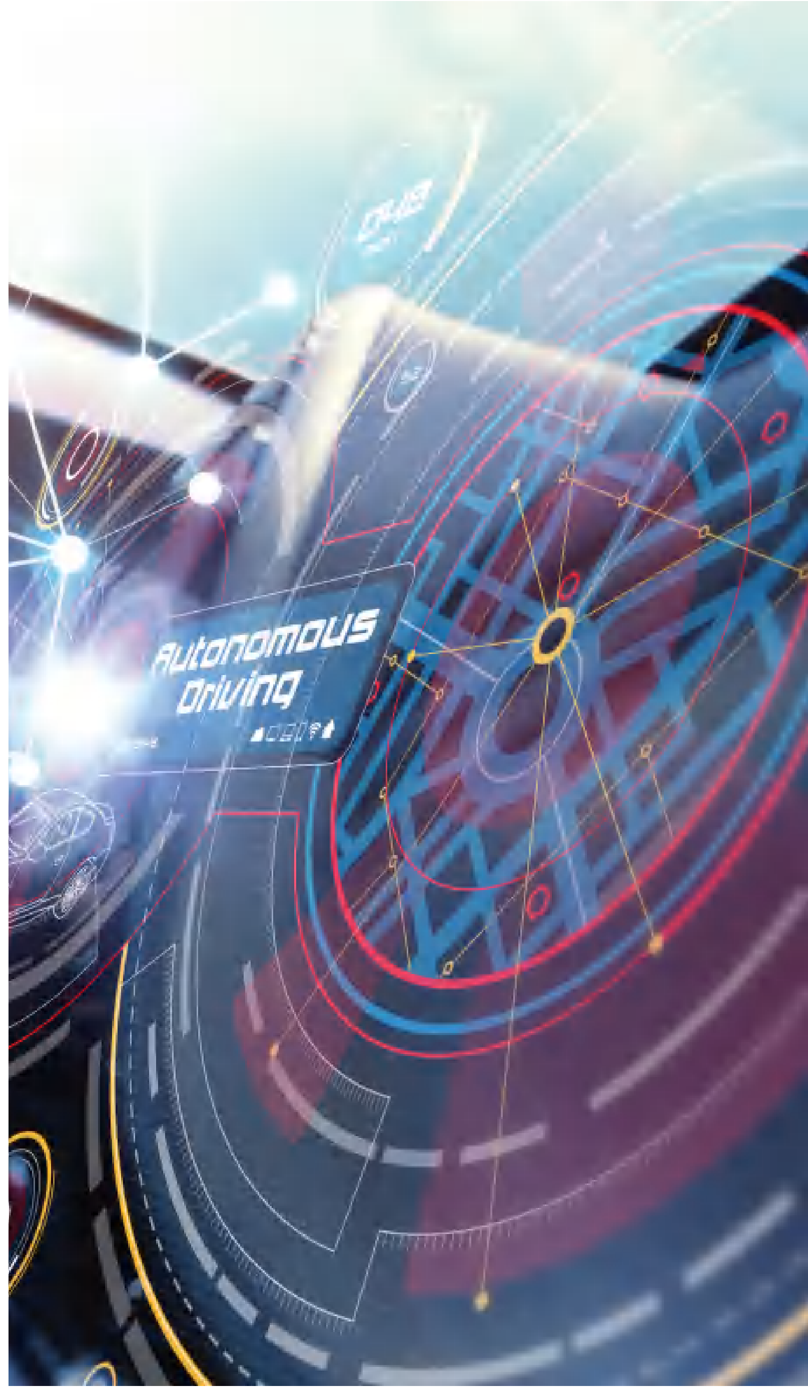


Figure 4: Flow-through design of the TPA6404-Q1

Combining metal-alloy 3.3µH inductors along with flow-through design yields the industry's smallest four-channel automotive Class-D amplifier size. **Figure 5** shows that the TPA6404-Q1 complete solution (including amplifier and all required passive components) measures just 4.5cm2.

Figure 5: Four-channel Class-D amplifier solution size

If you need to focus on reducing overall solution size and the heat generated in your entry-level infotainment head unit system, then I invite you to learn more details about how the TPA6404-Q1 2.1MHz Class-D amplifier can significantly help. You can also reduce the development time with the TPA6404-Q1 evaluation module (EVM), as well as the schematics, design files, and layout guidance, to kick-start your design.



Tiny Yet Mighty: Low Voltage Operational Amplifiers, with a Small Footprint

By Paul Golata, Mouser Electronics

You may not realize that ants and electronic amplifiers have some things in common. Learn how the tiny yet mighty ant shares the characteristics of small physical size and high performance with a look at Texas Instruments' TLV9062 low voltage operational amplifier.

An Ant Enters the Room

Recently, there was a scream in the house. I stepped out of my office and entered the kitchen where I ran into Joey, my 20-year-old daughter, screaming. I said, "What happened?" She responded, "Ants! They are all over the place." I did not see any. I said, "Where?" Joey pointed and said, "There!" I saw a towel on the floor. I picked it up. It was moist, and due to the hot weather here in Texas (>38˚C at present), I assumed the ants were taking advantage of the simultaneous joy of shade plus water. I quickly brushed them up and threw the dustpan out the door onto the lawn so that they could fend for themselves in the great wilderness of my backyard.

That got me thinking about how those amazing creatures can do so much while being so small. They seem to be able to show up anywhere, and because of their small size they can get into any location they deem of interest. In a completely different respect, they also have enormous power.

I have never measured the mass of an ant, but Google says it is on the order of 0.005g. While I am busy trying to stay fit so I can continue to bench press my weight (75kg), ants reportedly can lift two to three orders of magnitude over their body weight. If I could do so, I would be considered a superhero.

Ants to Amps

Obviously, I am not a myrmecologist (Greek myrmex, "ant" and logos, "study") who studies ants. However, I am an electronic engineer, and to that end, I have studied operational amplifiers or op-amps for short. I think that ants and op-amps have something in common: tThey are both tiny but mighty. After all, some of the best electronic innovations are inspired by and mimic many things found in nature.

Tiny

I live in the Dallas/Fort Worth, TX metroplex, not far from the corporate home of Texas Instruments. Texas Instruments has always provided the industry's best op-amps through differentiation and innovation. Their op-amps can solve your application needs. One of the ways they do so is through their small physical size.

Take for example the Texas Instruments TLV9062 Low Voltage Operational Amplifier **Figure 1**.

Figure 1: Texas Instruments TLV9062 Low Voltage Operational Amplifiers (Source: Mouser Electronics)

This eight-pin part is available in four distinct packaging types, including:

- Small-Outline Integrated Circuit (SOIC)
- Thin Shrink Small-Outline Package (TSSOP)
- Very-Thin-Shrink Small-Outline Packages (VSSOP)
- Very-Very-Thin Small-Outline No-Lead Package (WSON)

SOICs, TSSOPs, and VSSOPs are some of the industry's most common packages. Their commonality and general availability allow for easy employment in new designs.

However, when ensuring the smallest possible design for items such as mobile, portable, or wearable devices, sometimes the extremely tiny WSON, often referred to as a micro-sized package type, is the best choice. Employing a WSON package type may help designers save lots of board real estate due to its smaller footprint while also saving on volume **Table 1**. Additional benefits may include a low mass of product, thereby contributing to low-weight designs.

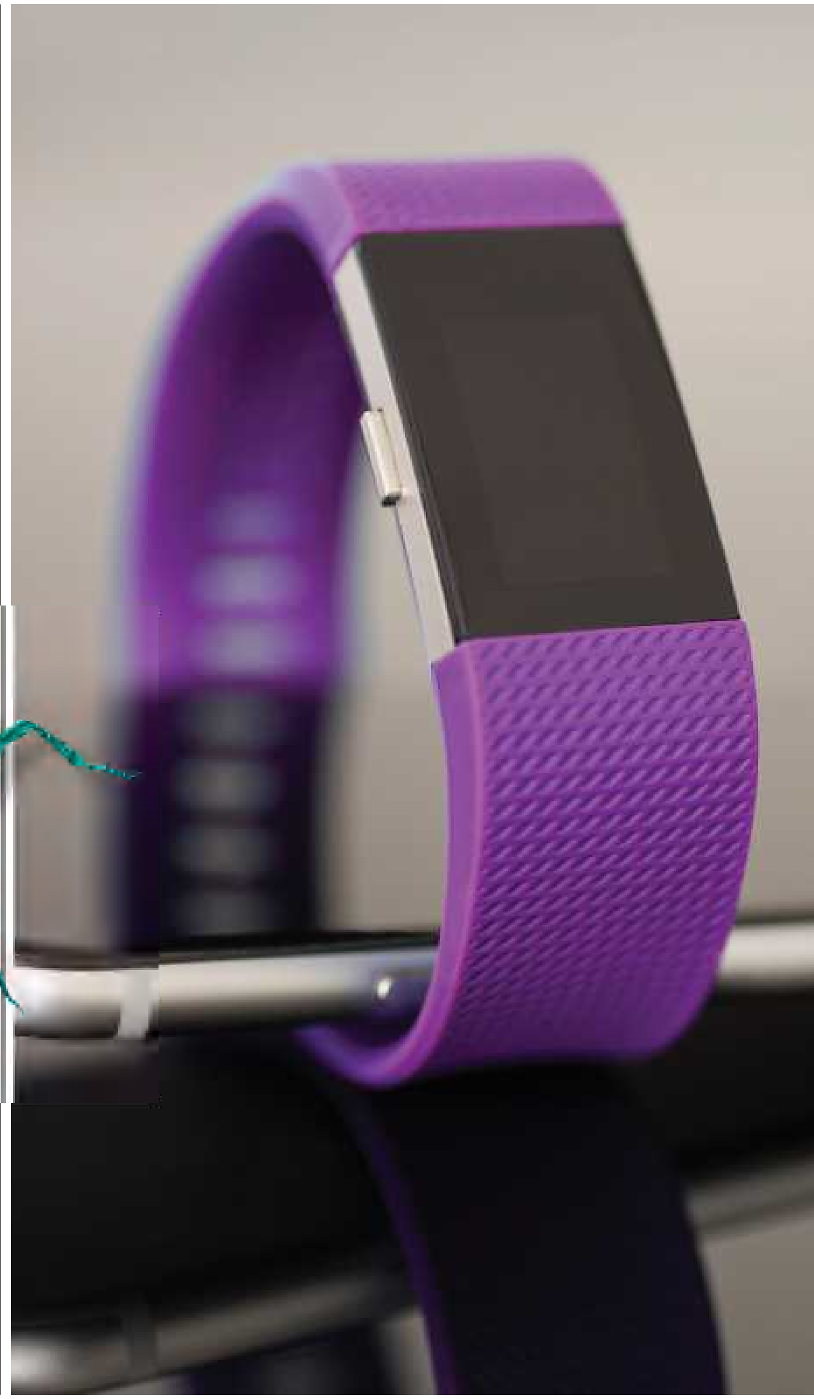
Table 1: A table showing the TLV9062 packaging type options, sizes, footprint, and volume. (Source: Mouser Electronics)

TLV9062	Package Type	Pins	W (mm)	L (mm)	D (mm)	Foot-print (mm2)	Volume (mm3)
IDGKR	VSSOP	8	5.3	3.4	1.4	18.0	25.2
IDGKT	VSSOP	8	5.3	3.4	1.4	18.0	25.2
IDR	SOIC	8	6.4	5.2	2.1	33.3	69.9
IDSGR	WSON	8	2.3	2.3	1.15	5.3	6.1
IDSGT	WSON	8	2.3	2.3	1.15	5.3	6.1
IPWR	TSSOP	8	7.0	3.6	1.6	25.2	40.3

Mighty

Like the tiny ant, the TLV9062 is also mighty, providing high performance for designers. With rail-to-rail input and output-swing (RRIO) capabilities, these dual-channel op-amps are highly cost-effective solutions for applications where the low-voltage operation (1.8VDC–5.5VDC), a tiny footprint, and high capacitive (100pF) load drive suit design requirements. With a unity-gain bandwidth of 10MHz, it offers low broadband noise (10nV/√Hz) and low quiescent current (IQ: 538µA). Like the entire TLV906x family, it is unity-gain stable, integrates the

RFI and EMI rejection filter, and provides no phase reversal in overdrive condition. Its extended temperature range (-40˚C to 125˚C) means it is capable of being employed in a wide range of applications, including home appliances, barcode scanners, E-bikes, HVAC systems, laptop computers, low-side current sensing, motor controls, power modules, sensor systems, and wearable devices.



Conclusion

While I do not make a point of welcoming tiny, mighty ants into my life, dispensing of them whenever our paths cross, when designing electronics I look for tiny, mighty op-amps like the Texas Instruments TLV9062. Not only does it provide significant space savings, but it also delivers tremendous performance capabilities.

TI Amplifiers Boost Product Development

By Phil Hipol for Mouser Electronics

Numerous op-amps, suppliers, and manufacturers make it difficult for electronic system designers to select the best op-amp for an application. Mouser Electronics and Texas Instruments offer the widest range of op-amps available, enabling designers to identify multiple approaches so that optimum designs can be developed in a faster and cost-efficient manner.

The successful design, development, and manufacture of electronic systems require engineers to overcome numerous technical, schedule, and cost obstacles that may occur throughout the process. Since it is not always feasible to perform extensive research to select the best system designs and components, the electronic system design engineer must rely on trusted suppliers in order to make informed decisions. This article describes how Texas Instruments (TI) amplifier products, solutions, and expertise can help design engineers rapidly solve their application needs and thereby boost their product development capabilities.

Electronic systems may include several key components that are critical in determining overall system characteristics. One of the first steps in the electronic system design process is to create a block diagram, which shows these principal components and how current, voltage, or data is transferred among them. The block diagram is then analyzed and optimized according to any number of design goals, such as performance, power efficiency, reliability, cost (including development, manufacturing or life cycle costs), physical size and weight, and component availability. This is usually an iterative process, whereby numerous potential system configurations and components must be considered to arrive at an optimum configuration.

Among the numerous challenges that an electronic system design engineer must face involves the selection of electronic components. On one hand, there are numerous so-called “foundational components” (e.g., resistors, capacitors, and inductors) that are easy to select since they are technically-mature products that perform identical functions and are readily available from numerous sources. On the other hand, as the complexity of the electronic component increases, they become more specialized and it becomes more difficult for electronic system designers to select the best components for their application. This is compounded by the fact that numerous suppliers may be competing to incorporate the latest technologies that may combine numerous functions, improve performance or reliability, or reduce size and cost.

One such component that is used in numerous electronic products is the operational amplifier, or op-amp. An op-amp is an electronic device that increases the voltage, current, or power of a signal. When used in an electronic circuit with other components, op-amps can perform many different functions, such as filtering, amplifying, and signal conditioning, or they can perform mathematical operations, such as adding, subtracting, integrating, and differentiating. This flexibility makes op-amps among the most widely used electronic devices today, in a variety of military, automotive, aerospace, industrial, scientific, and consumer devices. Op-amps are available in several different sizes, configurations, and form factors, an example of which is shown in **Figure 1**.

Figure 1: The TI INA828 precision op-amp for instrumentation applications.

Depending on the specific applications, op-amps are available in several different product configurations, performance levels, power output and efficiencies, and prices. Furthermore, op-amps, like many other electronic components, may require specific design modifications, environmental testing, or other built-in capabilities (such as fault tolerance) to be qualified for the applications in which they will be used. The numerous op-amp applications, products, and suppliers make it difficult for an electronics design engineer to efficiently research, select, and implement the best op-amp for an application. TI offers the widest range of op-amps and other electronic devices for numerous applications and industries.

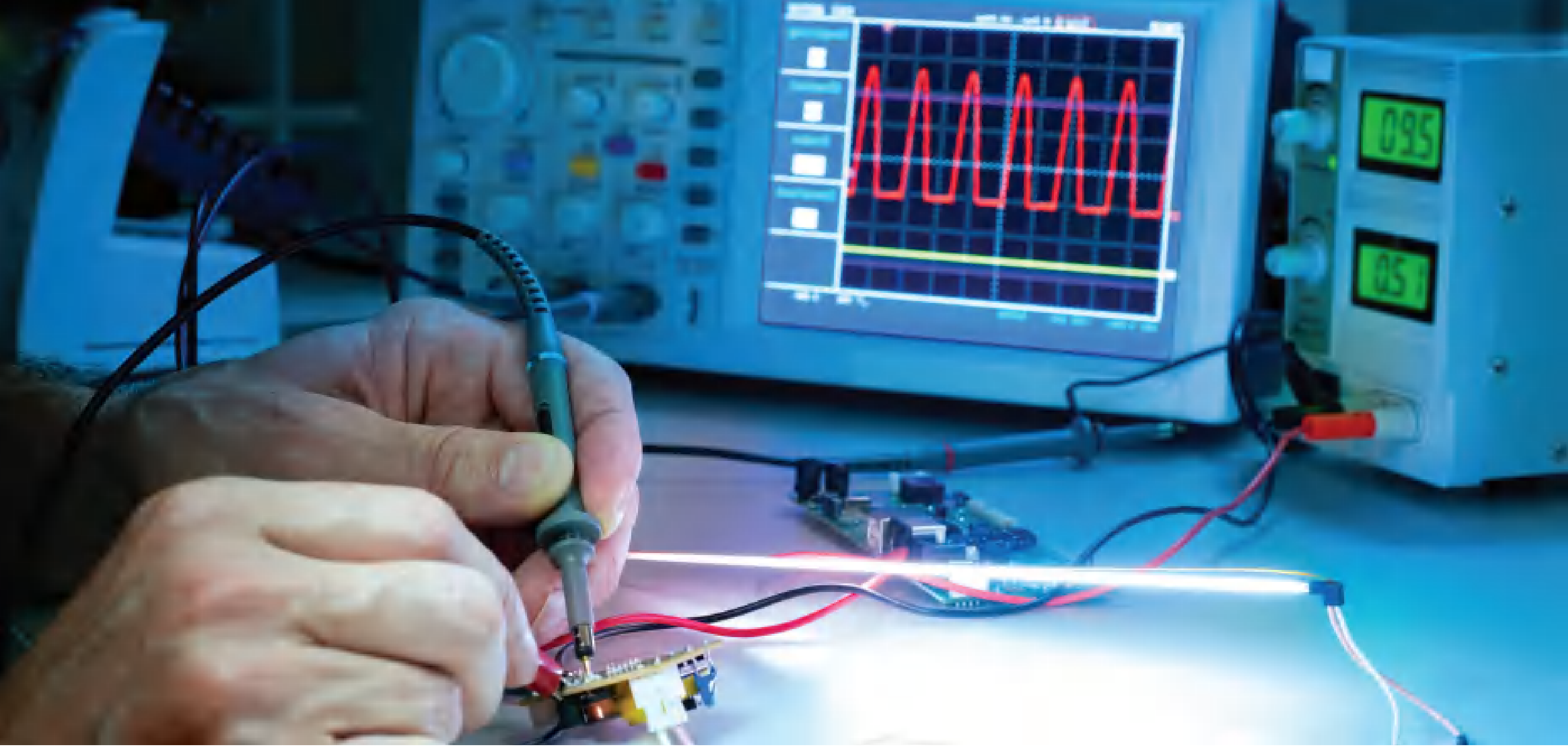
TI op-amps have been engineered and optimized to provide developers with the broadest selection of products and applications to satisfy numerous product development needs. Table 1 lists some of these op-amps and provides links to products that include some of the following features.

- High precision amplifiers include a broad range of innovative products and designs that improve DC accuracy, achieve low distortion, reduce system power, or enable wide bandwidths by processing and faster signal acquisition for use in precision applications such as wireless sensing nodes, instrumentation, home and factory automation equipment, and portable electronics.
- High voltage amplifiers provide a wide common mode range, high sensing capabilities and great supply compatibility for use in industrial, automotive, and communications systems, including hybrid electric or electric vehicles (HEV/EV), infotainment, factory automation, medical, motor drive, appliances, test and measurement, power delivery, and wireless and telecommunications infrastructure.
- Low power consumption amplifiers enable light, portable systems with low-capacity batteries and long lifetimes, enabling the use of small batteries to reduce the size and cost of building and factory automation equipment, test and measurement devices, personal electronics, and automotive systems.
- Small size amplifiers enable compact designs with some of the world's tiniest amplifiers while maintaining high performance in space-constrained systems such as personal electronics, factory automation, test and measurement devices, grid infrastructure, telecommunications, and small form factor industrial applications.

TI offers best-in-class operational amplifiers (op-amps) for a wide variety of applications, including precision, high-speed, ultra-low-power, audio, fully-differential, power, or general-purpose op-amps. Furthermore, TI provides an on-line product selector, a competitor product cross-reference guide, technical support, plus numerous reference designs, software, and technical documents. These resources are provided to boost product development by helping electronic design engineers quickly navigate through the wide variety of op-amps that TI offers and select ideal components that will get their products to market faster and more efficiently.

Table 1: Texas Instruments amplifier products

INA828	INA828 Precision Instrumentation Amplifiers
LPV802	LPV801 and LPV802 Nanopower Operational Amplifiers
OPA1622	OPA1622 SoundPlus™ Audio Operational Amplifier
OPA837	OPA837 Voltage-Feedback Operational Amplifiers
TAS6424	TAS6424-Q1 Class-D Audio Amplifier
TLV1702	TLV170x/TLV170x-Q1 microPower Comparators
TLV3691	0.9V to 6.5V, Nanopower Comparator
TLV7011	Small-Size, Micro-Power, Low-Voltage Comparators
TLV9061	TLV906x Low Voltage Operational Amplifiers
TPA3136D2	TPA3136D2 Class-D Audio Amplifier

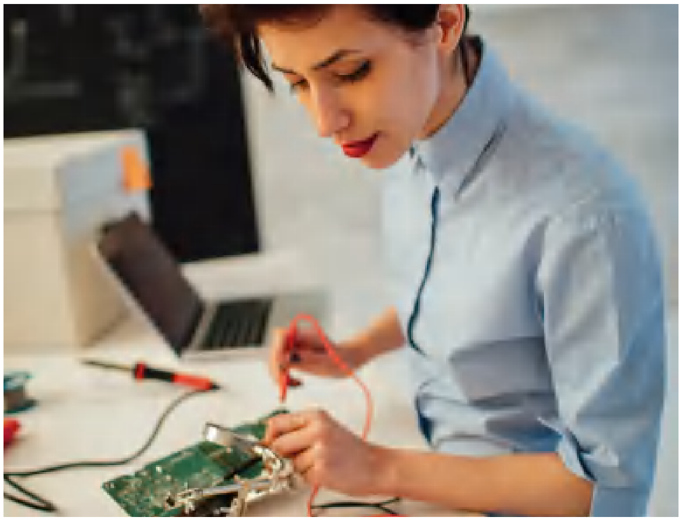


How to Make Precision Measurements on a Nanopower Budget

By Texas Instruments

Heightened accuracy and speed in an operational amplifier (op-amp) has a direct relationship with the magnitude of its power consumption. Decreasing the current consumption decreases the gain bandwidth; conversely, decreasing the offset voltage increases the current consumption.

Many such interactions between op-amp electrical characteristics influence one another. With the increasing need for low power consumption in applications like wireless sensing nodes, the Internet of Things (IoT) and building automation, understanding these trade-offs has become vital to ensure optimal end-equipment performance with the lowest possible power consumption. Learn more about the power-to-performance trade-offs of DC gain in precision nanopower op amps. Learn more



MUX-Friendly Precision Operational Amplifiers

By Tamara Alani, Richard Barthel, Texas Instruments

Multiplexing is a frequently used technique to perform data acquisition in multi-channel systems with minimal signal-chain requirements. In this context, the role of the multiplexer (MUX) in an acquisition system is to switch between channels and send each signal as fast as possible to a single data converter—maximizing system throughput and minimizing delay. To ensure accurate processing, a precision amplifier is placed downstream from the multiplexer to precisely drive the analog-to-digital converter (ADC).

Traditional Amplifier Architecture

Traditional CMOS-input amplifier architectures consist of a differential transistor pair with the metal-oxide semiconductor field-effect transistor (MOSFET) sources connected together and then taken to ground via an active current source, shown in **Figure 1**. Modern transistor manufacturing techniques attempt to maximize MOSFET transconductance (gm) by reducing oxide thickness (tox)—however, this trade-off results in breakdown voltages of approximately 5V from the gate to source. Large gate to source voltages typically stem from large input differential signals, which are commonly seen during slewing or open-loop operation. To protect the input from permanent damage, amplifiers have two robust anti-parallel diodes between the inputs of the amplifier with a clamp voltage of typically, ±0.5V to ±1.5V. This will limit the voltage swing across the inputs to one or two forward diode voltage drops, which is well below the breakdown voltage. While these inputs provide a level of protection, they do have considerable drawbacks.

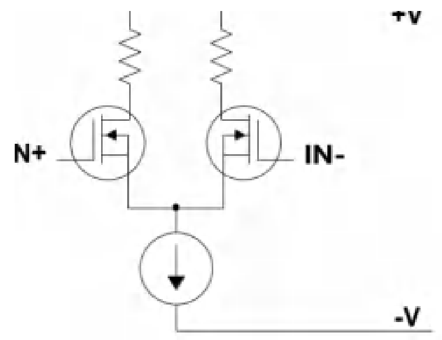


Figure 1: Transistor Differential Input Pair

Large Differential Inputs with Traditional Op-Amps

Figure 2 shows a MUX with two channels: Channel A and Channel B. When the output of the MUX is connected to Channel A, 10V is present at the non- inverting input of the op-amp. Since the amplifier is operating linearly, the potential across the inputs is 0V (neglecting offset voltage). As soon as the MUX switches from channel A to channel B, the noninverting input potential of the op-amp instantly changes to –10V. Since the op-amp output voltage does not change instantly, a large differential voltage appears at the inputs and the anti-parallel diodes begin to conduct current, causing a sharp increase in input bias current and drop in input impedance. Without the input anti-parallel diodes described earlier, this large differential voltage would have surpassed the breakdown voltage and thus permanently damaged the op-amp. With the input anti-parallel diodes, outlined in blue in **Figure 2**, the inputs are protected from large differential voltages—however, large inrush current flows through the diodes. If passive filtering or high source impedance is present, large inrush current can disturb settling time, limiting the throughput of the system and degrading signal chain precision.

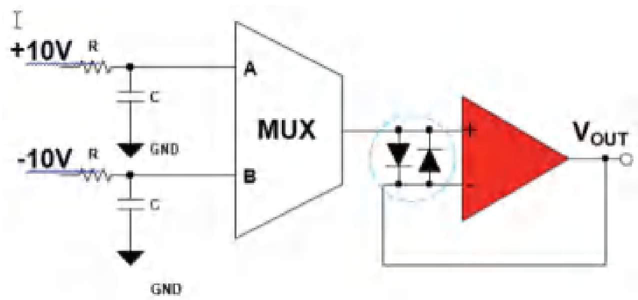


Figure 2: MUX with Buffer-Configured Op-Amp

The time the op-amp takes to settle its output can be detrimental to high-speed or high-throughput applications. Most MUXs operate with nanosecond rise-times, far faster than most precision op-amps. If the slew rate of the op-amp cannot keep up with the slew rate of the MUX, a differential voltage develops and settling time worsens due to input current. When the MUX switches between channels, it will take an extended length of time for the output to respond to the input and the system performance may suffer.

Some amplifiers attempt to solve this problem with high slew rate, but trade-off power consumption and stability. TI's Precision Amplifier team has developed a unique patented technology, which combines high slew rate with a diode-less front-end to achieve accurate signal processing without the tradeoffs of high-slew rate amplifiers. Its performance following a switched MUX is shown in Figure 3. Take note of the source-loading effects of a non-MUX-friendly amplifier (black) and a MUX-friendly amplifier (red). The top half of Figure 3 illustrates the inrush of current, which can reach several tens or hundreds of milliamperes depending on the amplifier's output current limit. The bottom half of **Figure 3** illustrates the effects of settling time while slewing. Although the traditional amplifier output moves quickly due to the input diodes, the RC- network settling is disturbed and the system takes longer to settle.

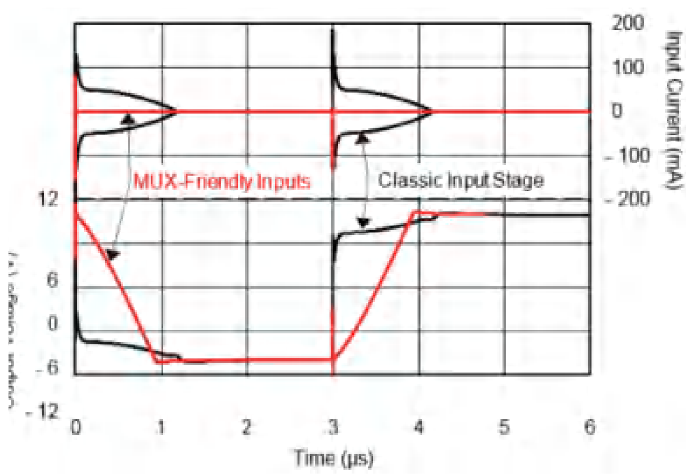


Figure 3: Switching Timing Diagram

MUX-Friendly Op-Amps

Along with junction gate field-effect transistor (JFET) input amplifiers, which are inherently MUX-friendly, TI has developed a new input circuitry for 36-V Complementary metal–oxide–semiconductor (CMOS) inputs, which does not require the anti- parallel diodes for device protection. These MUX-friendly amplifiers are still able to maintain the same level of protection and robustness while also improving settling time for switched systems. This patented input protection scheme uses a set of internal switches, which switch open and close to protect the input of the op-amp when large voltage steps are applied. This protection scheme has the added benefit of no inrush current. **Figure 4** shows this new MUX-friendly protection scheme in its quiescent state. Notice that both switches are closed and the diodes are inactive.

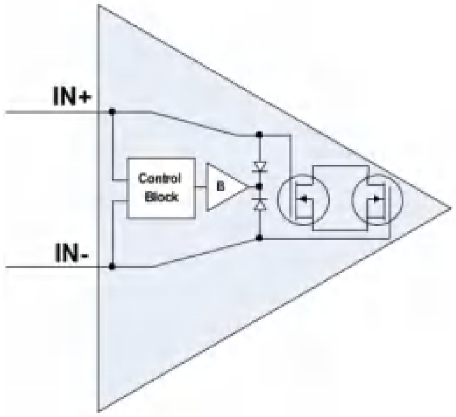


Figure 4: MUX-Friendly Scheme

When the positive input goes low (10V to –10V), the control block opens the switch at the inverting terminal (IN-) and activates one of the diodes, illustrated in **Figure 5**. When the positive input goes high (–10V to 10V), the control block opens the switch at the non-inverting terminal (IN+) and activates the other diode.

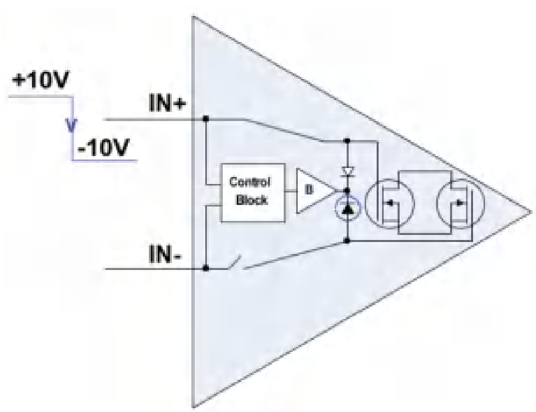


Figure 5: High to Low Input Step

The internal buffer op-amp, labeled "B", isolates the diode current from the input signal. This prevents current from flowing through the input pins of the op-amp. This new MUX-friendly architecture prevents any additional settling time—this means systems can quickly switch between MUX channels without compromising precision.

Additional Resources

Table 1: TI MUX-Friendly Amplifiers

Device	Optimized Parameters
OPA191	CMOS input 25µV offset max, 0.8µV/°C drift max, 2.5MHz, 200µA supply current max
OPA192	CMOS input 25µV offset max, 0.5µV/°C drift max, 10MHz, 1.2mA supply current max
OPA189	CMOS input 2.5µV offset max, 0.02µV/°C drift typ, 14MHz, 1.7mA supply current max
OPA145	JFET input 150µV offset max, 1µV/°C drift typ, 5.5MHz, 475µA supply current max
OPA827	JFET input 150µV offset max, 2µV/°C drift typ, 22MHz, 5.2mA supply current max