Technical Article

Sensor Module Power Efficiency Innovations of Today Drive the Future of System Evolution

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Industrial, Internet of Things (IoT), home medical wearable, fitness, and health monitors are experiencing explosive growth as systems become more data centric. These data-centric systems have an ever-increasing demand for more functionality and lower power consumption. The trend is driven by intelligent systems that actively monitor a person or an environment to predictively respond with alerts, actions, or recommended operations. The response is only as good as the data provided, which is why these systems require volumes of highly accurate data collected through a single sensor or network of wireless sensors.

The challenge for engineers designing sensor applications is the need for a sensor module with minimal footprint while maintaining a high level of accuracy and extending battery life. To do this, there are two schools of thought: maximize the power efficiency of components and system operation or invest in a new lower power architecture. The first approach promises to help designers achieve their goals in the short term by developing systems that operate longer on a battery charge, making them more responsive and accurate.

Maximizing Power Efficiency

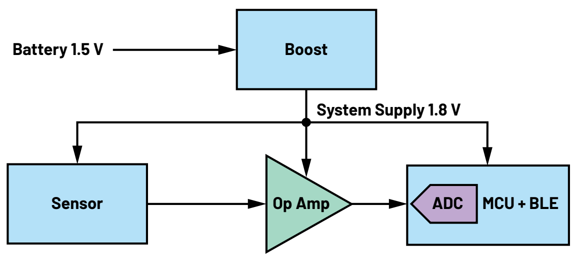

Figure 1. The current generation of AI systems uses a design depicted in the sensor block diagram.

Figure 1 shows a typical block diagram of a sensor application. The four basic blocks of the solution are the system power, sensor, sensor signal amplification, and signal processing. Selecting the right devices is critical to maximizing the battery life of the sensor module. Let us take a closer look at each of the blocks and see what can be done to improve power efficiency and provide a more precise measurement.

Sensor Selection

The first consideration is the sensor. There are two main types of sensors used in today's sensor modules: single-ended and differential sensors. Single-ended sensors include electrochemical sensors for blood glucose, gas sensing, and wearable medical sensors. A differential sensor typically utilizes an instrument amplifier in applications such as industrial pressure or force applications, industrial temperature applications, and air-inline and occlusion sensors in medical applications. These are common in medical insulin pumps and air-inline detectors.

The more common type of sensors are the electrochemical sensors. These are low power sensors that include blood glucose sensors that millions of diabetics use to control their blood glucose levels. Other applications include gas sensors such as carbon dioxide (CO_2) sensors, water quality (conductivity, pH, etc.) sensors, alcohol sensors for motor oil degradation, and sensors to detect explosives.

Most of the applications for electrochemical sensors are portable and battery-powered. While a home CO_2 sensor is normally good for five to seven years, it is likely to need a new battery about every six months to a year. To extend battery life, manufacturers use the latest low power devices, which draw minimal current from the battery.

Next, let us take a closer look at a specific type of electrochemical sensor—an ethanol sensor—and learn how it operates.

Ethanol Sensor Operation

The ethanol sensor used in Figure 1 is an amperometric gas sensor, which generates a current proportional to the volumetric fraction of a gas. It is a three-electrode device where the ethanol is measured at the working (or sensing) electrode (WE). The counter electrode (CE) completes the circuit, while the reference electrode (RE) provides a stable electrochemical potential in the electrolyte, which is not exposed to the ethanol. In the case of the SPEC sensor, a 600 mV bias voltage is applied to the RE.

Since many electrochemical sensors require a fixed bias to operate correctly, they place an extra burden on battery life. Now let us consider the power requirements for the system.

Power Requirements

The power budget of the system and its battery capacity ultimately determine the operating life of the sensor. The typical goal for a battery-powered solution that requires a small footprint is to use a single 1.5 V cell battery. Using a single-cell battery reduces capacity, impacting the sensor operating life. So, what can be done to optimize the operating life span of the single cell?

When fully charged, at the beginning of its life, a single cell is at 1.5 V. This voltage drops progressively over time until it reaches its end of life at 0.9 V. To maximize the lifespan of a single-cell battery, the application must operate between 0.9 V to 1.5 V to get the longest application operation time. Because other system components operate at 1.8 V, it is important to select a DC-to-DC boost converter that maximizes the active and standby current efficiency and operates within the 0.9 V to 1.5 V operating range.

Having a high efficiency of 95% is not the only consideration for efficient power conversion. Boost regulators must also be efficient across a wide current range. This enables a lower quiescent current (IQ) and reduces heat dissipation during operation. As the application spends most of its time in standby mode, it is critical that the boost converter is efficient during the light-load standby state to extend battery life. A shutdown feature can also greatly reduce power consumption by turning off portions of the circuit, which brings down the current consumption to the single nanoamp range.

Signal Chain Solution

Sensors typically produce a weak output signal in the order of microvolts whereas analog-to-digital converters require a signal in the order of volts. This makes the selection of a low power, high precision amplifier the next important consideration in the design.

Two important aspects of low power amplifiers are current consumption and operating voltage since many sensors require bias current to maintain accuracy. This requires the sensor portion of the application to be on to maintain an accurate reading. Also, a low operating voltage from 0.9 V to 1.5 V enables single-cell battery operation, eliminating the need for a boost converter.

Typically, there are trade-offs when selecting low power amplifiers, which result in reduced accuracy. But there are low power amplifiers that can maintain a high level of accuracy even at low operating currents and voltage. Some features of precision amplifiers include sub-microvolt (µV) input offset voltage, voltage drifts in the order of nV/°C, and input bias currents in the picoamp range.

Combining a low power microcontroller with an integrated ADC creates a low power sensor solution that maximizes battery life while maintaining a small application footprint.

Ethanol Sensor Solution Measurements

Beyond improvements at the device level, system architecture can also be optimized to achieve lower power consumption with the same level of precision measurement. To prove this, we will provide two lab measurements of an ethanol sensor solution using similar devices and one theoretical measurement for a future sensor solution that shows the power savings.

This experiment uses the following devices, which have identical duty cycles for ethanol electrochemical sensor measurements.

- SPEC electrochemical ethanol sensor
- MAX40108 1 V precision operational amplifier/1.8 V operational amplifier
- MAX17220 0.4 V to 5.5 V nanopower synchronous boost converter with True Shutdown™
- MAX32660 1.8 V ultra low power Arm® Cortex®-M4 processor
- Single 1.5 V AA battery

Legacy 1.8 V System

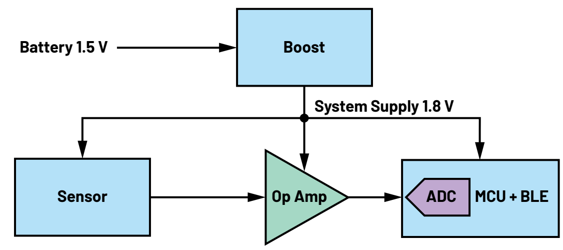

Figure 2. A 1.8 V legacy sensor system solution.

The 1.8 V system solution is powered using a single-cell battery, which uses an efficient boost converter to provide a 1.8 V system supply to the ethanol sensor, op amp, and microprocessor with an ADC. The 0.1% active-duty cycle is controlled by the microcontroller, which wakes up to take a measurement and then goes back into sleep mode.

The sensor in standby mode utilizes the boost converter to maintain power to the sensor, op amp, and microcontroller in sleep mode. In the standby state, the system consumes 150.8 µA of current. During the active state, the microcontroller wakes up and takes a sensor measurement. In the active state, the system consumes 14 mA for a short duration. Because the active state only occurs 0.1% of the time, the calculated average current of the combined active and standby modes is 164 µA, which is typical of a real-world sensor application.

1 V Amplifier System

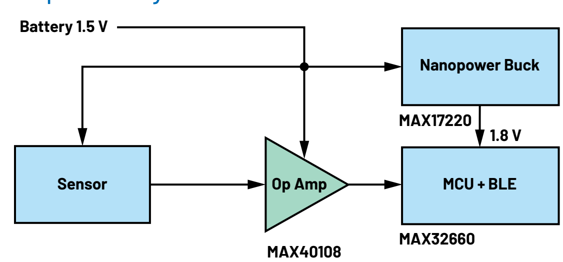

Figure 3. A next-generation 1 V amplifier sensor solution.

In the 1 V amplifier solution, both the SPEC ethanol sensor and the MAX40108 1 V operational amplifier are directly connected to the battery. This requires an amplifier that can operate down to 0.9 V, maintain a high level of precision, and maximize the battery life of the single-cell battery.

The remaining circuit is similar with a boost regulator that powers the microcontroller and supports circuitry at 1.8 V. In this configuration, the current is substantially reduced to 81.9 µA, a reduction of 45%, and an average current down to 95.7 µA, which is a reduction of 41.79%. As a result, the battery life of the system using the MAX40108 1 V operational amplifier is almost double that of the legacy system.

Future 1 V Signal Chain System

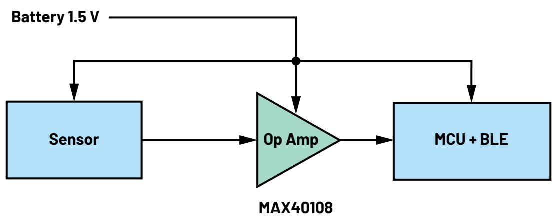

Figure 4. A futuristic 1 V sensor system solution.

In this futuristic 1 V signal chain solution, the amplifier, ADC, and microcontroller all operate down to 0.9 V while maintaining a high level of precision. This enables the entire signal chain solution to be powered from a single-cell battery, which removes the need for a boost converter, therefore maximizing the battery life of the sensor solution.

Conclusion

As the demand for more intelligent AI systems grows, so does the need for sensors with additional functionality, a higher degree of accuracy, and longer operating life. The sensors must offer a small solution size that can be either worn by a person or networked together to determine the health of a person, production floor, building, or city to enable systems to be proactive as opposed to reactive. Taking this one step further, proactivity leads to better health, lower costs, higher productivity, and greater safety for those who benefit from adopting these next-generation systems.

Innovation is occurring at many different levels in the network of sensors that enable AI systems. IC manufacturers in particular are developing lower power sensor building blocks that help engineers of today to create more intelligent and more efficient systems of tomorrow.

About the Author

Tom Bui is a marketing manager of automotive at Analog Devices, where he's responsible for managing and developing Gigabit Multimedia Serial Link™ (GMSL) ADAS products within the Automotive Business Unit. With more than 13 years at ADI, he has held positions as a marketing manager, applications engineer, business manager, and product manager.

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