DWYEROMEGA™

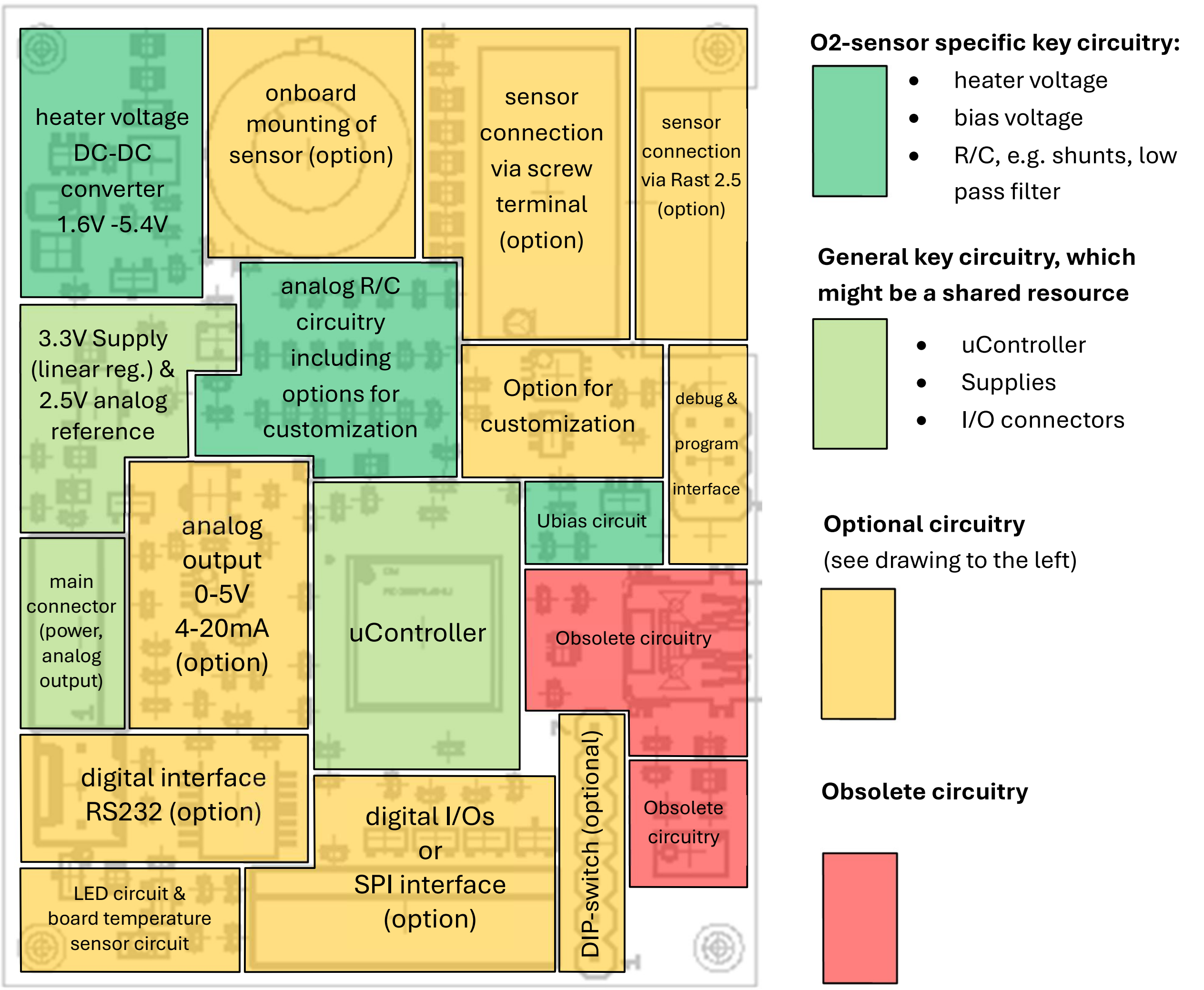
O2-sensor electronic circuit design

AN009e-0 (07/2026)

Scope

This application note complements **AN001 (Basic Sensor Operation)** and **AN003 (Heater Operation Modes)** by presenting a practical implementation example based on SENSORE's Generic Sensor Board (GSB). It illustrates the implementation of the sensor bias, signal measurement, and heater-control circuits and serves as a reference for customers integrating the sensor circuitry into their own hardware designs.

1 GSB-Layout (65mm x 50mm) to estimate footprint requirements



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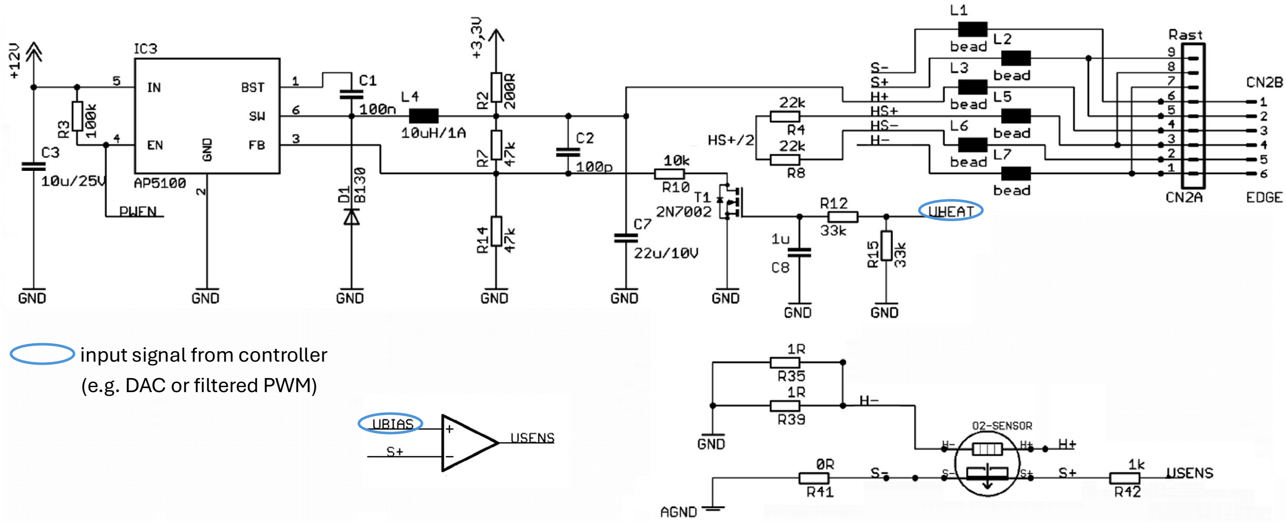
2 O2 sensor circuit similar to the implementation on the GSB



2.1 Sensor heater supply circuit:

The sensor heater is powered by a dedicated supply circuit designed to provide stable and adjustable heater voltage while protecting the sensor during startup and operation. The sensor heater is controlled using a **4-wire (Kelvin) connection**, which enables accurate regulation of the heater voltage and resistance independent of cable, connector, and PCB trace resistances.

- **H+** and **H−** are the **force terminals**, supplying current to the heater element.
- **HS+** and **HS−** are the **sense terminals**, used exclusively for voltage measurement and feedback control.

2.1.1 Heater Supply Architecture

- A DC/DC converter (AP5100, Diodes Inc.) generates the heater supply voltage.
- A closed-loop control system regulates the heater voltage at the HS+ terminal.
- The controller continuously measures the actual heater voltage or heater resistance and adjusts the supply accordingly.

2.1.2 Feedback Signals (heater voltage or heater resistance)

- Heater voltage measurement
  - The actual heater voltage is measured between the sense terminals **HS-** and **HS+**.
  - Due to the limited ADC input range, the GSB measures the voltage between **HS−** and **HS+/2** and then multiplies the result by two to determine the actual heater voltage.
- Heater resistance measurement
  - The heater current I_{Heat} is measured via the 0.5 Ω shunt resistor between **H−** and **GND**. The heater resistance is then calculated using Ohm's law: $R_{Heat} = \frac{U_{HS} - U_{HS-}}{I_{Heat}}$
  - Maintaining a constant heater resistance provides a reliable method of regulating the sensor's operating temperature.

2.1.3 Control Actuator

The actuator signal of the control-loop is UHEAT (blue circle in the schematic).

- The signal **UHEAT** controls transistor T1, which operates as an adjustable resistor.
- Ideally, **UHEAT** should cover a range of approximately 0.2 V to 3.0 V, for example by using a filtered PWM signal.
- Due to the non-linear transfer characteristics of the FET, most of the effective resistance adjustment occurs within a relatively small portion of the available control-voltage range.

If improved control performance is required, the FET-based approach may be replaced by:

- a programmable resistor or digital potentiometer solution, or
- a more advanced architecture that directly controls the DC/DC converter through a dedicated feedback path.

2.1.4 Operating Range

- Adjustable heater voltage range: 1.6 V to 5.4 V
  - Defined by resistor values R7, R10, and R14
- Typical stabilized heater voltage: 3.4 V to 4.2 V
  - Typical stabilized heater current: approximately 400 mA

2.1.5 Inrush Current Protection

To avoid excessive current during sensor warm-up, inrush current protection should be implemented. Recommended approaches are:

1. Voltage ramp
   - Gradually increase the heater voltage from 1.6 V to approximately 3.8 V (about 30 seconds).
2. Current limiting
   - Limit the heater current to a maximum value of 500 mA during startup.

Both methods effectively reduce thermal stress on the heater and improve long-term sensor reliability.

2.2 Sensor Bias Voltage and Sensor Measurement Circuit

The sensor measurement circuit provides a stable bias voltage for the electrochemical sensor while simultaneously measuring the sensor current.

2.2.1 Sensor Current Measurement

- The sensor current flows through **R42**, a 1 kΩ shunt resistor.
- The resulting voltage signal, **USENS**, is proportional to the sensor current and serves as the primary measurement signal.
- The sensor current is derived from the voltage drop across R42, i.e. the differential voltage between **USENS** and **S+** (**UBIAS**). Sensor current $I_{sens} = \frac{USENS - UBIA}{1k\Omega}$

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2.2.2 Bias Voltage Control

- A closed-loop control circuit maintains a stable sensor bias voltage.
- The actual bias voltage can be measured between **S+** and **GND** and is used as the feedback signal for the control loop.
- The desired bias voltage is defined by the input signal **UBIAS**, which may be generated by a DAC or by a filtered PWM output.

2.2.3 Implementation Note

The control-loop can be implemented using an analog feedback circuit (e.g., an operational amplifier). However, the GSB employs a **digital closed-loop control approach**, in which the bias voltage is measured by the microcontroller and actively regulated via software.
This digital implementation provides greater flexibility for parameter adjustment, calibration, diagnostics, and control-loop optimization while maintaining the required bias-voltage stability for accurate sensor operation.

3 Remarks regarding accuracy, linearity and signal noise

3.1 Accuracy requirements for heater control and bias voltage

The heater control and sensor bias voltage together establish the sensor's operating point. In general, the stability of these setpoints is more important than their absolute accuracy. However, the requirements for heater control and bias voltage differ and should therefore be considered separately.

- **Heater control:** Quasi-static deviations of the heater-control setpoint directly affect the sensor temperature and can therefore influence sensor sensitivity and measurement accuracy. In addition, short-term variations of the heater voltage or temperature around the setpoint may introduce noise or ringing into the sensor signal. Consequently, both the long-term stability and the short-term stability of the heater control are important.
- **Bias voltage:** Quasi-static deviations of the bias-voltage setpoint generally have little or no direct effect on sensor accuracy, provided that the bias voltage remains within the specified operating range. However, variations, noise, or drift of the bias voltage can couple into the sensor signal and cause additional measurement noise or signal ringing. Therefore, voltage stability and low noise are typically more important than absolute bias-voltage accuracy.

As a general guideline, the heater-control circuit should provide both an accurate and stable operating point, whereas the bias-voltage circuit should primarily provide a stable, low-noise output. Long-term drift, ripple, and control-loop instability of either circuit can adversely affect sensor performance and should therefore be minimized.

3.2 Noise or ringing on the sensor signal

The sensor-chip temperature has a small influence on the O_2 sensor current, with the effect being most pronounced at full-scale readings. To minimize external thermal influences, the sensor temperature is actively controlled by regulating the heater resistance to a constant value, thereby maintaining a stable sensor-chip temperature.

However, the heater control-loop itself can introduce a small amount of noise or ringing into the sensor signal. The amplitude of these disturbances can be reduced by improving the stability of the heater supply voltage and optimizing the control-loop dynamics. Any residual noise or ringing can subsequently be mitigated through signal averaging or digital filtering.

As a result, under normal operating conditions, heater-induced signal disturbances can be reduced to a level where they have only a negligible impact on measurement accuracy.

3.3 Impact of the ADC accuracy

The analog-to-digital conversion in the GSB is performed by the ADC integrated in the microcontroller (ATXMEGA32-A4U, 11–12-bit ADC). The specified accuracy and linearity of this ADC are generally better than the typical accuracy, linearity, and measurement uncertainty of the O_2 sensor itself. Consequently, the integrated ADC does not represent a limiting factor in overall system performance and is therefore considered fully adequate for sensor operation.

As a result, the measurement accuracy of the GSB is primarily determined by the characteristics of the O_2 sensor rather than by the performance of the ADC.

3.4 When is a higher-performance ADC beneficial?

Measurements at or below the sensor’s lower detection limit may benefit from a higher-performance ADC, but only under ideal conditions (e.g., very clean O_2/N_2 mixtures):

- At very low sensor currents, ADC offset error can become a dominant source of measurement uncertainty. In such cases, ADC zero-offset calibration can significantly improve overall accuracy. In addition, oversampling or the use of ADCs with resolutions greater than 12 bits can enhance measurement resolution at low signal levels.
- For O_2/N_2 mixtures containing impurities (such as traces of combustible gases, CO_2, H_2O, etc.), using a higher-performance ADC provides little or no benefit at very low sensor currents. Under these conditions, the sensor’s inherent cross-sensitivities become the dominant source of error and ultimately limit measurement accuracy, regardless of ADC performance.

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