

Circuits from the Lab[®]
Reference Designs

Circuits from the Lab[®] reference designs are engineered and tested for quick and easy system integration to help solve today's analog, mixed-signal, and RF design challenges. For more information and/or support, visit www.analog.com/CN0588.

Devices Connected/Referenced

ADXL1002	Low Noise, High Frequency MEMS Accelerometers
ADR5043/ ADR5045	Precision, Micropower Shunt Mode Voltage References
LT6015	3.2 MHz, 0.8 V/μs Low Power, Over-The-Top Precision Op Amps

DC to 10 kHz MEMS-Based IEPE Vibration Sensor

EVALUATION AND DESIGN SUPPORT

- ▶ Circuit Evaluation Boards
 - ▶ [CN0588 Circuit Evaluation Board \(EVAL-CN0588-EBZ\)](#)
- ▶ Design and Integration Files
 - ▶ [Schematics, Layout Files, Bill of Materials](#)

CIRCUIT FUNCTIONS AND BENEFITS

Condition-based monitoring (CbM) enables early detection and diagnosis of machine and system abnormalities. CbM typically uses data from vibration, current, and temperature which provide key insights into the health of equipment ranging from motors and pumps to bearings and encoders. These machine health insights result in increased productivity, improved efficiency, and maximized uptime. Ultimately, by tracking the vibration analysis data over time, a fault or failure can be predicted, along with the source of the fault.

Vibration detection is the most popular method used in machine condition-based monitoring. This is done by collecting large data-

sets, which are used to identify a baseline operating point for the equipment in both normal operating modes and failure scenarios in order to provide an accurate understanding of machinery that requires monitoring. Once this information has been gathered, an algorithm or threshold detection procedure can be developed to monitor and analyze the equipment.

The integrated electronics piezoelectric (IEPE) standard is a prominent signaling interface standard for today's high-end piezoelectric and microelectronic mechanical systems (MEMS) vibration sensors.

The reference design shown in [Figure 1](#) is a MEMS-based IEPE vibration sensor optimized for condition-based monitoring applications. The solution has a current supply of 4 mA and an excitation voltage of 24 V to 28 V. This vibration sensor also features a DC voltage bias ranging from 8.75 V to 14.75 V, and a sensitivity of 60 mV/g.

The board comes with a carefully designed mechanical enclosure, which houses the integrated sensor and ensures that high quality vibration data is extracted from the monitored asset.

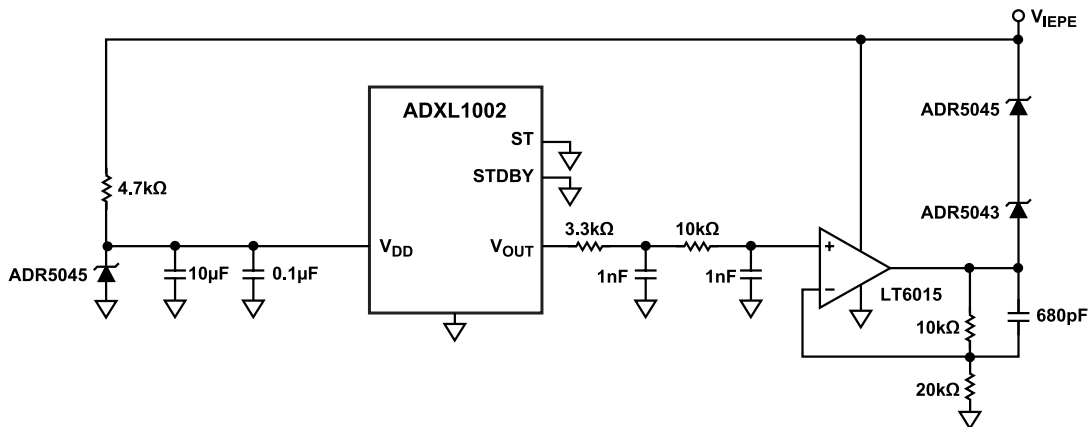


Figure 1. CN0588 Simplified Block Diagram

CIRCUIT DESCRIPTION

The circuit shown in [Figure 1](#) demonstrates a MEMS vibration sensing solution with included IEPE compatible interface circuitry at 8.75 V to 14.75 V bias and 4 mA current consumption.

VIBRATION SENSOR TYPES PIEZO VS. MEMS

Piezoelectric (piezo) and microelectromechanical systems or MEMS are two different types of sensor technologies commonly used for various applications, including measuring physical parameters such as acceleration, pressure, and temperature. The choice between these technologies can impact the way the sensor responds to different input signals, including AC and DC signals, and how it affects the input bandwidth.

Traditionally, piezoelectric sensors have been the benchmark for vibration monitoring and are still the sensor of choice in the highest sensitivity applications, or where very high accelerations are involved. MEMS sensors were previously deemed unusable due to their limited bandwidth, g-range, and noise performance across frequency. However, recent advancements in MEMS sensor technology (especially with frequency response and noise performance) make MEMS sensors a viable alternative in many CbM applications.

Piezoelectric sensors may offer better noise performance than MEMS at higher frequencies, but at low frequencies MEMS sensors offer lower noise all the way to DC. Being able to measure these low frequencies is very useful for wind turbines, and other types of slow rotating machinery used in metal processing, pulp/paper processing, and food/beverage industries where slow rotating speeds of assets below 60 rpm (1 Hz) are common.

Overall, MEMS sensors are typically smaller, have a lower cost, lower power consumption, and now have a greater frequency response. [Table 1](#) shows the key differences between these two sensor types.

Table 1. Comparison of Piezoelectric and MEMS Sensors for CbM Applications

Key Considerations	Sensor Type	
	Piezoelectric	MEMS
Cost	\$25 to \$500+	\$10 to \$30+
Noise	<1 $\mu\text{g}/\sqrt{\text{Hz}}$ to 50 $\mu\text{g}/\sqrt{\text{Hz}}$	25 $\mu\text{g}/\sqrt{\text{Hz}}$ to 100 $\mu\text{g}/\sqrt{\text{Hz}}$
3 dB Bandwidth	2.5 kHz to 30 kHz+	3 kHz to 20 kHz+
Potential Battery Life	Short to medium	Medium to long
DC Response	No	Yes
Self-Test	No	Yes
Integrated Features	No	Yes

SENSOR

The core of the [CN0588](#) is the [ADXL1002](#) high frequency, single-axis MEMS accelerometer. The noise spectral density of the ADXL1002 is 25 $\mu\text{g}/\sqrt{\text{Hz}}$ and its 3 dB bandwidth is 11 kHz with sensor resonance frequency of 21 kHz. The noise and bandwidth is comparable with a piezoelectric sensor while the ADXL1002 provides superior performance in temperature sensitivity, DC to low frequency response, phase response (and thus, group delay), shock tolerance, and shock recovery. The sensor has a linear (within $\pm 0.1\%$ FSR) measurement range of ± 50 g, which is large enough to support the majority of CbM applications. The ADXL1002 also has an integrated full electrostatic self-test (ST) function and an overrange (OR) indicator that allow advanced system level features and are useful for embedded applications.

IEPE INTERFACE

The IEPE interface is a 2-wire protocol, signal and ground. An instrument, such as data logger, supplies power via the signal line to the vibration sensor as current with an arbitrary voltage, typically between 10 V to 30 V. Because the signal line is supplied by a current source, the sensor device can modulate the acceleration data on the voltage rail. Therefore, the single wire can be used for both the power supply and the modulated output voltage of the sensor.

[Figure 2](#) shows an example of the IEPE output with a bias voltage of approximately 11.75 V and a full-scale range swing of ± 3 V.

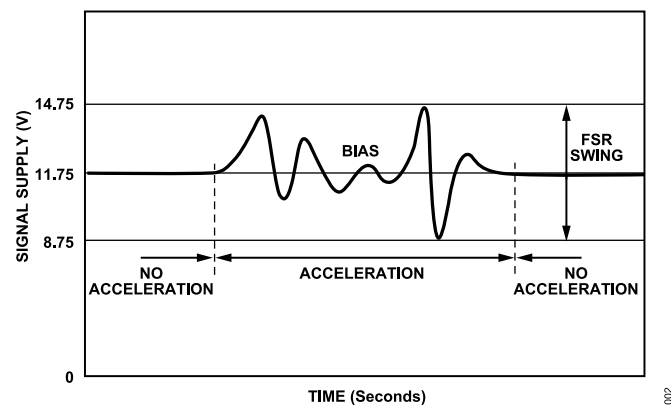


Figure 2. CN0588 IEPE Signal

SIGNAL CONDITIONING

The circuit shown in [Figure 1](#) must be supplied with a 4 mA constant current, which can be provided by an IEPE vibration measurement setup or a current source. [Figure 3](#) depicts the signal conditioning circuitry of the [CN0588](#). In this design, the [ADR5045](#) precision voltage reference acts as the voltage source to the ADXL1002 as it generates a stable V_{DD} to power the sensor. The [LT6015](#) op amp is configured to amplify the filtered output of the ADXL1002 ($2.5 \text{ V} \pm 2 \text{ V}$) by a factor of 1.5x. Then, the [ADR5045](#) and [ADR5043](#) are connected in series to introduce a DC offset of approximately 8 V. This configuration complies to the IEPE standard and operates within the voltage range of 8.75 V to 14.75 V. The V_{IEPE} also supplies the [LT6015](#) op amp in this signal

conditioning circuit. A 4.7 k Ω resistor is used to regulate the voltage from the IEPE signal to at least the minimum current to supply the ADXL1002.

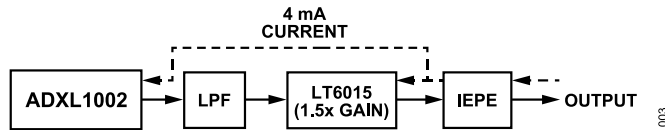


Figure 3. CN0588 Signal Conditioning Circuit

COMMON VARIATIONS

The CN0588 can accommodate different MEMS sensors for different applications. The design is based on the ADXL1002, with a sensor resonant frequency of 21 kHz. However, the same circuit can be used as an IEPE compatible interface for other MEMS accelerometer in the ADXL100x family. When using another sensor, make sure to select the low pass filter cutoff frequency based on the chosen sensor's resonant frequency.

CIRCUIT EVALUATION AND TEST

This section covers the setup and procedure for evaluating the CN0588. For complete details, visit the [EVAL-CN0588-EBZ User Guide](#)

EQUIPMENT NEEDED

- ▶ EVAL-CN0588-EBZ circuit evaluation board
- ▶ Current source (for example, Keithley 6220) or an IEPE-compatible DAQ such as the [EVAL-CN0582-USBZ](#), [EVAL-CN0540-ARDZ](#), or [EVAL-CN0579-ARDZ](#)
- ▶ Vibration shaker (for example, King Design 9363-ED-2F4K-5N)
- ▶ Signal generator
- ▶ SMA cable (10-32)
- ▶ BNC cable

GETTING STARTED

The basic steps for evaluating the functionality of the CN0588 follow:

1. Mount the EVAL-CN0588-EBZ to the vibration shaker.
2. Connect the SMA cable to the EVAL-CN0588-EBZ.
3. Connect the other end of the SMA cable to the current source.
4. Set the output constant current to 4 mA, and controlled voltage to 26 V.
5. Connect the BNC cable to the vibration shaker.
6. Connect the other end of the BNC cable to the signal generator (output).
7. Set the frequency settings to your requirement.
8. The voltage of the current source is the output. Without an external acceleration, the IEPE output should be around 12 V.

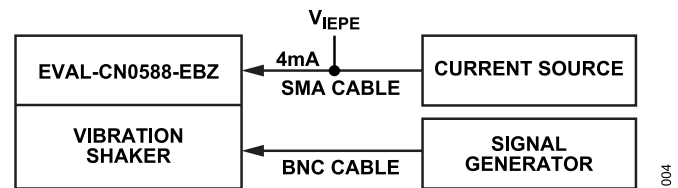


Figure 4. CN0588 Test Setup

TEST RESULTS

To verify the performance of the CN0588 for vibration measurement applications, the circuit was tested using a vibration shaker (King Design 9363-ED-2F4K-5N), a reference sensor (PCBM352C67), and an IEPE vibration measurement platform ([EVAL-CN0582-USBZ](#)). The circuit is characterized for its frequency response. To validate the mechanical design of the casing, power spectral density test was simulated. Details and results of each test follow.

Frequency Response Measurement

As shown in [Figure 5](#) the EVAL-CN0588-EBZ and the reference sensor are attached to the vibration shaker. The EVAL-CN0582-USBZ acts as the signal generator to control the vibration shaker from 100 Hz to 15 kHz, with step frequency of 100 Hz. The EVAL-CN0582-USBZ also serves as the current source for both the EVAL-CN0588-EBZ and the reference sensor. The output of the IEPE circuit and the reference sensor are recorded using the CN0582 evaluation software.

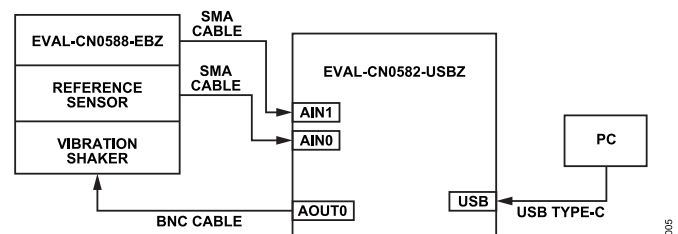


Figure 5. CN0588 Test Setup Using CN0582 as IEPE Vibration Measurement Platform

[Figure 6](#) shows the output of the frequency sweep of the sensor, where the resonant frequency measured is around 12.5 kHz. In this circuit evaluation and in any other high frequency vibration tests, mechanical signal path integrity is very important. There must be no attenuation (due to damping) nor amplification (due to resonance) of the vibration signal from the source to the sensor. The electrical and mechanical design of the CN0588 guarantees a flat mechanical response for the frequency range of interest, which is 10 kHz.

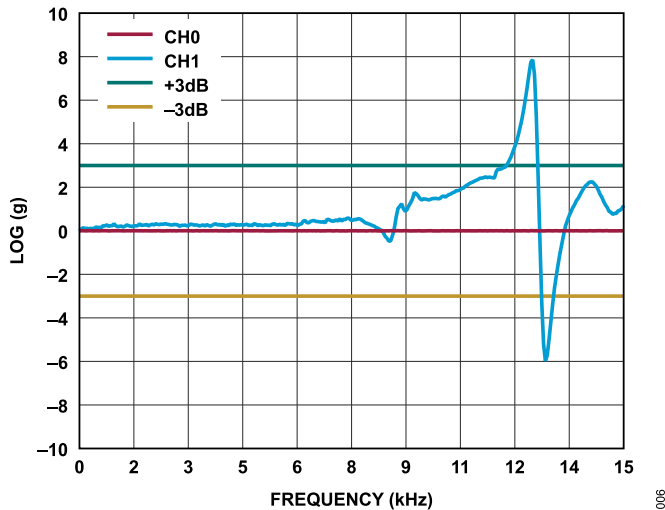


Figure 6. CN0588 Frequency Response

Mechanical Enclosure Stress Test

The mechanical design of the CN0588 was tested through a power spectral density simulation. The von Mises stress criterion is commonly used in mechanical engineering to evaluate the yield criterion of the materials under complex loading conditions. Figure 7 shows the simulation results. Boundary conditions used for the simulation are as follows:

- ▶ Simulation type: Random Vibration
 - ▶ External Load: Uniform Base Excitation
 - ▶ Type: Acceleration
 - ▶ Acceleration: 1 g²/Hz (Y-Direction)
- ▶ Damping ratio: 1%
- ▶ No. of Frequency: 20
 - ▶ Lower limit: 1000 Hz
 - ▶ Upper limit: 20000 Hz

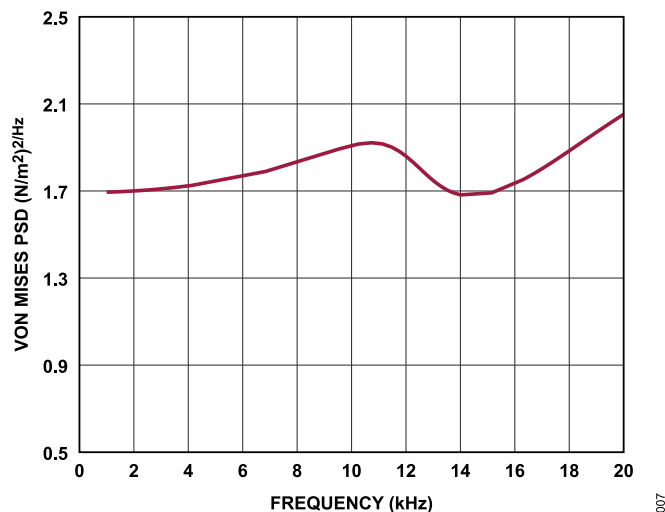


Figure 7. CN0588 Mechanical Design Stress Simulation

LEARN MORE

CN0588 Design Support Package

CN0532. *"IEPE-Compatible Interface for Wideband MEMS Accelerometer Sensors."* Analog Devices.

CN0582. *"USB 3.0 Quad-Channel IEPE Vibration Sensor Measurement System."* Analog Devices.

Anslow, Richard. *"How to Design a Good Vibration Sensor Enclosure Using Modal Analysis."* Analog Devices.

Murphy, Chris. *"Why MEMS Accelerometers Are Becoming the Designer's Best Choice for CbM Applications."* Analog Devices..

Murphy, Chris. *"Choosing the Most Suitable Predictive Maintenance Sensor."* Analog Devices.

DATA SHEETS AND EVALUATION BOARDS

[ADXL1002 Data Sheet](#)

[ADXL1002 Evaluation Board](#)

[ADR5043/ADR5045 Data Sheet](#)

[LT6015 Data Sheet](#)

REVISION HISTORY

04/2024—Revision 0: Initial Version



ESD Caution

ESD (electrostatic discharge) sensitive device. Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

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