LPV801 Micropower Ionization Smoke Detector

Paul Grohe

ABSTRACT

Ionization detectors, as used in smoke alarms, output a very low current that requires a buffer amplifier to interface to the alarm circuitry. This requires a buffer amplifier with low input bias current, and, since a smoke detector is a "always-on" device, the amplifier must also have a very low quiescent current to maximize the battery life. This application note demonstrates the use of the LPV801 nanopower operational amplifier as the buffer amplifier in a common ionization chamber application.

Contents

List of Figures

All trademarks are the property of their respective owners.

1   Introduction

Ionization smoke detectors were developed in the early 1950s, and with advancements in semiconductor technology, have been mass produced since the late 1960s.

Openly flaming combustion generates smaller smoke particles than non-flaming (smouldering) combustion. Ionization detectors respond much faster to the smaller smoke particles of flaming fires than photoelectric detectors. Photoelectric detectors respond faster to smouldering fires that generate larger smoke particles. It has been recommended that both ionization and photoelectric detectors be used for maximum response time.

Ionization detectors output a very low current that requires a very high input impedance buffer amplifier to interface to the alarm circuitry. This requires a buffer amplifier with very low input bias current, and, since a smoke detector is an "always-on" device, the amplifier must also have a very low quiescent current to maximize the battery life.

With a bias current typically less than 1pA at room temperatures, and a quiescent current typically less than 500nA, the LPV801 nanopower operational amplifier is ideal for this buffer amplifier application.

This Application Note will show the performance of the LPV801 when paired with a ionization chamber utilized by a major smoke alarm manufacturer. Other chambers will have similar functionality but may have different results.

2   Ionization Chamber Operational Theory

Figure 1 shows an example of a typical ionization chamber and a the buffer amplifer circuitry.
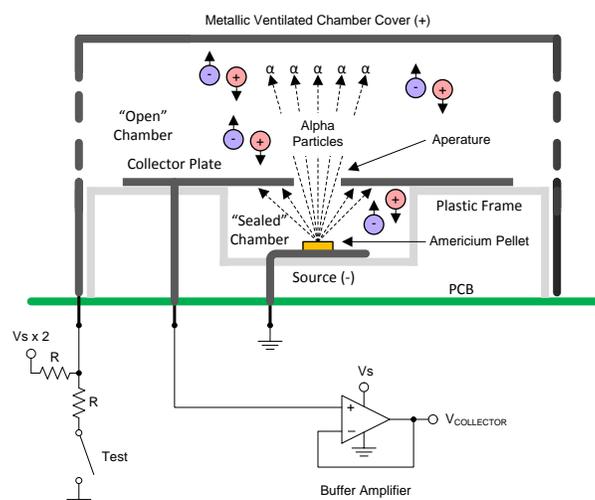
Figure 1. Typical Ionization Chamber

The chamber consists of three main parts; an open air chamber, a collector plate, and a low level ionizing radiation source.

The radiation source consists of less than 1 Microcurie of Americium 241 foil mounted in a "pellet" container. The Americium mainly emits low energy alpha particles, which are absorbed by a few centimeters of air or the plastic enclosure and pose little risk when handled properly. The Americium pellet is placed on the grounded (negative) pedestal.

The alpha particles collide with the air molecules and split them into positive and negative ions. Opposites attract, so the negative ions are attracted to positively charged chamber housing, and positive ions attracted to negative source. This flow creates a continuous current flow between plates.

When a fire starts, smoke particles enter the chamber and disturbs the current flow, causing a decrease in the current flow.

Humidity can also cause a change in the current, so to minimize this effect; the chamber is divided into two chambers by a perforated collector plate. One chamber is exposed to the open air, and one chamber is protected from direct airflow (but still exposed to ambient air and humidity). The collector plate now measures the difference between the two chambers.

To help accelerate the charges, which increases the effective sensitivity, the positive chamber cover is maintained at a higher voltage relative to the negative source.

Smoke causes imbalance between "open" and "sealed" chamber currents, and the collector plate detects this difference in chamber charges. Depending on the ratio of the chamber volumes, clean air output voltage on collector plate is between 1/2 to 5/8 the chamber voltage. The collector plate is connected to the LPV801 high impedance buffer amplifier which drives the alarm circuitry.

2.1 Typical Application Circuit

Figure 2 shows a typical application circuit.
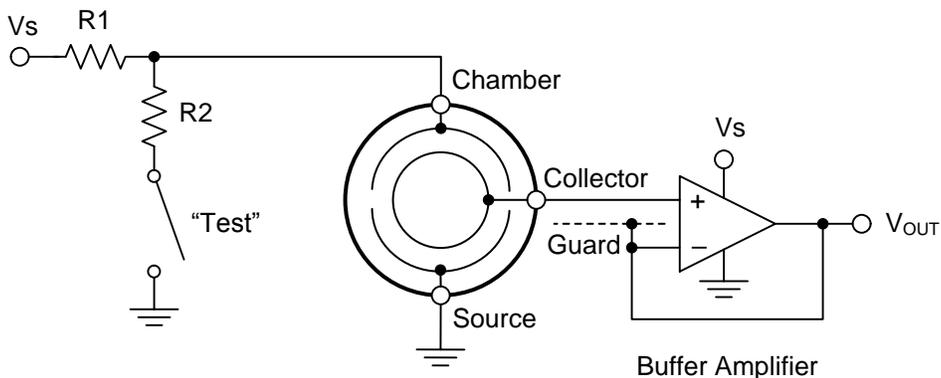
Figure 2. Simplified Schematic Diagram

The buffer input is connected directly chamber collector plate. This is a critical high-impedance (sub pA) node and requires careful layout and low leakage layout techniques.

To minimize leakage, a "Guard" trace is placed surrounding the input trace. The guard trace is driven by the buffer output to maintain the guard at nearly the same potential as the input trace. By maintaining the guard at the same potential as the input trace, any leakages between the guard and the input trace are reduced to near zero.

V_{OUT} is then applied to a simple threshold comparator, or, into a ADC input on the alarm controller.

In order not to disturb the charges on the plate and avoid lengthy settling times, the amplifier must be powered continuously.

2.1.1 Test Function

The UL specification requires that the alarm provide a self-test function. In most detectors, this is accomplished by a "Test" button that allows the user to test the alarm.

To perform the self-test, the chamber voltage is reduced, which should then cause a corresponding drop in the collector voltage. Simple detector circuits would interpret the corresponding voltage drop as a fire event and sound the alarm.

To accomplish the drop in chamber voltage, the chamber voltage is supplied through a resistor (R1). Due to the sub pA chamber currents, there is almost no voltage drop across the resistor (<1uV) during normal operation.

A second resistor (R2) is connected between the chamber and the test switch. When the switch is pressed, a voltage divider is created by the R1 and R2 resistors and the chamber voltage decreases by the resistor ratio. A ratio of one half is common.

The "test" button can be a simple contact switch, as shown above, or can be initiated by the controller using an open collector transistor or MOSFET in place of the switch. Controller based detectors can perform the self-check at regular intervals without sounding the alarm.

The results of an actual chamber test is shown in Figure 5.

2.2 *Chamber Measurement*

To provide an initial performance point, the detector collector voltage was measured with a Keithley 617 Electrometer (A voltmeter with >200 TΩ input impedance). The chamber voltage was set to 5.2 V. The collector measured 2.12 V in clean air.

When the input to an op-amp is unconnected, the input potential will naturally float to the point of zero bias current (or to where all the leakages cancel). Ideally this should be somewhere within the operating range and not drifting down all the way to the rails. This test will verify the amplifier is not loading down the chamber with excessive leakage.

To test for this, the bare input (with sensor disconnected) was briefly touched to GND, 0.5V or 2V potentials then left floating to see where the input voltage would settle. Figure 3 shows the results of these tests. All three showed that the input would eventually float to about +950 mV. Electrometer tests confirmed that the "zero" bias current was also around 950 mV, and also corresponds to the input bias current graphs on the LPV801 datasheet. The bias current at 2 V was about 120 fA, which also correlates to the LPV801 datasheet curve.
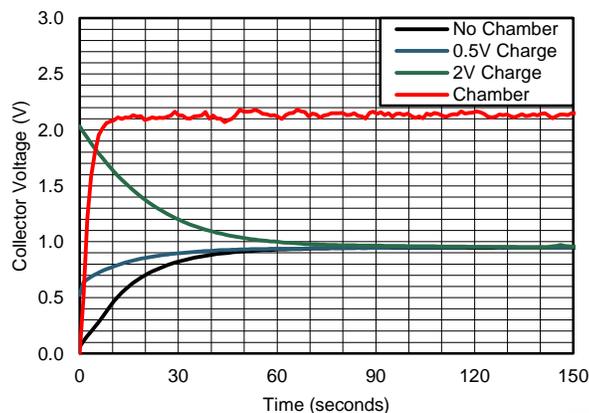
Figure 3. Chamber Measurement

The chamber output was measured. The collector was briefly shorted to ground to make sure there were no stored charges, and that the resulting charge was due to the ionization charges. The voltage quickly rose to around 2.12V, as shown in Figure 3. This shows a strong output from the sensor. The 2.12V also agrees with the electrometer reading, so the amplifier is not loading down the sensor.

It should be noted that the "noise" on the sensor output is expected. This is due to the random charge peaks of the Americium and not due to amplifier or environmental noise. The buffer does not contain any filtering, so the "noise" is passed un-attenuated, and the charge peaks can be seen. A post filter would be required to integrate the output to reveal long-term trends before applying to the alarm threshold comparator.

2.2.1 Smoke Measurement

Figure 4 below shows the collector output when a lit match stick was dropped into a loosely sealed container (soup can) containing the sensor. The match was dropped at the 60 second time point.
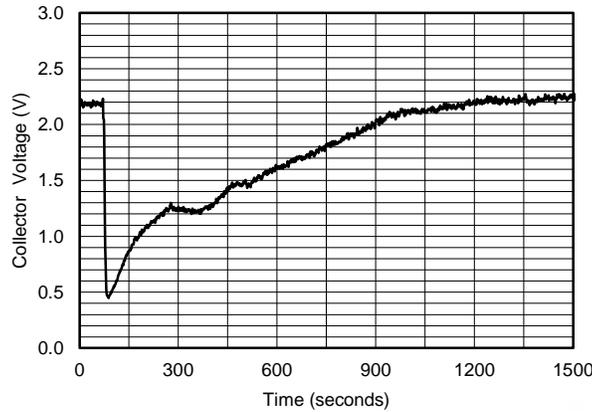

Figure 4. Smoke Exposure Results

The detector output responded almost immediately, dropping to a low of 460mV, and then then rising as the smoke dissipated. Some step changes can be seen, most likely the result of the smoke settling at different levels due to the thermals in the container, then slowly dissipating. The lid was opened at 1300 seconds (very little change).

2.2.2 Zero Check Measurement

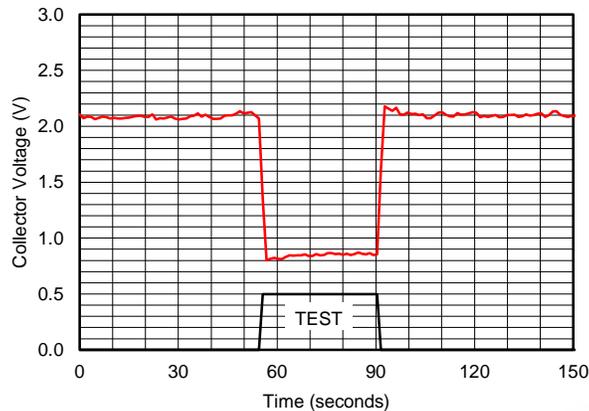Figure 5 below shows the sensor behavior during the self check test.

Figure 5. Clean-Air Self Check Results

The chamber voltage dropped from 5.23V to 2.66V during the self check period. The collector output immediately followed and dropped from 2.1V to 0.846V, and returned to 2.1V after about 5 seconds. The slight over and undershoot is most likely attributable to stray capacitance causing charge injection due to the relatively fast edge rate of the chamber voltage.

The output clearly showed a reaction and would easily pass the self-check test.

3 Temperature Range

UL 217 specifies a detector ambient operating range of 0°C to 49°C. While the temperature does not have a significant effect on the ionization chamber operation, it will have an effect on the bias current of the amplifier. Most CMOS amplifier inputs will have a doubling of the input bias current for every 10°C increase in junction temperature. For the LPV801, the bias current is typically around 950fA at 50°C.

Figure 6 shows the collector output voltage over ambient temperature. The effects of the exponential bias current over temperature are clearly visible.

The results show a 200mV change from 25°C to the UL specified 49°C maximum.
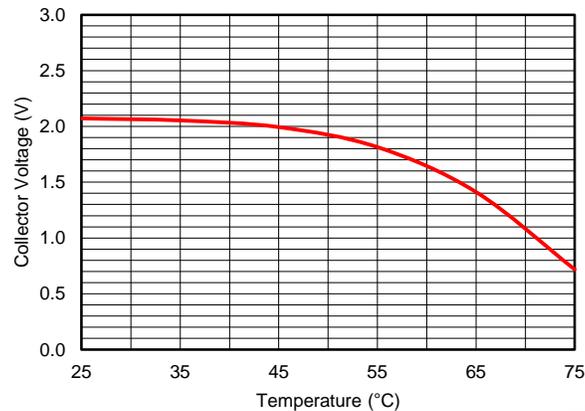
Figure 6. Collector Voltage vs. Temperature

It should also be noted that the UL specification also has a storage and accelerated aging test temperature requirement of up to +70°C. While non-operating, this may have an effect on materials used inside the detector. To reduce the effects of humidity, it is common to coat the board in paraffin "beeswax" or similar material. This material can melt and become liquid at these extended temperatures. The customer is cautioned about this possibility and precautions should be taken to prevent the wax from flowing into areas where it can do harm.

4 Conclusion

The UL217 rev 8 specification mandates that from 2019 onwards, smoke detectors should be able to detect both fast flaming and smoldering fires. New smoke detectors have both ionization and photoelectric sensing to detect both these types of fires.

This application note shows the typical application circuit for ionization smoke detectors. LPV801, industry's first nanopower precision amplifier, with low bias current and ultra-low quiescent current consumption is ideally suited for this application.

5 References

- LPV801/802 Datasheet. Texas Instruments, Inc. SNOSCZ3
- "UL 217: Standard for Safety Single and Multiple Station Smoke Alarms". Underwriters Laboratories Inc., Northbrook, IL., Revision 8, October, 2015. Available from http://http://ulstandards.ul.com/
- "How Smoke Detector is Made". *Madehow.com*. Advameg. Retrieved from http://www.madehow.com/Volume-2/Smoke-Detector.html October, 2016.
- "Ionization Detectors". Wotiz, Richard. Circuit Cellar, November 2011, Issue 256, pp 60-65, http://www.circuitcellar.com.

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have *not* been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products		Applications	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Applications Processors	www.ti.com/omap	**TI E2E Community**	e2e.ti.com
Wireless Connectivity	www.ti.com/wirelessconnectivity		

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265