Passing UL 217 8th Edition – Smoke Detector Reference Design & Algorithm

PRESENTER(S):

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Proposed Outline

- Agenda:
  - Importance of Smoke Detection
  - Smoke Detectors Standards
    - UL 217 8th Edition Updates
  - Common types of Smoke Detection
    - Technology - Ionization vs Photoelectric
    - ADPD188BI with Smoke Chamber
  - CN0537 Smoke Detector Reference Design
  - Solving the new UL 217 Challenges
    - UL 217 data measurements
    - Large statistical relevant datasets
  - Algorithm Methodology
    - Algorithm development, optimizations, and test harness
  - Embedded Software
    - Requirements, Features, Partitioning, and Power
  - Tested and Verified Results

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Macro Trend Impact

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Urbanization

Population density

>65% populations in cities by 2050

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Climate Change

Buildings: Global energy consumption

Environment

Regulations & Standards

Certification

More stringent safety and wellness regulations

Data Privacy

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Fire Detection – Saving Lives

3 out of **5** Deaths

Properties without working smoke alarms

23% of deaths

Smoke Alarms present but disabled due to false alarms

83% Less Time

To escape a fire than in 1970's due to advances in synthetic building materials

Driving increasing regulatory requirement for more reliable smoke detection

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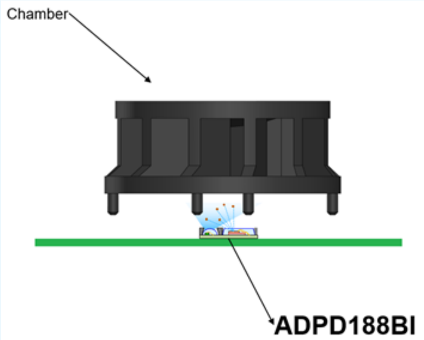
Major Smoke Detector Regulations

- US and Canadian
  - UL 268 - Smoke Detectors for Fire Alarm Systems
    - 7th edition - in effect 30th June 2021
  - UL 217 - Smoke Alarms
    - 8th edition - in effect 30th June 2021
  - ***Updates to flaming polyurethane and cooking nuisance (hamburger) test***
- European
  - EN 14604 - Smoke alarm devices (2006)
  - BS EN 54 - Fire detection and fire alarm systems (2015)
    - Part 29: Multi-sensor fire detectors — Point detectors using a combination of smoke and heat sensors
- International
  - ISO 7240 - Fire detection and alarm systems (2018)
    - Part 7: Point-type smoke detectors using scattered light, transmitted light or ionization
    - Chinese standard for point-type smoke detectors follows 2003 edition of this standard



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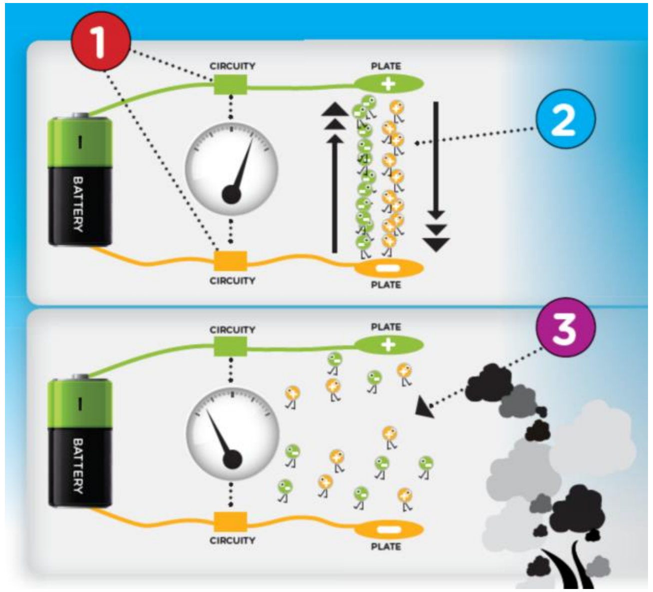
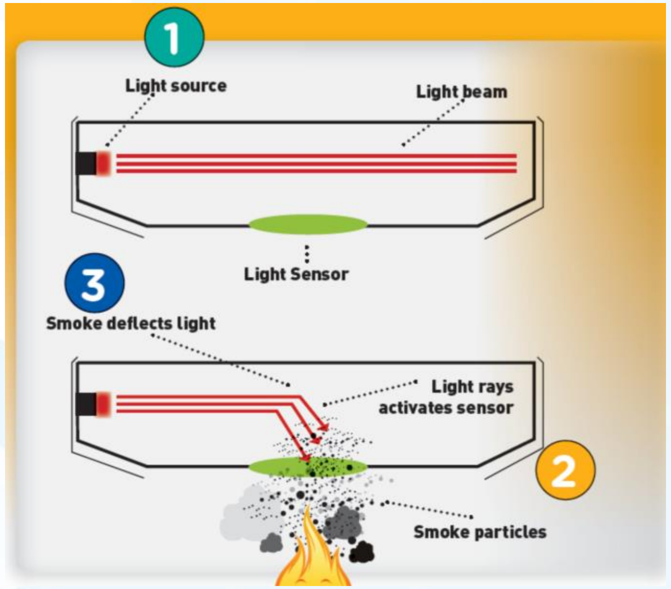
Typical Smoke Detector Technology Today

- Ionization – Flaming Fires
  - Two electrodes with excited with a voltage and radiation source.
  - As smoke enters detector, ions bond with the smoke and disrupt that measurement, leading to the alarm.



- Photoelectric – Smoldering Fires
  - LED or Laser which sends light across chamber (forward scattering)
  - Smoke enters the chamber, scattering the light
  - Photocell receives that light and alarms when the proper measurement is reached



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ADPD188BI Integrated Smoke Sensor

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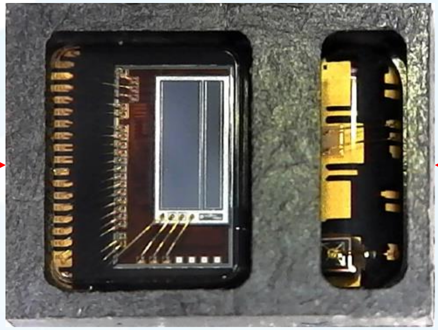
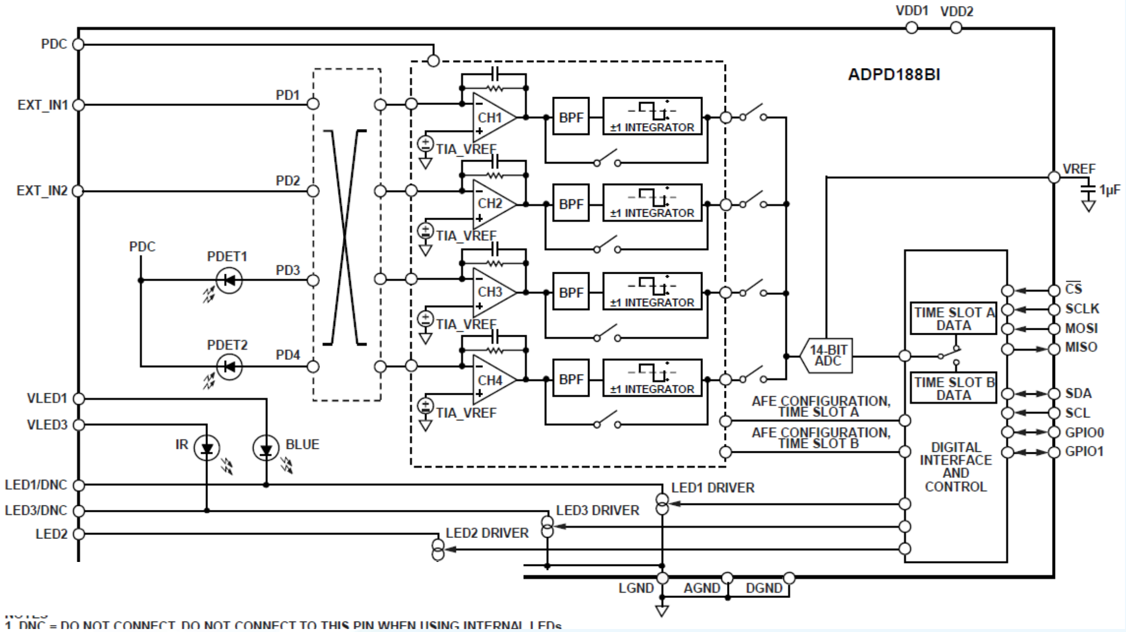
Key Benefits

- ADPD188BI integrates LEDs, photodiode, and AFE
  - Sensitivity ~0.1% obscuration/ft at 10 µA avg. current
  - LED wavelengths: 470 nm, 850 nm
  - Mean scattering angle: 85 ±50º
  - Part-to-part variation using fuse data: <±10%
  - Temp range: -40°C to +85°C
- Less nuisance alarms
  - Dual wavelength, wider dynamic range, and higher SNR
  - Meets UL-217 8th edition smoke tests
- Reduced Footprint
  - 3.8 mm × 5.0 mm × 0.9 mm
  - Small size enables more industrial design options
- Lower power dissipation
  - 25uW average (4 pulse configuration)
- Factory calibrated
  - Simpler and lower cost production flow
- Higher reliability
  - Reduced component count
  - Eliminates LED supply chain management requirements
- Complete sensor solution
  - ADPD188BI integrated sensor module
  - ADI designed smoke chamber from partner
  - Complete UL-217 tested reference design

Photodiode and ADPD1080 AFE



Blue and IR LEDs



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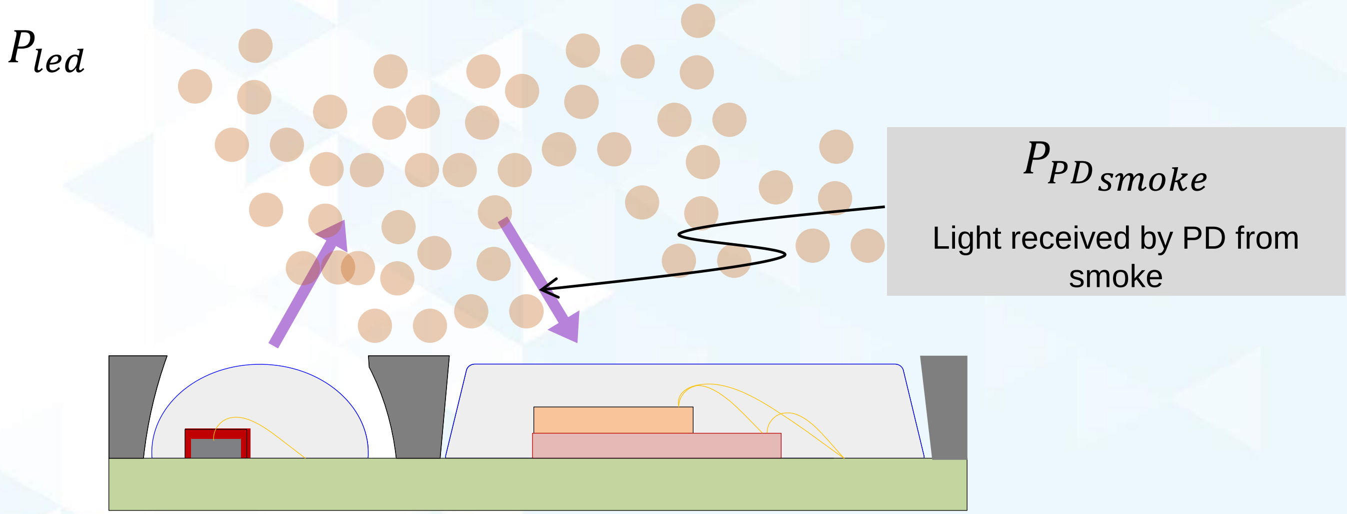
Optical Scattering Power Transfer Ratio (*PTR*)

- *PTR* is the power received at the photodiode per power supplied to the LED
- Dimensionless quantity that allows easy scaling
- Application of e-fuse calibration constant normalizes all parts
- PTR_{smoke} is the PTR for smoke signals
- AN-2033 is written on PTR and CN-0537 also outlines how the PTR calculation is performed using the chamber and ADPD188BI



$$PTR_{smoke} = \frac{P_{PD\,smoke}}{P_{led}}$$

$PTR \equiv$ Power Transfer Ratio in nW/mW

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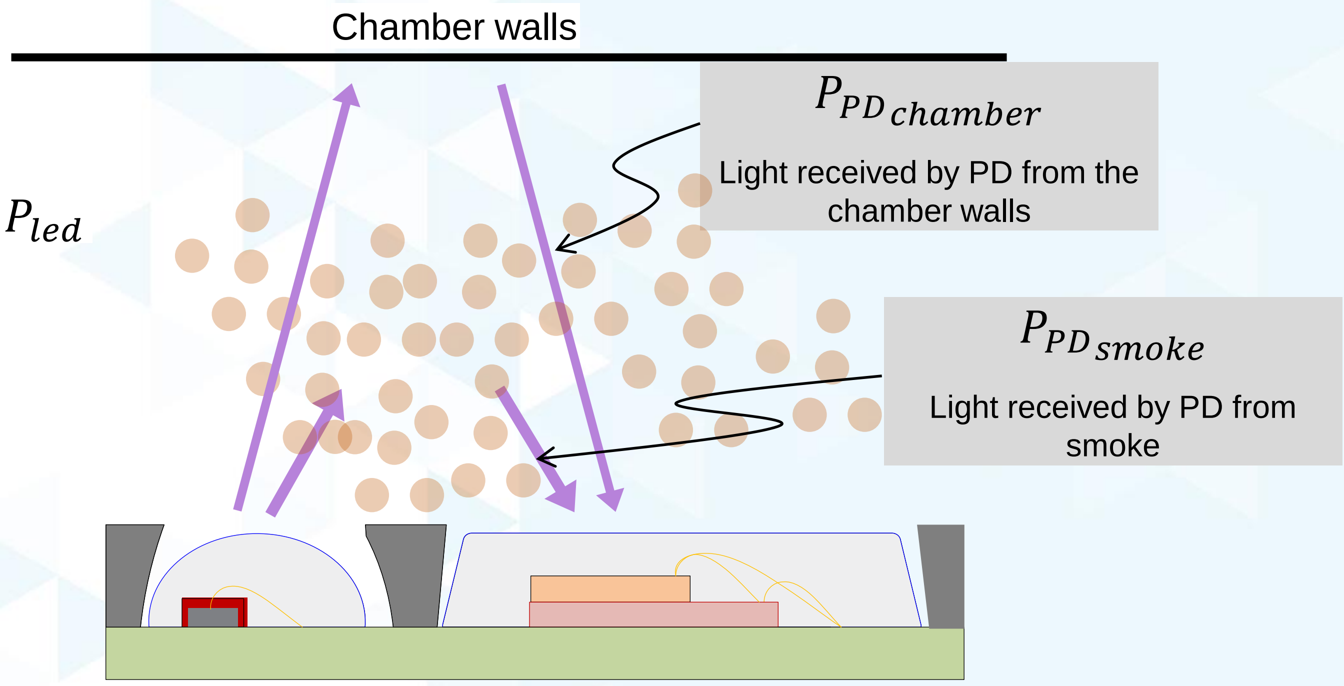
Background Subtraction and Chamber

- Sensor also receives small signal from chamber and other background sources
- $PTR_{chamber}$ is the PTR for the chamber signals and other backgrounds
- $PTR_{chamber}$ is a slowly varying signal that changes due to effects like long term dust accumulation
- $PTR_{chamber}$ allows active measurement of the health of the detector

$$PTR_{smoke} = PTR - PTR_{chamber}$$



$$PTR_{chamber} = \frac{P_{PD\,chamber}}{P_{led}} \qquad PTR_{smoke} = \frac{P_{PD\,smoke}}{P_{led}}$$

$PTR \equiv$ Power Transfer Ratio in nW/mW

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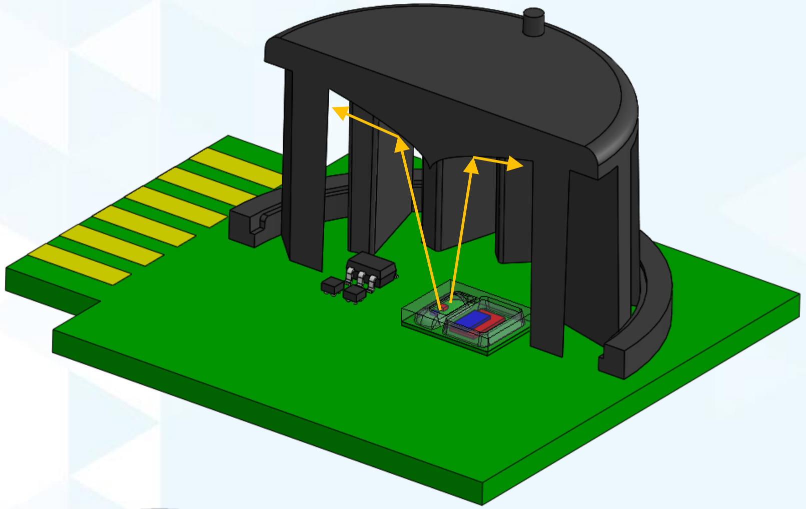
Smoke Chamber Requirements

- Characteristics of a good chamber:
  - Low attenuation of smoke
    - Low resistance to airflow
  - Low scatter for the LED light such that chamber PTR ~ smoke PTR
  - Small and easy to mount

- LED light is pointed “up” and any surface can reflect light rays back to the photodetector.
  - A small PTR of the chamber has many benefits:
    - Self-Diagnostics
      - Positive verification of working part
      - Direct measurement of contaminated smoke detector
    - Transfer of calibration “on-the-fly”.

- Optimized chamber design
  - Chamber PTR ~ 20 nW/mW



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CN0537 Smoke Detector Reference Design

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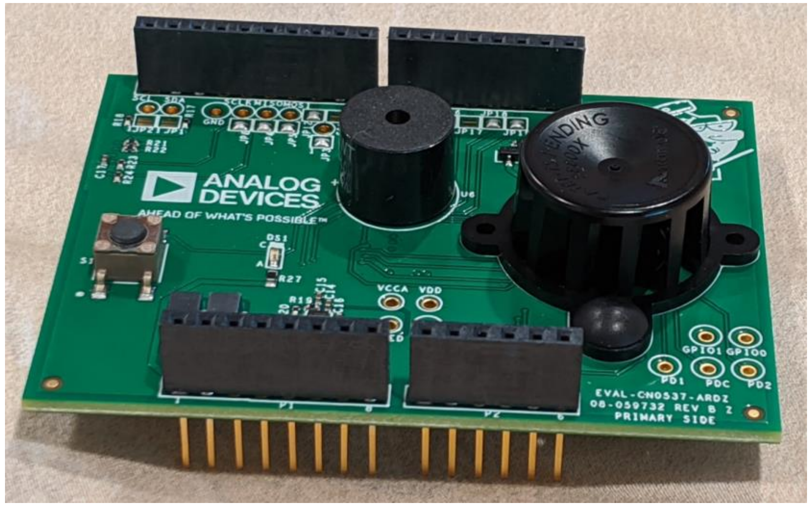
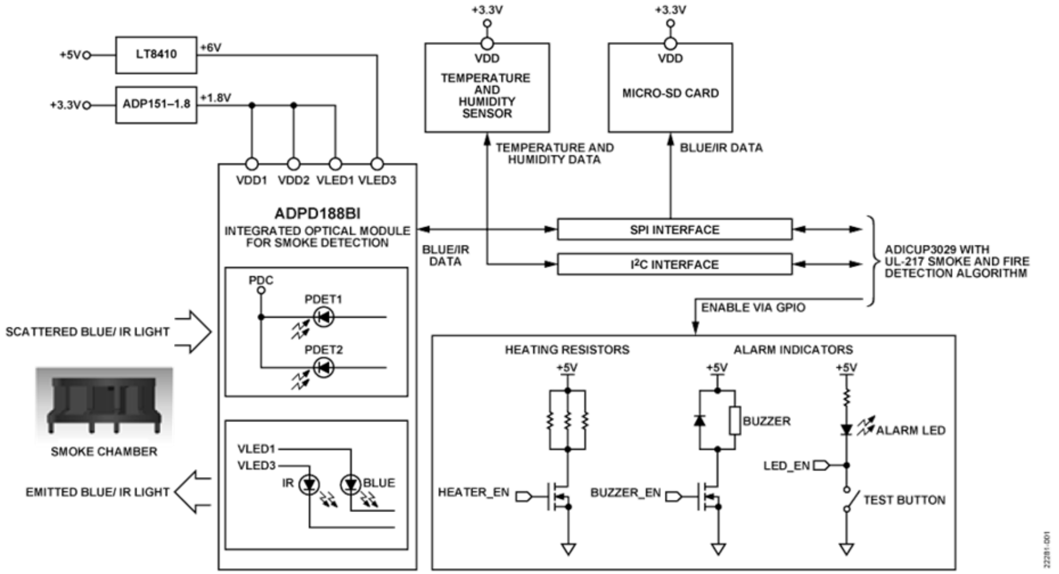


Key Benefits

- UL 217 (8th Ed.) tested and verified algorithm accelerates system development, lowers risk and reduces development cost
- Data package that includes over 1000 smoke dataset taken at UL 217 certified facilities for algorithm development
- Designed with ADPD188BI high performance particulate sensor and includes environmental compensation at measurement location
- Combined with optimized, precision smoke chamber which enables smallest form factor and enhanced industrial design options
- Low power hardware design and low computational algorithm extending battery lifetime / reduced battery size, cost
- Arduino form factor smoke detector reference design for prototyping and development



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CN0537 Reference Design Offerings

Algorithm

- Software
  - CN0537 Source Code including UL 217 8th Ed. Detection Algorithm (.c)
  - MATLAB & Python UL 217 Projects
- Data
  - UL 217 Test Dataset Files
- Documentation
  - UL 217 Algorithm Documentation
  - UL 217 Test Datasets User Guide
  - MATLAB/Python User Guide
- Support
  - 10 hours of phone support

EVAL-CN0537-ALGO

Data

- Data
  - UL 217 Test Datasets Files
- Software
  - CN0537 Source Code (excl. detection algorithm)
- Documentation
  - UL 217 Test Datasets User Guide

EVAL-CN0537-DATA

Hardware

- Hardware
  - CN0537 Reference Design
  - ADICUP3029 Microcontroller Board
- Software
  - Embedded UL217 algorithm (.hex)
  - ADPD188BI no-OS driver
- Documentation
  - Circuit Note
  - CN0537 User Guide
  - UL 217 Test Results (Intertek)

EVAL-CN0537-ARDZ
EVAL-ADICUP3029

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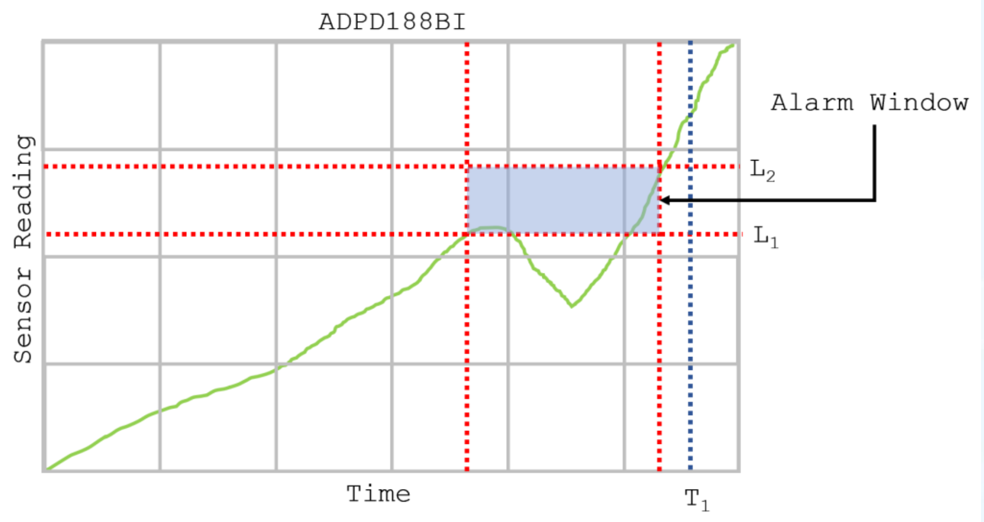
UL 217 8th Edition Motivations & Specification

- UL 217 8th Edition Specification to cut down false alarms
  - Smoke vs non-Smoke
  - Real alarm vs Nuisance alarm
- Research and understand how the ADPD188BI responds to smoke events
- What will it take to meet the new UL 217 requirements with our sensor

Fire Source	Alarm Time Spec.	Alarm Obscuration Spec.
Smoldering Wood	-----	before 10%/foot
Smoldering PU	-----	before 12%/foot
Nuisance	-----	NOT before 1.5%/foot
Paper	Less than 4 minutes from test start	-----
Flaming PU	Less than 4 minutes from test start	before 5%/foot
Flaming Wood	Less than 4 minutes from test start	-----
Nuisance+PU	Less than 4 minutes from test start	NOT before 1.5%/foot



- UL 217 8th Edition specifies handling of nuisance events and fire events
  - Minimum levels in which alarm conditions result in a failure
  - Maximum levels in which not alarming results in a failure
  - Time bounded constraints in which alarming to late results in a failure

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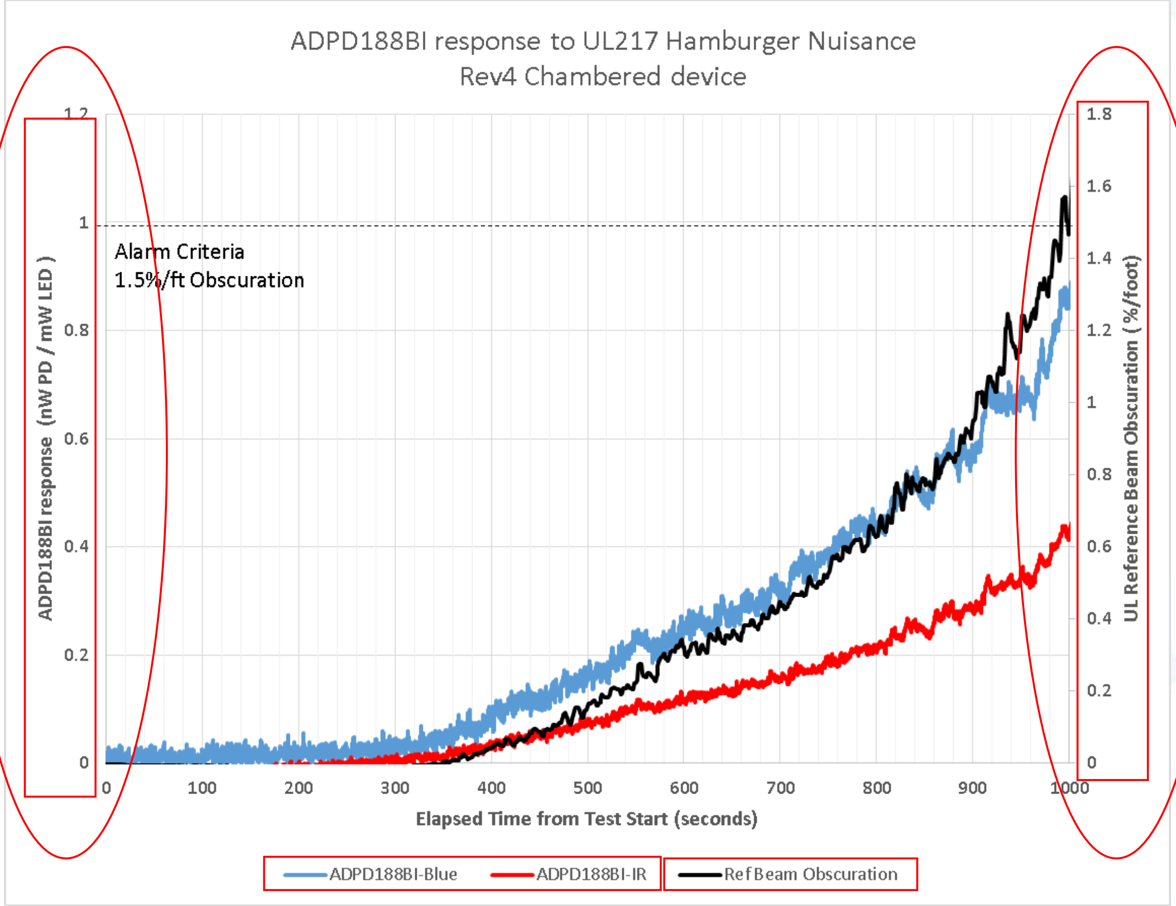
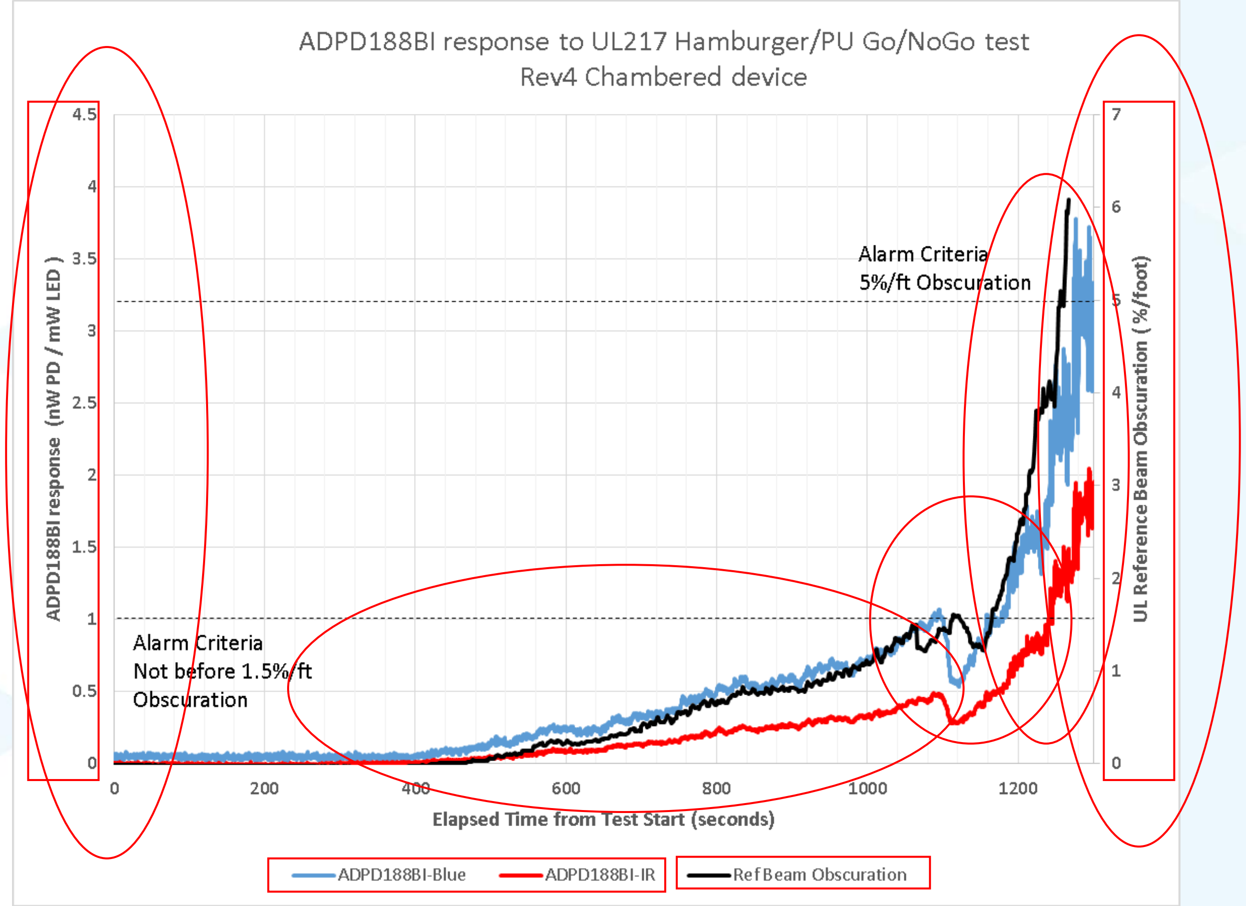
UL 217 8th Edition Nuisance Test



► Hamburger Nuisance Test



► Hamburger Nuisance + Polyurethane Test

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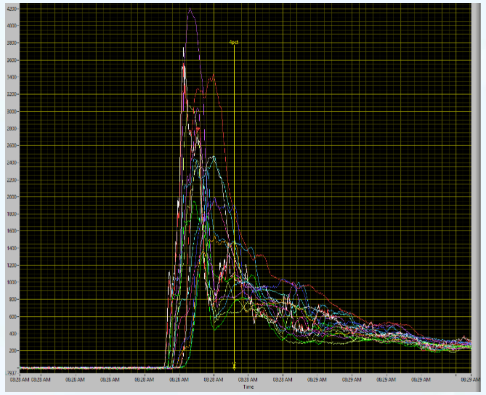
CN0537 UL 217 Test Datasets

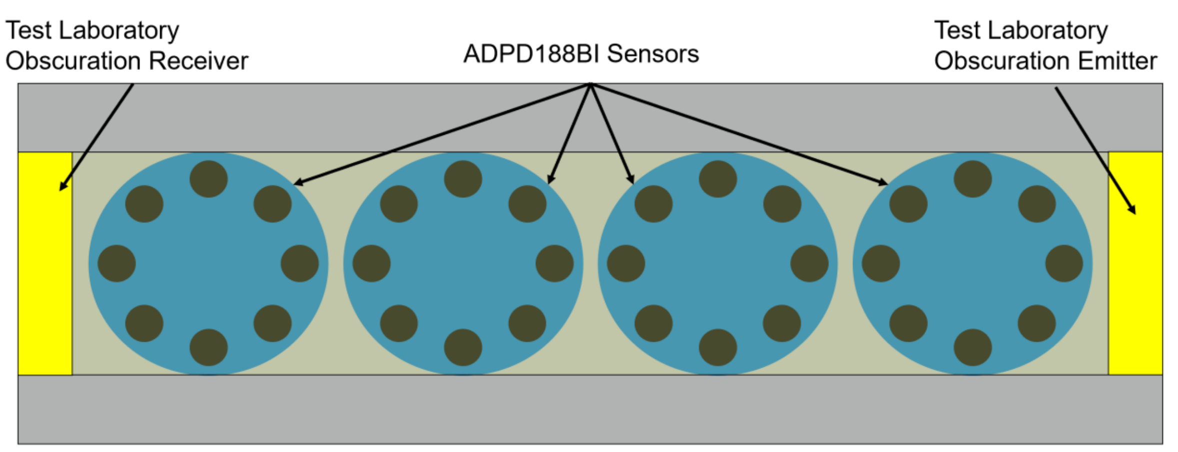
- UL 217 data collected at Occupational Safety and Health Administration(*OSHA*) recognized testing facilities Intertek and Underwriters Laboratory(UL)
- EVAL-CN0537-DATA Datasets contain:
  - Reference obscuration/humidity/CO2 levels of UL 217 test scenarios
  - High sample rate sensor data from multiple ADPD188BI parts across all tests
  - 1000+ unique part specific datasets
- Test data covers UL 217 specific tests relating to smoke sensing performance
- Data can be used to further refine algorithms, create custom algorithms, or complement existing test harness

Datasets

UL Section	UL 8th Edition Test
42	Sensitivity
51.2	Paper Fire
51.3	Wood Fire
51.4	Flaming PolyUrethane
52	Smoldering Smoke
53	Smoldering PolyUrethane
54	Cooking Nuisance
	UL 9th Edition Test
54	Go/No Go Cooking Nuisance



Multiple ADPD188BI Under Test



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Smoke Detector Algorithm Approach

- Traditional threshold techniques proved to be challenging with the new standards
- Two different models were investigated for algorithm development, a change detection model as well as neural network model.
- Decision to use the modified CUSUM technique was chosen to reduce embedded code size, power consumption, and processing complexity
  - The design was based on Cumulative Sum (CUSUM) control chart algorithm
    - Belongs to a class of techniques called change detection algorithms
    - Uses raw data to extract moving average and alarm when a substantial change is detected
- Using the UL 217 standard as the guideline for data classification and algorithm development. Fires can be broadly categorized as slow-catching or fast-burning.
  - slow-burning: smoldering wood, smoldering polyurethane, hamburger
  - fast-catching: paper, flaming polyurethane, flaming wood
  - combination: hamburger + polyurethane
- Gathered >1000 smoke and fire tests samples datasets from the UL-217 test configurations.

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Smoke Detection Algorithm Block Diagram

- CN0537 smoke detection algorithm consists of three computation steps:
  1) (Optional) Window average of PTR values
  2) Modified CUSUM of the window average
  3) Adaptive thresholding to identify slow burning and fast catching fires, in a mutually exclusive manner
- Each stage is governed by tuning parameters that affect the computational load and performance of the algorithm.
- More than 1500 combinations of tuning parameters have been tested that meet UL specifications to varying degrees.

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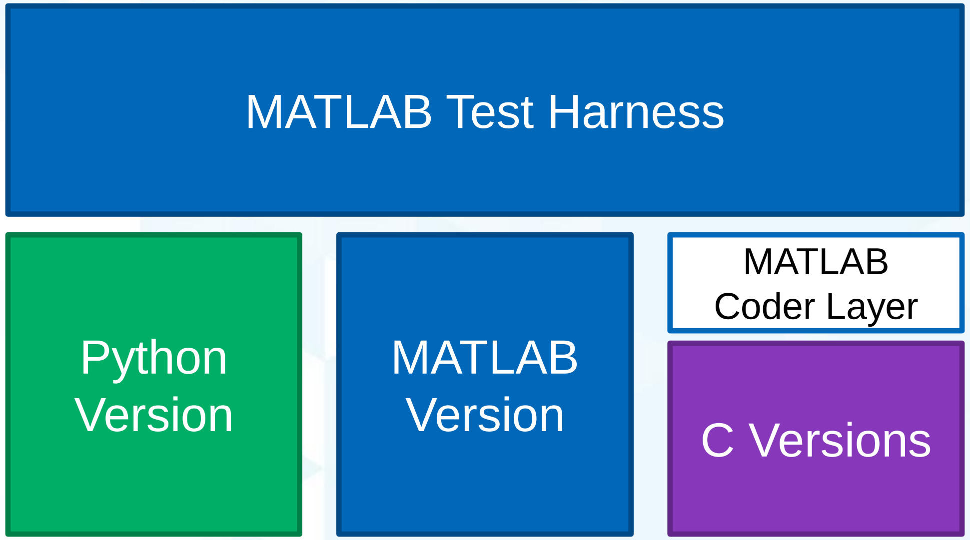
Data and Algorithm Testing Harness

- Fully integrated testing harness across implementations include MATLAB/Python/C
  - Allows for direct comparison as the algorithm is moved embedded to scaled to use more tools in python
- The harness itself is written in MATLAB and utilizes MATLAB Coder to interface with C and MATLAB's standard python integration
- Testing harness generates plots to help visualize the margins with which the research fire tests comply with UL 217 8th edition
- Python testing harness aids users in generating combinations of tuning parameters



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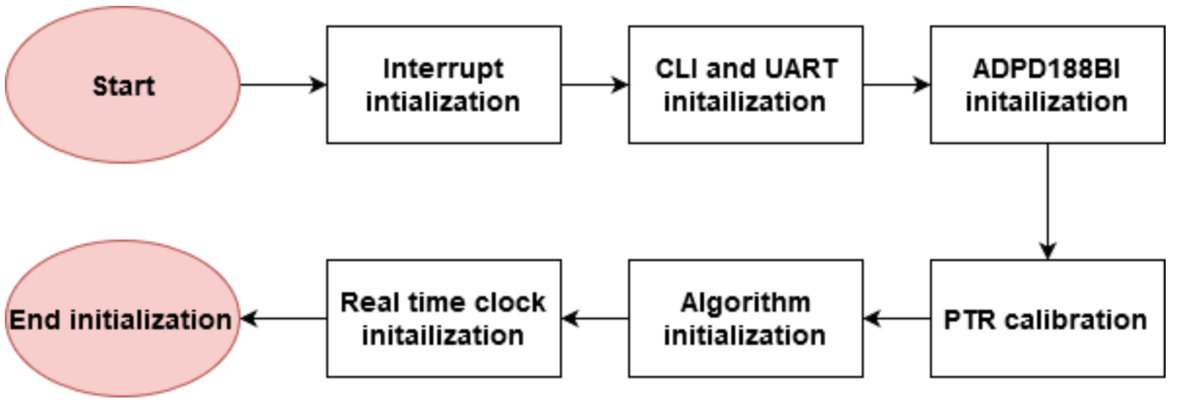
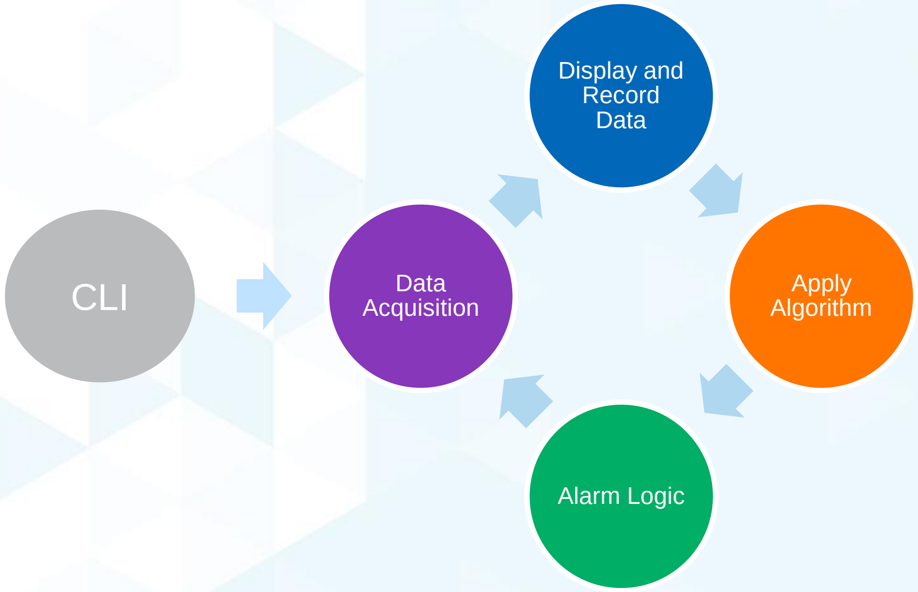
CN0537 Software and Algorithm Source Code

- Initialization setup up the connected devices, interrupts, calibration, compensation, and data pre-processing
- Main process repeats indefinitely and implements:
  - User CLI
  - Data acquisition
  - Display and store data
  - Algorithm
  - Alarm logic
- Algorithm is implemented by feeding PTR data to its API and returning an “Alarm” or “No Alarm” status.





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CN0537 Processing and Power Requirements

- The modified CUSUM algorithm reduces embedded code size, power consumption, and processing complexity.
- The code size is minimized to fit on most microprocessors
  - 32-bit processor required
    - ARM Cortex M0 or M3 recommended
  - Hardware floating point computation recommended
  - SPI and I2C Peripherals required
- Code optimizations and controller power modes could reduce power even further
- ADPD188BI settings are set to the lowest power modes while still being able to achieve an operational UL 217 tested and verified algorithm

Process Requirements	**Value**	**Optimized**
Code Size (Flash)	93.5 kB	~50 kB
Memory Usage (SRAM)	13.5 kB	~10 kB

Processor Computations (Per Input Sample – ADuCM3029)	**Value**
Algorithm Multiplications	~3+4/90
Algorithm Adds	~1+3/90
Processor power (while measuring)	~2.55 mA
ADPD188BI Settings	**Value**
Sample Rate	0.166 Hz
LED Peak Power	~190 mA
LED Pulses per time slot	4
Active time slots	2
LED Offset	15 µs
LED Pulse Period	3 µs
Decimation Ratio	1
Sensor Power Consumed	~3.3 µA
ADuCM3029 + ADPD188BI Power (median current over 6 seconds)	**~20-30 µA**

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UL 217 8TH Edition Testing Results

- Tested the EVAL-CN0537-ALGO against UL 217 8th Edition Smoke Tests
  - Using EVAL-CN0537-ARDZ and EVAL-ADICUP3029 hardware platforms

- Passed smoke sensor related tests outlined in UL 217 8th Edition

- Complete documentation can be found here
  - Note – Tested and verified with the current ADPD188BI, smoke chamber, and algorithm.

Smoke Alarms [UL 217:2015 Ed.8+R:23Nov2016]

SECTION 1

SUMMARY

Intertek wishes to inform you that we have completed the research UL217 8th Ed performance testing on your EVAL-CN0537-ALGO Smoke sensor. The following list of tests were performed and resulted in a passing result.

TEST	UL 217 8th	Result
Directionality	43	Pass
Sensitivity	42	Pass
UL – Paper Fire	51.2	Pass
UL – Wood Fire	51.3	Pass
UL – Flaming polyurethane Foam Test	51.4	Pass
UL – Smoldering Smoke Test	52	Pass
UL – Smoldering Polyurethane Foam Test	53	Pass
UL – Cooking Nuisance Smoke Test	54	Pass
UL - Go/No Go Flaming Polyurethane Foam Test	54	Pass
Velocity-Sensitivity Test	44	Pass
Variable Ambient (0 & 49c)	62	Pass
Humidity	63	Pass

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Session Summary

- The CN0537 is a UL 217 8th Edition tested and verified smoke detector reference design
  - Completed at a certified UL 217 test laboratory
- There are multiple offerings available
  - Algorithm package is the most comprehensive, most useful for limited smoke application experience or condensed timeframes for next generation products
  - Datasets package contains all the sample data and reference details, used for creating your own algorithm if you have those skillsets on staff
  - Hardware package includes the reference design and executable software for testing solution without committing to other offering. Will allow for data collection as well.
- Thank you for watching! Any questions or comments?

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