

Understanding the Mini Gamma Sensor: Q&A

Q1: What conditions should be maintained to ensure the Mini Gamma sensor remains within its effective operational range?

A1: The Mini Gamma sensors have very long shelf life because of the construction using cesium-iodide crystal, which is one kind of highly stable material. There's no special storage condition requirement and they can be stored under standard environmental conditions without risking degradation.

Q2: What type of scintillation crystal is used in the Mini Gamma sensor? Is the crystal brittle or hygroscopic?

A2: The Mini Gamma sensor uses CsI(Tl) (thallium-doped cesium iodide), which is the most commonly used scintillator for X-ray and gamma-ray detection due to its high light yield and good stability. All cesium iodide (CsI) crystals are somewhat brittle and hygroscopic (sensitive to moisture). Among them, CsI(Tl) is the least hygroscopic but should still be kept in a dry environment and protected from direct contact with water or high humidity. Regular ambient humidity is generally acceptable if the crystal is properly sealed.

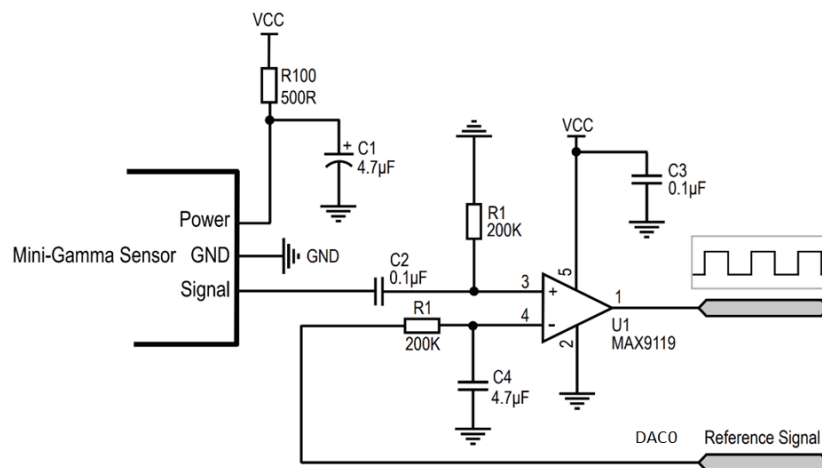
Q3: What is the cross-sectional size and the length of the gamma sensor wires?

A3: The wires are solid with a diameter of 0.45 mm, corresponding to AWG #25. The sleeve diameter is 0.8 mm, and the wire length, as specified in the datasheet, is 72.0 ± 5.0 mm.

Q4: What is the maximum capacitance and inductance inside the gamma sensor?

A4: The maximum total capacitance of the circuit is not precisely known, but the largest individual capacitor is $4.7 \mu\text{F}$, located in the power supply section. This is the only capacitor of that size; all others are in the nanofarad range, resulting in a total capacitance of less than $5 \mu\text{F}$. The circuit contains no inductive components, so its overall inductance is effectively zero.

Q5: What is a recommended schematic for interfacing with the Mini Gamma sensor?



A5: The output of the CsI gamma sensor is approximately a Gaussian-shaped pulse, with amplitudes proportional to the energy of the incident gamma photons detected by the sensor. In most applications, it is not necessary to perform

detailed energy spectroscopy; therefore, a simple discriminator circuit, composed mainly of a MAX9119 comparator followed by a counting system, can be used to determine gamma intensity through the pulse counting rate.

The inverting input (pin 4) of the MAX9119 receives a threshold voltage generated by the DAC output of the MCU. Only sensor pulses whose amplitudes exceed this threshold will pass through the comparator; smaller pulses—typically noise—are blocked. The subsequent counter system counts the passed pulses and calculates the gamma dose rate based on the pulse rate.

The reference voltage at pin 4 should not be fixed; it must be adjusted according to the sensor's electronic noise level. You can measure this noise level using an oscilloscope. In the absence of any radioactive source, observe the amplitude of noise pulses and set the threshold slightly above the maximum noise peak.

Without a radiation source, you will observe a noise pulse band centered around 0 V. The width of this band corresponds to the maximum noise amplitude. Pulses exceeding this band are likely true gamma events. Typically, all pulses—regardless of amplitude—have approximately the same full width at half maximum (FWHM), determined by the sensor's and amplifier's time constant.

Q6: How can we understand the Mini Gamma Sensor circuit and its principle?

A6: The Mini Gamma Sensor outputs pulses that resemble Gaussian-shaped pulses, a common waveform in radiation detection systems. The amplitude (height) of each pulse is proportional to the energy of the incident gamma photon detected by the sensor, the higher the gamma photon energy, the larger the pulse amplitude.

In most applications, it is not necessary to measure the exact energy of each gamma photon. Instead, the system focuses on counting the detection events and analyzing their intensity through the pulse counting rate.

A discriminator circuit is used to filter out unwanted signals and electronic noise. The MAX9119 comparator is the key component of this circuit. It compares each incoming pulse with a threshold level set by the DAC (Digital-to-Analog Converter) output from the MCU (Microcontroller Unit). This threshold defines the minimum pulse amplitude required for a signal to be recognized as a valid event.

Pulses with amplitudes higher than the threshold pass through the comparator and are counted. Those with lower amplitudes (typically caused by noise or weak, insignificant events) are blocked, ensuring that only meaningful pulses are analyzed.

After the discriminator, a counting system collects the valid pulses and counts them over a defined time interval. The pulse counting rate is then used to calculate the gamma dose rate, which represents the intensity of the gamma radiation.

Q7: What is the voltage reference that needs to be set on the inverting input (Pin 4) of the MAX9119 according to the Mini Gamma Sensor circuit diagram?

A7: The voltage reference on Pin 4 of the MAX9119 is not a fixed value. It must be set according to the magnitude of the sensor's electronic noise pulses. The reference voltage is adjustable and should be tailored to the specific noise level of the sensor in its operating environment.

To set this reference voltage correctly, measure the amplitude of the noise pulses generated by the sensor when no radiation source is present. This can be done using an oscilloscope, which allows you to observe the electronic noise waveform and determine the maximum noise amplitude. The threshold (reference voltage) should then be set slightly above this maximum noise level to ensure that only true gamma detection pulses are counted, while noise is effectively suppressed.

Q8: When following the recommended circuit, what is the typical output bias without any interaction with a radioactive source?

A8: The sensor output typically has a small DC bias of about 0.08 V to 0.12 V when no radioactive source is present. It is recommended to insert a blocking (coupling) capacitor between the sensor output and the following circuit (such as the MAX9119 comparator) to remove this DC component. After the blocking capacitor, the signal's DC level depends on the bias applied to the other side of the capacitor, which can be adjusted by the user according to their circuit design requirements.

Q9: In the recommended schematic for Mini Gamma sensor, are there any guidelines for setting the DAC0 reference to the comparator?

A9: The DAC0 setpoint should be configured around 60 mV for the Mini Gamma sensor to match this threshold.

Q10: What do CPS and FWHM mean?

A10: Counts Per Second (CPS) is a key metric that quantifies the number of gamma photons detected by a sensor per second. This real-time measure reflects radiation intensity and is influenced by both the sensor's sensitivity and the strength of the radiation source. CPS indicates the rate at which a sensor registers individual gamma photon interactions, also referred to as "events," over time. Higher CPS values correspond to stronger radiation fields or sources and are proportional to the radiation source's activity and the sensor's proximity to it. CPS readings can be calibrated into specific radiation dose rate units, such as micro-sieverts per hour ($\mu\text{Sv/h}$) or micro-roentgens per hour ($\mu\text{R/h}$), using a conversion factor established during sensor calibration. This enables CPS values to be interpreted within the context of radiation safety standards and exposure levels.

Full Width at Half Maximum (FWHM) is a critical parameter for defining a gamma sensor's energy resolution, which measures its ability to differentiate between gamma-ray energies. This capability is essential for identifying specific isotopes or radiation sources. FWHM represents the width of a gamma-ray energy peak measured at half its maximum height and is typically expressed in energy units like kiloelectronvolts (keV) or as a percentage of the peak's centroid value. A lower FWHM value signifies superior energy resolution, enabling the sensor to accurately distinguish closely spaced energy peaks. FWHM is commonly used to differentiate isotopes emitting gamma rays with similar energies and serves as a standard for comparing resolution performance across gamma sensors. Additionally, the FWHM of a pulse—measured at half of its maximum height—remains consistent regardless of the pulse's size. This consistency suggests uniformity in pulse shape, which is crucial for ensuring reliable measurements across varying amplitudes.

Q11: Is counting the number of pulses within a set period sufficient to determine radiation intensity, or are additional processing steps required?

A11: Yes. The number of pulses detected within a given period is directly proportional to the radiation intensity, the more pulses counted, the higher the gamma radiation dose rate.

Q12: What background radiation level does a Mini Gamma Sensor indicate when 14 pulses per minute are detected?

A12: If a mini-gamma sensor detects 14 pulses per minute, this corresponds to a background radiation level of 14 $\mu\text{R/h}$.

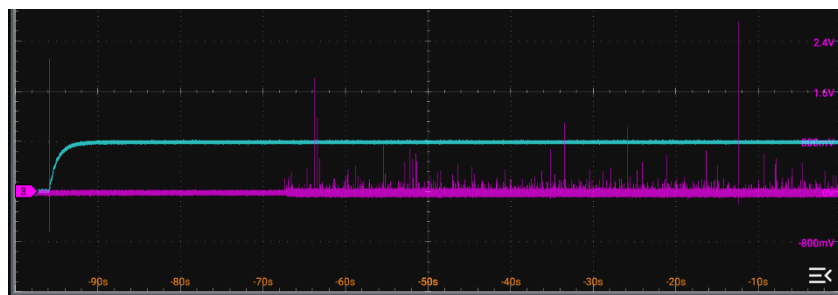
Q13: Is there a specific timing or filtering algorithm recommended for handling the quasi-Gaussian pulses?

A13: Yes. Since the sensor output pulses have a quasi-Gaussian shape and random arrival times, we recommend using a 200 ms counting window to capture pulse events. The readings from several consecutive windows can then be averaged over 1 to 2 seconds to smooth short-term statistical fluctuations and produce a stable indication of radiation intensity.

Q14: What occurs when radiation intensity exceeds the upper limit? Will the sensor saturate or provide inaccurate readings? Should the firmware handle saturation scenarios, and if so, what is the recommended approach? Does the sensor require any specific startup or warm-up time that should be considered in the firmware?

A14: When the radiation intensity exceeds the upper measurement limit, the pulse rate becomes too high, and individual pulses may begin to overlap (pulse pile-up). This results in count losses and leads to underestimation of the actual radiation level. In such cases, the firmware should detect this condition and display a “Saturation” or “Over Range” warning to indicate that the measurement is no longer accurate. After power-on, the sensor typically requires about 30 seconds of stabilization time before readings become stable and reliable. The firmware should account for this warm-up period before reporting valid dose rate data.

Q15: During testing of the gamma sensor, the output (magenta-colored trace) is captured on the oscilloscope. Are the spikes observed in the sensor output expected?



A15: Yes, that's correct. The spikes represent the gamma sensor's response to the radiation source. If you extend the horizontal time axis sufficiently, each spike should reveal a quasi-Gaussian pulse shape, as illustrated in the datasheet.

Q16: When following the recommended circuit, what amplitude is considered meaningful output and what is considered noise?

A16: Without a radioactive source, a pulse noise band can be observed, formed by the sensor's electronic noise. The bandwidth represents the maximum noise amplitude relative to 0 V. Pulses with amplitudes larger than this noise band are considered meaningful signals, corresponding to actual gamma detection events.

Q17: Does the output pulse width get shorter as the amplitude gets smaller in magnitude?

A17: In general, all pulses have approximately the same full width at half maximum (FWHM) regardless of their amplitude. By measuring the FWHM of several pulses with different amplitudes, you will find that the widths remain nearly constant, even though the pulse heights vary.

Q18: Why does the sensor sometimes show higher-than-expected background counts?

A18: Many small pulses originate from electronic noise, not from actual gamma events. To suppress these noise pulses, increase the reference voltage (discrimination threshold) applied to the comparator's inverting input pin. Select an appropriate threshold so that no pulses are counted when there is no radioactive source present. This adjustment ensures that all noise pulses are blocked. The process of setting this threshold is called discrimination threshold calibration. The reference voltage is not a fixed value; it must be set according to the magnitude of the sensor's electronic noise pulses. You can measure the noise level using an oscilloscope. In a natural background environment (without a radiation source), observe the amplitude of the noise pulses and set the threshold slightly above the maximum noise amplitude. Based on SemeaTech's tests, the typical threshold is around 0.08 V. The sensor uses a PIN photodiode with an ultra-high-gain preamplifier, which can also amplify the diode's intrinsic noise. Because the noise amplitude varies among individual PIN diodes, the threshold must be adjusted for each sensor. Typical values range from 0.06 V to 0.10 V, although slightly higher or lower thresholds may be required for some photodiodes.

Q19: Is there anything that can be done to prevent count loss from occurring? And is there a maximum count rate (in CPS) beyond which the sensor is no longer effective?

A19: Some degree of count loss is unavoidable due to pulse pile-up at high radiation intensities, where pulses begin to overlap and cannot be individually resolved. In principle, a quadratic correction function can be applied in firmware or data processing to compensate for this nonlinearity to some extent. Without correction, the maximum count rate for reliable operation is approximately 1500 counts per second (cps), at which point the measurement precision is about $\pm 30\%$. It is generally difficult to achieve accuracy better than $\pm 10\%$ with this type of compact sensor. For comparison, the Honeywell GammaRAE II R, which uses the similar CsI crystal but with roughly 10 times larger crystal volume, specifies an accuracy of $\pm 20\%$ (see user manual: Honeywell GammaRAE II R Manual).

Q20: How to explain gamma sensors' linear regression?

A20: Linear regression is a statistical method used to model the relationship between sensor output (CPS) and radiation levels, which shows how well the sensor's output follows a straight-line pattern as radiation increases. This helps in understanding how the sensor responds to different radiation strengths. To evaluate the sensor's linearity, a sample batch of sensors is tested by exposing them to different radiation levels. The resulting measurements are plotted as data points on a chart. The linear regression line fitted to the data points best represents how the entire lot of sensors behave in terms of their response to radiation, ensuring that all sensors in that batch are assessed for their linearity. With 95% confidence level, all sensors in the batch will have their performance (measured CPS vs. radiation) within $\pm 30\%$ of the linear regression line, which means that the sensor's readings are expected to be within 30% of ideal response as defined by the linear model. If the sensor's linearity (as defined by the regression line) is integrated into systems like gamma or X-ray detectors, the accuracy of the overall system will be $\pm 30\%$.

CPS (Counts Per Second) is the measure used to track the number of events (radiation counts) detected by the sensor in one second. This data can be utilized to create a linear regression model. One data point represents the average CPS over a period of time to reduce noise from short-term fluctuations. CPS fluctuates due to the random nature of radiation detection, so to smooth the data and make it more stable, a moving average filter is applied. The filter window size is adjusted depending on the CPS value to account for these fluctuations.

For weaker radiation sources, larger samples are required to get accurate average because fewer events are detected. For stronger sources, fewer CPS are needed for each data point because the number of detected events is higher. In high radiation environments (with high CPS, like greater than 1000 CPS), the data points are more frequent, so a small window (2–3 data points) can be used for averaging without losing stability. But in low radiation environments, a larger window is required to gather enough data for stable reading when the CPS is lower. The exact size of the filter window depends on the specific user's requirements for how stable the readings need to be. Therefore, it cannot be fixed and should be adjusted based on the situation.

Q21: How is linear regression used to evaluate SemeaTech gamma sensor linearity?

A21: To assess linearity, we typically select a sample of ~30 sensors from different production batches and expose them to multiple radiation sources of varying intensities. We plot the resulting CPS (counts per second) against known dose rates and apply linear regression to characterize the average response. Based on our data, 95% of sensors fall within $\pm 30\%$ of this regression line, which reflects the expected linearity when integrated into higher-level systems like gamma or X-ray detectors. Due to inherent CPS fluctuations, we apply a moving average filter to stabilize readings. The filter window size is adaptive: for high CPS (>1000), a narrow window (2–3 points) suffices; for low CPS, a wider window is needed. The exact window depends on the user's stability requirements. Sensor-to-sensor variation is within $\pm 15\%$ without screening. At low radiation levels (e.g., low GBq sources), greater variation may occur due to limited CPS statistics.

Q22: Does temperature affect SemeaTech gamma sensor outputs? If yes, what is the calibration procedure?

A22: Temperature has minimal impact on the detection of gamma photons due to their high energy and the physical nature of radiation detection, which is inherently temperature insensitive. Changes in ambient temperature within the sensor's operating range (-20°C to 60°C) do not significantly affect the Cesium Iodide (CsI) crystal's detection efficiency of gamma photons or the magnitude of the pulse amplitude from photoelectric conversion.

However, temperature does influence the performance of the photodiode. At temperatures above 40°C , the amplitude of Silicon PIN photodiode noise increases significantly, and at 50°C , the noise can drown out pulses generated by low-energy gamma rays. Conversely, when transitioning from a high-temperature environment to a low-temperature one, the noise level decreases as the sensor reaches thermal equilibrium, and the opposite occurs when moving from low to high temperatures. Without proper temperature compensation, the pulse count rate decreases when moving from high to low temperatures, and increases from low to high temperatures.

For the Silicon PIN photodiode (Hamamatsu S5106) used in 3cc gamma sensor. As the temperature increases, these variations become more pronounced. For instance, one gamma sensor may register 100 pulses to indicate $30\text{ }\mu\text{REM/hr}$, while another may register 150 pulses for the same dose rate. On the other hand, the photodiode (Hamamatsu S5106) is very sensitive to ambient temperature especially when the temperature increases to 40°C and above. This is why gamma sensors must be calibrated after being installed in gamma monitors, and the gamma monitor must have thermistors to compensate for the ambient temperature variations.

It's worth noting that radiation sources are not required for temperature calibration. Instead, calibration involves verifying the sensor's performance across its temperature range by analyzing how noise levels behave under different conditions. Additionally, a pulse amplitude screener is commonly used to separate gamma radiation pulses from noise. The screener's threshold is typically set to the noise height of the photodiode, but as temperature rises, the increased noise amplitude necessitates raising the screening level. This adjustment can block some low-energy gamma photon pulses, potentially reducing the pulse count rate in the user's application system (not the gamma sensor itself).

Since the relationship between noise and temperature lacks fixed quantitative metrics, each gamma sensor must be calibrated in actual applications, as the performance of individual photodiodes can vary.

At ambient temperatures reaching 35°C, thermal noise can interfere with and overlap radiation signal outputs. To counteract this, a higher-intensity radiation source is required to produce a more distinguishable output. Once the pulses are detected (with a lower pulse count in this case), a compensatory software algorithm must be implemented to maintain the linearity of the sensor outputs. Americium-241 is too weak and doesn't work for it. Using a higher-energy Cesium-137 should be the solution.

To calibrate the sensor, begin by establishing its baseline noise level in the absence of any Cs-137 source. Once the baseline is recorded, introduce the Cs-137 and measure the sensor's response to determine the change in output relative to the background level.

Q23: How can the quadratic function ($aX^2 + bX + c$) be explained in the context of gamma sensors?

A23: Calibration at the system level is crucial to ensure the accurate performance of gamma sensors. Without proper calibration, users may encounter unreliable readings, as each sensor can behave differently. Therefore, individual calibration is necessary for achieving precision.

During the calibration process, measurements are taken at various points, comparing the sensor's output with a known reference or input. These data points are then plotted on a chart. To represent the sensor's response accurately, a mathematical curve - specifically a quadratic function ($aX^2 + bX + c$) - is fitted to the data. Once the quadratic function is applied, the sensor's actual readings should align closely with the curve, within an acceptable error margin of $\pm 10\%$. This means that the sensor's readings are expected to generally fall within 10% of the predictions made by the quadratic model.

Because each sensor has unique characteristics, it requires its own specific quadratic function that best fits its calibration data at the system level. The calibration curve for one sensor is exclusive to that sensor and is not interchangeable, even with sensors of the same model.

Q24: Why is there a significant difference in sensor-to-sensor variation in the CoC (Calibration or Correlation) data?

A24: A slight difference in the positioning of each sensor relative to the radiation source can cause noticeable variation in the count rate (CPS). Even small positional shifts can significantly affect the detected intensity due to geometric and angular sensitivity. In addition, in a strong radiation field, some sensors may experience pulse overlap (pile-up), leading to count loss. When two or more pulses overlap and are recorded as a single event, the

total count within a fixed time period will be underestimated.

The pulse width can also vary slightly from sensor to sensor due to tolerances in their electronic components. Sensors that produce wider pulses are more prone to saturation and pulse overlap, which further contributes to measurement variation. In a low radiation field, the likelihood of pulse overlap is much lower, and pulses remain well separated in time, resulting in more consistent readings among sensors.

Q25: Why do Mini Gamma sensors sometimes show a decline in sensitivity after long-term use?

A25: The possible reasons for the decline in sensitivity include: (i) Cold Weather Environment: In low-temperature conditions, especially during winter, the sensitivity of gamma sensors may decrease. Extreme cold can affect the physical and electronic properties of the sensor components, reducing the ability to detect gamma radiation accurately. (ii) Radioactive Source Half-Life: The Mini Gamma sensor uses Cesium-137 (Cs-137) as its built-in calibration source, which has a half-life of approximately 16 years. The sensor's sensitivity is directly related to the activity of this source. Therefore, when a sensor is used for many years, its output will gradually decrease in proportion to the source decay. Our recommended actions are: (i) Verify that the Cs-137 source is still within its effective operational period based on its half-life. (ii) Use a set of "golden sample" sensors (calibrated reference sensors) to perform periodic comparison tests, helping identify any deviations in sensitivity and ensuring long-term accuracy.

Q26: How can the EMI effect on the Mini Gamma sensor be mitigated?

A26: SemeaTech's 3cc Gamma sensor is designed with two layers of EMI shielding, while the Mini Gamma sensor has only a single shielding layer. To reduce susceptibility to electromagnetic interference, we recommend enhancing the Mini Gamma sensor's shielding design. Please consider the following measures: (i) Dual-Layer Shielding: Add a second shielding layer, and maintain a small gap or insert a non-conductive dielectric between the two layers to prevent electrical coupling and improve EMI attenuation. (ii) Seamless Enclosure: Ensure the shielding enclosure is continuous metal around all sides, without seams or openings that could allow high-frequency interference to penetrate. (iii) Cable Shielding: Properly shield and ground both power and signal cables to minimize EMI ingress through wiring paths.

Q27: Is there a "Dead Time" associated with the gamma sensor?

A27: This is an electronics concept rooted in theoretical knowledge. It occurs due to the gradual attenuation of light, causing photons to form a long-tail shape on the detector. When the count rate increases (indicating higher radiation intensity), the probability of subsequent pulses overlapping with the tail of the preceding pulse rises. As a result, two or more signals may merge into one, leading to fewer counts being recorded than the actual number of incoming photons. The stronger the radiation, the greater the discrepancy between the actual and recorded counts. This explains why the count rate from our detector slows down as radiation intensity increases.

Like other companies designing and producing gamma sensors, SemeaTech lacks sufficient equipment to directly measure this parameter. We recommend using the relationship between count rate and radiation intensity to calculate and develop a mathematical model on gamma detectors, which can enhance measurement accuracy and extend the measurement range. If only a standard quadratic curve is used for fitting, gamma detectors with 3cc gamma sensors may have a measurement limit of around 8000 $\mu\text{R/hr}$, and the accuracy may be difficult to ensure. However, a well-developed mathematical model can push the measurement limit up to 15,000 $\mu\text{R/hr}$, with an accuracy of $\pm 30\%$.