

3cc Gamma Sensor

1. Introduction

SemeaTech's 3cc Cesium Iodine Gamma Sensor integrates a Cesium Iodide (CsI) crystal, a photodiode, and a high-gain preamplifier. It is designed to detect gamma (γ) and X radiation within the energy range of 50 keV to 3 MeV, delivering high sensitivity and a rapid response time of under one second. Capable of detecting even minor variations in X and gamma radiation at levels as low as 0.01 $\mu\text{Sv/h}$, this sensor's compact form factor and exceptional performance make it ideal for use in portable devices, such as portable monitors, providing real-time or near-real-time measurements of gamma and X radiation. Refer to Table 1 for detailed specifications

The scintillation material used in the sensor is a cesium iodide (CsI) crystal. When gamma or X rays interact with the CsI crystal, the energy is transferred to the scintillator, causing it to emit light (photons). The emitted light's intensity is directly proportional to the energy of the incoming gamma or X rays, with each interaction generating a flash of green light. Within a radiation field, the photons excite the CsI crystal, resulting in the emission of green light, as shown in Figure 1.

Output	A full width at half maximum of appr. 60 μs quasi-Gaussian pulse
Power	2.7V to 3.3V
Bias Voltage	30 V recommended, maximum 50 V
Noise Level	80 mV $\pm$ 15 mV at room temperature
Energy Detection Range	50 keV ~ 3 MeV
Response Time	1 sec.
Signal Amplitude	0.9V+0.1 V @ 662 keV
Detection Efficiency	25,000 + 20% count/uSv @ 662 keV
Static Current	< 600 μA @ 3.3 V
Power consumption	less than 2mW @3V power supply
Working Temperature	-20°C ~ 50°C
Lifespan	5 years
Upper Limit of Measurable Dose Rate	20 mRem/h
Machanical Structure	45mm x 24mm x 18mm
Electric Connector	4-lines cable with 4-pin MOLEX PicoBlade 1.25mm (0.49") conector (Part No.51021-0400)

Table 1 Specifications

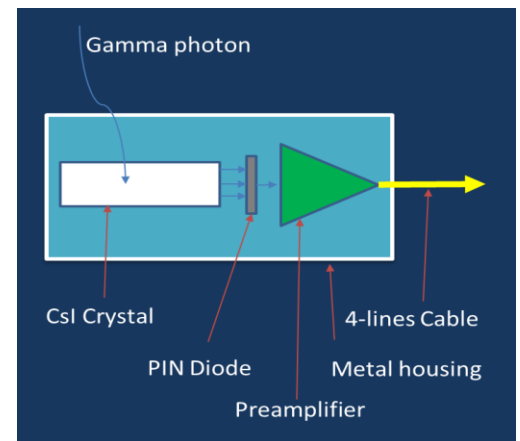


Figure 1 3cc Gamma sensor principal

The process of output formation unfolds through the following steps:

- Gamma photons within the radiation field promptly excite the CsI crystal, causing it to emit green light.
- The emitted green light passes through the crystal's output window and enters the PIN diode, where it generates a light current.

- This light current is then received by the preamplifier, which, using its semi-Gaussian shaping circuits, converts the current into a pulse wave.
- These pulse waves are subsequently transmitted to additional circuits for further processing.

It is important to note that not all output pulses are a result of gamma photon interactions. Noise output pulses can arise from the dark current noise of the PIN diode or the electronic circuits within the preamplifier. Moreover, external factors such as strong electromagnetic radiation or mechanical vibrations may contribute to noise outputs. Fluctuations in the preamplifier's power supply can also produce noise pulses.

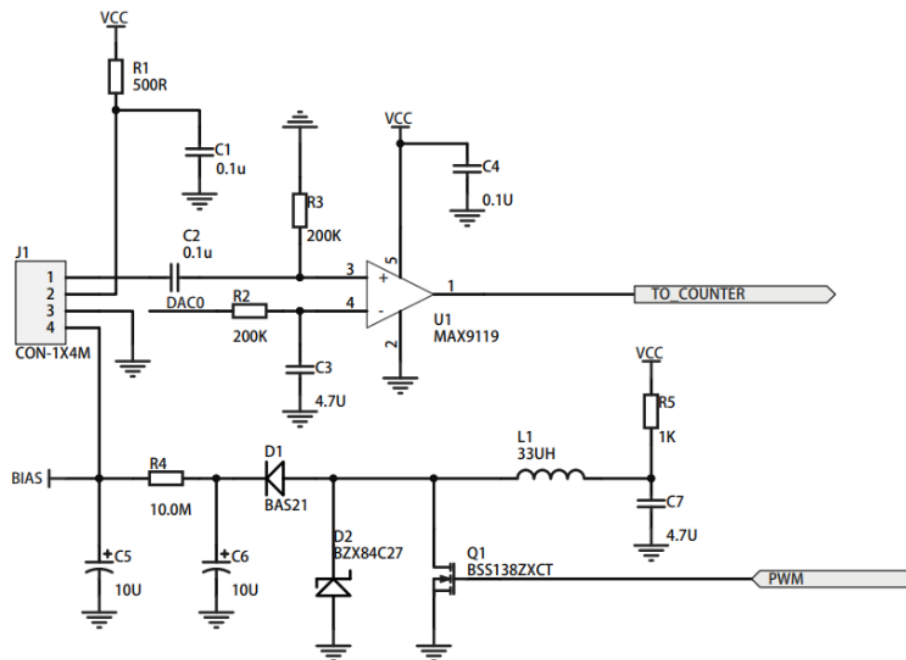


Figure 2 3cc Gamma sensor recommended Schematic

2. Recommended Schematic for Interfacing with the 3cc Gamma Sensor

Figure 2 above illustrates the circuit connecting the gamma sensor to the MCU. J1 represents the MOLEX connector for the gamma sensor. Detailed information about the connector pin signals can be found in the specifications in Table 1. The circuit is divided into the following two blocks:

- The upper section, consisting mainly of U1, R4, and C3, serves as a noise discriminator. The negative pin (pin 4) of U1 is connected to DAC0, generated from the MCU's internal DAC output. This needs to be adjusted in response to environmental temperature changes, meaning that devices using the gamma sensor for radiation measurement should monitor the ambient temperature. Calibration of the DAC0 value based on temperature is necessary before application. The output of U1 can be directly connected to the MCU's pin for counting.

- The lower part is called pump power source builder, including Q1, L1, D1, C5, R5, C4. They form a complete pump power supply source system. The input PWM comes from MCU's pulse width with the form of 2k to 4kHz sine wave. D2 limits the output bias to 27V.

3. Calibrations

The 3cc Gamma sensor is not recommended for dose measurement but is better suited for monitoring environmental radiation intensity. Typically, the sensor's output pulse counting rate is used to determine radiation intensity. However, a second-degree polynomial should be applied to accurately correlate the pulse counting rate with radiation intensity. The formula is $I = A \times R^2 + B \times R + C$, where I represents radiation intensity, R is the sensor's output counting rate, and A , B , and C are coefficients that must be determined through calibration. This calibration requires professional equipment capable of generating different radiation fields.

Another necessary calibration is for DAC0 (as mentioned in the previous page in the discriminator circuit). The relationship can be expressed using a second-degree polynomial formula: $\text{DAC0 value} = A \times T^2 + B \times T + C$, where T represents the environmental temperature, and A , B , and C are calibration coefficients. This calibration can be performed at the manufacturing facility of the device.

For intensity calibration, at least three intensity points are required to determine the A , B , and C coefficients. The recommended points are as follows:

- 100 $\mu\text{rem/h}$ (low intensity),
- 5000 $\mu\text{rem/h}$ (medium intensity),
- 12000 $\mu\text{rem/h}$ (high intensity).

All of these radiation fields can be generated using a Cs-137 source.

For DAC0 calibration, at least three temperature points are also necessary. The recommended temperature points are:

- -10°C , as the low-temperature point
- 20°C , as the middle-temperature point
- 45°C , as the high-temperature point

This calibration does not require a radiation source and can be performed in a natural environment. To carry out the calibration, place the device at each of the three temperatures and adjust DAC0 to ensure the displayed intensity is between 10 and 13 $\mu\text{rem/h}$ (China), 6 and 8 $\mu\text{rem/h}$ (USA), or matches the local environmental radiation intensity.

Calibrations should only be performed once during the device's lifetime at the factory, unless additional user management requirements necessitate otherwise.

In general, the precision for radiation intensity measurements is $\pm 30\%$. It is important to complete the DAC temperature calibration prior to the intensity calibration.

4. Questions and Answers

- Q1: What conditions should be maintained to ensure the 3cc Gamma sensor remains within its effective operational range?
- A1: The 3cc Gamma sensor 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.
- A2: What is maximum capacitance inside the Gamma sensor?
- Q2: The maximum capacitance of the entire circuit is unknown, but the largest individual capacitor is 4.7 μ F (on power supply area), with only one present. All other capacitors are in the nanofarad range, making the total capacitance less than 5 μ F.
- A3: What is maximum inductance inside the Gamma sensor?
- Q3: There is no inductance for the entire circuit.
- Q4: In the recommended schematic for the 3cc Gamma sensor, are there any guidelines for setting the DAC0 reference to the comparator?
- A4: According to the datasheet, the noise level is approximately 80 mV. Therefore, the DAC0 setpoint should be configured around 80 mV to match this threshold.
- Q5: What are the power consumption, current profile, and absolute maximum electrical ratings?
- A5: • The static current is approximately 600 μ A, with an operating voltage range of 2.7–3.3 V. Based on this, the typical power consumption is around 2 mW.
• As pulse counting increases (i.e., as more pulses are detected), power consumption rises accordingly. The current may increase slightly, reaching up to approximately 1 mA from the static current of 600 μ A.
• The absolute maximum voltage rating is 5 V. However, the sensor does not function correctly within the voltage range of 3.7–5 V.
- Q6: Do you have an example of the PWM drive signal to Q1, and does the PWM duty cycle need to be adjusted during operation?
- A6: The PWM duty cycle is 1:1, and its frequency is approximately 2kHz. This specification does not require dynamic adjustment during application.
- Q7: What ADC/DAC resolution should be used for the temperature measurement and DAC0 output? Is 8-bit sufficient?
- A7: An 8-bit ADC is sufficient for temperature measurement. DAC0, however, requires a 12-bit resolution. An 8-bit ADC can produce 256 discrete levels (since $2^8 = 256$), which means it can measure the temperature in 256 different steps or levels. This resolution might be adequate for temperature measurement in many applications, depending on how precise the measurements is required.

Q8: Will the recommended specifications for inductor L1 affect the performance of the boost circuit?

A8: L1 is a coil-type inductor that generates minimal noise.

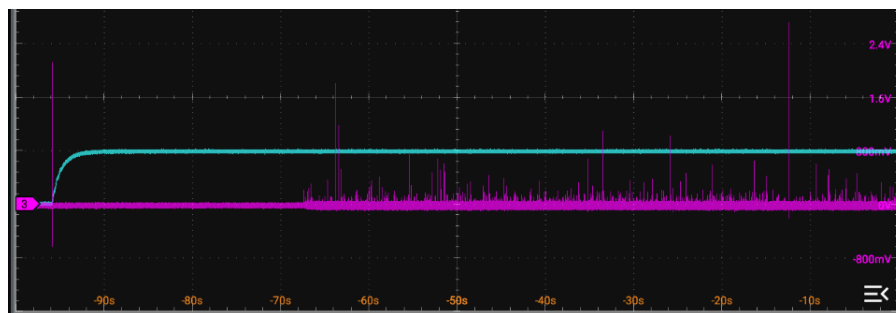
Q9: Will the recommended specifications for inductor L1 affect performance of the boost circuit?

A9: In this circuit, L1 works in conjunction with the transistor (Q1) and other components to form boost converter. The inductor temporarily stores energy as a magnetic field when Q1 is conducting and then releases this energy to the load when Q1 turns off. This process "boosts" the voltage to a higher level. Noise (EMI or switching noise) from the inductor can affect the stability of the circuit, cause signal distortion, or create issues in other parts of the system, which ensures the circuit runs efficiently and without significant electromagnetic interference. The recommended specifications for L1 (inductor) are crucial for the boost circuit's performance. An inductor with appropriate inductance, current-handling capability and low noise characteristics ensures efficient energy transfer, stable voltage output, and minimal interference, which are all essential for the reliable operation of the circuit.

Q10: What is the expected turn-on time for the boost circuit, and should measurements be delayed until the 27V has stabilized? The R5 and C4 components form a long time constant, causing the BIAS voltage at pin 4 to rise slowly toward 27V.

A10: Yes, the bias voltage requires a significant amount of time to stabilize. Since this bias directly affects the photodiode in the sensor, any ripple or instability can introduce noise into the sensor's output. Allowing sufficient time for the bias to fully settle helps minimize such noise and ensures more accurate measurements.

Q11: 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?



A11: 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.

Q12: Is counting the number of pulses within a defined time interval sufficient to determine radiation intensity, or are additional processing steps required?

- A12: Yes, pulse count within a set period is directly proportional to radiation intensity, the more pulses detected, the higher the intensity. No additional processing is typically required for basic intensity estimation.
- Q13: Is there a specific timing or filtering algorithm recommended for handling quasi-Gaussian pulses?
- A13: A 200 ms window is recommended for pulse detection, followed by a 1 to 2-second interval for averaging.
- 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: Pulses may overlap and the sensor will lose counts of pulses. The firmware should show "Saturation". After 30 seconds the sensor's response to radiation starts stable.
- Q15: Does the adjustment of bias voltage affect gamma sensor sensitivity?
- A15: The adjustment of bias voltage does not impact the sensitivity of gamma sensors. However, it can influence the amplitude of sensor noise.
- Q16: Does temperature affect SemeaTech gamma sensor outputs? If yes, what is the calibration procedure?
- A16: 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 the 3cc Gamma sensor. As the temperature increases, these variations become more pronounced. For instance, one gamma sensor may register 100 pulses to indicate 30 μ 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.

- Q17: What is the typical output bias without any interaction with a radioactive source when following the recommended circuit?
- A17: The sensor's output signal is not centered around zero volts; It has a constant voltage offset. DC bias could be due to the way the sensor is designed or due to inherent properties of the sensor's internal electronics. It's essentially a constant voltage that shifts the signal away from zero volts. It's recommended to use blocking capacitors (MAX9119) between sensor output and following circuits. Many circuits (like amplifiers or ADCs) might only care about the fluctuations in the signal (the AC component), not the constant DC level. By using a blocking capacitor, DC bias can be effectively removed, ensuring that only the useful, changing signal is sent to the following circuits. The comparator could be used to process the signal after the DC bias has been removed by the blocking capacitor. It helps to convert the AC signal into a binary output, which is easier to process in digital circuits.
- Q18: How can the quadratic function ($aX^2 + bX + C$) be explained in the context of gamma sensors?
- A18: 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.

Q19: How to explain gamma sensors' linear regression?

A19: 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.

Q20: Is there a "Dead Time" associated with the gamma sensor?

A20: 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 $\pm 30\%$.

Q21: What do CPS and FWHM mean?

A21: 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.