Why shot noise in LGAD does not degrade time resolution?

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Why shot noise in LGAD does not degrade time resolution?

Time resolution in LGAD is determined by jitter and charge non uniformity:

\[ \sigma_t^2 = \left( \frac{N}{dV/dt} \right)^2 + \sigma_{Landau Noise}^2 \]

The jitter term contains electronic noise and shot noise:

\[ \text{Jitter} = \sqrt{N_{el}^2 + N_{Shot Noise}^2} \]
Measure quantities:
1. **Total current** (guard ring plus sensor)
2. **Noise** due to the current from the sensor
The shot noise $\sigma_{\text{Shot Noise}}^2$ is the sum of two terms: current that is multiplied (bulk current) and current that is not multiplied (surface current):

$$\sigma_{\text{Surface}}^2 (\text{no gain}) = 2qI_{\text{surface}} \times BW$$

$$\sigma_{\text{Bulk}}^2 (\text{gain}) = 2qI_{\text{bulk}} \times G^2 \times F \times BW$$

$$\sigma_{\text{Shot Noise}}^2 = \sigma_{\text{Bulk}}^2 + \sigma_{\text{Surface}}^2$$
Noise increase as a function of fluence and gain

Who is generating the noise that we see?

Data and model look similar.
Shot noise from bulk current or surface current

Two possibilities: 1) noise from surface current or 2) noise from bulk current

1) If the total current is surface current:

\[ \sigma_{\text{Shot Noise}} \sim \sigma_{\text{Surface}} \propto \sqrt{I} \]

Not a good model

2) If the total current is bulk current:

\[ \sigma_{\text{Shot Noise}} \sim \sigma_{\text{Bulk}} \propto G\sqrt{I} \]

Almost a good model

Conclusion: the noise is dominated by bulk current
Noise as a tool to measure bulk current

Who is generating the bulk shot noise that we measure?

1) The whole measured current is bulk current

\[ \text{Noise} = \sqrt{2q I_{\text{measured}} \times G \times F \times BW} \]

→ would generate too much noise

2) Bulk current due to irradiation

\[ I_{\text{bulk}} = \alpha \times V \times \phi \]

\[ \text{Noise} = \sqrt{2q I_{\text{bulk}} \times G^2 \times F \times BW} \]

→ Found compatible noise value

Noise indicates the amount of bulk current is compatible with theoretical values from fluence
The role of the excess noise factor

Calculated Shot noise
FBK 55-micron sensors

- W6 4R NEU 8E14 -20C
- W6 4R NEU 8E14 -20C (F = 1)

Excess noise factor: noise of the multiplication process

\[ F = Gk + \left( 2 - \frac{1}{G} \right) \times (1 - k) \]

Shot noise is actually dominated by the excess noise factor: at gain = 20 the excess noise factor more than doubles the shot noise
The Jitter, instead of decreasing, is becoming constant due to the contribution of the shot noise.

The calculated Jitter from shot noise well reproduces the measured jitter at high gain \( \Rightarrow \text{Calculated bulk current} \sim \text{real bulk current} \)
What is the fraction of bulk current?

Most of the current is not "bulk current"
→ does not generate noise
Conclusion

• Noise increase is driven by bulk current shot noise
• The calculated noise values are within 20% of the measured values
• The shot noise is large only when the gain and the bulk leakage current are high \( \Rightarrow \) not very common
• After irradiation, the gain decreases, and as a unintended consequence, the shot noise stays small.
• The values of shot noise are below the Landau noise
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