Wide Bandgap – Wide Bandwith?

Thoughts about multi-Ghz readouts for thin WBG sensors

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HEPHY
24th January 2024

Contents

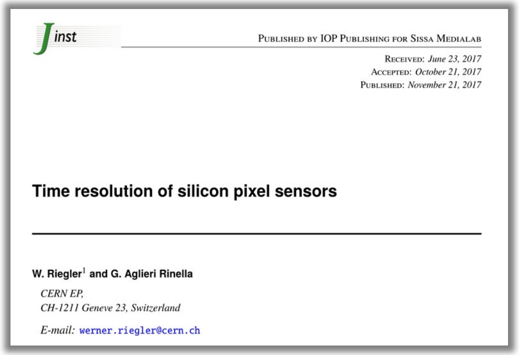
- Theoretical background
- Design considerations for high-BW readouts
- Prototype results from HEPHY

Two Questions

1) For WBG sensors with higher drift velocities than silicon, what is the optimal readout for optimal timing?

2) If we want to apply TCT to thin (< 100 μm) WBG sensors, how can we achieve the required readout bandwidths (irrespective of noise), in order to extract features such μ_e, μ_h ?

Time Resolution



JINST

PUBLISHED BY IOP PUBLISHING FOR SISSA MEDIALAB

RECEIVED: *June 23, 2017*
ACCEPTED: *October 21, 2017*
PUBLISHED: *November 21, 2017*

Time resolution of silicon pixel sensors

W. Riegler[1] **and G. Aglieri Rinella**
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Analytical treatment by Riegler et. al.

Can be minimized

$(1/f_{sample})$ / √12
Negligible for fast oscilloscopes or can use interpolation

$$\sigma_t^2 = \sigma_{\text{Jitter}}^2 + \sigma_{\text{Ionization}}^2 + \sigma_{\text{Distortion}}^2 + \sigma_{\text{TDC}}^2$$

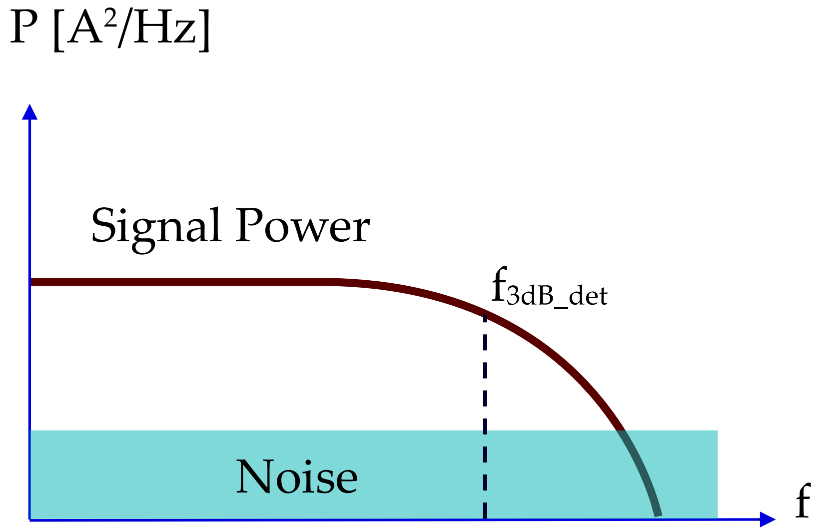
Very sensitive to readout electronics!

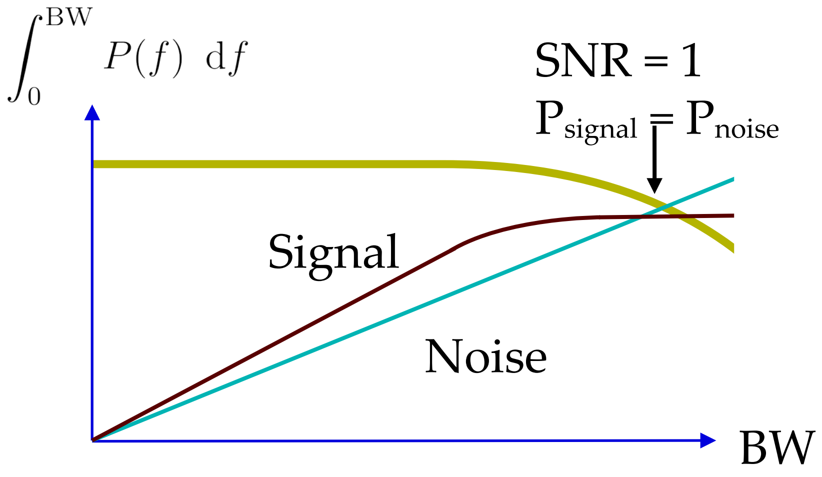
$$\sigma_{\text{Jitter}} = \frac{N}{dV/dt} \approx \frac{t_r}{S/N}$$

Decreases monotonically for thinner detectors and high drift velocities

SNR vs Bandwidth

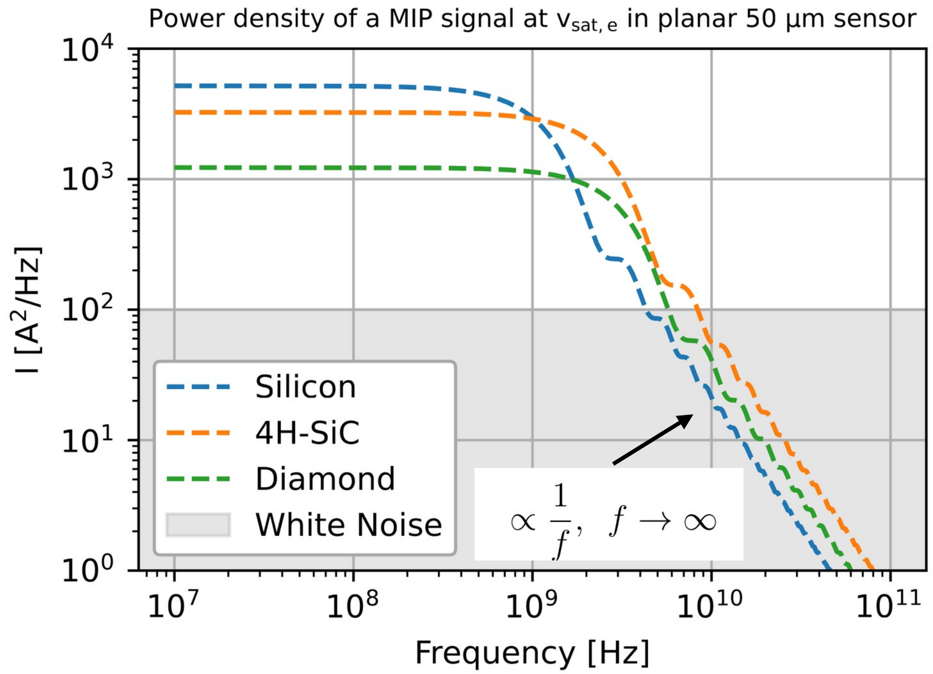
- For white noise, the SNR is constant with frequency, up to the detector signal frequency cutoff
- After the limit of detector bandwidth, the SNR drops below 1

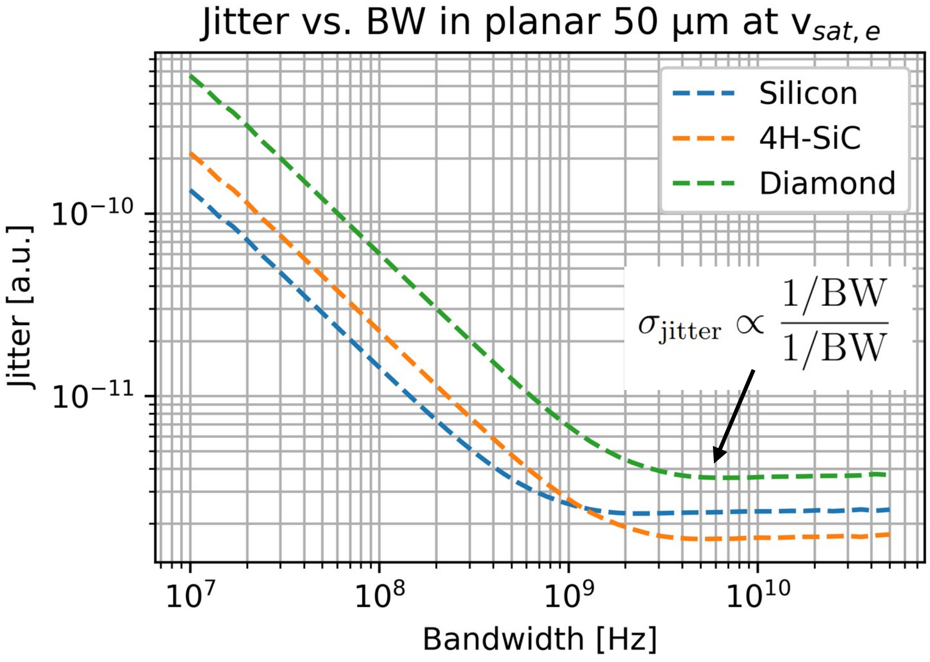




Jitter vs Bandwidth

- Toy model for planar sensors, $v_e = v_h = v_{sat}$, see 2nd DRD3 Week
- In the limit of high frequencies, jitter is constant (rise time grows as fast as SNR is decreasing)





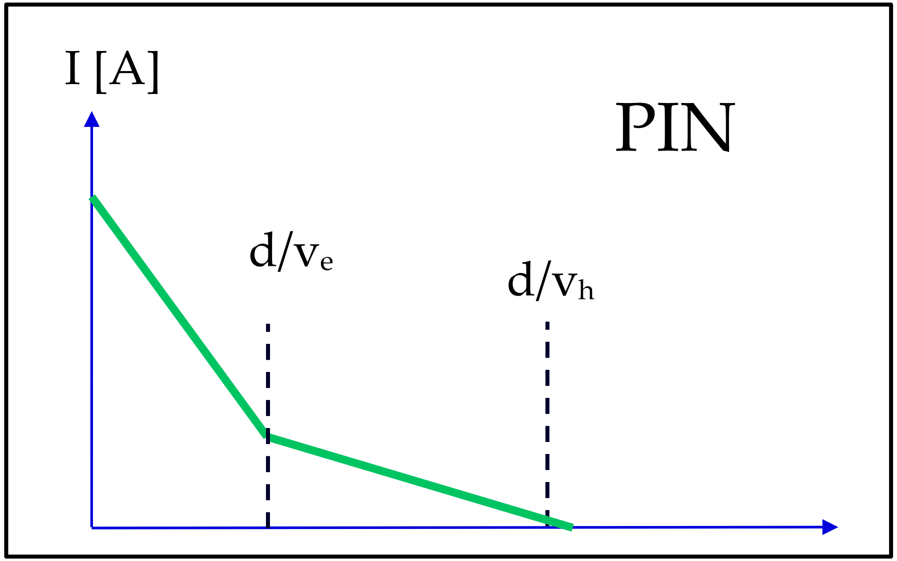
Assuming power SNR, not amplitude SNR

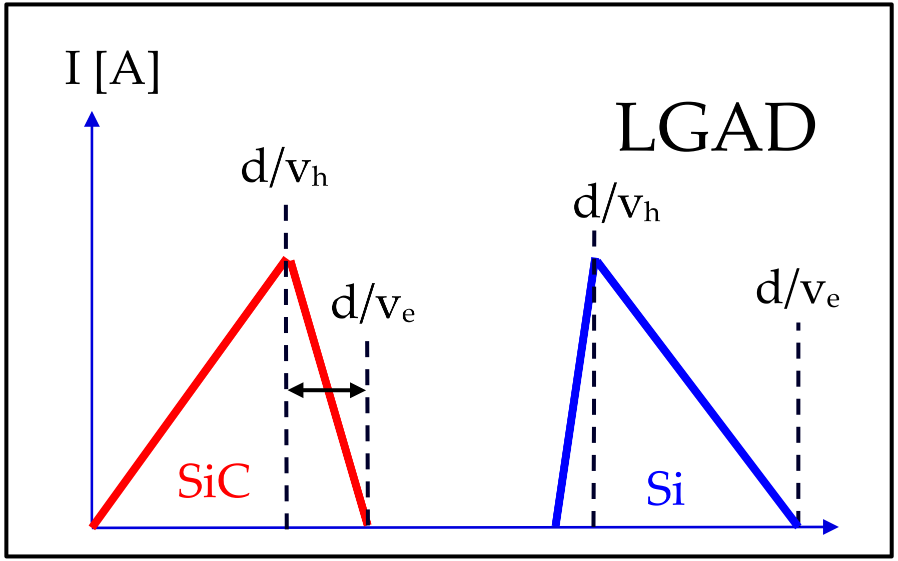
WBG PIN and LGADs

- In PIN devices : maximum current at t = 0
- For LGADs, maximum current after charge carrier drift to gain layer
- For 4H-SiC : n-type, hole multiplication
- P-LGAD : p-type, electron multiplication

$$f_{signal} \propto v_{e,h} / d$$

Diamond , SiC : $v_e = 2 \times v_{e(Si)}$





Detector thickness d, $V_e > v_h$

WBG Readouts

Timing readout (2-3 GHz):

- Minimal noise
- Rather small, low-power components to allow for multi-channel readout
- Waveforms can be shaped or (optimally) filtered, waveform shape is irrelevant

TCT readout (> 5 GHz)

- Noise can be much higher (averaging laser signals, large charge depositions, i.e. alpha source)
- Single or a few channels (can use large, power-hungry components)
- Want constant gain and impedances up to multiple GHz to be able to reconstruct signal shape

Future Readouts

Timing readout (2-3 GHz):

- Minimal noise
- Rather small, low-power components to allow for multi-channel readout
- Waveforms can be shaped or (optimally) filtered, waveform shape is irrelevant

TCT readout (> 5 GHz)

- Noise can be much higher (averaging laser signals, large charge depositions, i.e. alpha source)
- Single or a few channels (can use large, power-hungry components)
- Want constant gain and impedances up to multiple GHz to be able to reconstruct signal shape

High BW Readout Recipe

- Using discrete components not really feasible anymore, especially for feedback circuits (parasitics of SMD components)
- Move to MMIC (micro-wave monolothic integrated circuit) amplifiers / ASICs ?
- Keep impedance matched to 50 Ω (or have input impedance < 50 Ω?)

- Minimize detector capacitance and parasitic capacitances
- Take care of AC return path (Vias, etc.)
- Use adequate PCB substrates (Rogers)
- Bondwires as short as possible (and multiple of them $1/L_{tot} = 1/L_1 + 1/L_2 + \dots$)

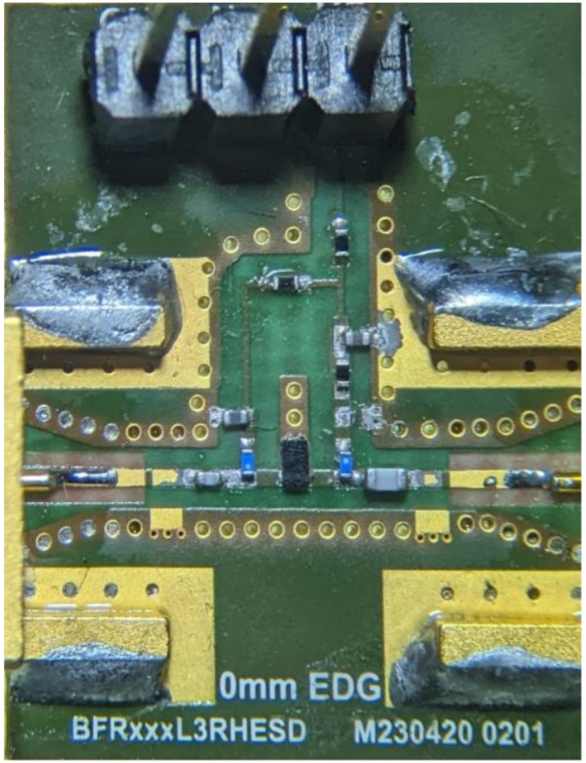
Challenge for WBG : Do all of this for high voltages (≥ 1kV)

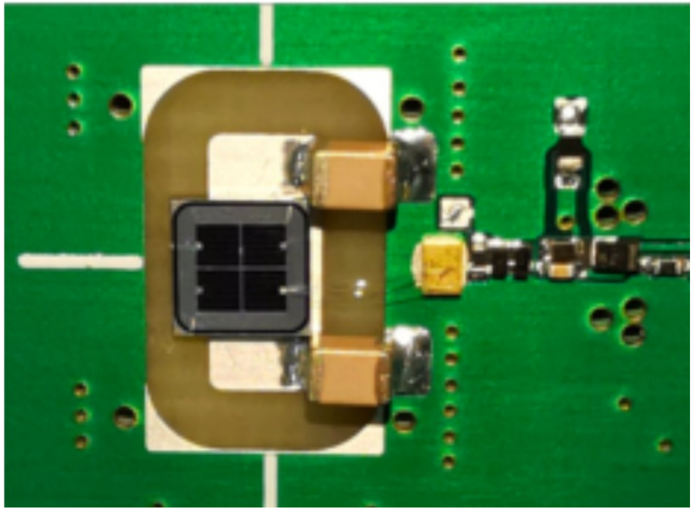
(HV to full deplete sensors and to arrive a v_{sat})

Readout Boards in the Community

- BFR840 based circuit introduced by SCIPP
- Widely used (Chubut board, 2-stage design at UZH)
- Other solutions : Galli amplifiers (FNAL 16ch), Cividec
- All optimized for < 2 GHz

BFR840L3RHESD
Infineon Reference Design

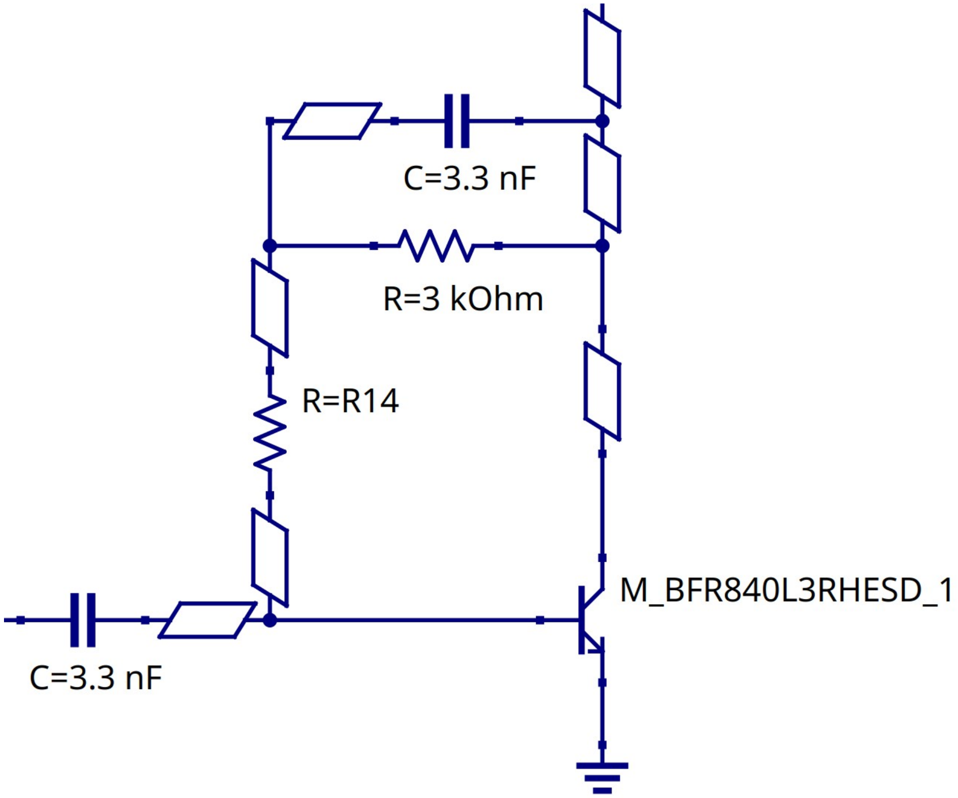




UCSC LGAD board

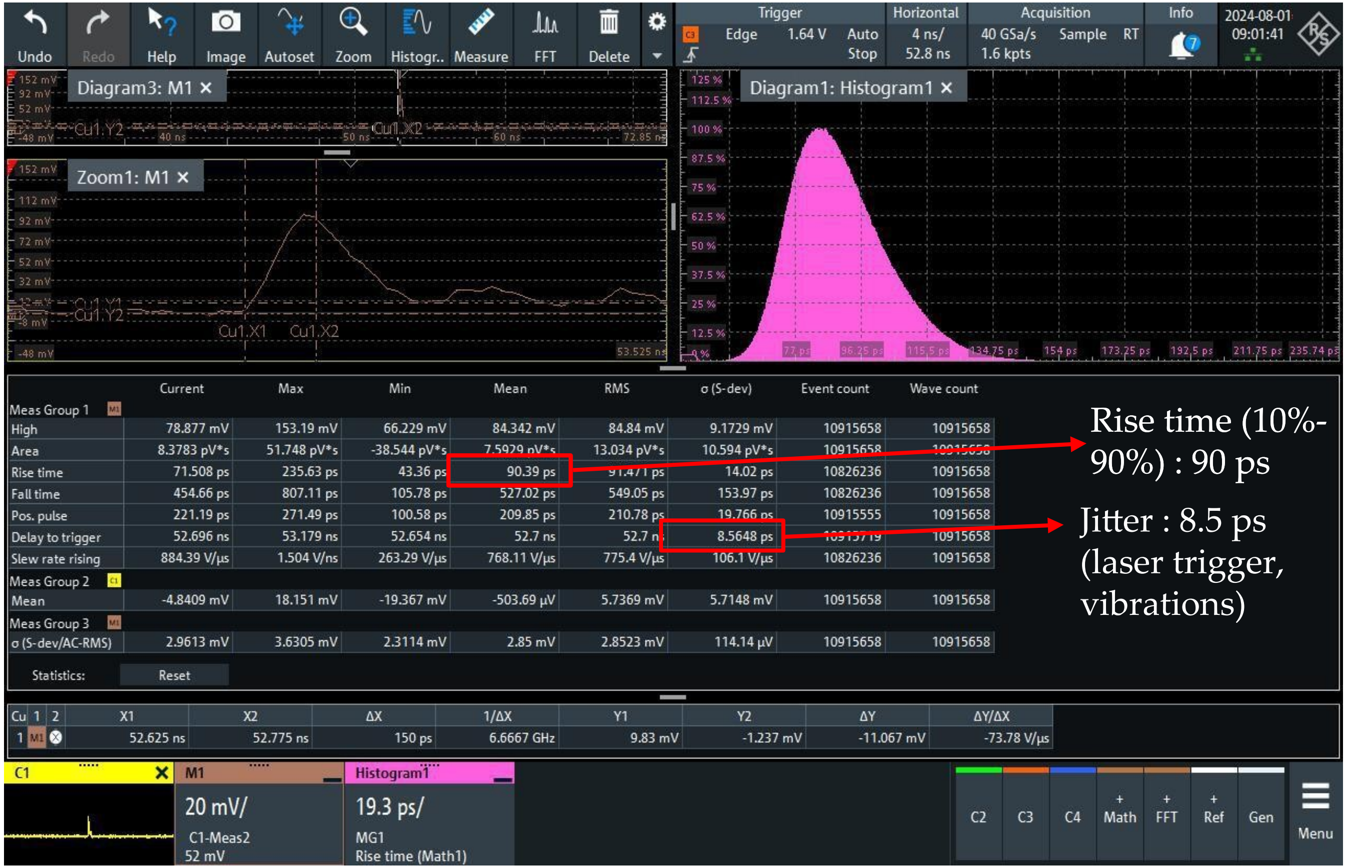
BFR840 Based Readouts

- How far can we go with the BFR840?
- Transimpedance (i.e. gain) and BW determined by feedback resistor R14
- Simply reduce R_{14} and get more BW (with worse SNR)?



UCSC Board Tests

- UCSC board with feedback $R_{14} = 82\ \Omega$
- 4H-SiC detector with $C_{det} = 0.5$ pF, UV-TCT with ~3 ps jitter
- Achieved 90 ps risetime!
- Eqv. BW = 3.9 GHz
- However, oscillations in signal, esp. for $R_{14} < 82\ \Omega$
- Would need a more HF adequate design and HF resistors



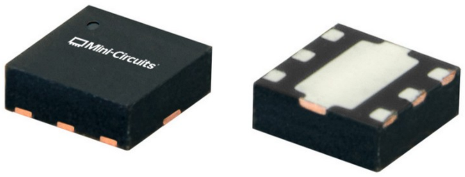
Rise time (10%-90%) : 90 ps

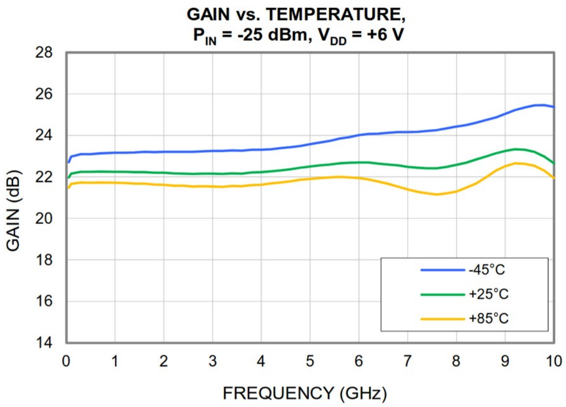
Jitter : 8.5 ps (laser trigger, vibrations)

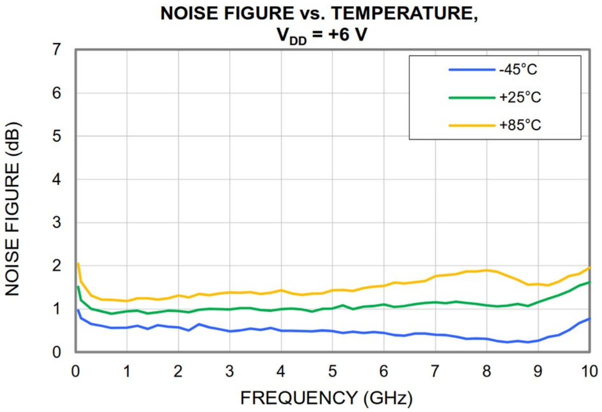
$$1/(2 * \pi * 0.5\ \text{pF} * 82\ \text{Ohm}) = 3.88\ \text{GHz}$$

MMIC Prototype

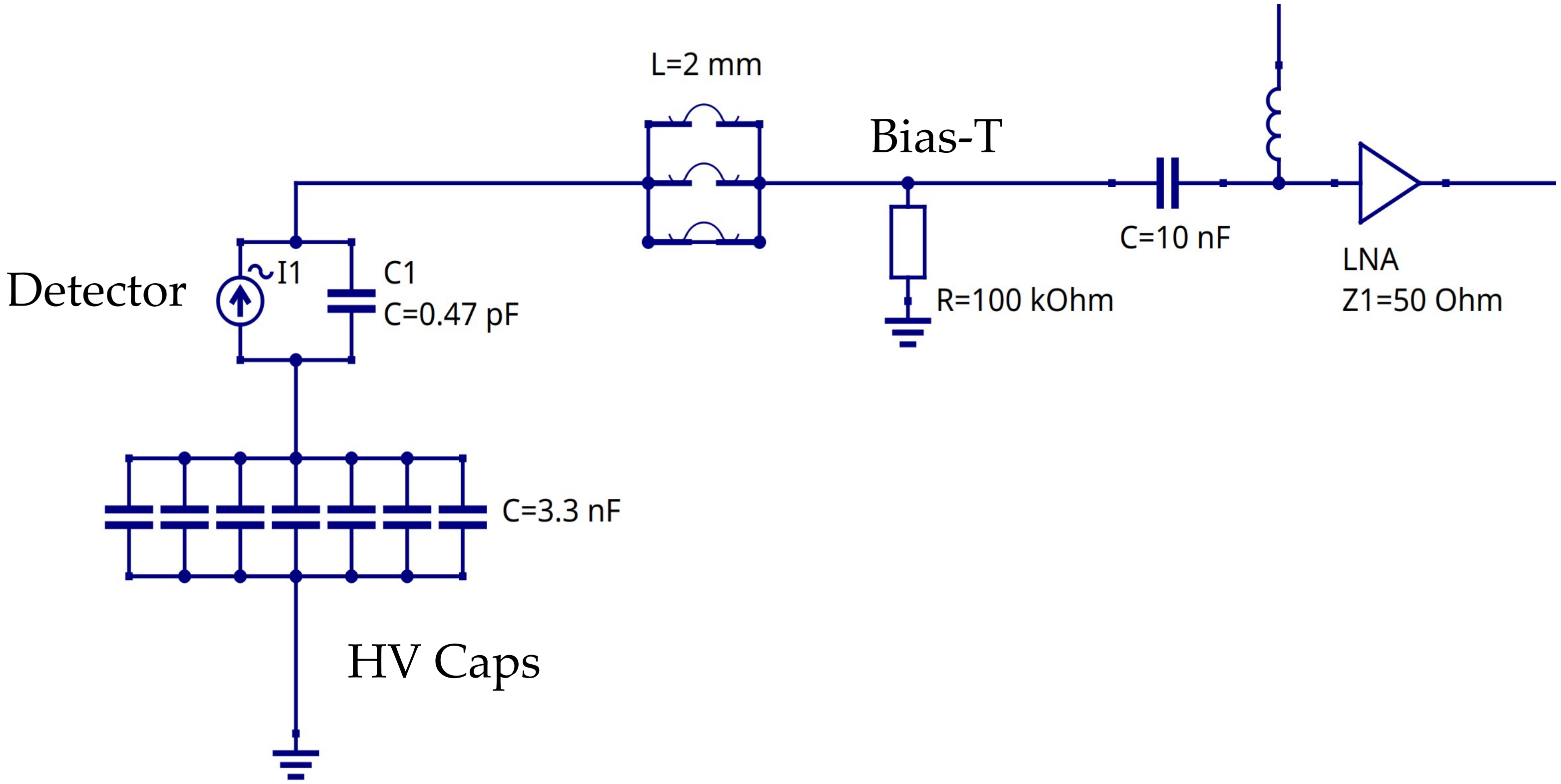
- If the transistor feedback circuit is challenging at high frequencies, why not use an IC / MMIC?
- Treat as a 50 Ω black box
- Wire-bond as directly as possible (bare dies available!)





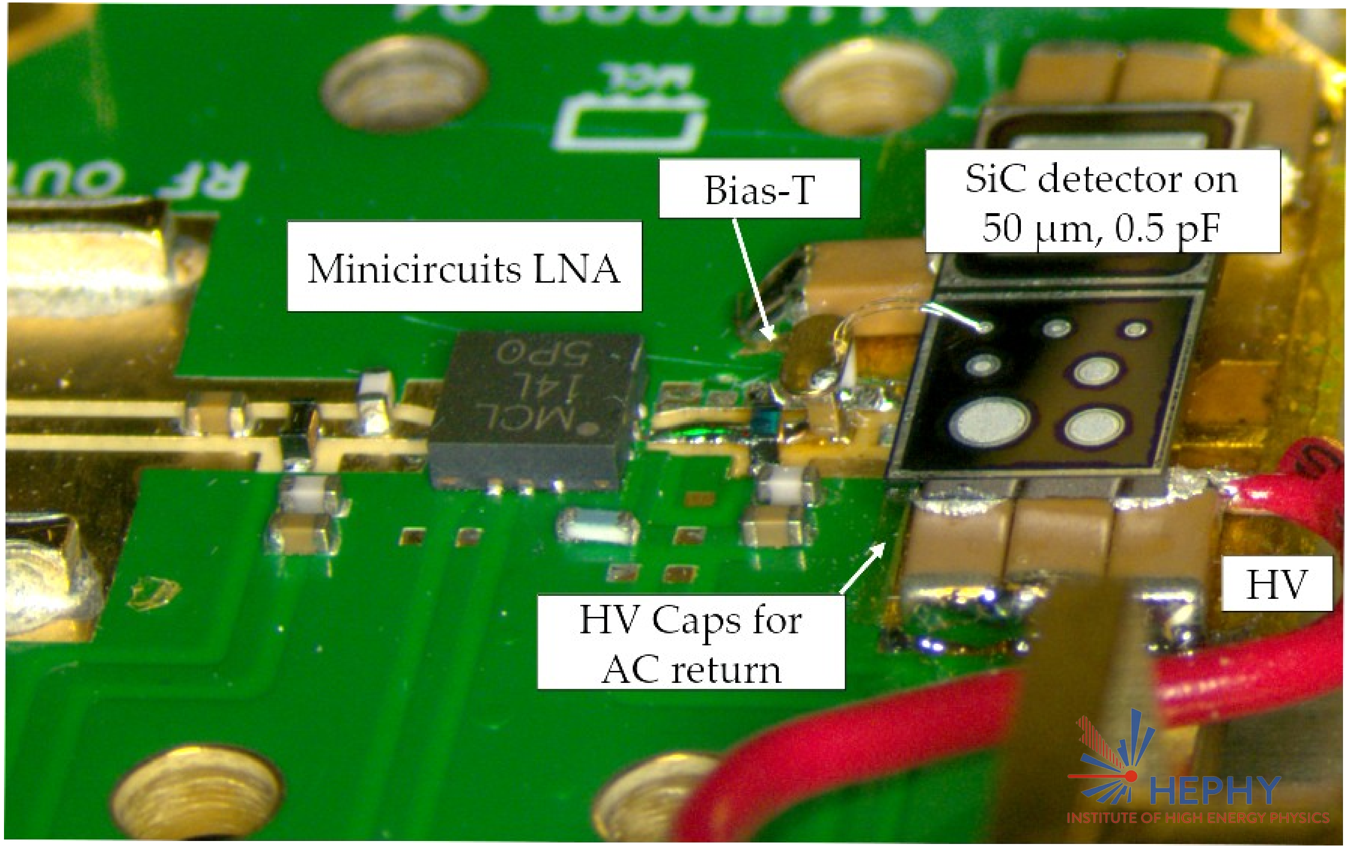


MMIC Prototype Circuit



MMIC-based prototype

- SiC sensor mounted on LNA board (RO4350B)
- Minicircuits LNA
  50 Ω, stable gain up to 10 GHz, NF = 1.1 dB
- RC-bandwidth :
  6.3 GHz
- Bondwires : 3x 2mm



MMIC Prototype Results

- Very fresh results (few hours old)
- UV-TCT laser (370 nm)
- Risetime : 55 ps (~ 6.4 GHz BW)
- Partially limited by laser pulse (45 ps FWHM)
- (Almost) no reflections!

	Current	Max	Min	Mean	RMS	σ (S-dev)	Event count	Wave count
Max	15.253 mV	15.658 mV	14.391 mV	15.117 mV	15.119 mV	235.73 µV	14134	14134
Min	-300.92 µV	-81.192 µV	-528.63 µV	-281.09 µV	287 µV	57.945 µV	14134	14134
Rise time	55.972 ps	60.13 ps	52.295 ps	56.214 ps	56.221 ps	910.18 fs	14134	14134
Fall time	695.83 ps	776.23 ps	650.11 ps	696.27 ps	696.53 ps	18.894 ps	14134	14134
Pos. pulse	437.47 ps	478.54 ps	428.59 ps	451.96 ps	452.02 ps	7.2147 ps	14134	14134
Period	---	---	---	---	---	---	0	14134
Delay	1.0051 ns	3.3784 ns	-1.6128 ns	-86.07 ps	1.2495 ns	1.2465 ns	13452	14134

Next Steps

- Try to extract v_e/v_h from voltage scans / alpha measurements
- Design new PCB to optimize bond wire length
- Test with different low-capacitance sensors
  (small area planar, pixels, 3D sensors)