

Quantum Computer in the Solid State

Sensitivity of an Adiabatic Quantum Flux Parametron

Thomas Ortlepp^{1,2}, Dominik Karolewski¹, Bernhard Schwartz¹, Anna Reinhardt¹, Yuki Yamanashi², Noboyuki Yoshikawa²

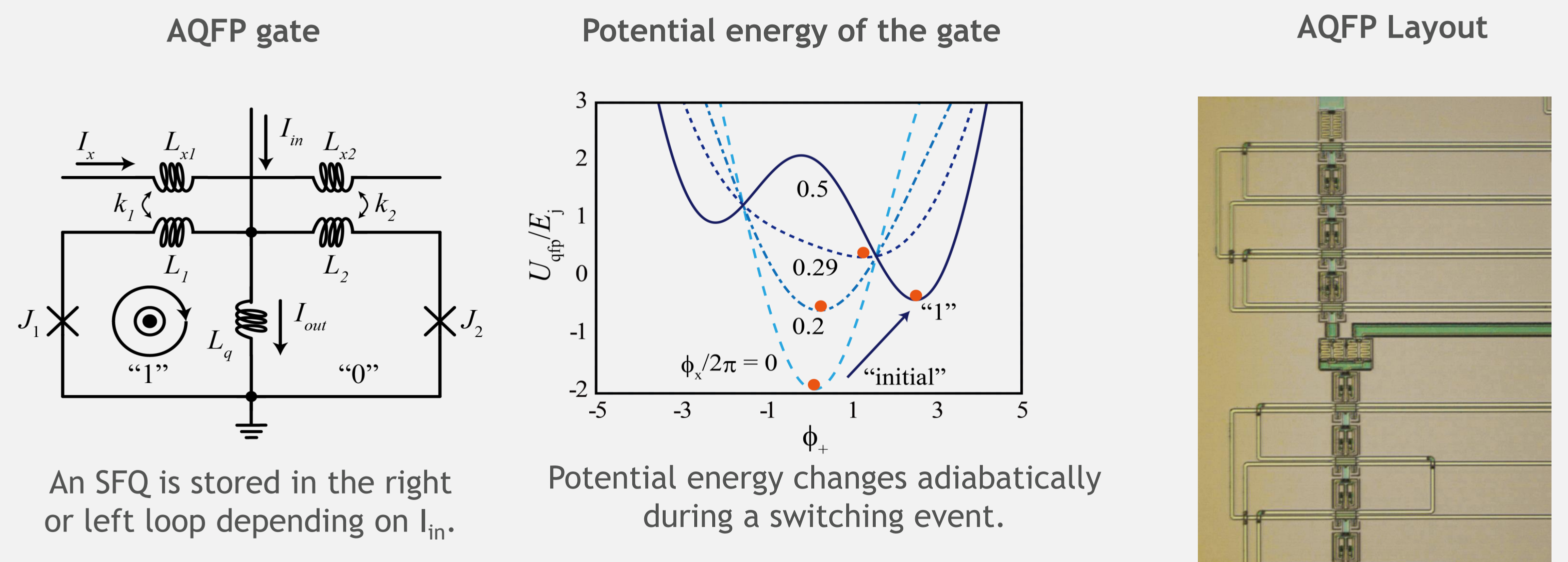
¹ CiS Forschungsinstitut für Mikrosensorik GmbH, ² Institute of Advanced Science, Yokohama National University

What matters in classical computation today? Energy dissipation per operation

Logic	Shift register circuit	Energy Dissipation [aJ/bit-op]	Operation Frequency [GHz]
RSFQ	DFF based	840	50
LV-RSFQ [1]	DFF based	4.0	18
eSFQ [2]	Modified DFF	0.3 - 0.8	20
AQFP [3]	QFL	0.12	5

[1] M. Tanaka et al., Jpn. J. Appl. Phys. 51, 053102 (2012)
 [2] M. H. Volkmann et al., Supercond. Sci. Tech. 26, 015002 (2013), I. Vernik et al. SuST 2014
 [3] N. Takeuchi et al., JOURNAL OF APPLIED PHYSICS, Vol. 115, No. 10, 103910, 2014

Principle operation of Adiabatic Quantum flux parametron

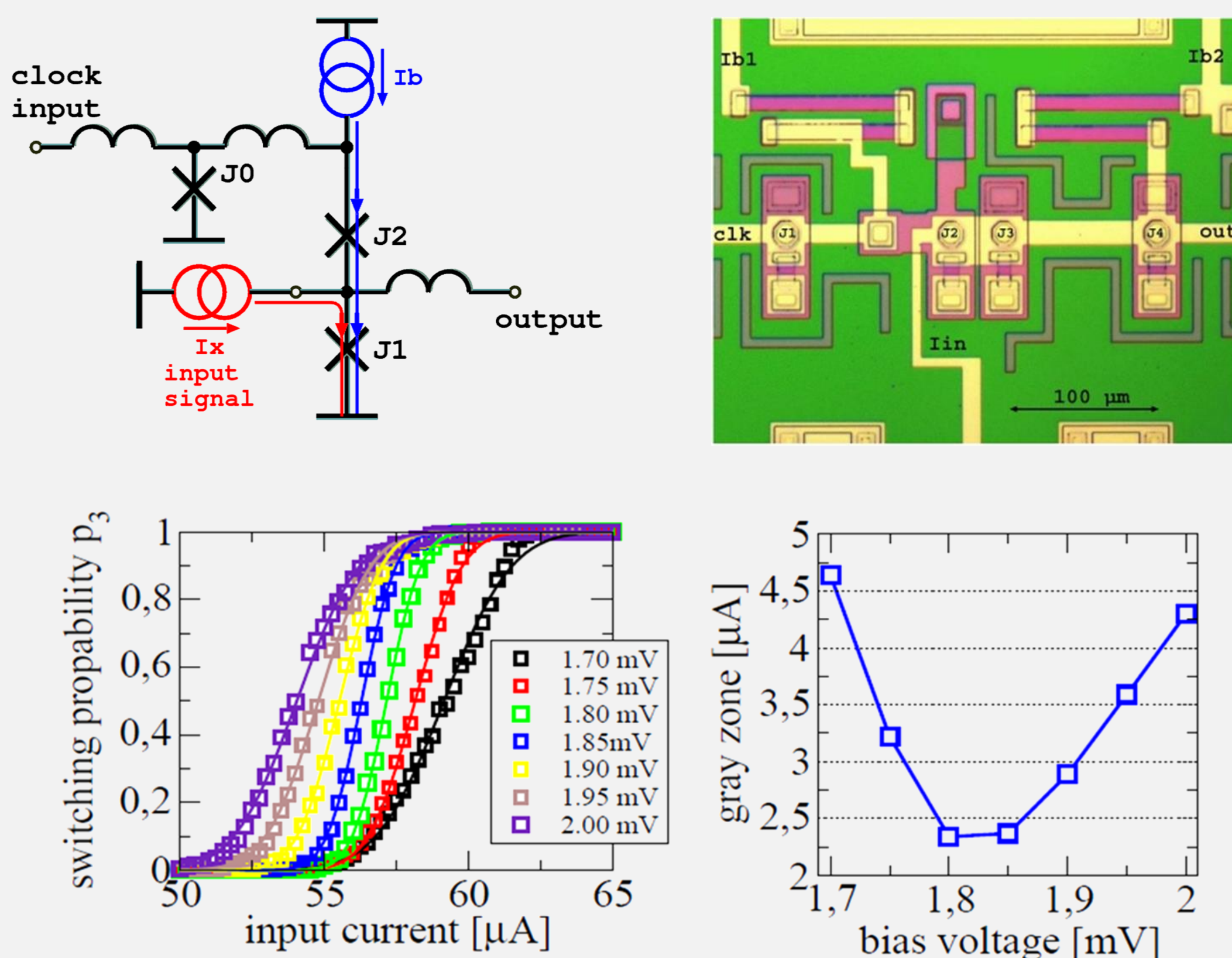


An SFQ is stored in the right or left loop depending on I_{in} .

Potential energy changes adiabatically during a switching event.

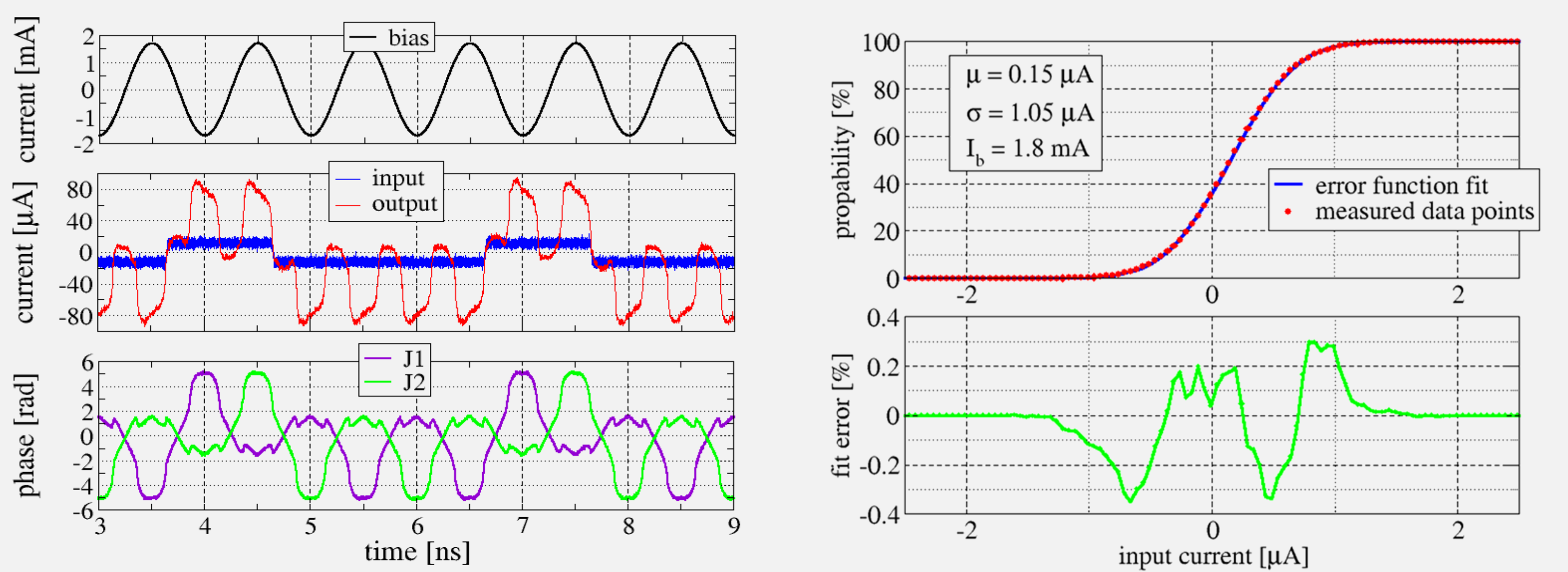
N. Takeuchi, Y. Yamanashi, N. Yoshikawa, Appl. Phys. Lett. 102, 052602 (2013).

Experimental analysis of Josephson comparator

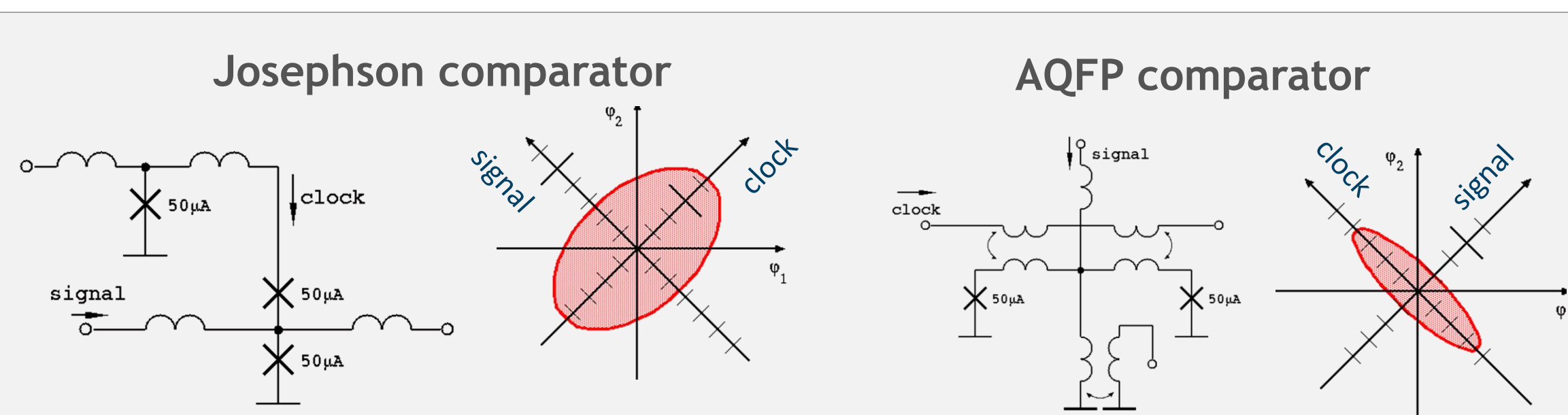


T. Haddad et al., "Experimental analysis of the bias dependent sensitivity of a Josephson comparator", IEEE Transactions on Applied Superconductivity, Vol. 25, No. 3, pp. 1301804 (4pp), 2015

Measured AQFP sensitivity at low speed

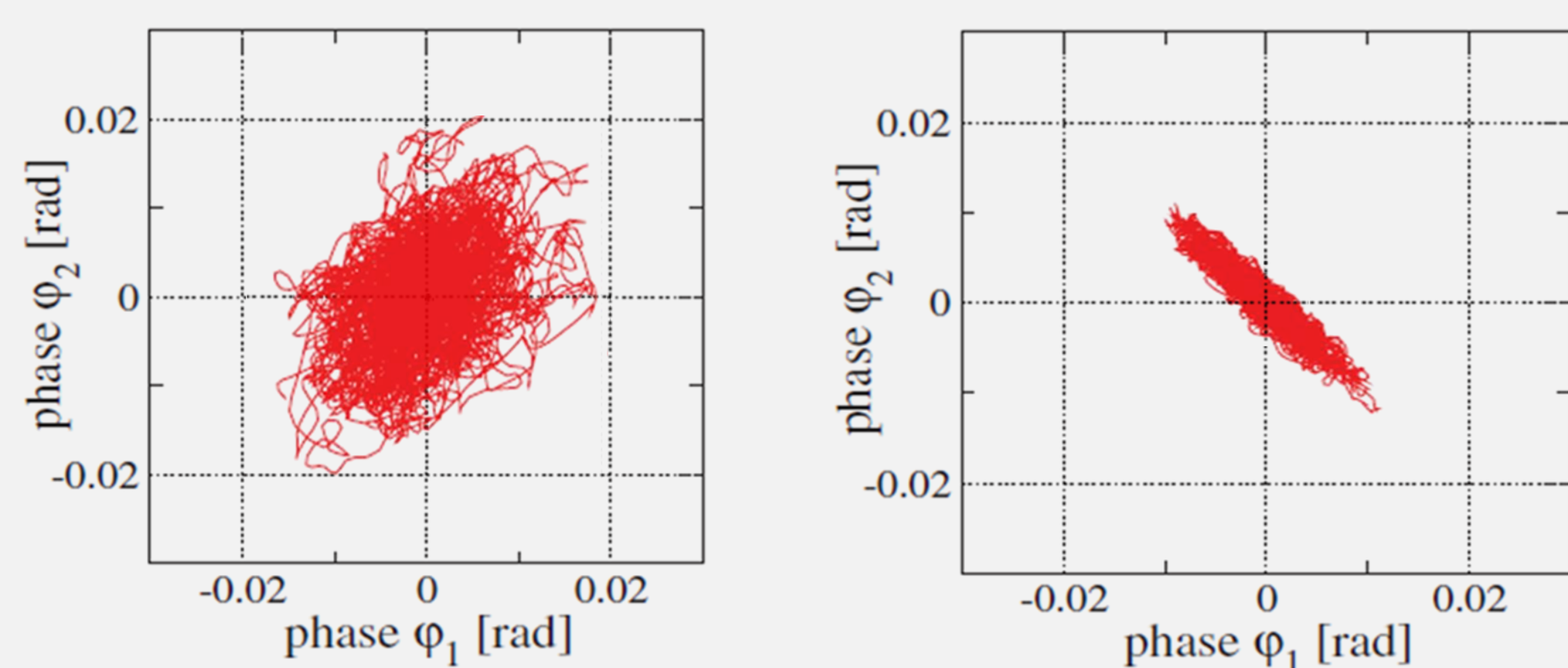


Very good agreement and deviation of less than 1 %



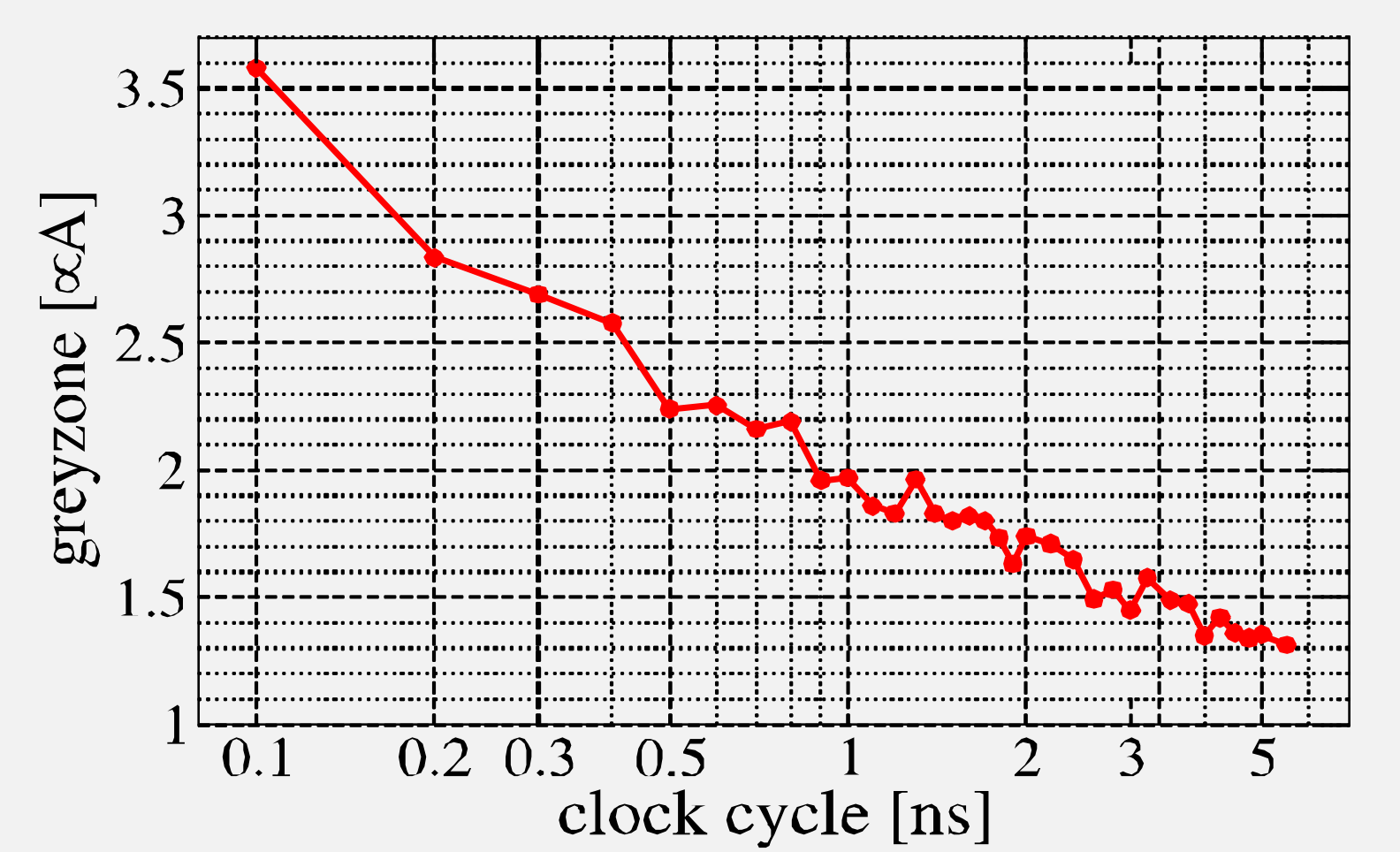
- clock current has same direction for both JJs
- input current is positive for J1 and negative for J2
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- clock current is positive for J1 and negative for J2

Noise driven phase variations depend on the circuit topology.



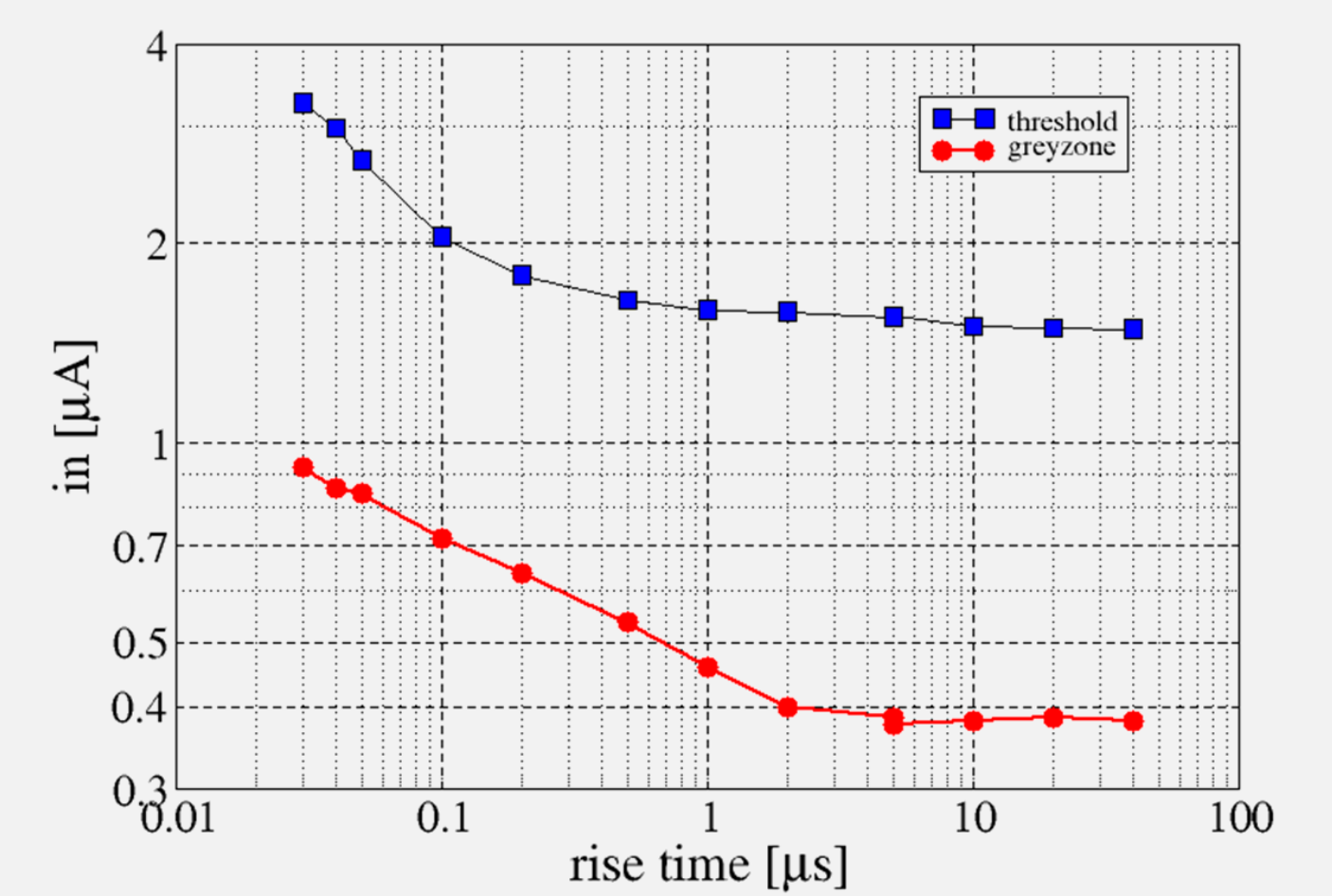
T. Ortlepp, S. Miyajima, H. Toepfer, A. Fujimaki, „Josephson comparator with modified dynamic behaviour for improved sensitivity“, Journal of Applied Physics, Vol. 111, No. 12, 123901 (5pp), 2012

Simulated AQFP sensitivity



20 ns -> 1.08 μ A grayzone slope a = 1.59

Measured AQFP sensitivity vs. rise time



20 ns -> grayzone = 1 μ A slope a = 1.56

Conclusion

- The minimum measured grayzone is about 0.38 μ A @ liquid helium.
- The grayzone is not influenced by the excitation bias.
- Experimental data enables excellent error function fit.
- The dependence on the rise time is confirmed by simulation. Same slope is obtained. This is a typical white noise dependence on effective bandwidth.
- Very robust operation for $I_c=50 \mu$ A and input current of 5 μ A
- Extrapolated bit error rate < 10^{-15} for maximum fan-out of four