Pulsed-assisted escape from zero voltage state in Josephson systems

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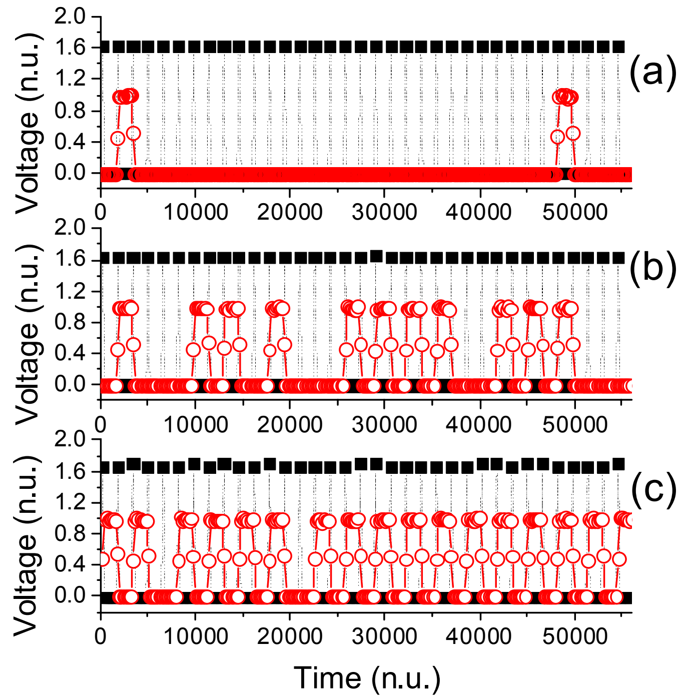

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Non Equilibrium phenomena

Non-equilibrium phenomena in Josephson junctions are among the most promising candidates for novel applications of superconducting electronics. Transistor-like devices [1], integration with fast optoelectronic devices [2,3], and finally bi-stable devices [4] have been recently developed.
In this poster we present numerical results on the behavior of a current biased Josephson Junction (JJ) under the influence of an electronic current pulse injected both directly in the junction via its bias current and from a second JJ forming a double tunnel junction stacked device.
We study the passage from the zero voltage state to the dissipative state produced by injected electronic pulses which have also the possibility of resetting, i.e., the pulse assisted return to zero voltage.

Two configurations studied

Single junction:

$$-\partial\varphi_{xx}+\partial\varphi_{tt}+\alpha\partial\varphi_{t}+\sin\varphi=\gamma_{B}+\gamma_{N}(x,t)+\gamma_{P}(x,t)$$

Stacked junctions [4]:

$$\varepsilon\partial_{xx}\varphi-\partial_{xx}\psi+\partial_{tt}\psi+\alpha\partial_{t}\psi+\sin\psi+\gamma_{P}(x,t)+\gamma_{N}(x,t)=0$$

$$\varepsilon\partial_{xx}\psi-\partial_{xx}\varphi+\partial_{tt}\varphi+\alpha\partial_{t}\varphi+\sin\varphi+\gamma_{B}+\gamma_{N}(x,t)=0$$

With times normalized to ω_J the plasma frequency and lengths to Josephson legth λ_J, α the normalized losses, γ_B a fixed bias current, $\gamma_N(x,t)$ a white Gaussian noise at 4.2 K(cf. ref.[5])

Pulse Modeling

$$\gamma_P(x,t) = \begin{cases} 2\Gamma\left(\dfrac{x}{l}\right)\left(\dfrac{t}{T}\right) & for\ 0 \le t \le \dfrac{T}{2} \\ 2\Gamma\left(\dfrac{x}{l}\right)\left(1-\dfrac{t}{T}\right) & for\ \dfrac{T}{2} \le t \le T \\ 0 & for\ T \le t \le T_p \end{cases}$$

The term $\gamma_P(x,t)$ corresponds to a pulse train of triangular pulses in time and linear in space along the Junctions.
For longest junctions the linear space shape is substituted by a peaked function near one of junction boundaries.

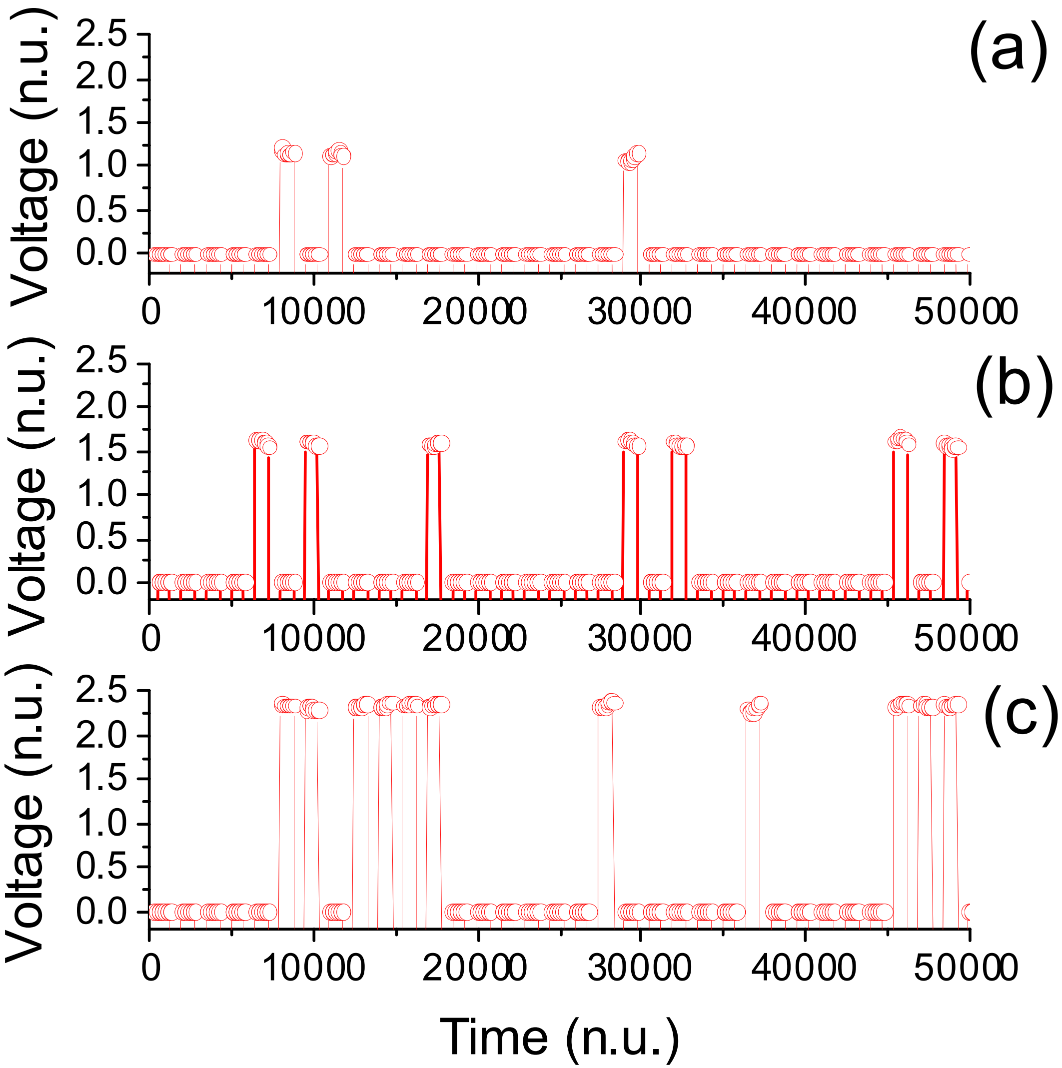
Escape rate evaluation

Simulations also show that increasing the temperature will smear the set on of transition to resistive state in bias current in both single and stacked configurations. This is very reminiscent of thermal escape from zero voltage in small or long junctions [5,9].
Pulses increase the energy of the Josephson oscillations causing a thermal escape toward resistive state.
If this is true the escape rate would depends exponentially on bias current and temperature, i.e.,

$$\Pi=(\omega_J/2\pi)\exp(-U_0(\gamma-\gamma_0)^{3/2}/kT)$$

Here U_0 and γ_0 are free parameters to be fitted
Escape rate is simply the inverse mean lifetime $P=1/\langle\tau\rangle$ of zero voltage state

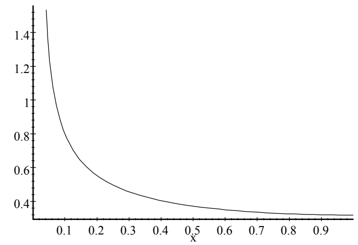
Single junction pulsed operation



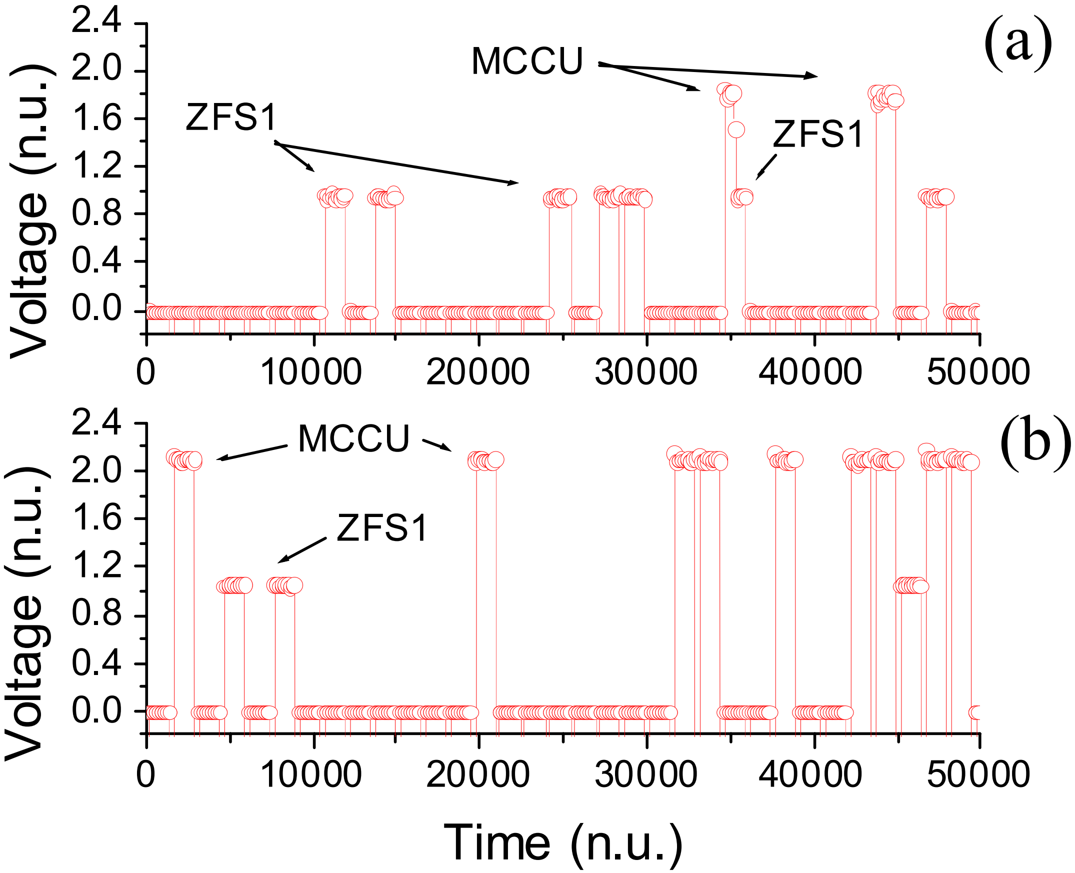
$l=1.0$
T=4.2 K
I_0=1 mA
α_0=0.15
T=100 n.u.
T_p=1500 n.u.
Γ=-20

(a) γ_B=0.21
(b) γ_B=0.25
(c) γ_B=0.35

Single junction: Long Junction case



Used peaked pulse cf. ref.[6]



$T=4.2$ K

$I_0=1$ mA

$\alpha_0=0.15$

$T=100$ n.u.

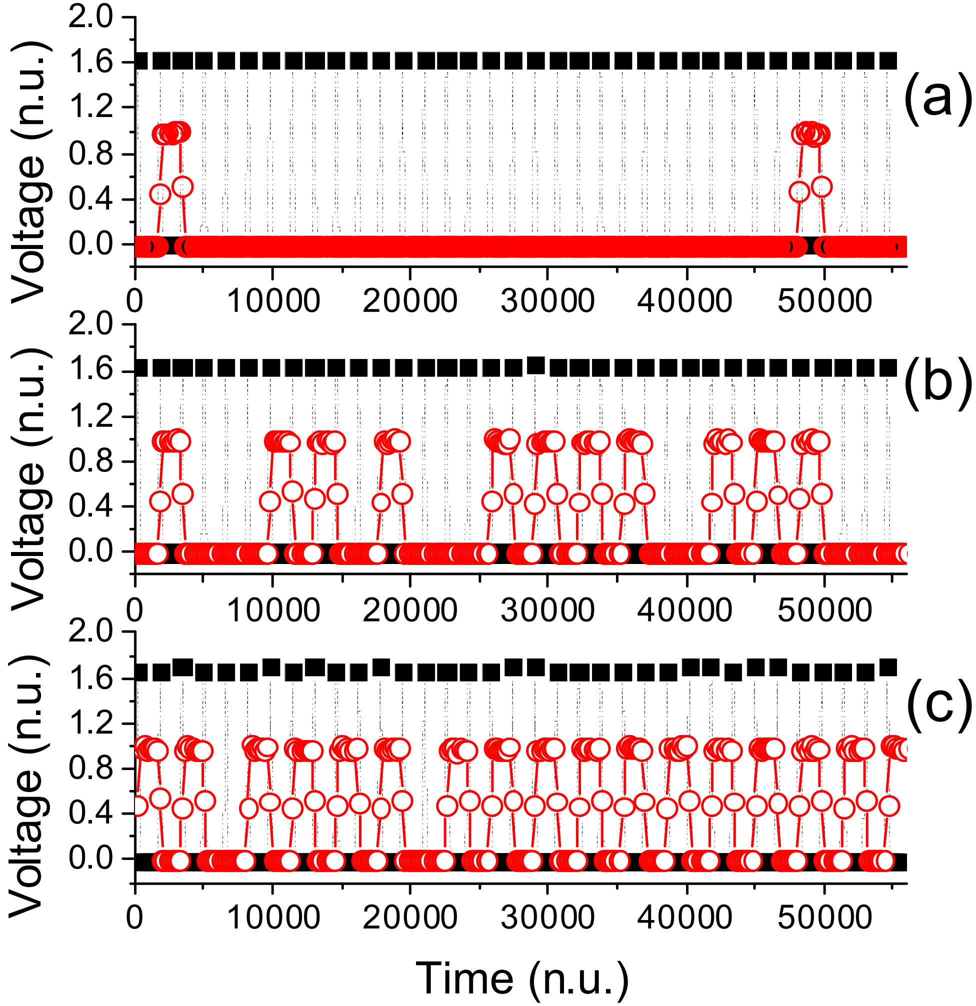
$T_p=1500$ n.u.

$\Gamma=-20$

(a) $\gamma_B=0.28$, $l=5.0$

(b) $\gamma_B=0.35$, $l=5.0$

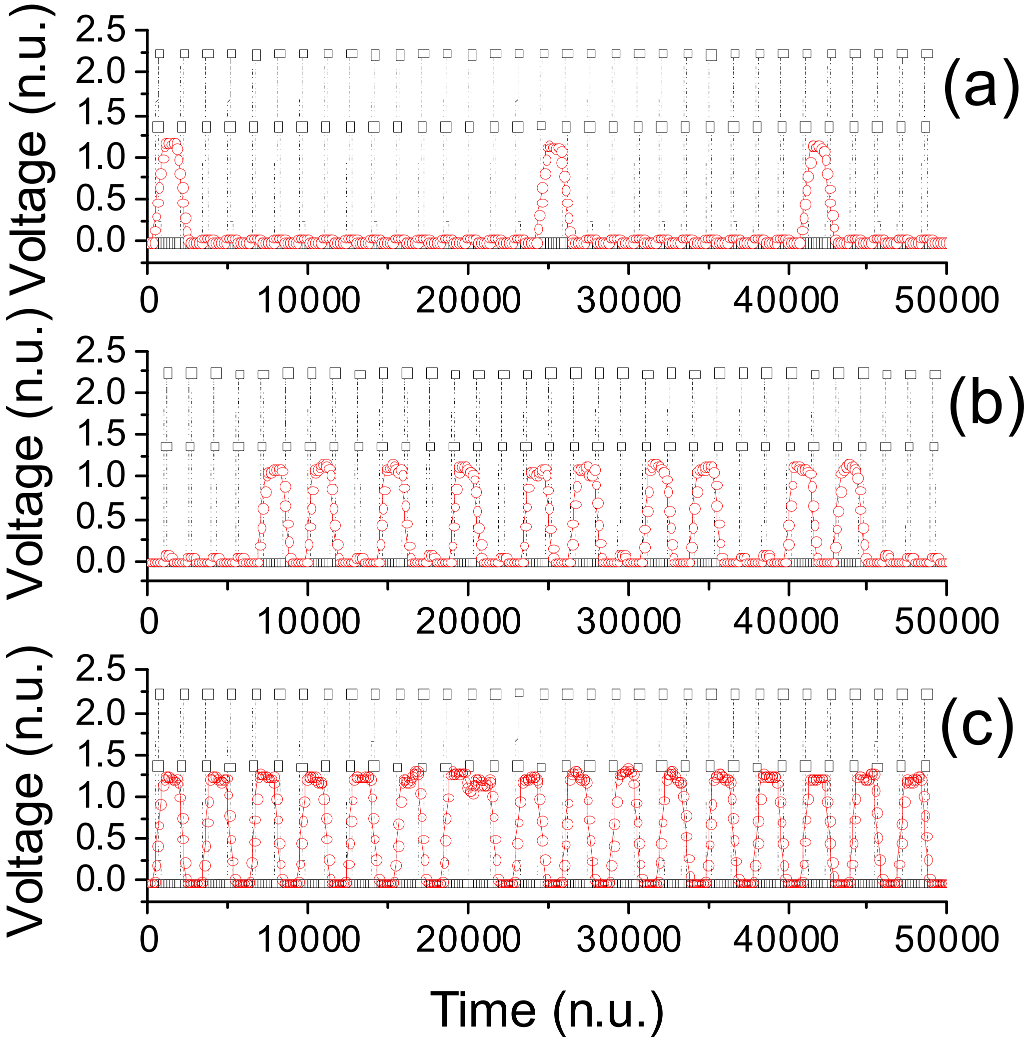
Stacked junctions configuration (pulse amplitude variation)



l=1.0
ε=-0.85
T=4.2 K
I_0=1 mA
α_0=0.15
T=100 n.u.
T_p=1500 n.u.
γ_B =0.20

(a) Γ=20.4
(b) Γ=20.6
(c) Γ=21.0

Stacked junctions configuration



l=1.0

ε=-0.85

T=4.2 K

I_0=1 mA

α_0=0.15

T=100 n.u.

T_p=1500 n.u.

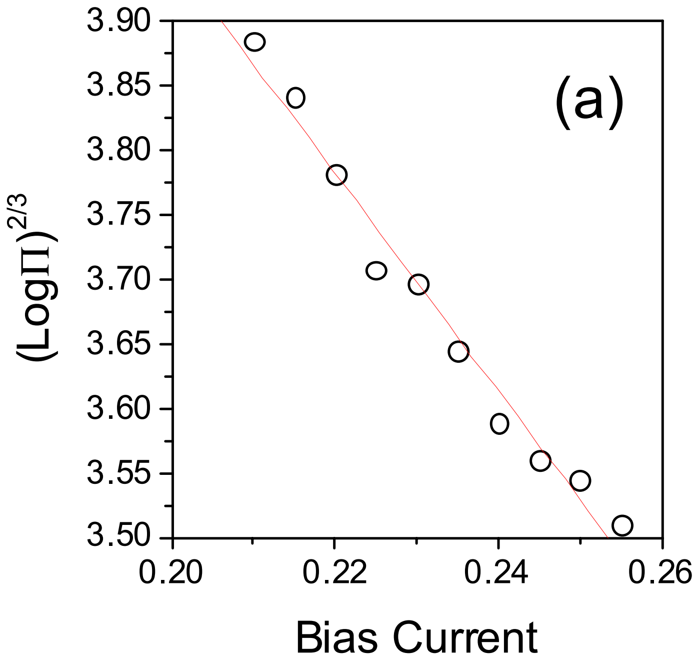
Γ=20

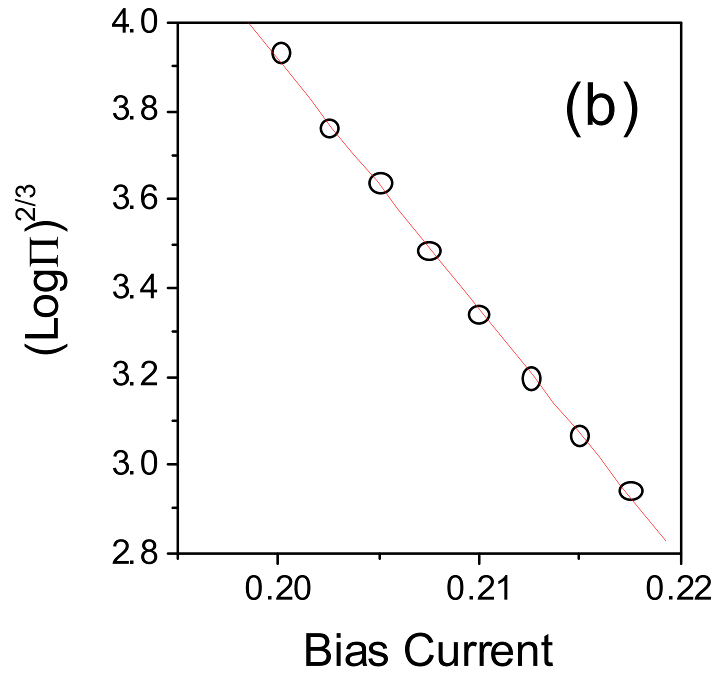
(a) γ_B=0.205

(b) γ_B=0.21

(c) γ_B=0.22

Fit of escape rates for both single and stacked cases

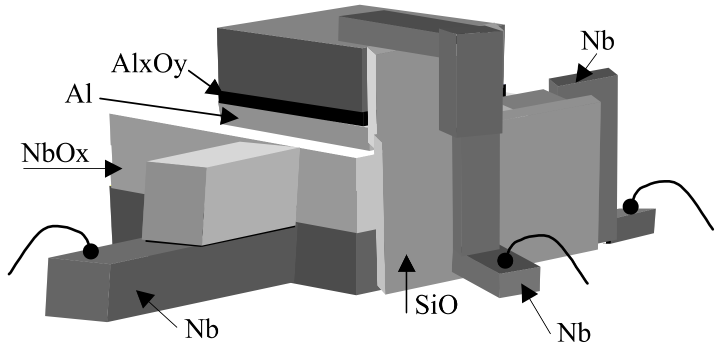




Single junction with l=1
γ_0=0.6
U_0=0.2 % J.Energy

Stacked junctions l=1
γ_0=0.267
U_0=2 % J.Energy

Experiment on a stacked device



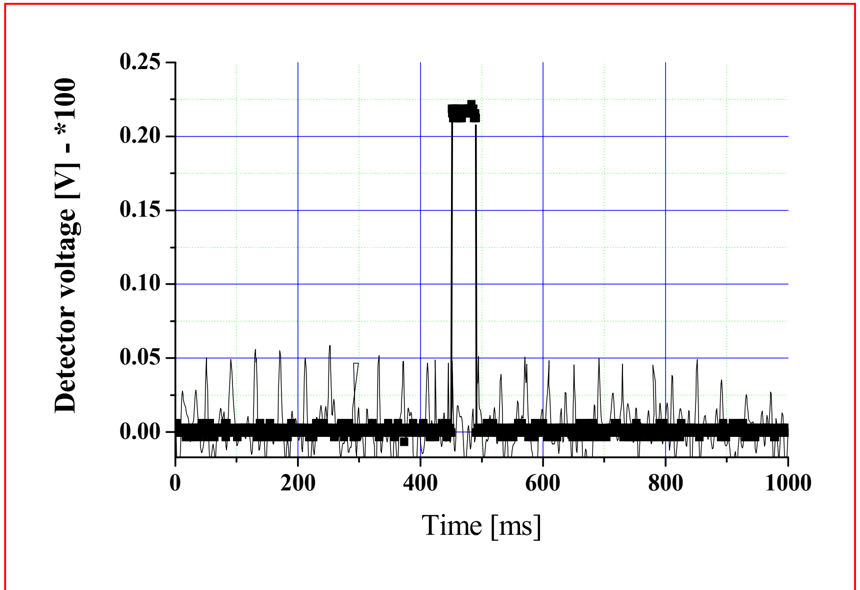
Stacked tunnel JJs have been fabricated by following a novel process developed for high-quality three terminals superconducting electronics [12]. The process and the junction characterization have been described in ref.[4].

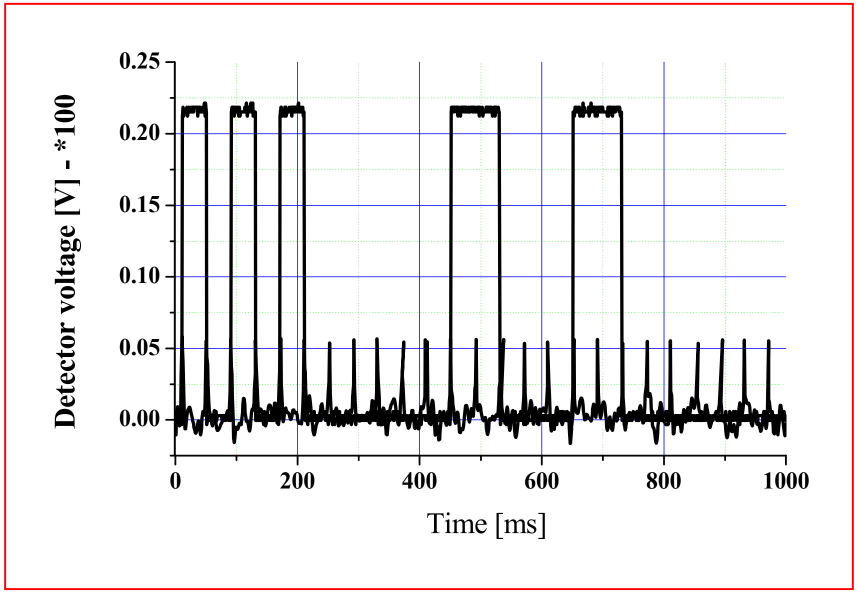
Here $L/l_J \approx 1.4$. The bottom junction was used as injector of current pulses, whose effect was observed across the top junction (detector). Injected pulses rise-times of 2 ns, 600 ms of duration, delay time 20 ms (pulse generator EG&G Mod. 480)

Each pulse was split and sent simultaneously to both the injector junction and to a digital oscilloscope (Le Croy Mod. 9361, 300MH) for triggering the waveforms acquisition.

With the detector biased at I<Ic, the output voltage across the detector was measured by a standard PAR Mod. 5113 pre-amplifier (300 kHz BW).

Experimental result on the stacked system





The detector junction output voltage as a function of injected electronic pulses across the coupled junction for increasing pulse amplitudes. The scale is referred to the detector output voltage, while pulses are reported in arbitrary units.

Conclusions

We presented numerical simulations and measurements of pulse activated transitions from the metastable to the running state and *viceversa* in a both single junctions and stacked configuration Josephson systems.
At least for the stacked configuration where the fitting is much realistic, an interval of bias currents exists (from about 0.2 to 0.235) where the numerical escape rate can be fitted by the simple short junction theoretical thermal escape rate. Experiments on stacked device compare favorable with numerical simulations of PSGE model applied to a stacked system.

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