Novel Quantum States in Condensed Matter 2017
Yukawa Institute for Theoretical Physics, Kyoto University, Japan

Dynamics and IV-characteristics of Josephson junctions and superconductor-ferromagnet-superconductor structures

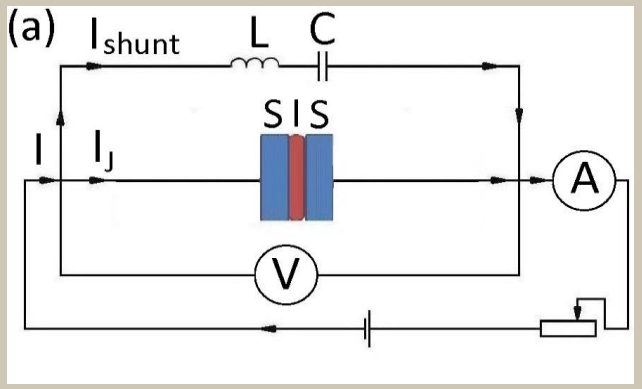
Yu. M. Shukrinov
BLTP, JINR, Dubna,, Russia

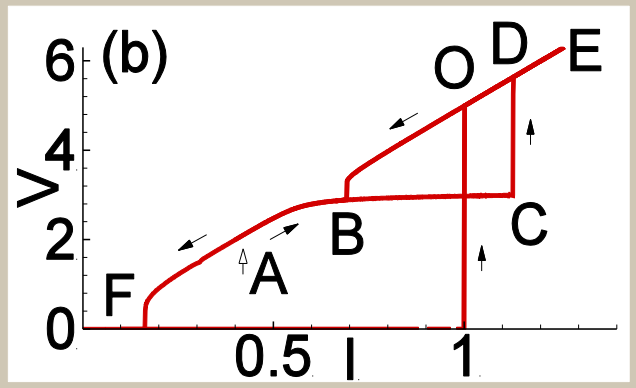
In collaboration with:
I. R. Rahmonov, A. Mazanik, K. V. Kulikov, S. Medvedeva, M. Maiti - JINR, Dubna, Russia
A. Buzdin - University Bordeaux, LOMA, Talence, France
K. Sengupta - IACS, Kolkata, India
M. Nashaat, H. El Samman, Th. M. El Sherbini - Cairo University, Egypt
A. E. Botha – INISA, SA
A. Irie – Utsunomiya University, Japan

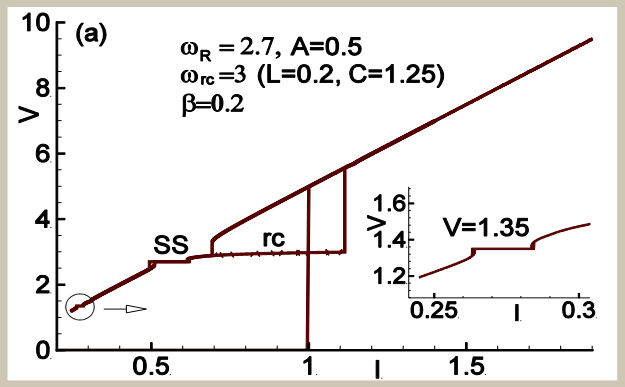
Part 2

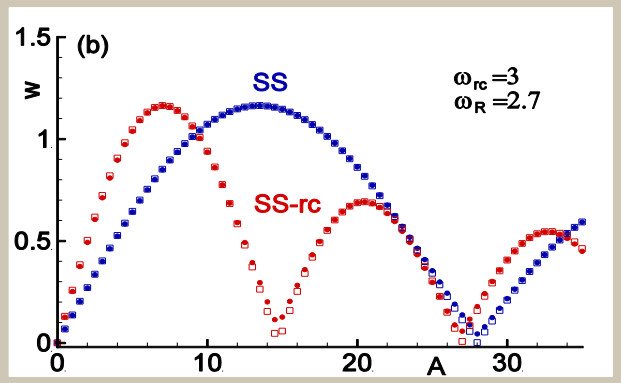
Shunting

Variation of amplitude dependence of SS width in resonance region





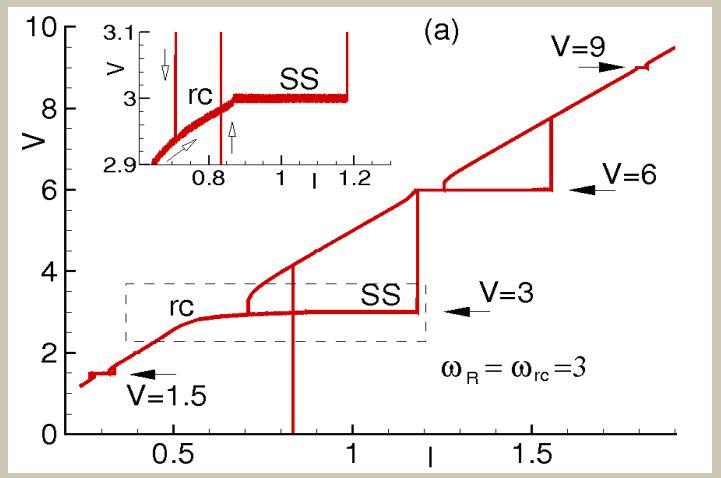


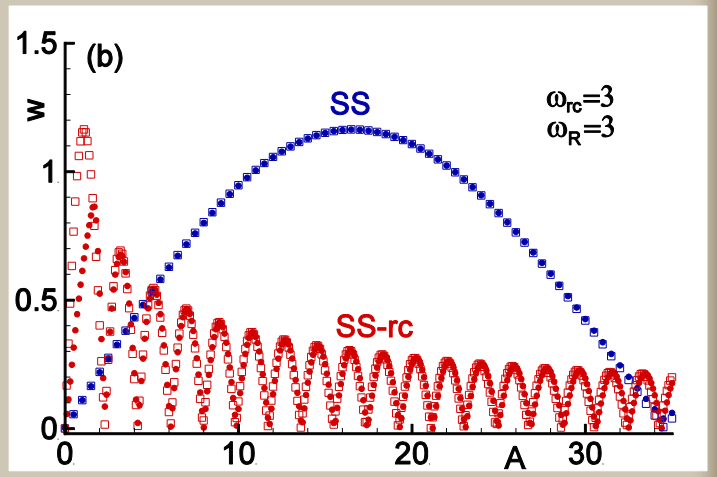


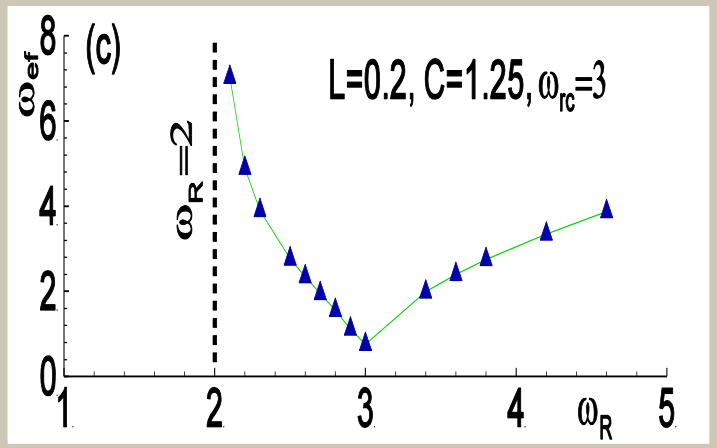
$$\Delta I = 2|J_n(Z)|, \qquad Z = \frac{A}{\omega_R}\frac{1}{\sqrt{\beta^2+\omega_R^2}}$$

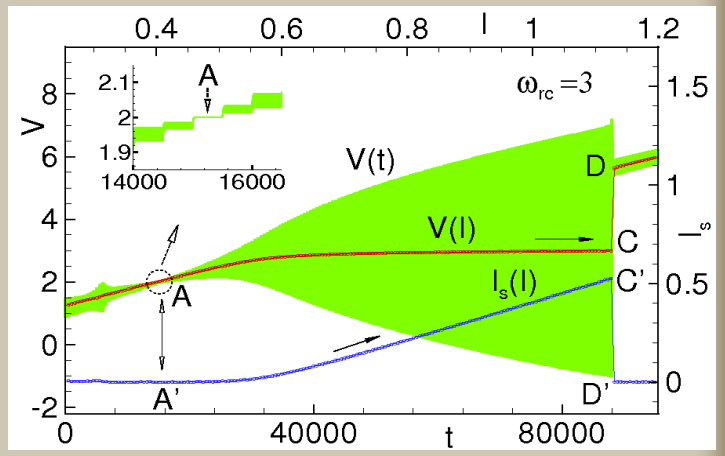
Yu. M. Shukrinov, I. R. Rahmonov, K. V. Kulikov and P. Seidel. - EPL, 110, 47001 (2015)

Resonance conditions

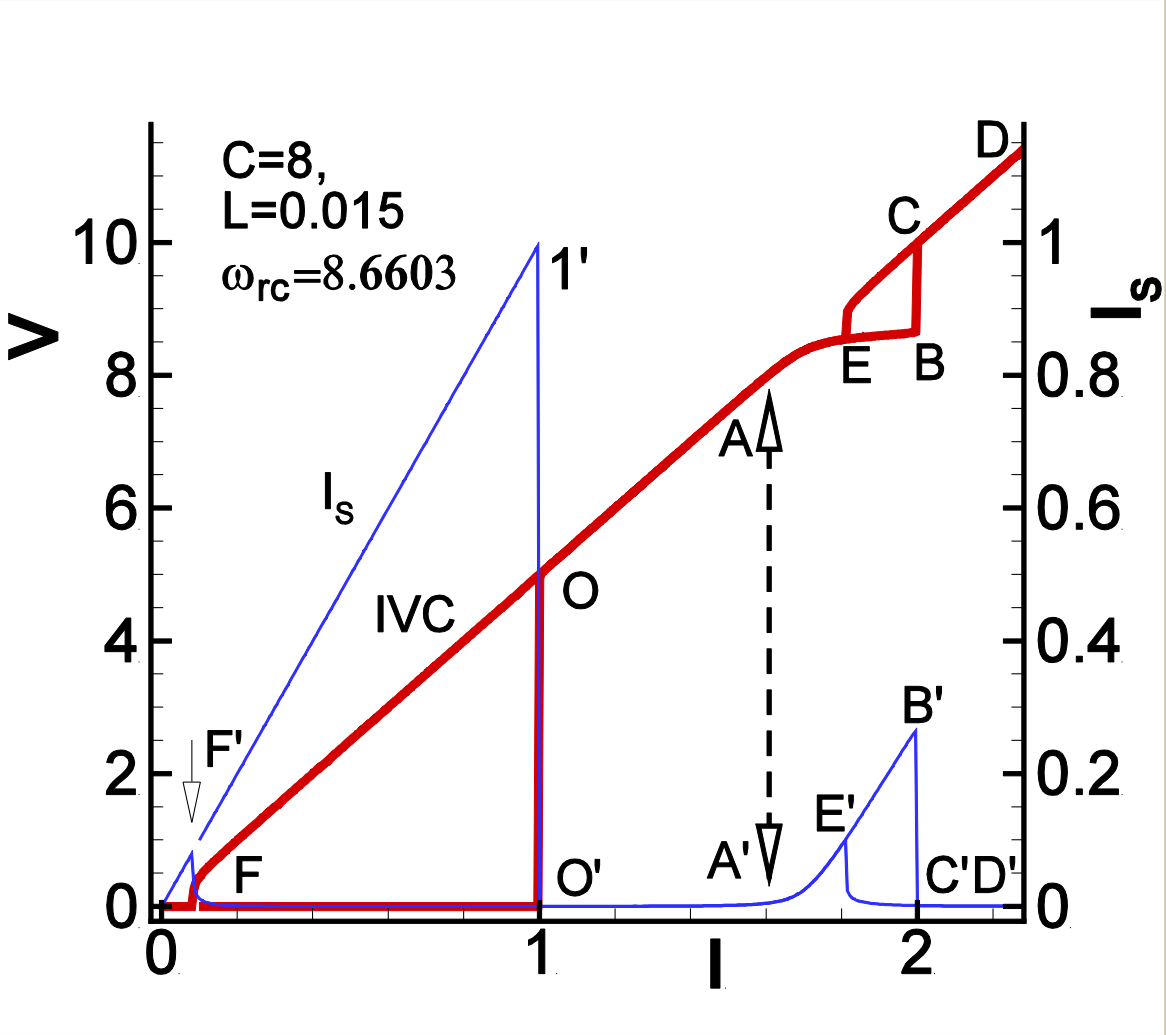






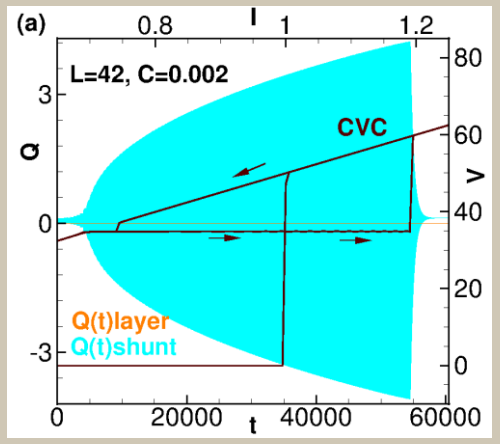


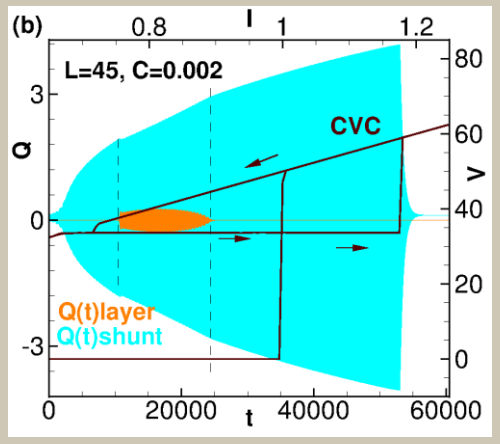
IV-characteristic and average superconducting current Is

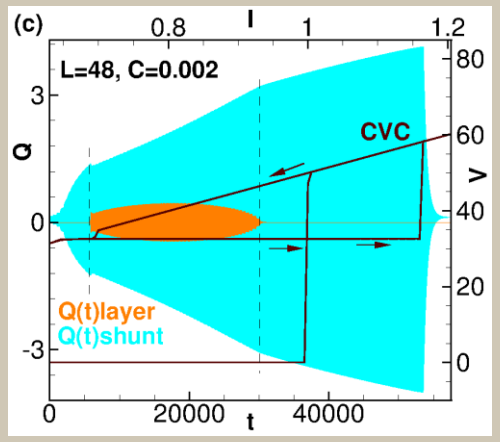


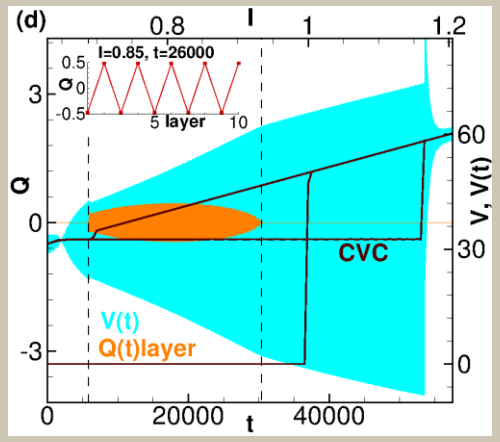
Yu. M. Shukrinov, I. R. Rahmonov, G. Filatrella, JETP, 2017

Charging of superconducting layers



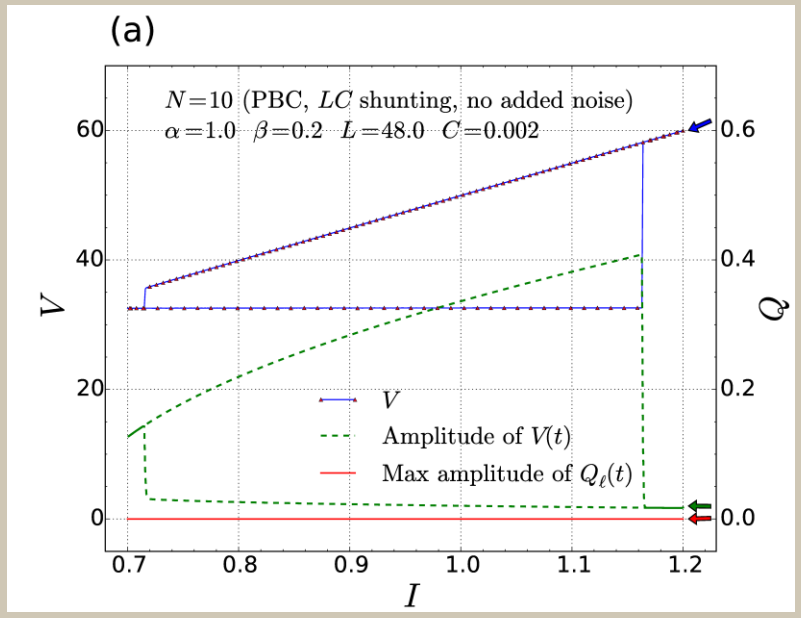


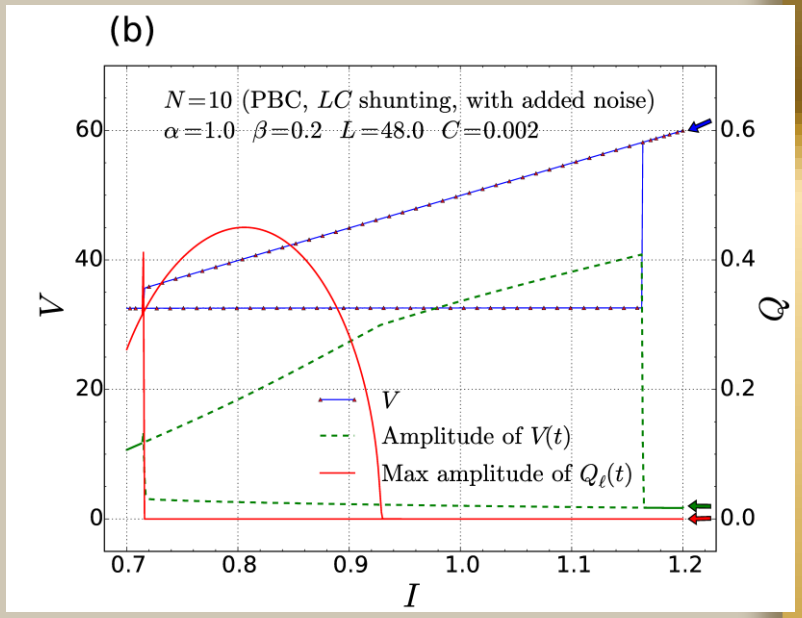




Yu. M. Shukrinov, I. R. Rahmonov, K. V. Kulikov, A. E. Botha, A. Plecenik, P. Seidel, W. Nawrocki,
Superconductor Science and Technology 30, 024006 (2017)

Slope in the V(t) dependence





Yu. M. Shukrinov, I. R. Rahmonov, K. V. Kulikov, A. E. Botha, A. Plecenik, P. Seidel, W. Nawrocki,
Superconductor Science and Technology 30, 024006 (2017)

Phi-0 Josephson Junction

Energy of the system:

$$E_{tot} = -\frac{\phi_0}{2\pi}\varphi I + E_s(\varphi,\varphi_0) + E_M(\varphi_0)$$

$$E_S(\varphi,\varphi_0) = E_J[1-\cos(\varphi-\varphi_0)]$$

$$E_M = \frac{-KV}{2}\left(\frac{M_Z}{M_0}\right)^2 \qquad E_J = \frac{\phi_0 I_c}{2\pi} \qquad \varphi_0 = l\frac{v_0}{v_F}\frac{M_y}{M_0},$$

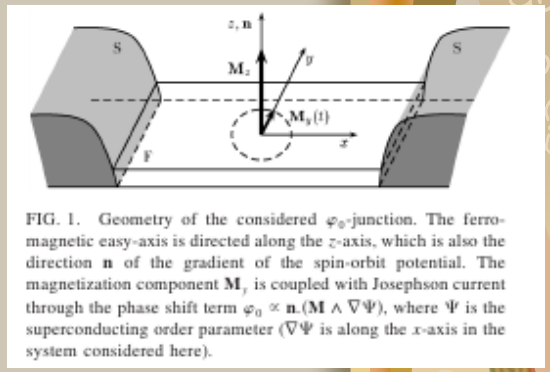


FIG. 1. Geometry of the considered φ_0-junction. The ferromagnetic easy-axis is directed along the z-axis, which is also the direction $\mathbf{n}$ of the gradient of the spin-orbit potential. The magnetization component $\mathbf{M}_y$ is coupled with Josephson current through the phase shift term $\varphi_0 \propto \mathbf{n}.(\mathbf{M} \wedge \nabla\Psi)$, where Ψ is the superconducting order parameter ($\nabla\Psi$ is along the x-axis in the system considered here).

A. Buzdin. Phys. Rev. Lett . 101, 107005 (2008) .
F . Konschelle, A. Buzdin. Phys. Rev. Lett. 102, 017001 (2009) .

Landau-Lifshitz-Gilbert equation:

$$\frac{dM}{dt} = -\gamma[M\times H_{eff}] + \frac{\alpha}{M_0}[M\times\frac{dM}{dt}]$$

$$H_{eff} = \frac{K}{M_0}\left[\Gamma\sin\left(\varphi - r\frac{M_y}{M_0}\right)\vec{y} + \frac{M_z}{M_0}\vec{z}\right]$$

$$\Gamma = Gr = \frac{E_J}{KV}l\frac{v_0}{v_F}, \qquad G = \frac{E_J}{KV}, \quad r = l\frac{v_0}{v_F}, \quad l = 4\frac{hL}{\hbar v_F}$$

System of equations

$$\frac{dm_x}{dt} = \frac{\omega_F}{1+(\alpha M^2)}\{m_y m_z - \Gamma m_z \sin(\varphi - r m_y) + \alpha[m_x m_z^2 + \Gamma m_x m_y \sin(\varphi - r m_y)]\},$$

$$\frac{dm_y}{dt} = \frac{\omega_F}{1+(\alpha M^2)}\{-m_x m_z + \alpha[m_y m_z^2 + \Gamma(m_z^2 + m_x^2)\sin(\varphi - r m_y)]\},$$

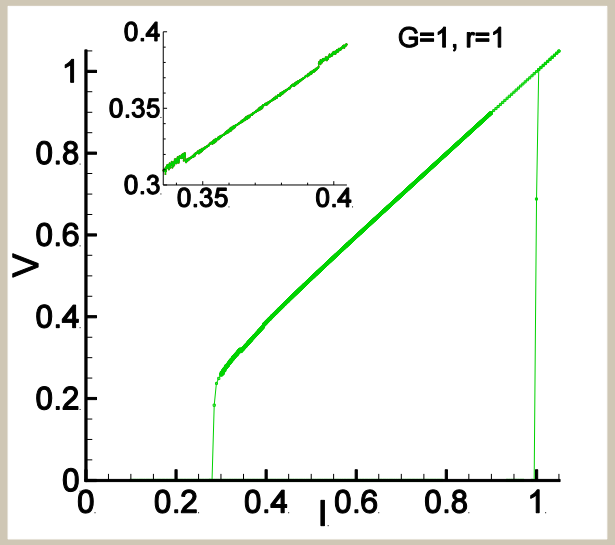
$$\frac{dm_z}{dt} = \frac{\omega_F}{1+(\alpha M^2)}\{\Gamma m_x \sin(\varphi - r m_y) + \alpha[\Gamma m_y m_z \sin(\varphi - r m_y) - m_z(m_x^2 + m_y^2)]\},$$

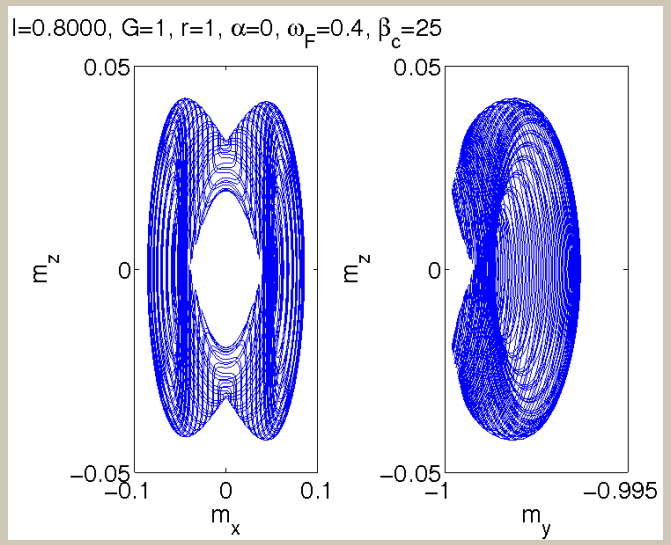
$$\frac{dV}{dt} = \frac{1}{\beta_c}[I - V - \sin(\varphi - r m_y) + A\sin(\omega t)],$$

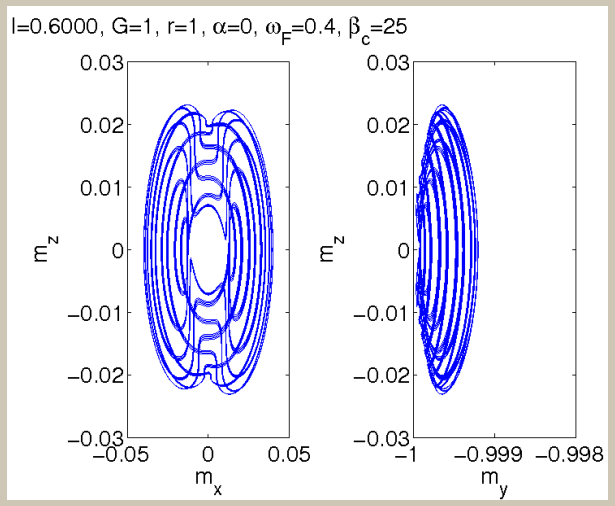
$$\frac{d\varphi}{dt} = V$$

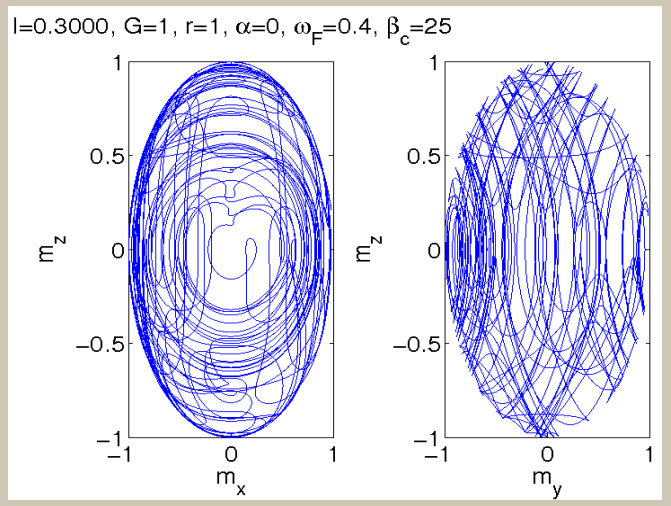
Magnetization dynamics along IV-characteristics of JJ.

Result of simulation of IV-characteristic

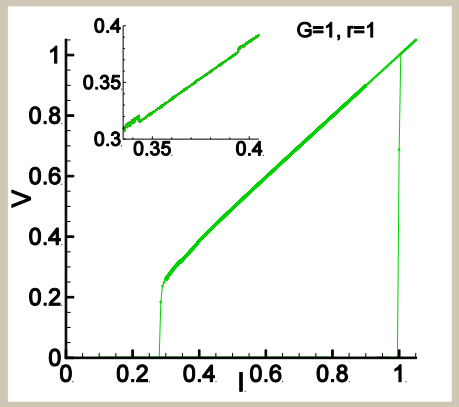


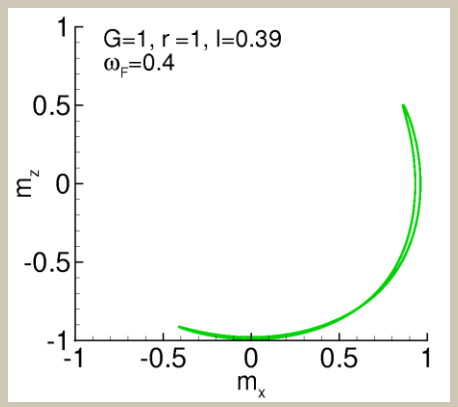


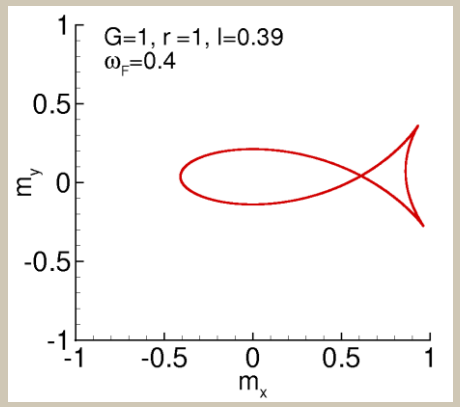




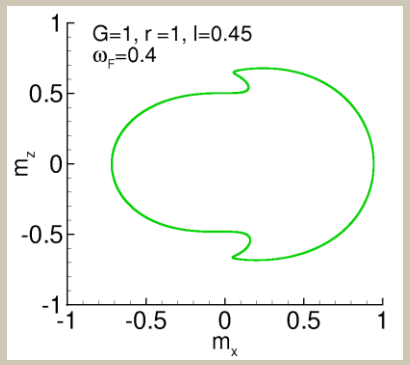
I = 0.39

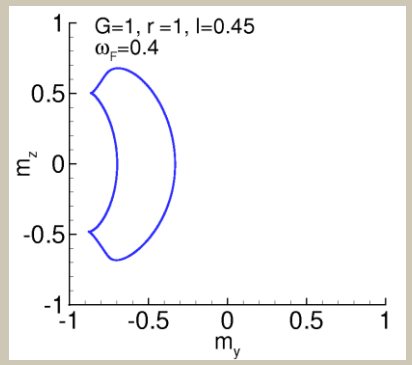


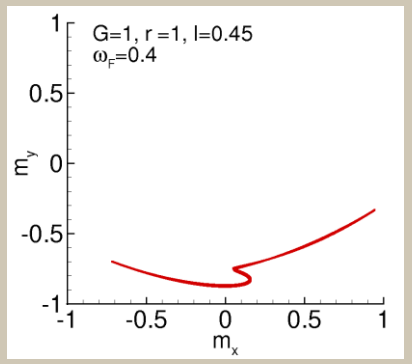




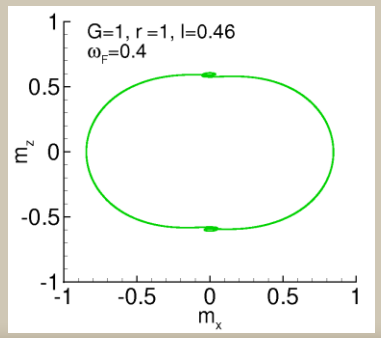
I = 0.45

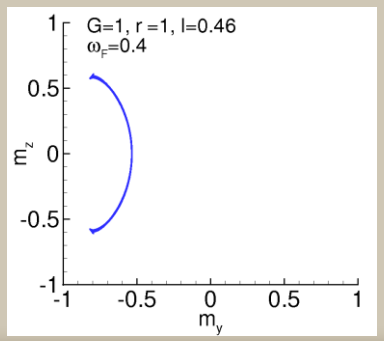


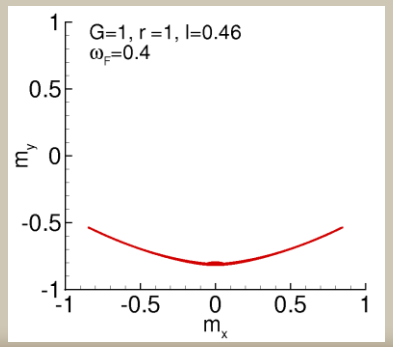




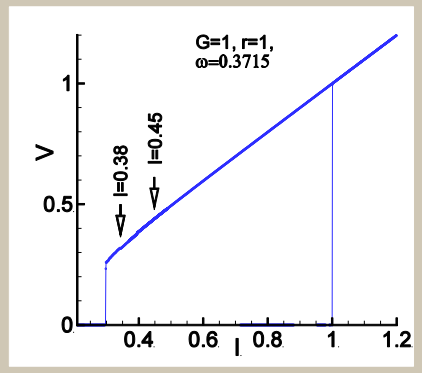
I = 0.46

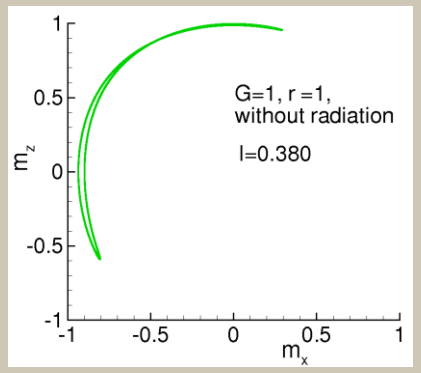


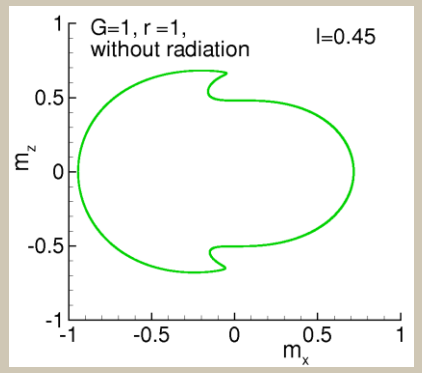


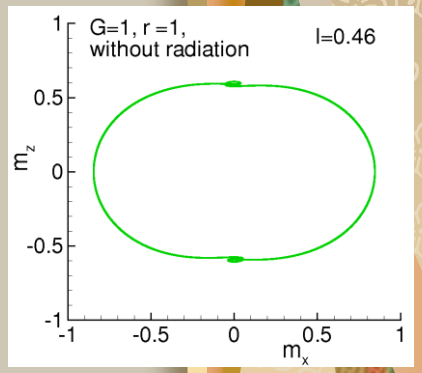


Without radiation

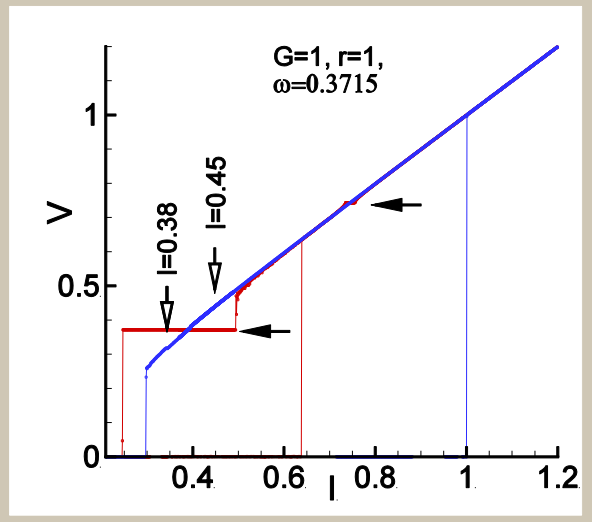


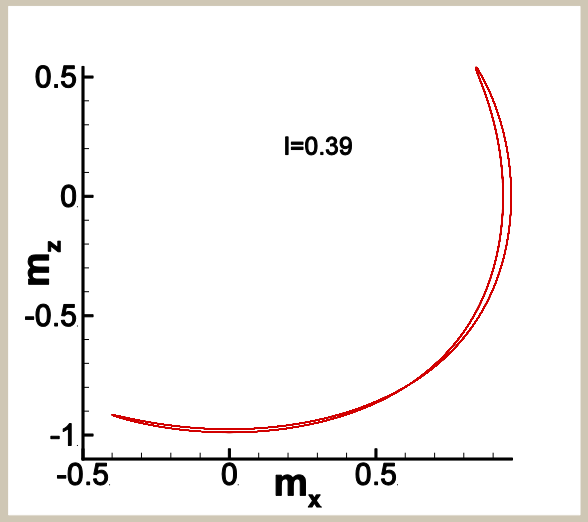


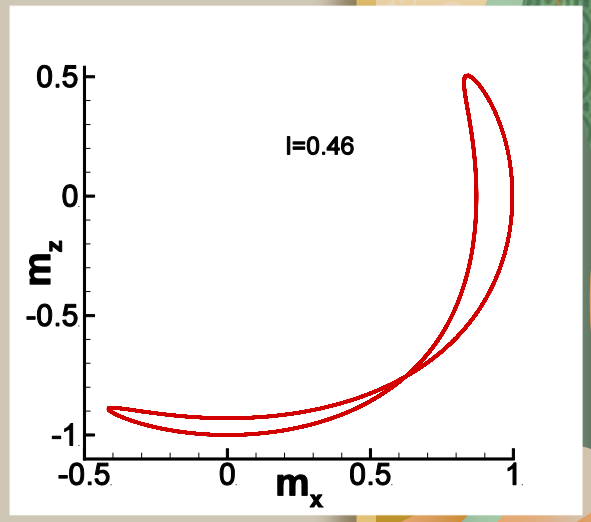




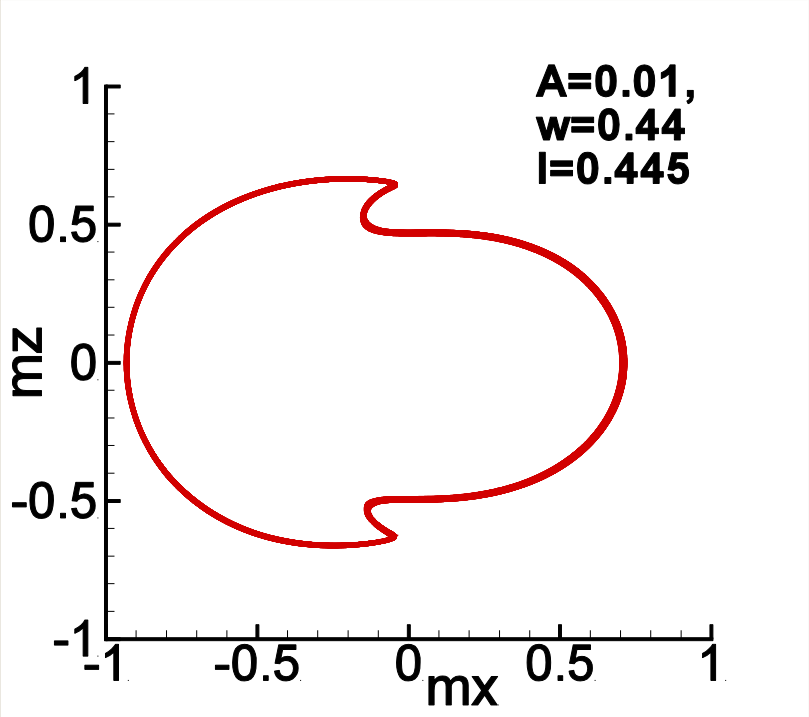
Under radiation, W=0.3715, A=1

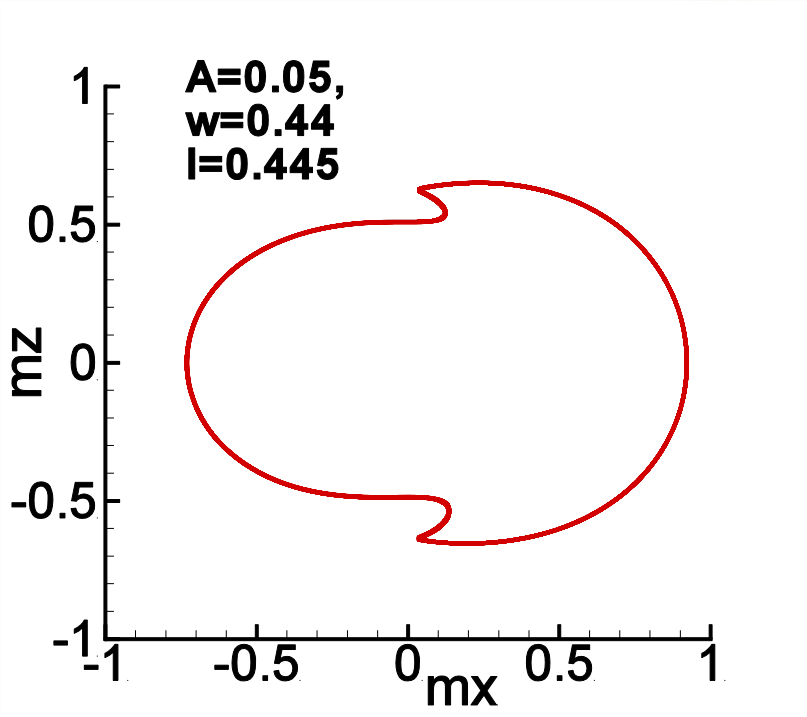






Left-right transformations by changing the amplitude value of external radiation

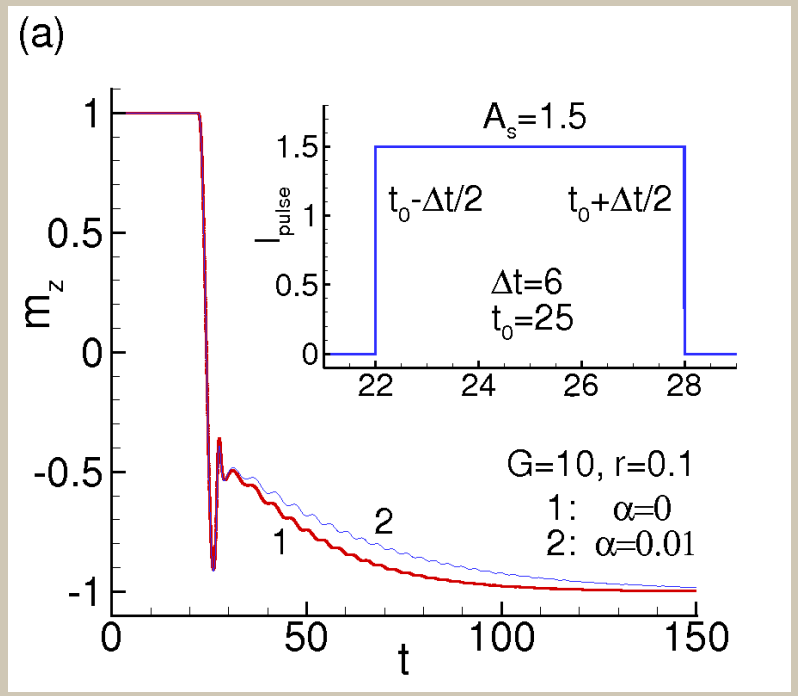


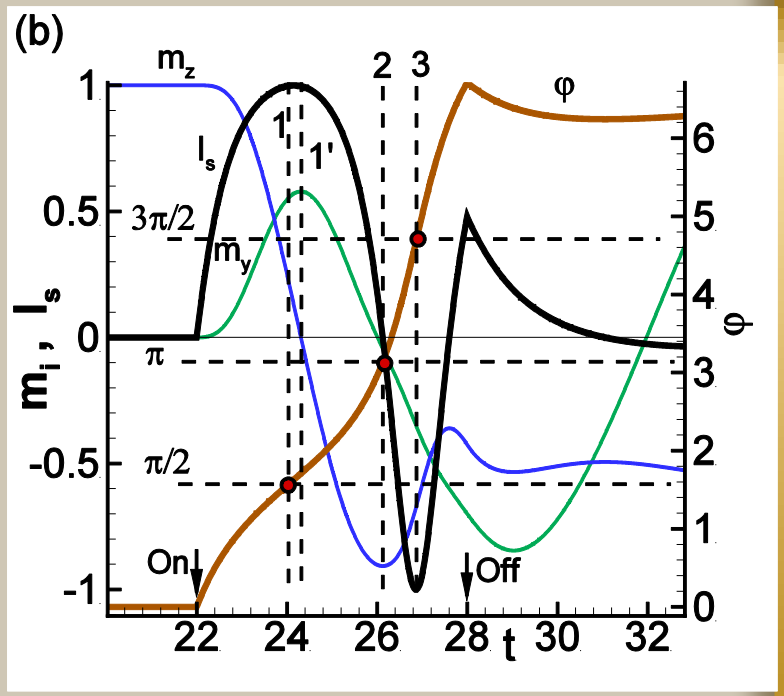


Magnetization reversal

Transition dynamics in the system under rectangular current pulse

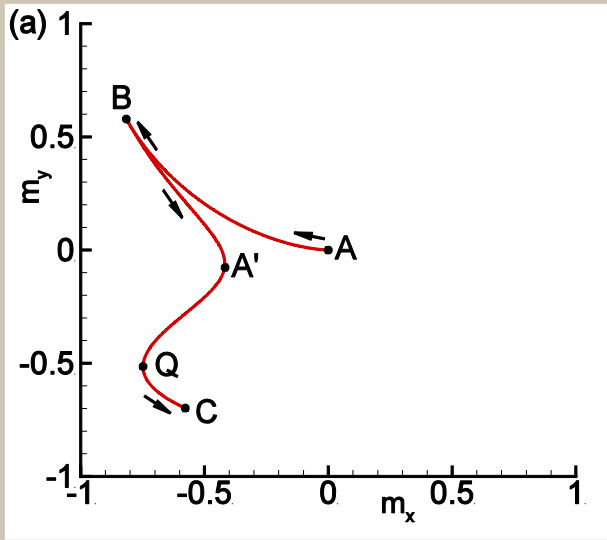
$$I_{pulse} = w\frac{d\varphi}{dt} + \sin(\varphi - rm_y)$$

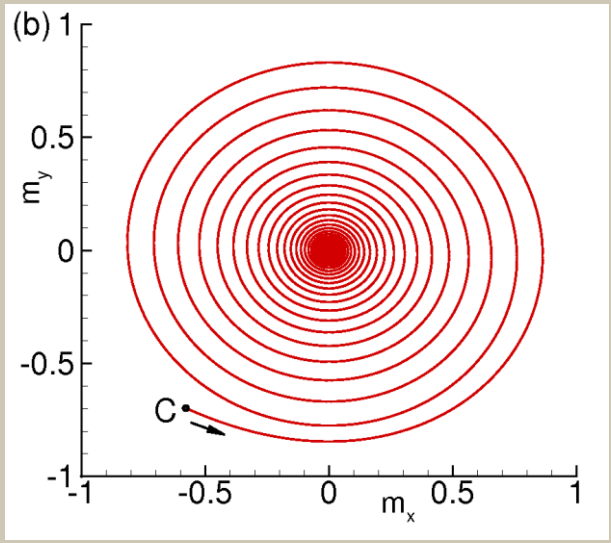


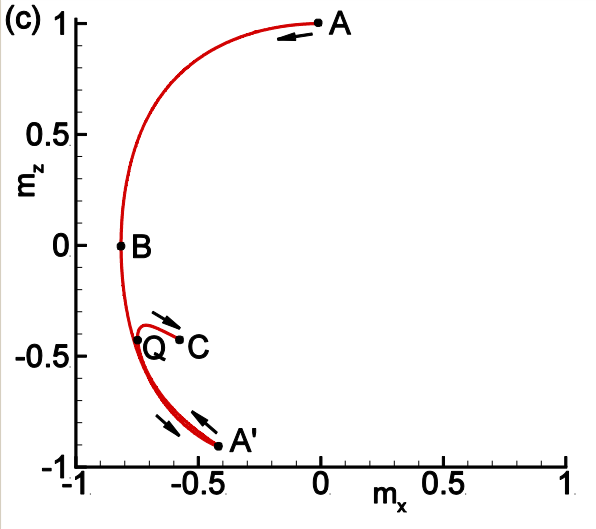


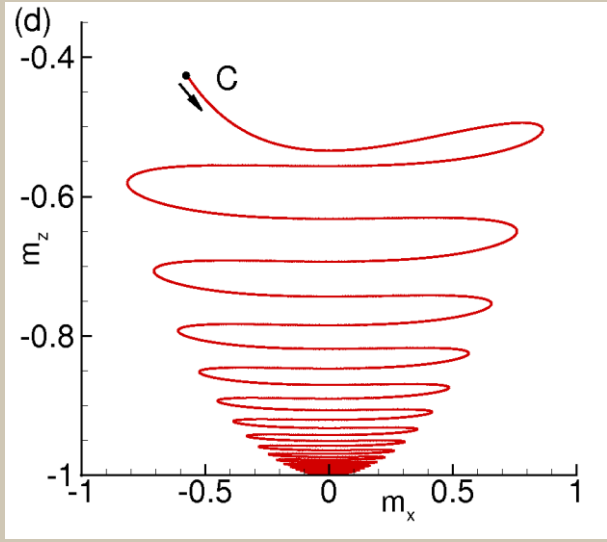
$$\sin\frac{1}{2}\left[\int_{t_{min}}^{t_{max}} V(t')dt' - r\left[m_y(t_{max}) - m_y\,(t_{min})\right]\right] = 1$$

Trajectories of magnetization in transition region



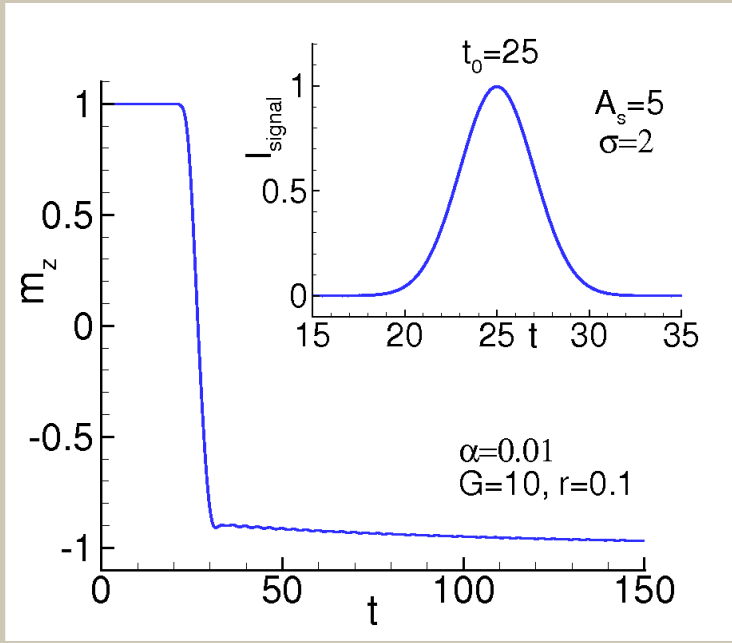






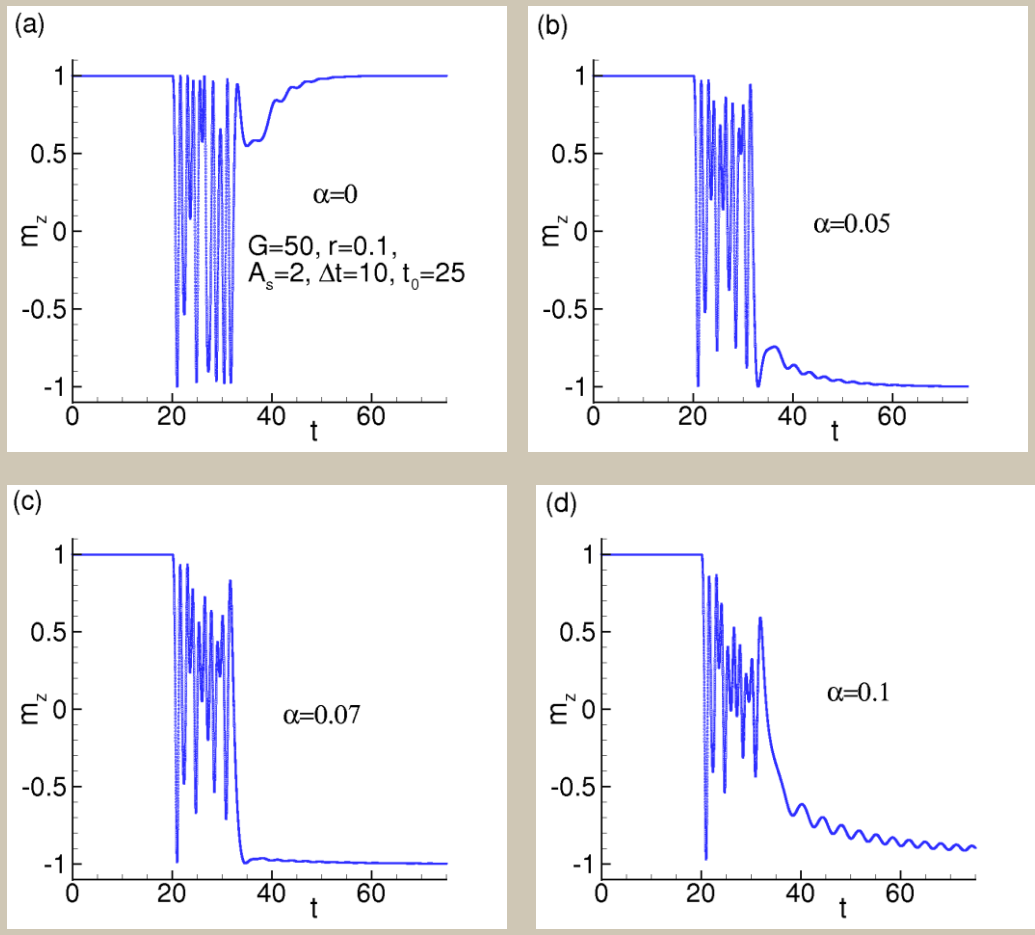
Transition dynamics under electric current pulse of the Gaussian form

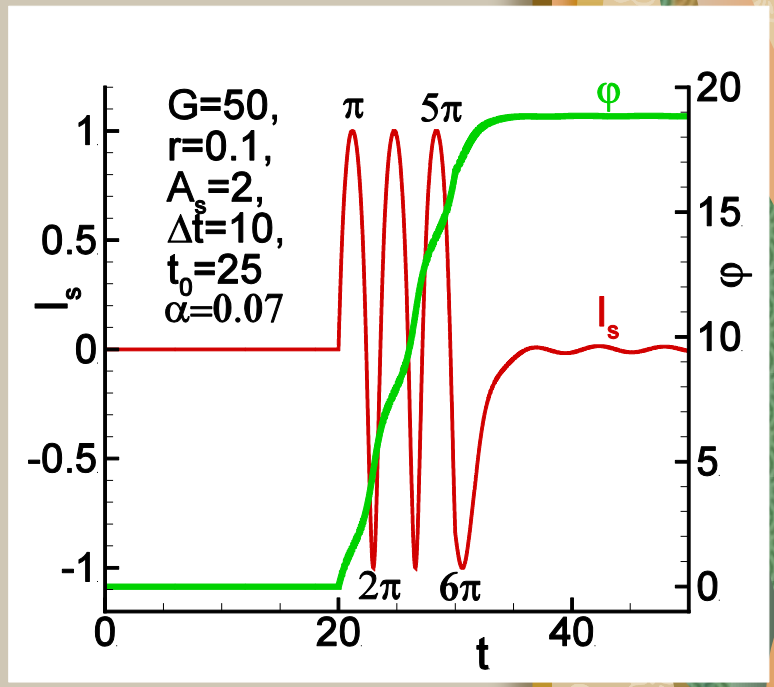
$$I_{pulse} = A\frac{1}{\sigma\sqrt{2\pi}}\exp\left(-\frac{(t-t_0)^2}{2\sigma^2}\right)$$



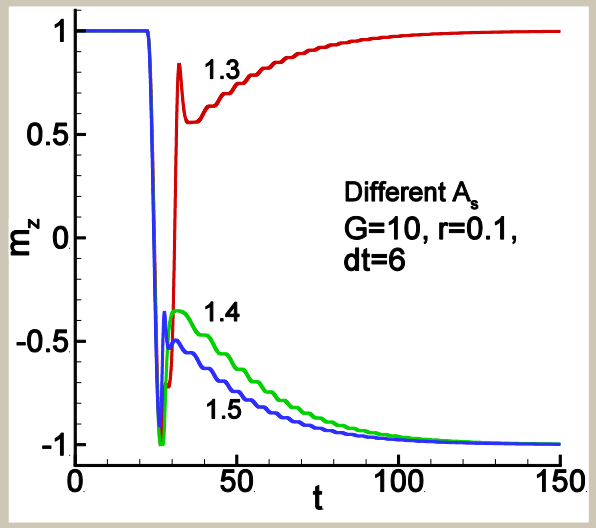
Yu.M. Shukrinov, I.R. Rahmonov, K. Sengupta, A.Buzdin, Appl. Phys. Lett. 110, 182407 (2017)

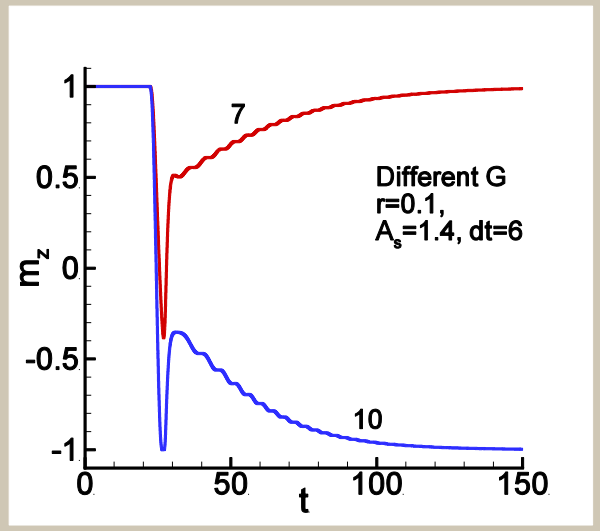
Magnetization dynamics under rectangular pulse signal in the system at different values of dissipation parameter

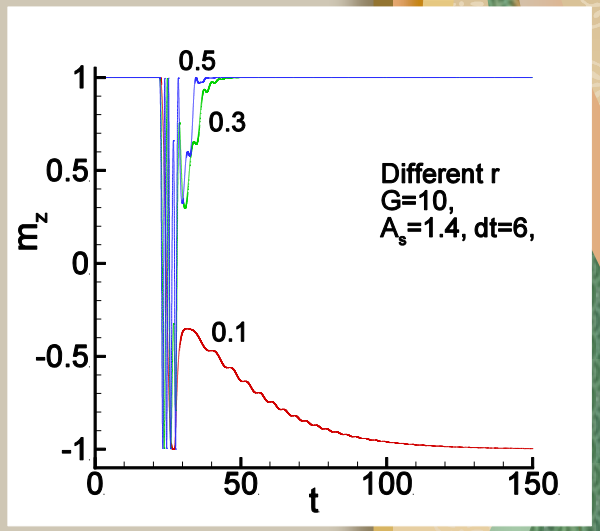




Different protocols for magnetization reversal

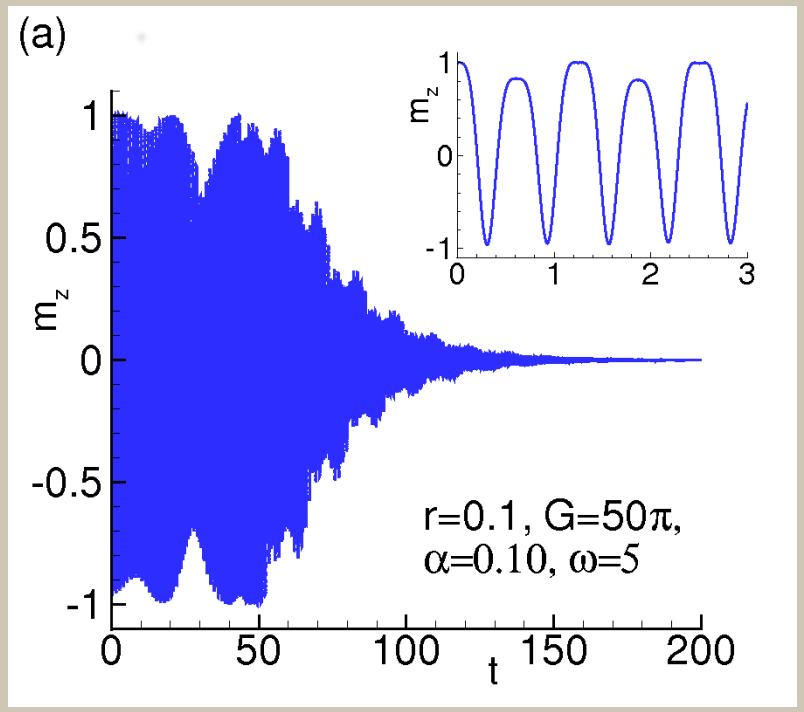


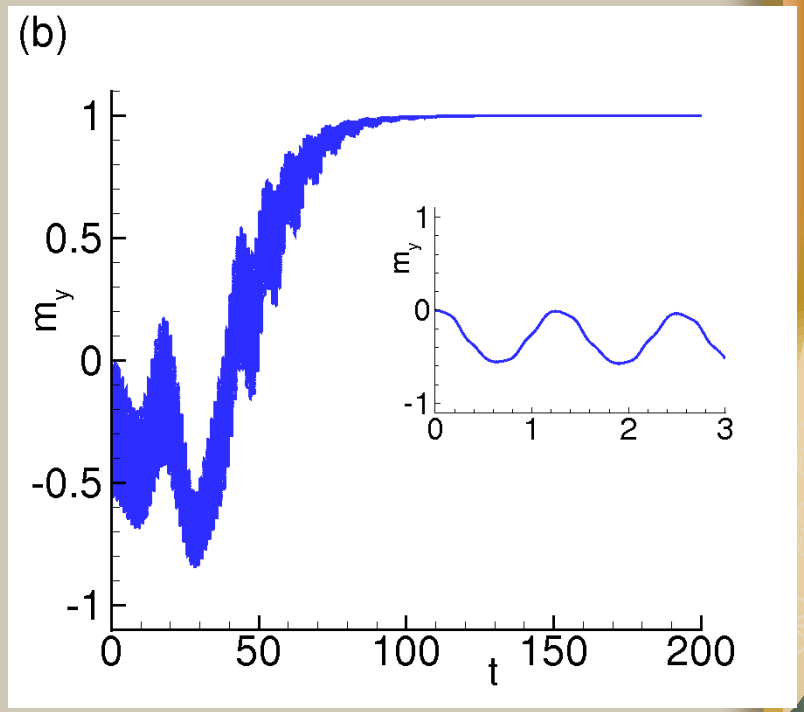




Yu.M. Shukrinov, I.R. Rahmonov, K. Sengupta, A.Buzdin,
Appl. Phys. Lett. 110, 182407 (2017)

Dynamics of magnetization components without signal





Yu.M. Shukrinov, I.R. Rahmonov, K. Sengupta, A.Buzdin,
APL, 110, 182407, 2017

Conclusions

- We propose a method which allows to register the charging of S-layers in HTSC.
- Reversal magnetization Phi_0 Josephson junction at different parameters of electric current pulse and JJ is shown.
- We have demonstrated variation of magnetic precession along IV-characteristic.
- External radiation fix a character of precession along Shapiro step.

Thank you
for your attention!