Modelling of Josephson Nanostructures and Intrinsic Josephson Junctions in HTS

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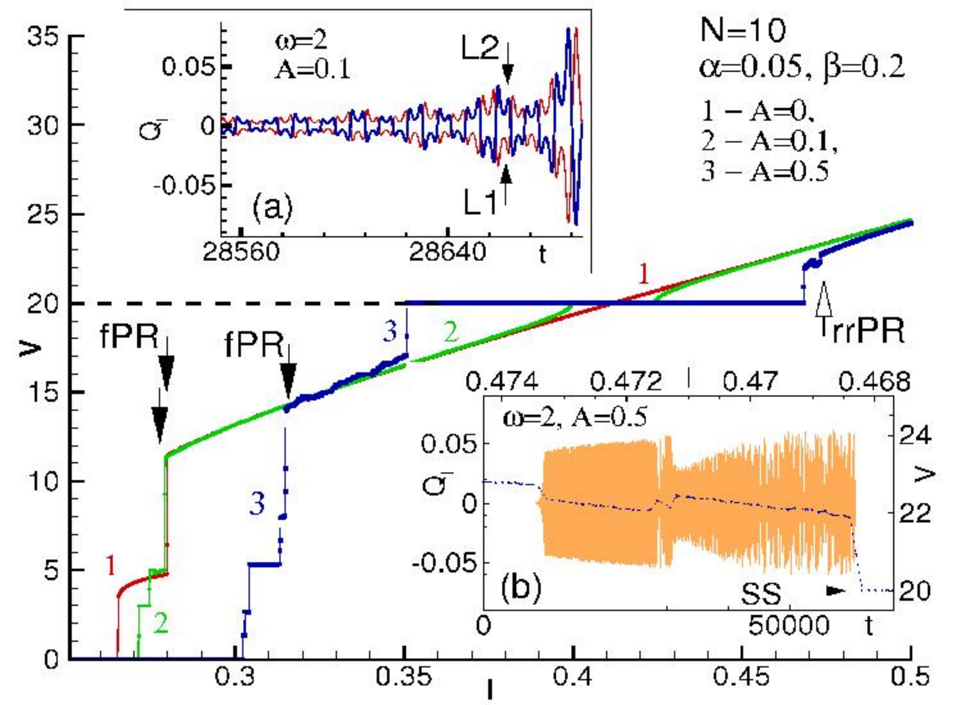
Waldemar Nawrocki (Poznan University, Poland)

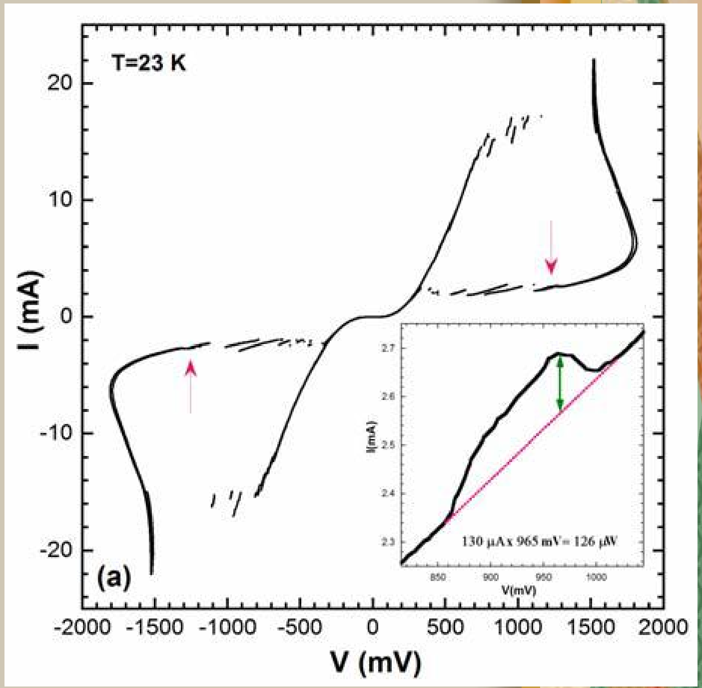
Outline

- Radiation effects
- Shunting and radiation
- Staircase structure of Shapiro steps

Radiation effects

IV-characteristics
without irradiation (curve 1)
under radiation with *A = 0.1 (curve 2)*
A = 0.5 (curve 3).

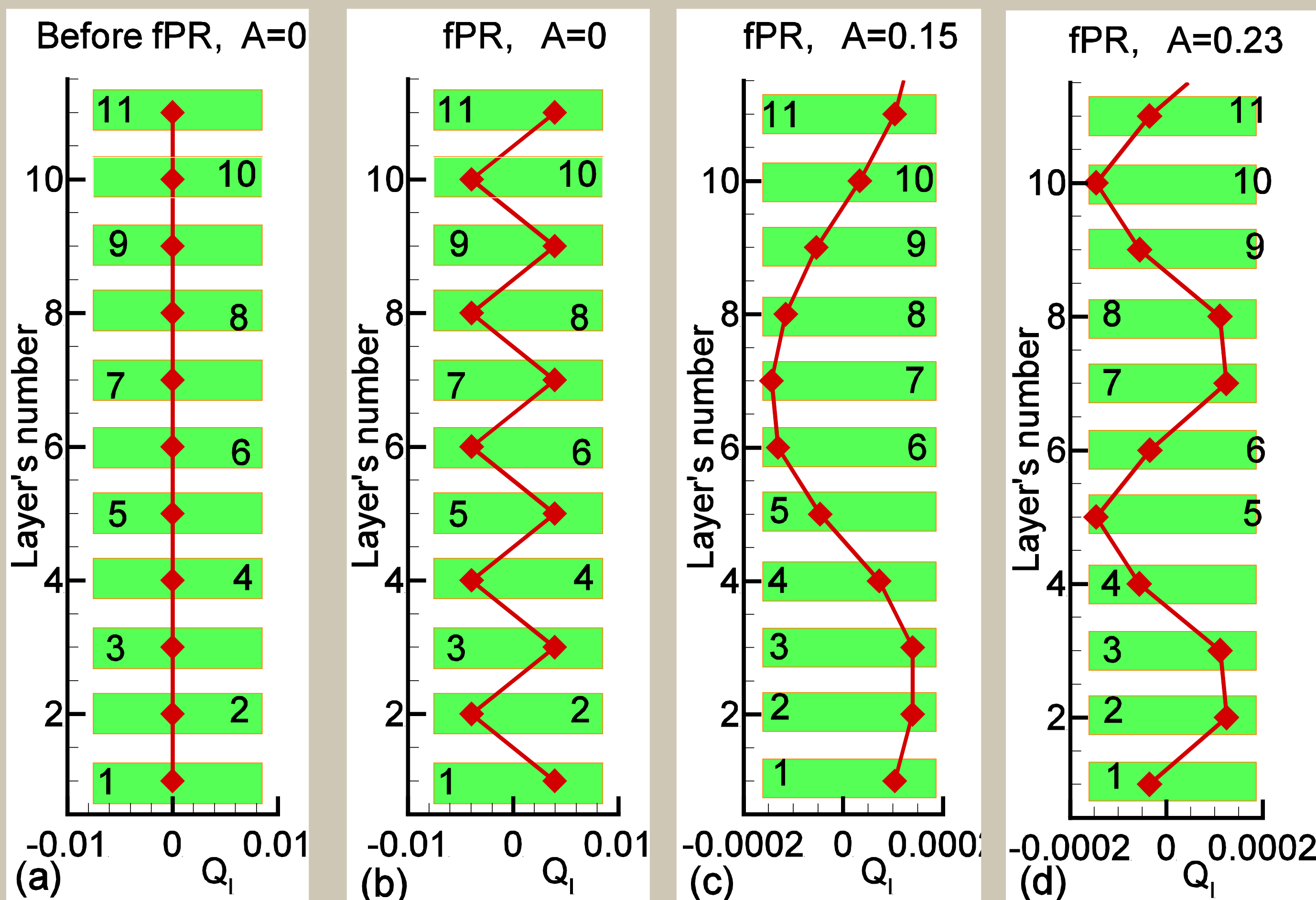




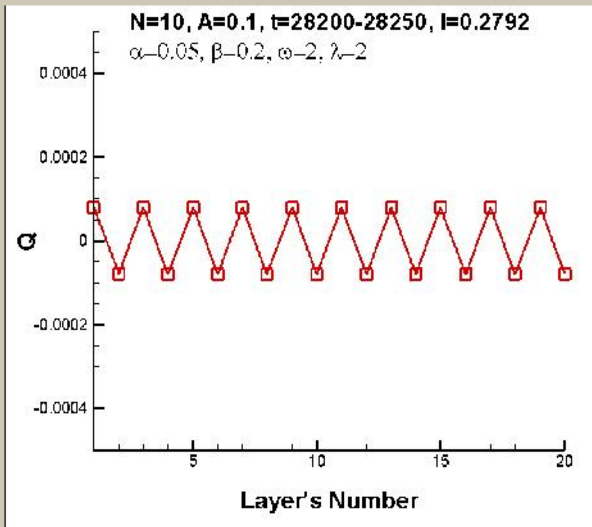
Yu.M.Shukrinov, I.Rahmonov, M. Gaafar, Phys.Rev.B, 86, 184502 (2012)

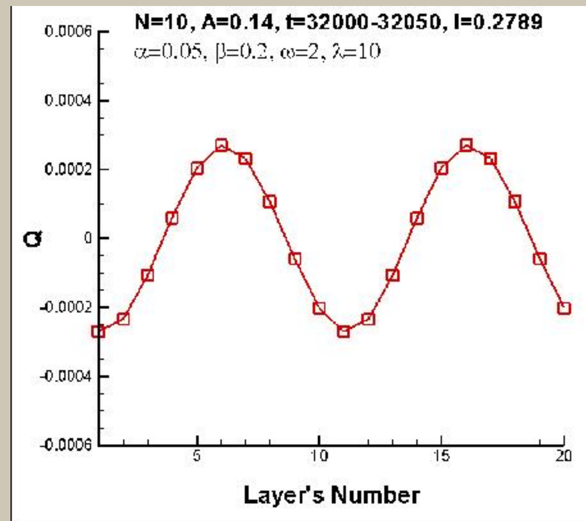
F Turkoglu, H Koseoglu, Y Demirhan, L Ozyuzer, S Preu, S Malzer, Y Simsek, P Müller, T Yamamoto and K Kadowaki 2012 *Supercond. Sci. Technol.* **25** 125004

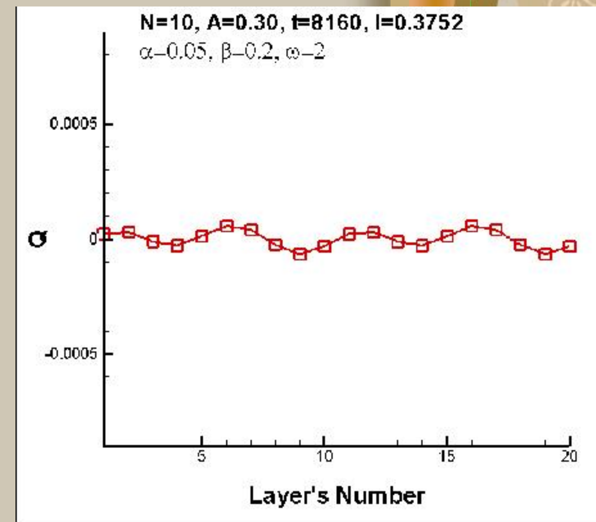
Demonstration of changing of LPW wavelength with an increase of the amplitude of radiation.

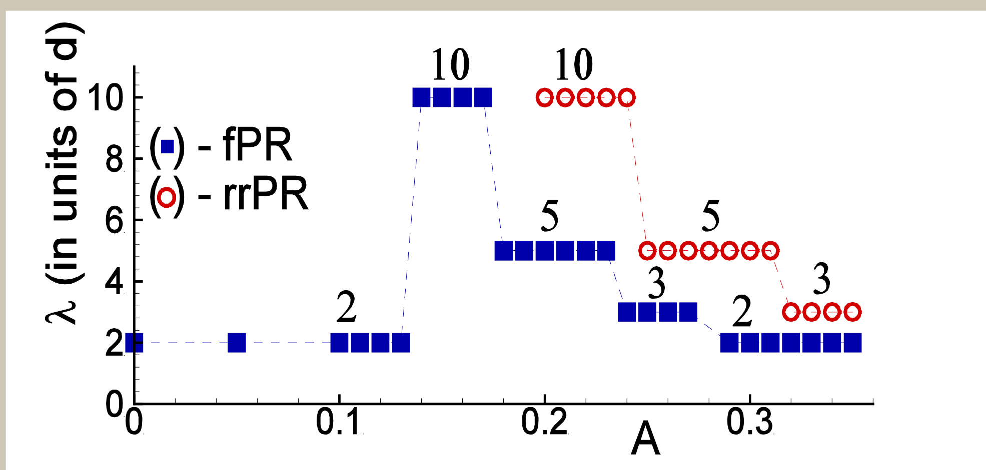


Waves in the stack of coupled JJ









LPW wavelengths at *w = 2*

Filled squares - fundamental PR

Circles - radiation related PR

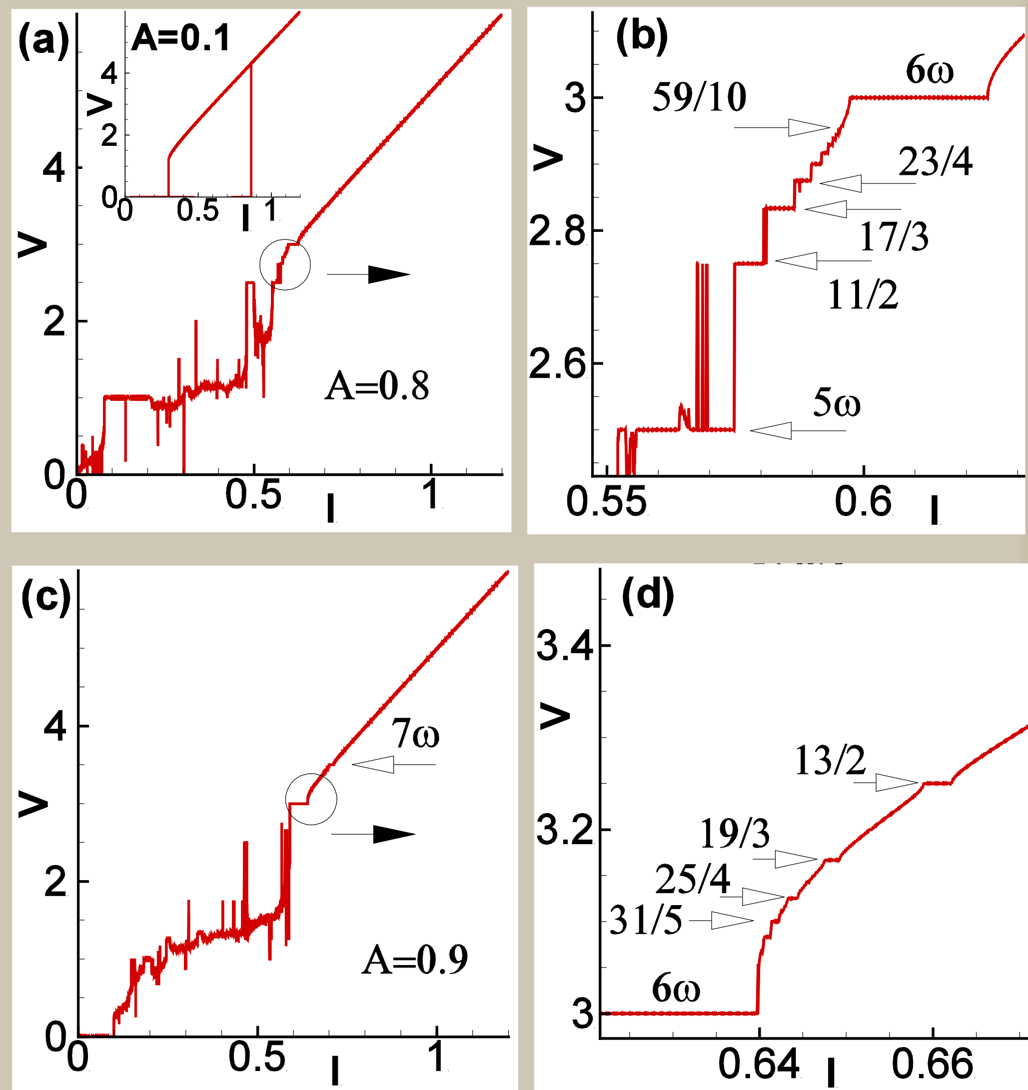
Yu.M.Shukrinov, I.Rahmonov, M. Gaafar, Phys.Rev.B, 86, 184502 (2012)

‘‘Devil’s Staircases” and Continued Fractions in Josephson Junctions.

Devil's Staircases in Josephson Junctions.

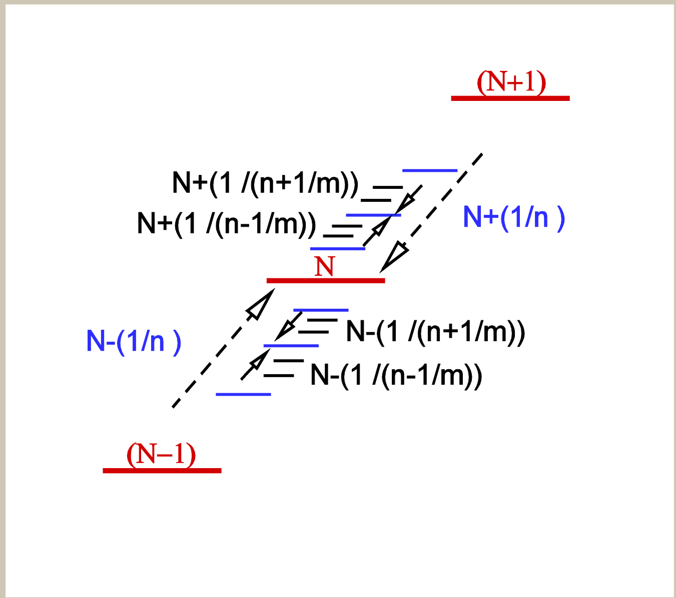
DS structure,
A=0.8

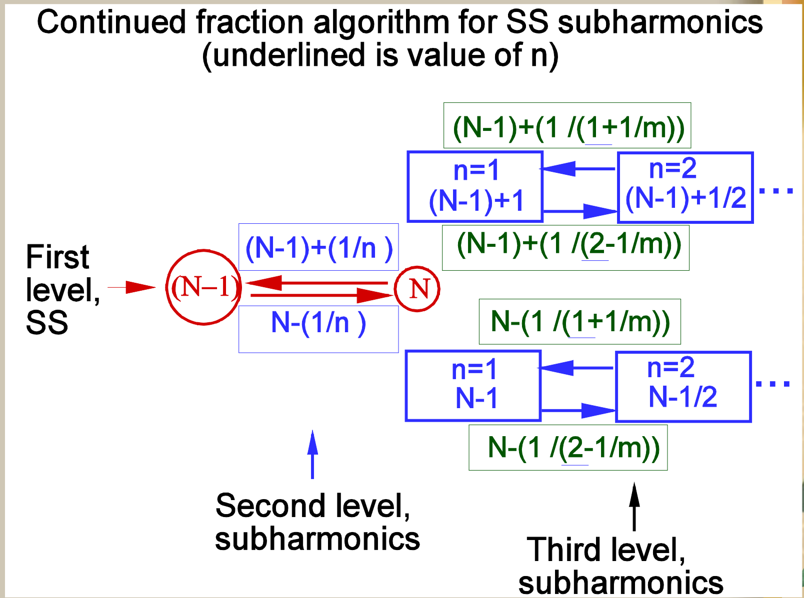
DS structure,
A=0.9



Continued Fractions in Josephson Junctions.

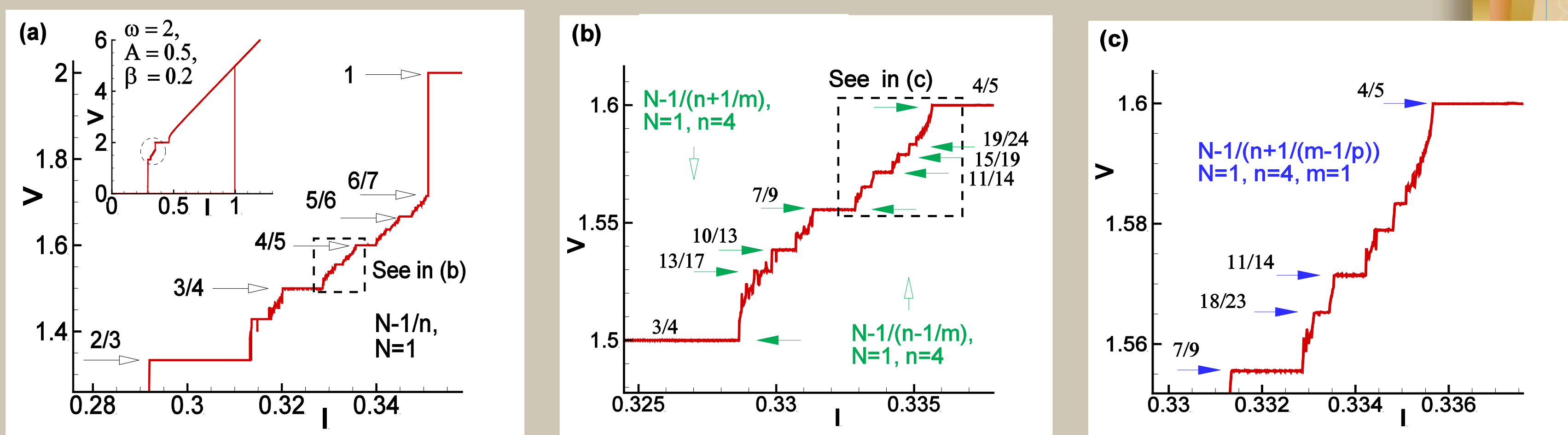
$$V = \left(N \pm \frac{1}{n \pm \frac{1}{m \pm \frac{1}{p \pm \ddots}}} \right) \omega$$





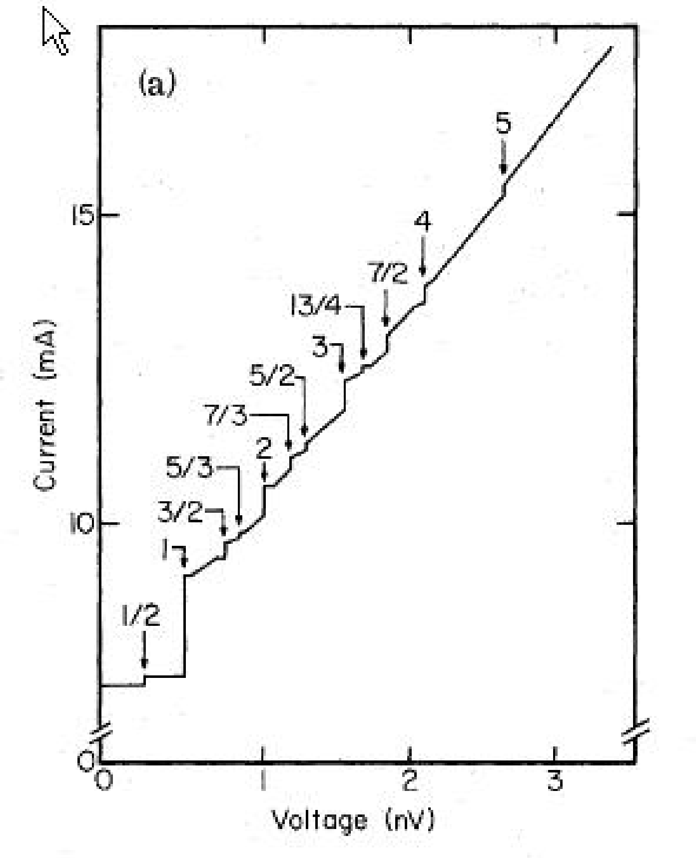
Yu. M. S., S. Yu. Medvedeva, A. E. Botha, M. R. Kolahchi, and A. Irie.,
- Phys. Rev. B, 88, 214515 (2013)

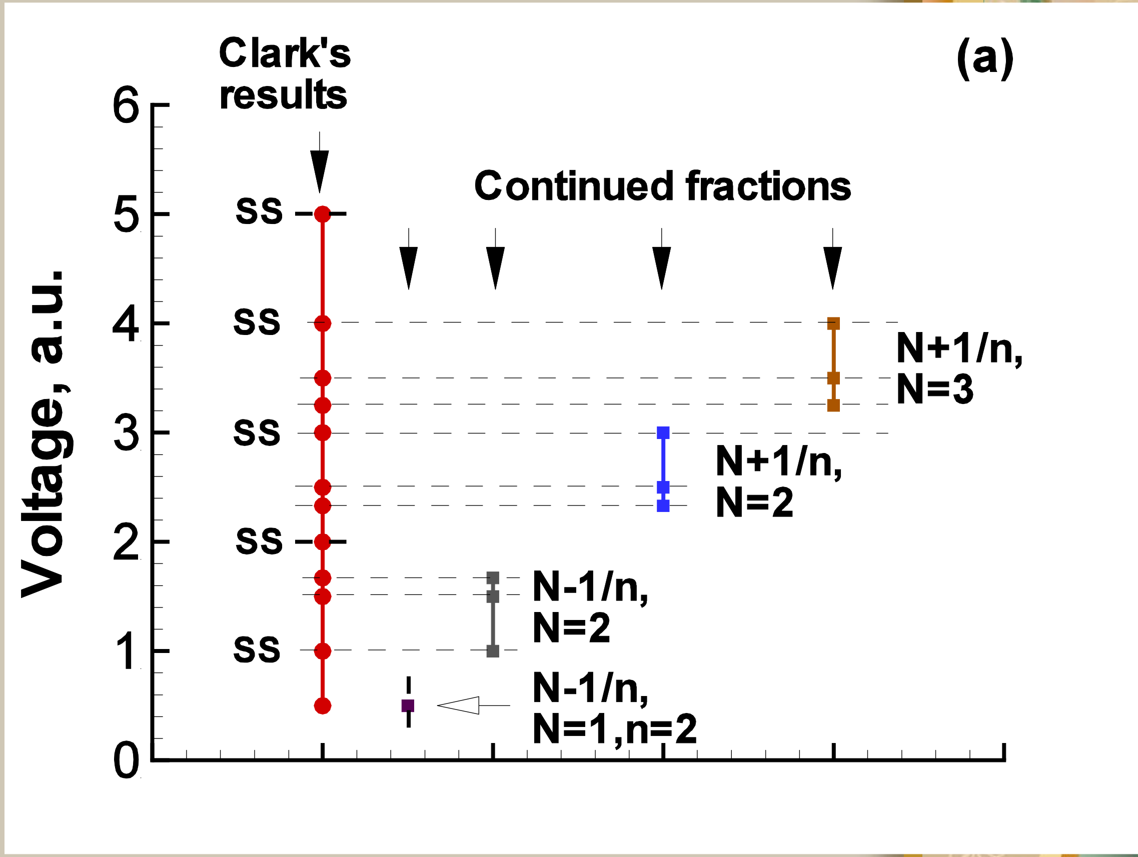
Fractal structure



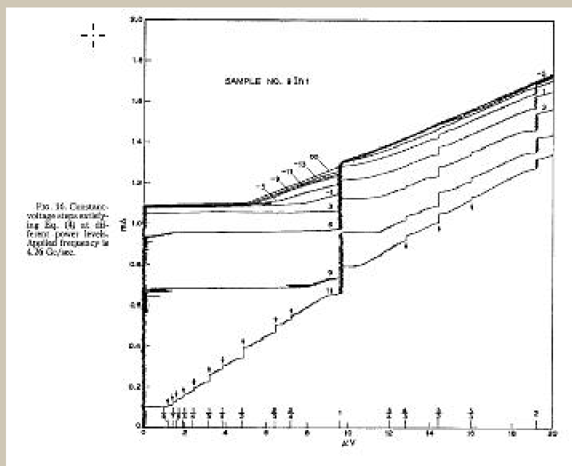
Yu. M. S., S. Yu. Medvedeva, A. E. Botha, M. R. Kolahchi, and A. Irie.,
- Phys. Rev. B, 88, 214515 (2013)

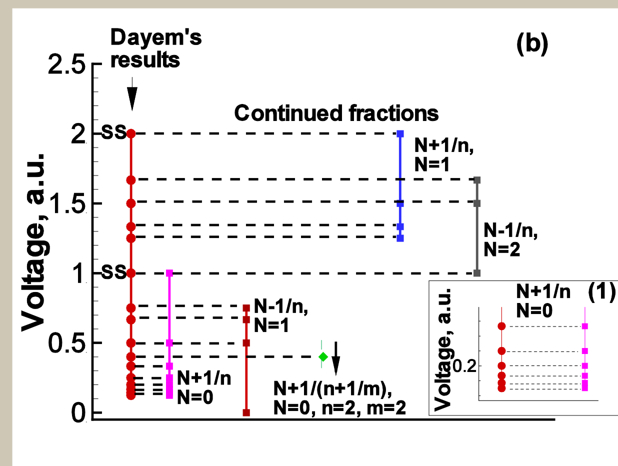
Comparison of the J. Clarke's experimental results [Phys. Rev 155, 419 (1967)] with continued fractions.

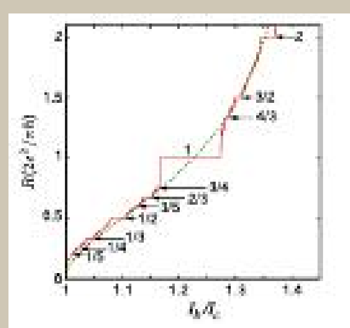




Comparison of the A. H. Dayem and J. J. Wiegand experimental results [Phys. Rev 155, 419 (1967)] with continued fractions.







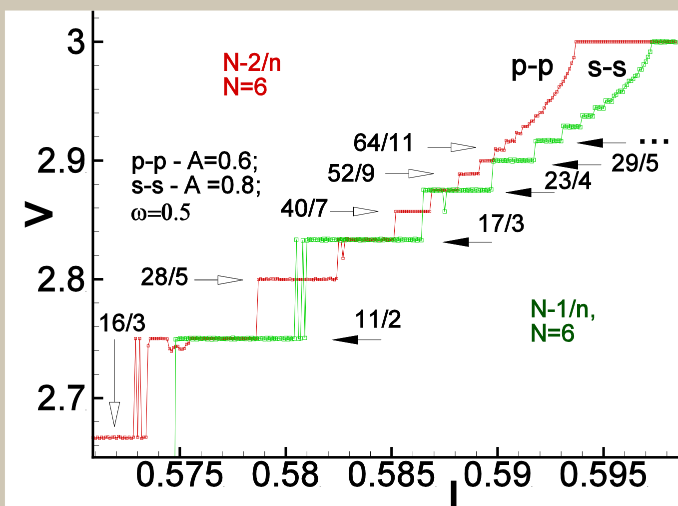
A. M. Hriscu and Yu. V. Nazarov

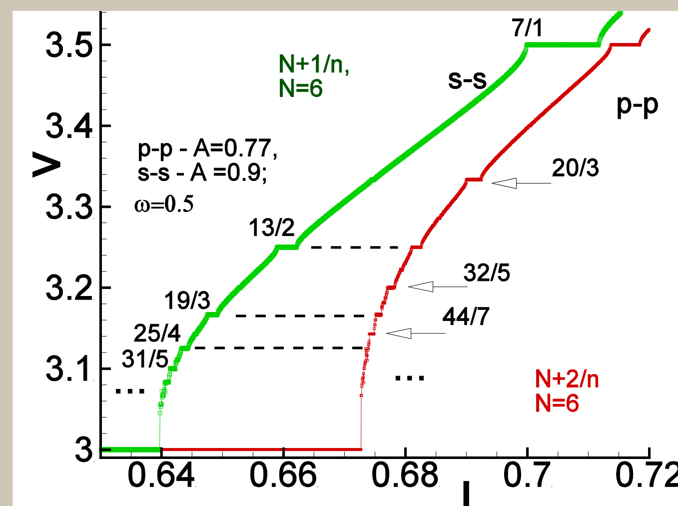
PHYSICAL REVIEW LETTERS

PRL 110, 097002 (2013)

Josephson junctions detectors for Majorana fermions

We demonstrate that the current-voltage (I-V) characteristics of resistively and capacitively shunted Josephson junctions (RCSJs) hosting localized subgap Majorana states provide a phase-sensitive method for their detection.
In addition, the RCSJs hosting Majorana bound states also display an additional sequence of steps in the devil's staircase structure seen in their I-V characteristics; such a sequence of steps makes their I-V characteristics qualitatively distinct from that of their conventional counterparts.

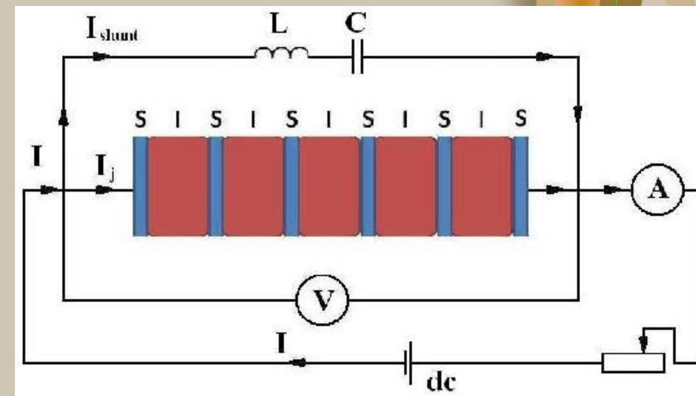




M. Maiti, K. M. Kulikov, K. Sengupta, and Y. M. Shukrinov,
(Physical Review B 92, 224501 (2015))

Shunting of Josephson junctions

Shunting



$$
\begin{cases}
\dfrac{\partial \varphi_l}{\partial \tau} = V_l - \alpha(V_{l+1} + V_{l-1} - 2V_l) \\
\dfrac{\partial V_l}{\partial \tau} = I - \sin\varphi_l - \beta\dfrac{\partial \varphi_l}{\partial \tau} - CU \\
\dfrac{\partial U}{\partial \tau} = \dfrac{1}{LC}\left(\displaystyle\sum_{l=1}^{N} V_l - u_c\right) \\
\dfrac{\partial u_c}{\partial \tau} = U
\end{cases}
$$

$I \to I_c;$

time$\to \tau = \omega_p t,\ \omega_p = \sqrt{\dfrac{2eI_c}{C_j\hbar}};$

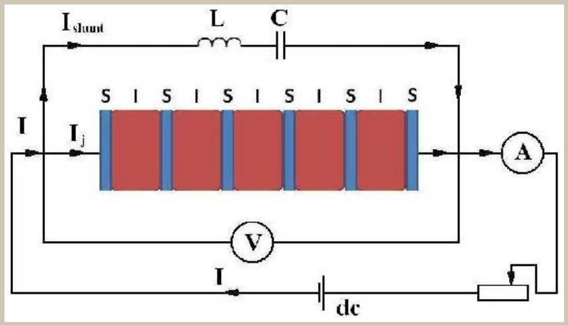
voltages V_l и $u_c \to V_0 = \dfrac{\hbar\omega_p}{2e};$

$C \to C_j;$

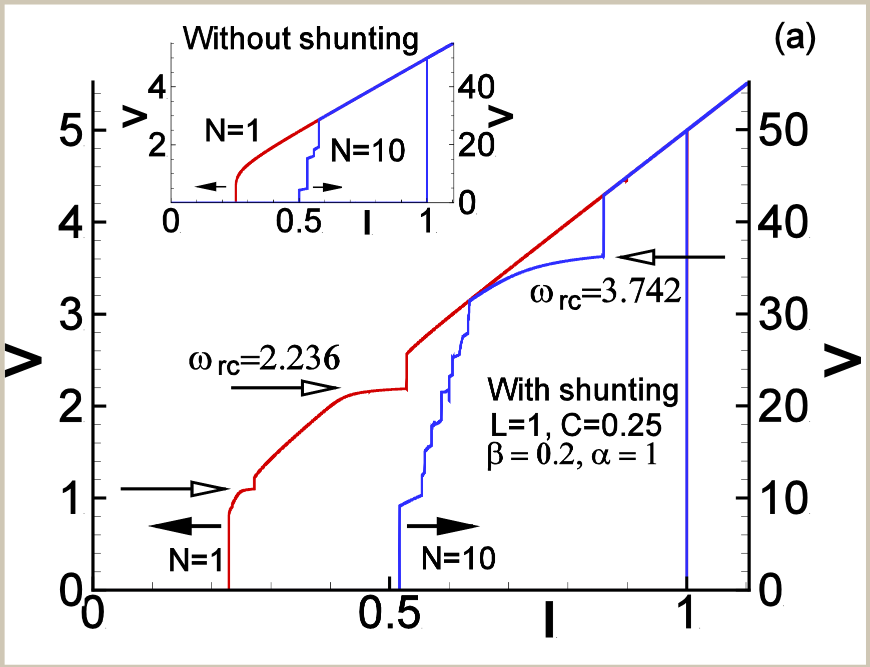
$L \to (C_j\omega_p^2)^{-1}.$

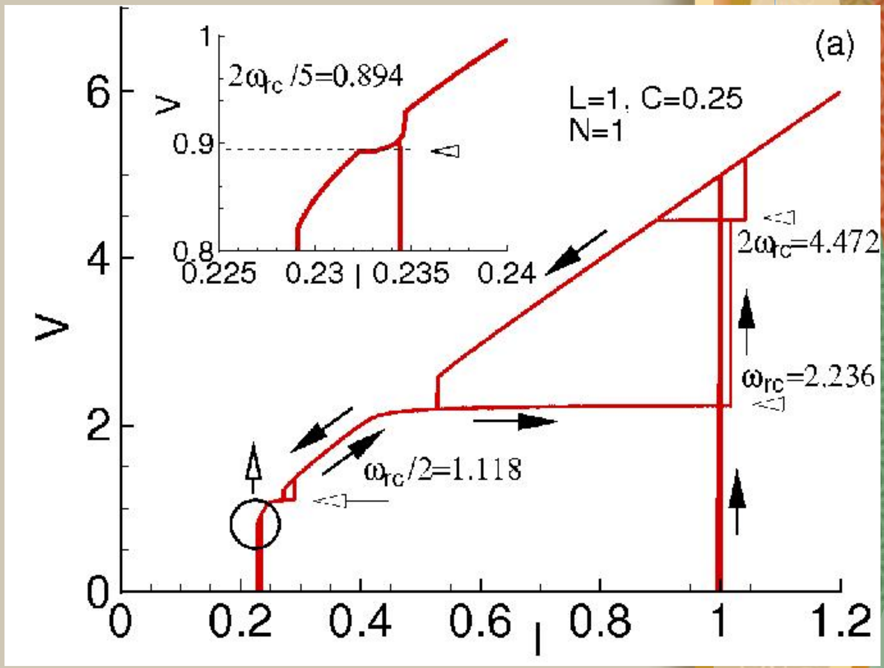
$$\beta = \frac{1}{R_j}\sqrt{\frac{\hbar}{2eI_cC_j}} = \frac{1}{\sqrt{\beta_c}}.$$

Resonance circuit branches



$$\omega_{rc} = \sqrt{\frac{1+NC}{LC}}$$

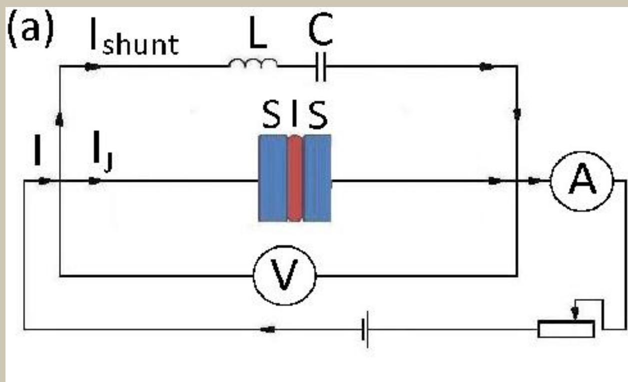


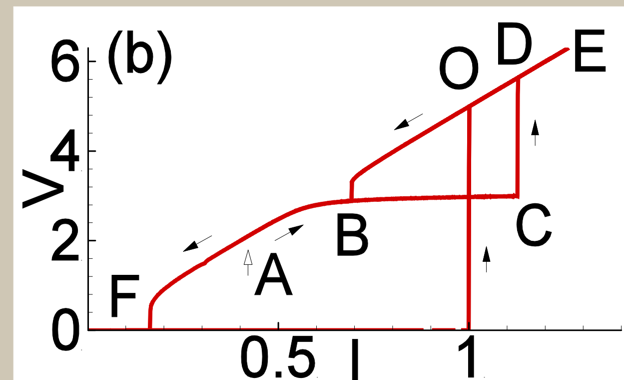


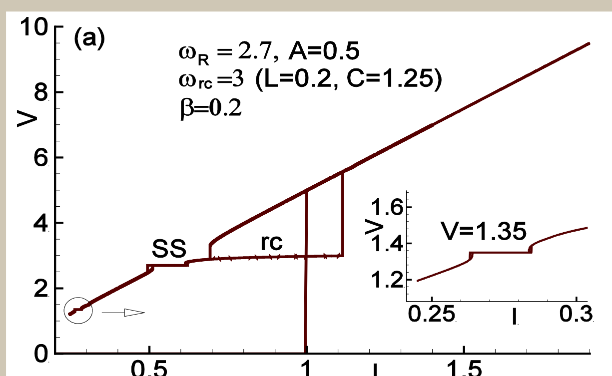
Yu. M. Shukrinov, I. R. Rahmonov, K. Kulikov - JETP Letters, 96, 657 (2012).

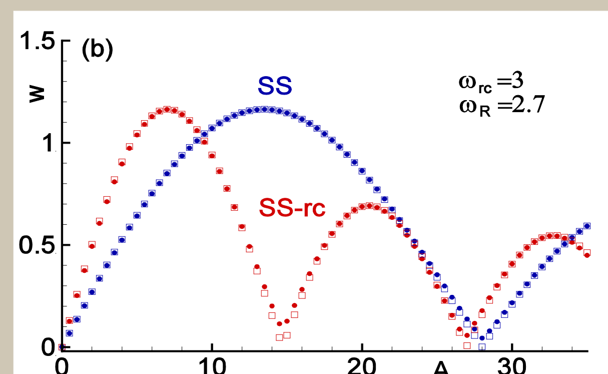
- Variation of amplitude dependence of SS width in IV-characteristics of single JJ

Variation of amplitude dependence of SS width in resonance region





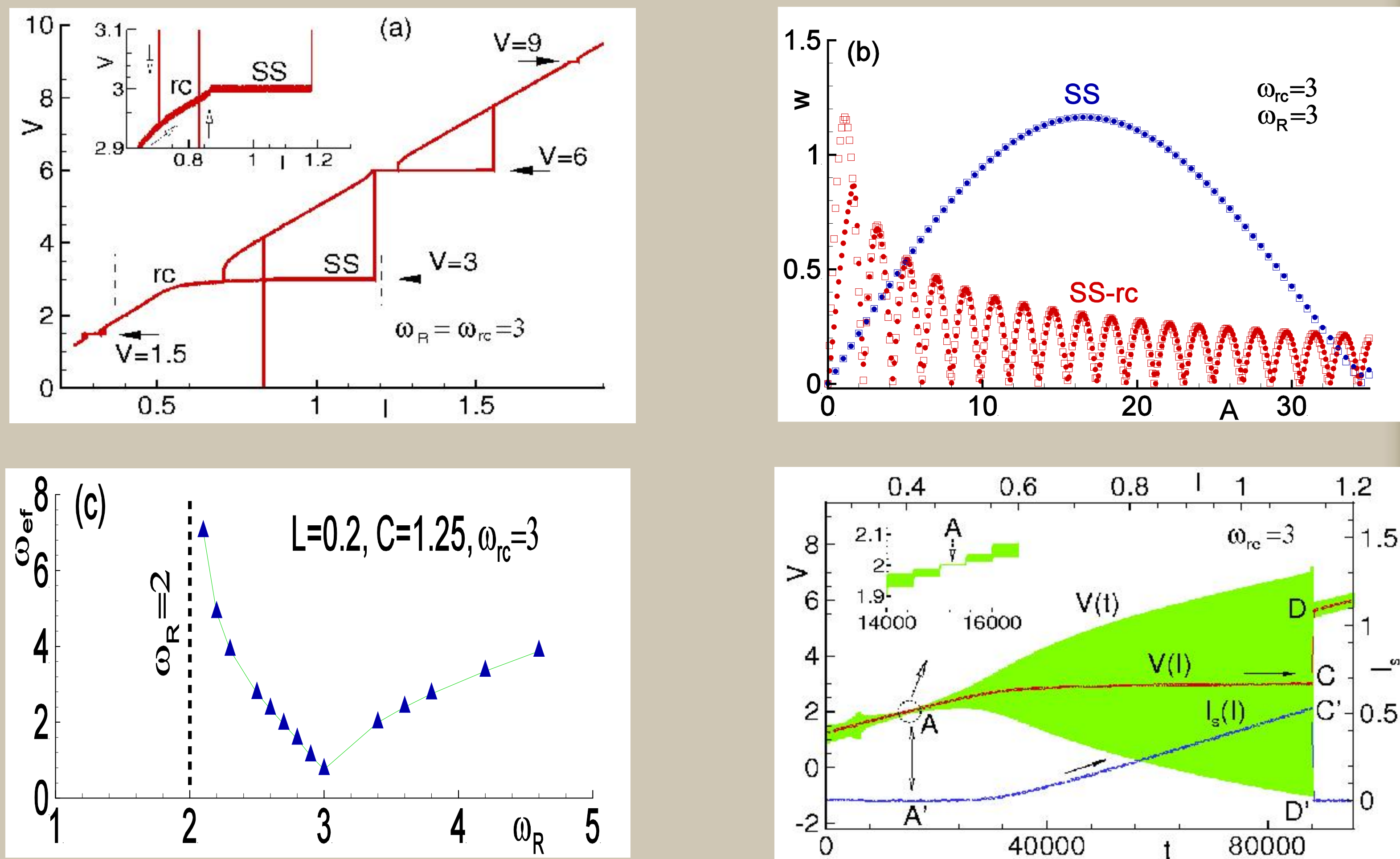




$$\Delta I = 2|J_n(Z)|, \qquad Z = \frac{A}{\omega_R}\frac{1}{\sqrt{\beta^2+\omega_R^2}}$$

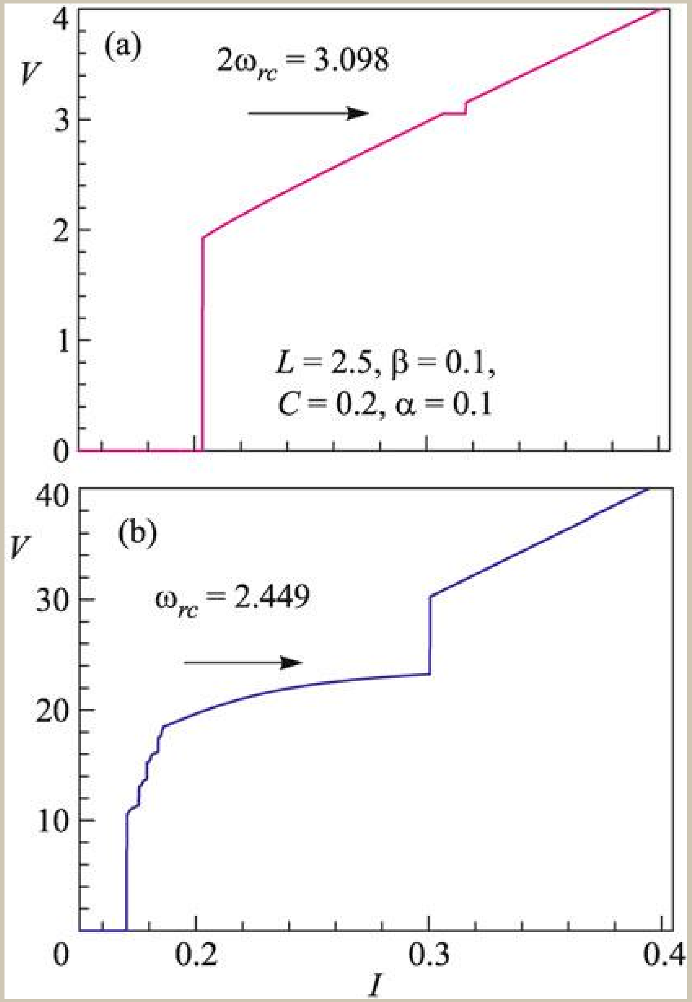
Yu. M. Shukrinov, I. R. Rahmonov, K. V. Kulikov and P. Seidel.
- EPL, 110, 47001 (2015)

Resonance conditions



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

Current–voltage characteristics for the cases N = *(a) 1 and (b) 10 calculated at the parameters** corresponding to BSCCO



- We calculate the necessary capacitance of theshunt at a given inductance *L = 50 pH using the typi*cal parameters for BSCCO
- *S = 1 μm^2,*
- *d_I = 12 × 10^(–10)m,*
- ε = 25,
- β = 0.1,
- α = 0.1,
- ω_p = 0.5 THz.
- At these parameters, the capacitance of the Josephson junction is *C_J = 0.2 pF.*
- At real inductance *L = 50 pH, the* dimensionless inductance is *L = 2.5. Consequently, the shunting capacitance Csh* = 0.04 pF is sufficient for the observation of the *rc* branch at *LC* =0.5,

* Presented by A. Ustinov and E. Ilichev

Experimental results of Klushin A., Institute of Microstructures, Nizhnii Novgorod, Russia

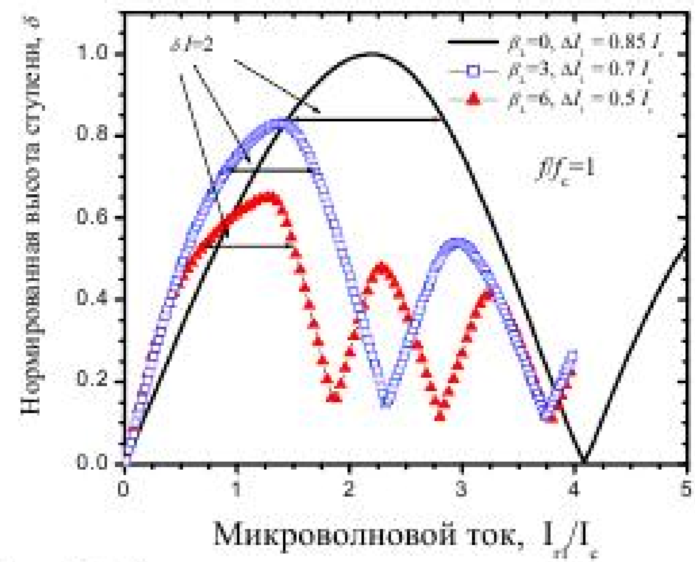
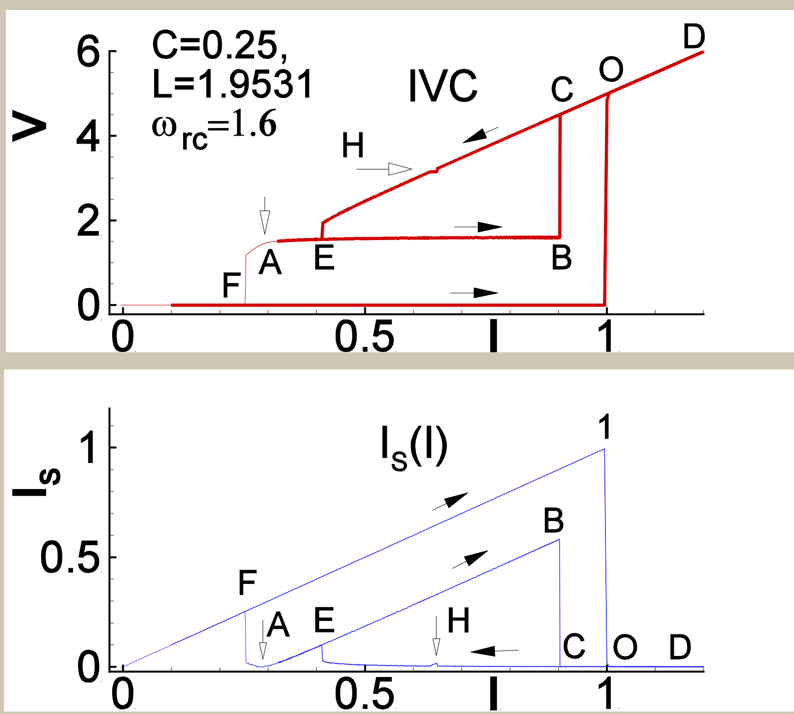


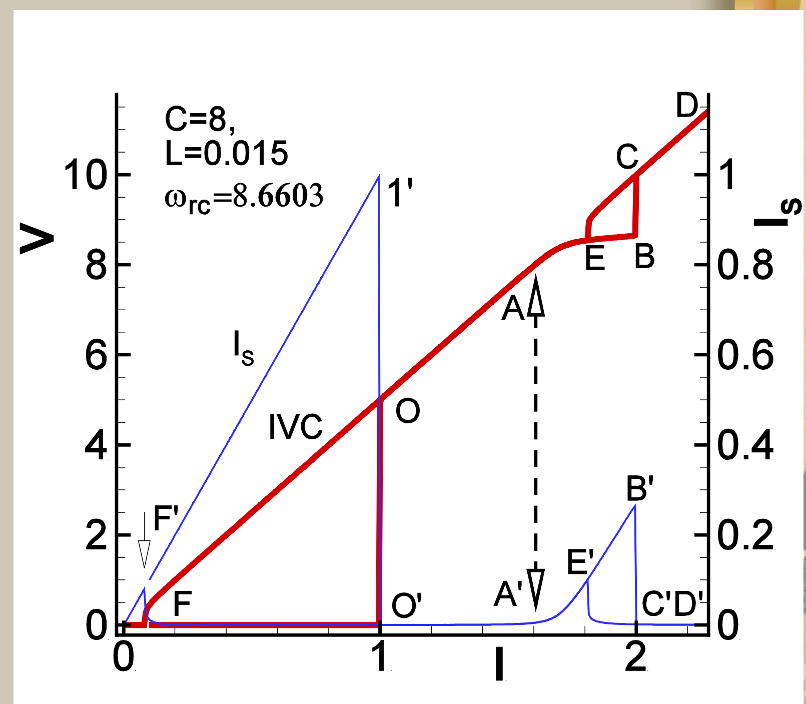
Рис. 2.6 Зависимость высоты ступени тока от мощности

Features of rc-branch

The rc-branch AB in IV-characteristics and I-dependence of the superconducting current (sweep along 01ODEAEBCDEF0)

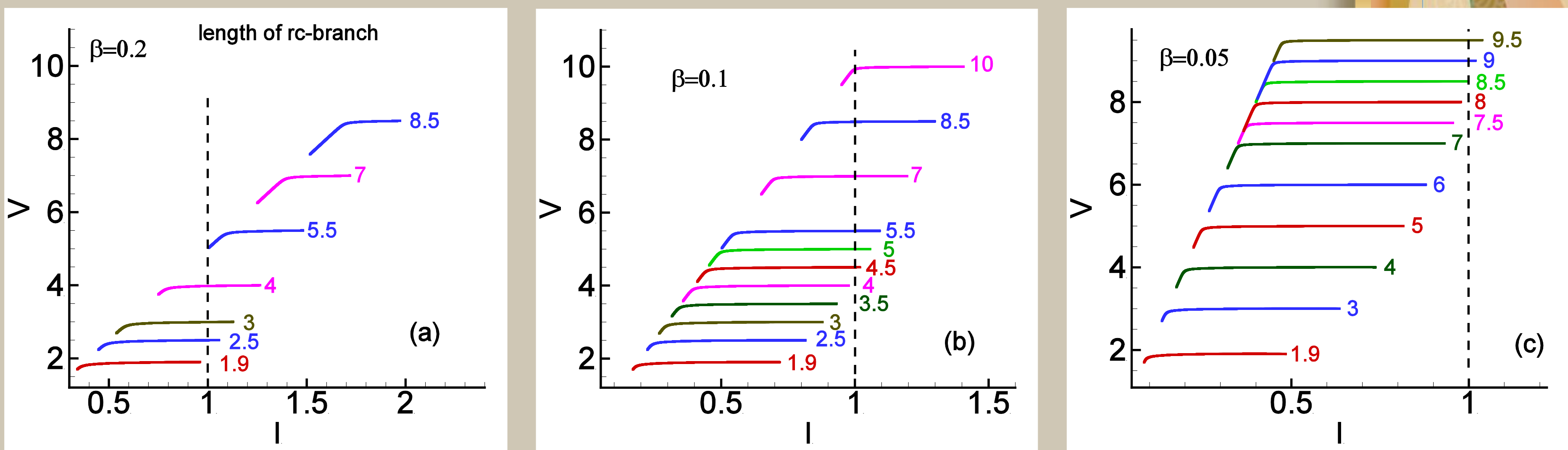
The IV-characteristic and I_s(I) dependence (sweeping along 01OBCDEBCEF0)





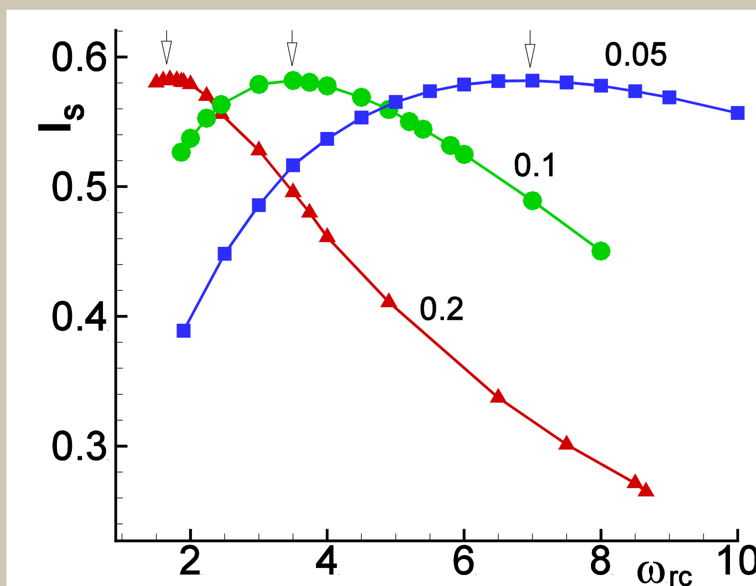
Yu. M. Shukrinov, I. R. Rahmonov, G. Filatrella, in preparation

The rc-branch at different resonance frequency and dissipation parameter

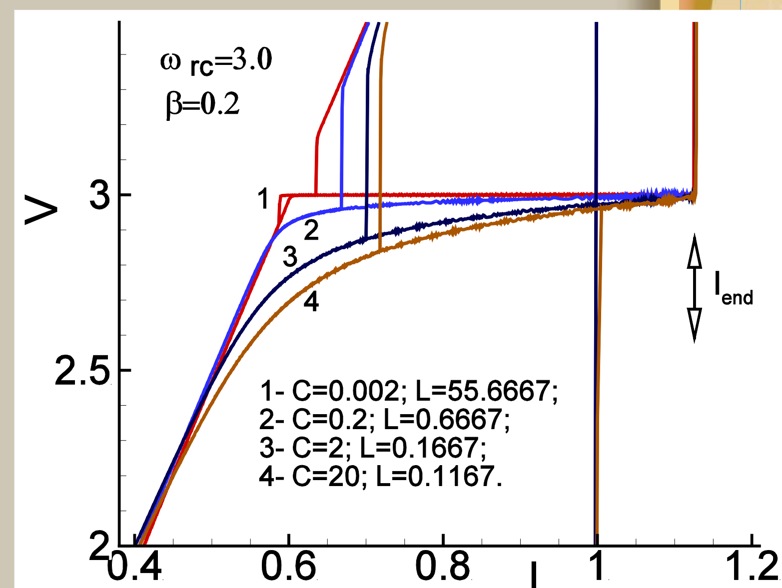


Yu. M. Shukrinov, I. R. Rahmonov, G. Filatrella, in preparation

Resonance frequency dependence of the maximal superconducting current



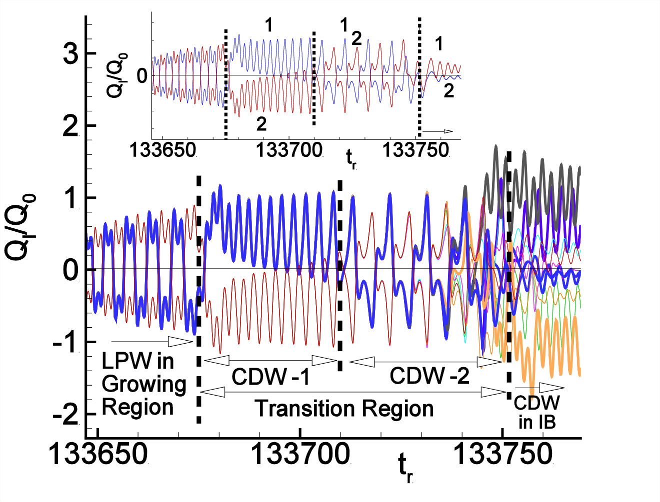
Independence of the rc-branch end point from shunt parameters at fixed resonance frequency

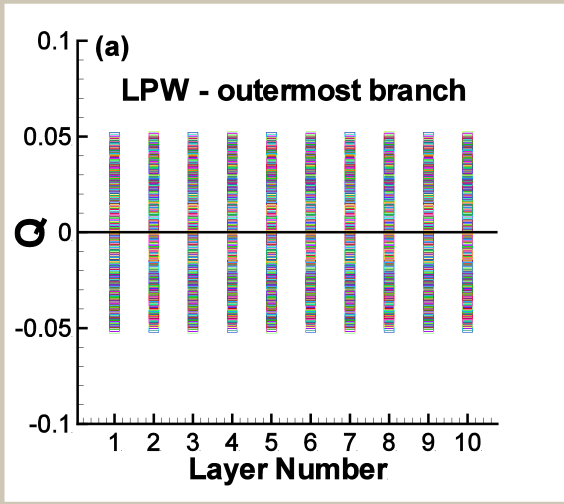


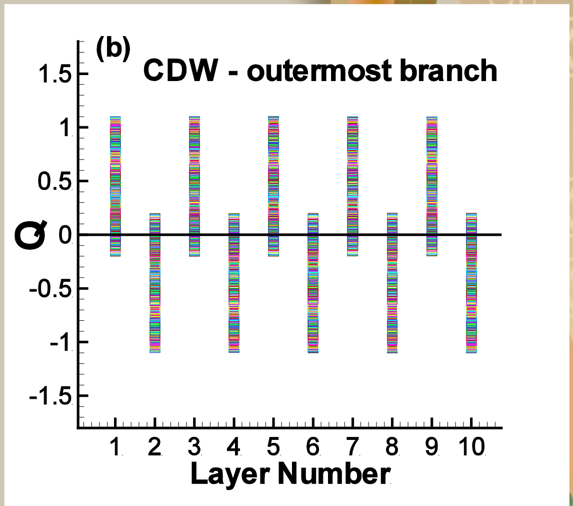
Yu. M. Shukrinov, I. R. Rahmonov, G. Filatrella, in preparation

Charge density waves

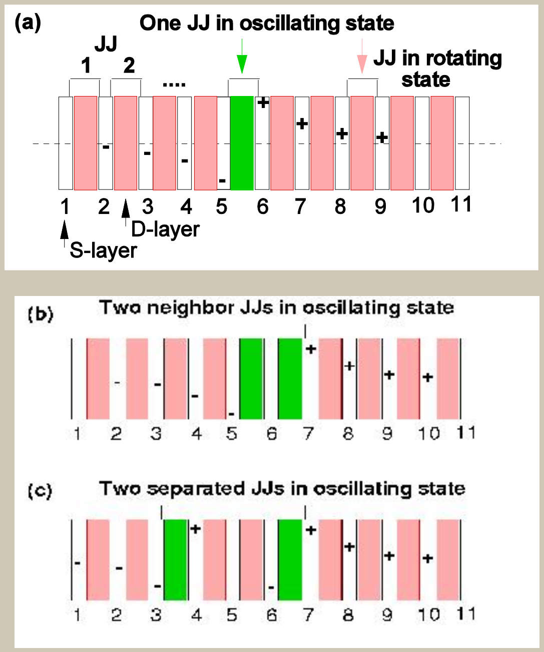
Charge Density Waves

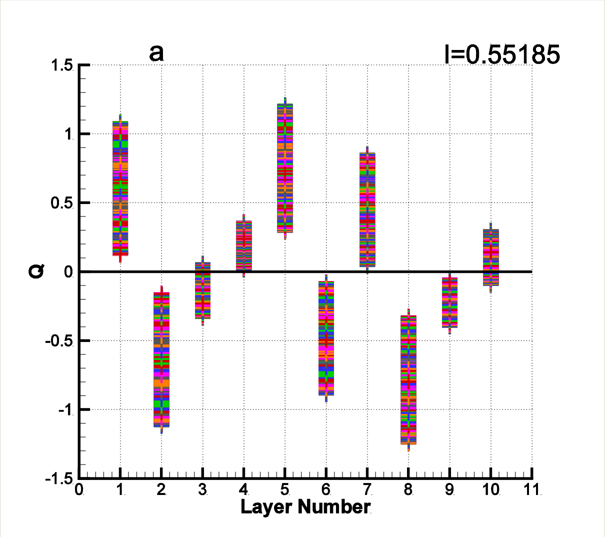


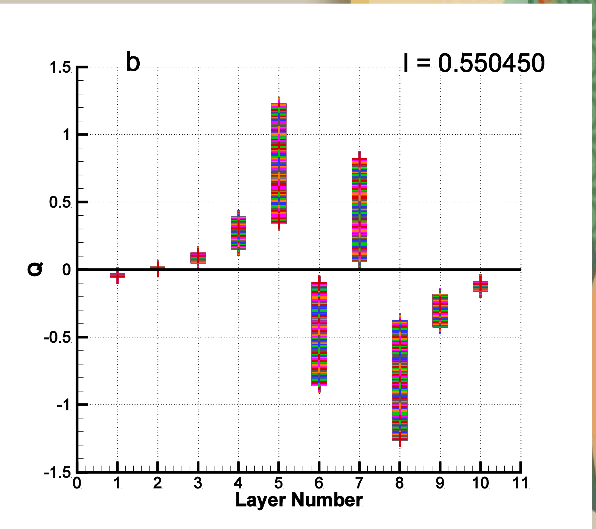




LPW→ CDW, CDW → CDW



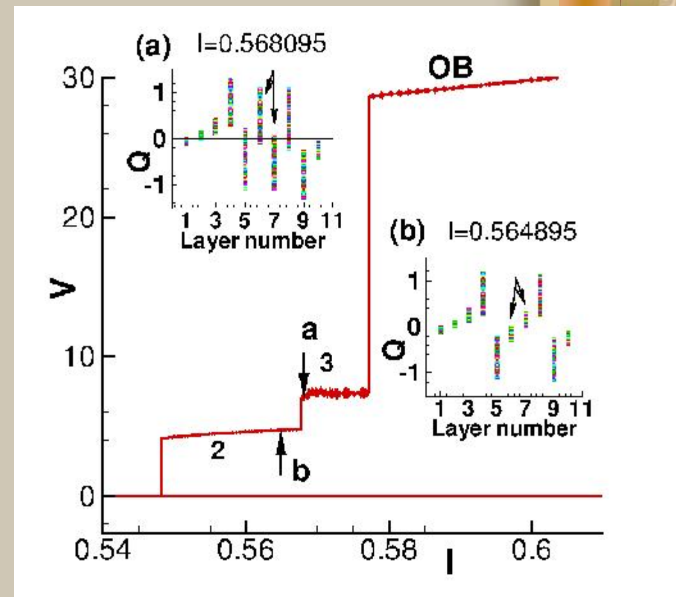


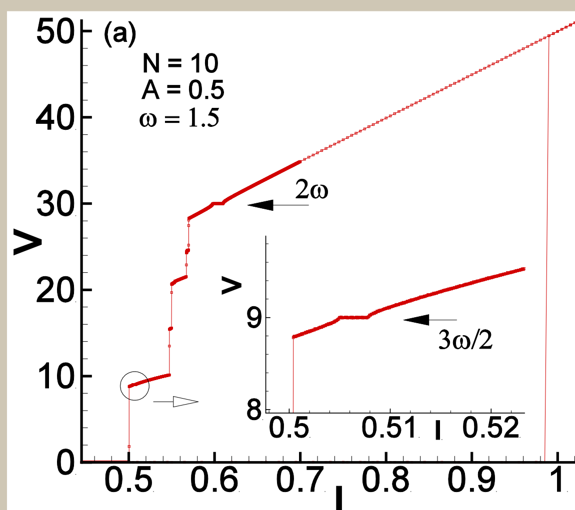


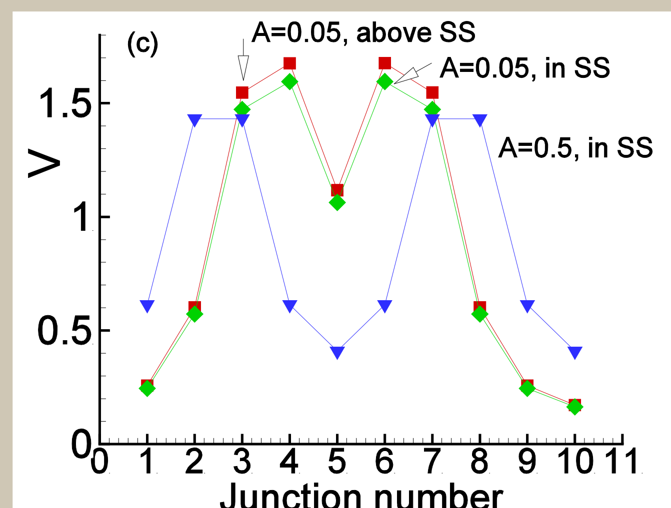
Yu. M. S., and H. Abdelhafiz., JETP Letters, 2013, Vol. 98, No. 9, 551

Breathing Charge Density Waves in Intrinsic Josephson Junctions

The effect of external electromagnetic radiation on the system of coupled Josephson junctions in the CDW state is completely different from the case of single JJ. It causes the appearance of the set of the Shapiro steps in the IV-characteristics of JJ of the stack related to the voltage distribution among JJs. However, usual harmonics and subharmonics of radiation frequency are observed in the total IV-characteristics of the stack.

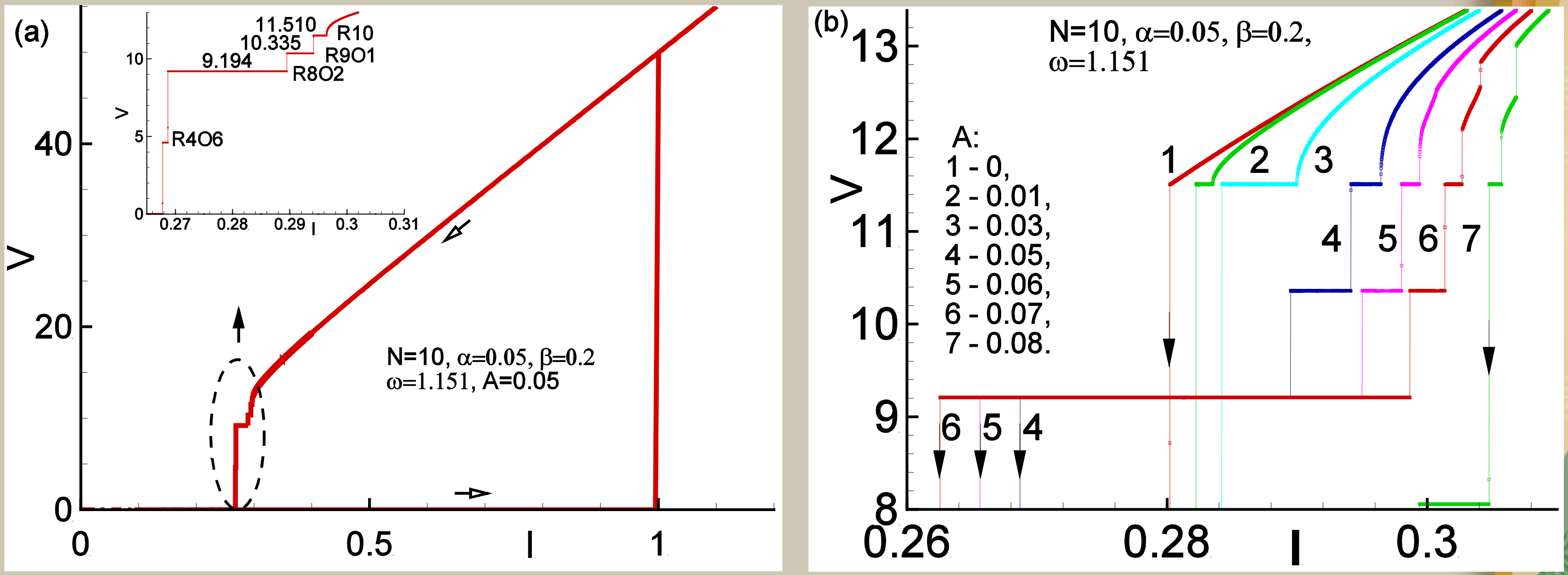






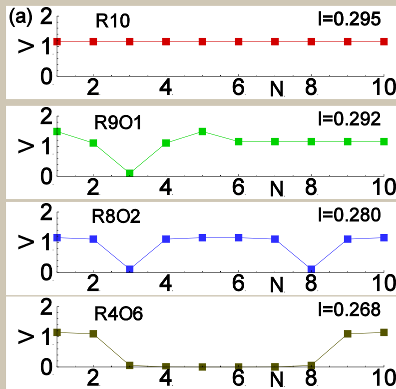
Yu. M. Shukrinov and H. Abdelhafiz. - Pis'ma v ZhETF, 98, (2013) 619--624; JETP Letters, 2013, Vol. 98, No. 9, pp. 551–556.

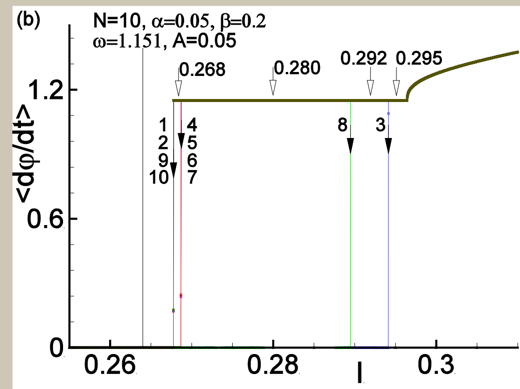
Staircase structure of Shapiro step



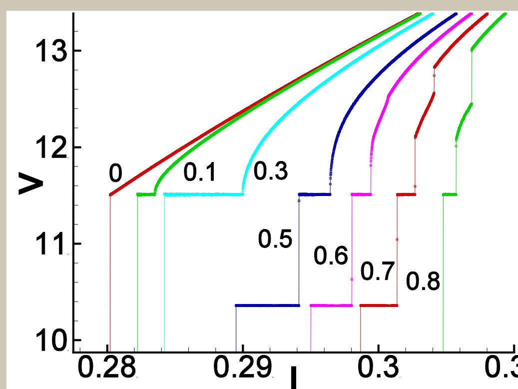
Yu. M. Shukrinov, I. R. Rahmonov, M. Nashaat, (JETP Letters, 102, 919, 2015

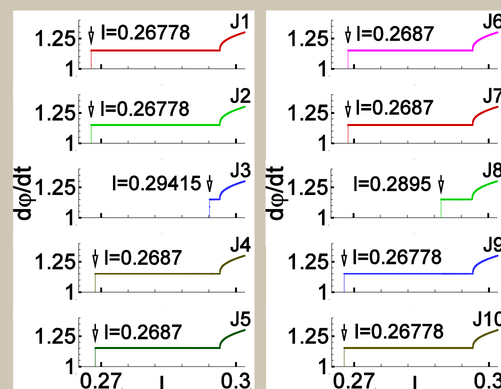
Different states of the stack, A=0.05,





What is Shapiro step? How to measure its width?





Position of the SS for intrinsic JJ does not correspond to the frequency of the external radiation (‘broken SS’)

Yu. M. Shukrinov, I. R. Rahmonov, M. Nashaat, (JETP Letters, 102, 919, 2015

Yu. M. Shukrinov, I. R. Rahmonov, A. Plecenik O. I. Streltsova, M. I. Zuev G. A. Ososkov, EPJ Web of Conferences, 02042, 2016

Conclusions

- We have demonstrated a series of novel effects in intrinsic Josephson junction in HTSC, particularly:
- Variation of longitudinal plasma wavelength with an increase of the amplitude of radiation
- The algorithm for the appearance and detection of subharmonics with increasing radiation amplitude is proposed.
- Variation of amplitude dependence of SS width in resonance region
- Position of the SS for intrinsic JJ does not correspond to the frequency of the external radiation (‘broken SS’)
- Breathing charge density waves

Thank you for your attention!
