Cherenkov radiation of Josephson vortices and Cherenkov Josephson Microwave oscillators for submm range.

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Abstract

The report is devoted to theoretical development of the concept of Cherenkov radiation of Josephson vortices and experimental investigation of characteristics of Cherenkov Josephson FluxFlow oscillators with different designs.

Now it is well known that josephson vortex moving in josephson transmission line with dispersion can radiate electromagnetc wave when cherenkov condition of equality of soliton velocity to phase velocity of the wave is fulfilled [1]. The scheme of Cherenkov oscillator contains Long Josephson Junction (LLJ)(or array of LLJ) electrodynamically built in some waveguide system which provides dispersion to make possible fulfilment of Cherenkov condition. This waveguide system may be simple strip lin e (even passive edges of LJJ may take part of it), periodical inhomogeneous strip lines or dielectric wave guide system. Besides, the Cherenkov radiation of vortices is possible in 2D Josephson Junctions [2,3]. Due to volume nature of interaction between vortices and electromagnetic waves the use of Cherenkov radiation will help to improve characteristics of existing types of josephson oscillators i.e. expand their frequency range and output power, make narrower spectral width of radiation.

Chere nkov oscillators based on single 1D linear and annular LJJ built in stripline with periodical varied width were experimentally tested. Some preliminary results regarding these designs of Cherenkov oscillators were published earlier [4,5].
IV curves for external magnetic field applied were measured and electromagnetic radiation at the frequency range 80120 GHz were registered by the roomtemperature receiver. The new band structure of Fiske steps corresponding to band spectrum of eigenmodes of peri odical transmission line was found and strong radiation with frequency and bandwidth depending on biasing current was observed. Experimental results are in a good agreement with theoretical predictions and simulation. New design of Cherenkov oscillators based on parallel and series arrays of several LLJs integrated into the only stripline was suggested and preliminary experiments were carried out.

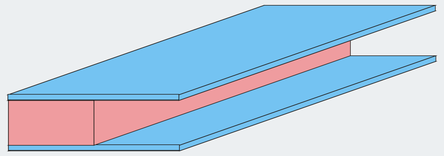
References

1. V.V. Kurin, A.V. Yulin, Radiation of Linear Waves by Solitons in a Josephson Transmission Line with Dispersion, Phys.Rev. B, 55, 9, 11659, 1997
2. V.V. Kurin, A.V. Yulin, I.A. Shereshevskii, and N.K. Vdovicheva, Cherenkov Radiation of Vortices in a Twodimensional Annular Josephson junction, Phys.Rev.Lett
3. A. Wallraff, A. Ustinov, V. Kurin, I. Shereshevsky, N. Vdovicheva, Observation of whispering gallery resonances in annular Josephson junction, Phys.Rev.Lett., 11, 1511, (2000)
4. V. Kurin, A. Yulin, E. Goldobin, A. Klushin, H. Kolstedt, M. Levichev, and N. Thyssen, Experimental investigation of Cherenkov Flux Flow Oscillators, IEEE tran
5. A.V. Baryshev, A.V. Yulin, V.V. Kurin, V.P. Koshelets, S.V. Shitov, A.V. Shchukin, P.N. Dmitriev, and L.V. Fillipenko,
Design and Fabrication of Cherenkov FluxFlow Oscillator, IEEE transaction on Applied Superconductivity, 9, 2, 3737, 1999

Josephson Transmission Lines with Dispersion =
Long Josephson Junction built in External wave-guide system

Examples of JTL's

Singlle LJJ in the Strip-line (SL)

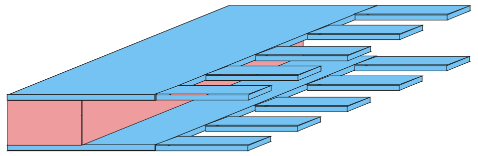


$$D(\omega,k) = -i\omega(-i\omega+\gamma)+k^2+\alpha\kappa^2\frac{\tanh \kappa W}{\kappa W}$$

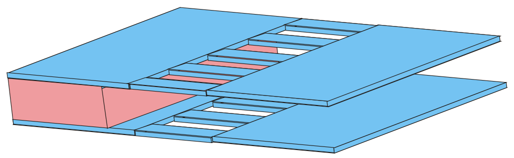
$$\kappa^2 = k^2 - \frac{\omega(\omega+i\Gamma)}{v^2}$$

$$\alpha = \frac{W L_J}{W_J L_{SL}}$$ -Coupling parameter

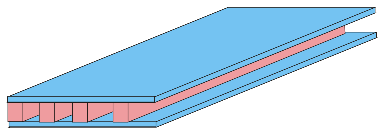
LJJ in the SL with side resonators



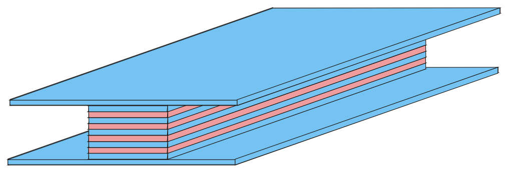
More complicated structure
with two Strip-Lines



Parallel LJJ array in SL



Josephson Superlattice in Strip-line



All system shown are two-dimensional and are described by 2-D Sine-Gordon equation

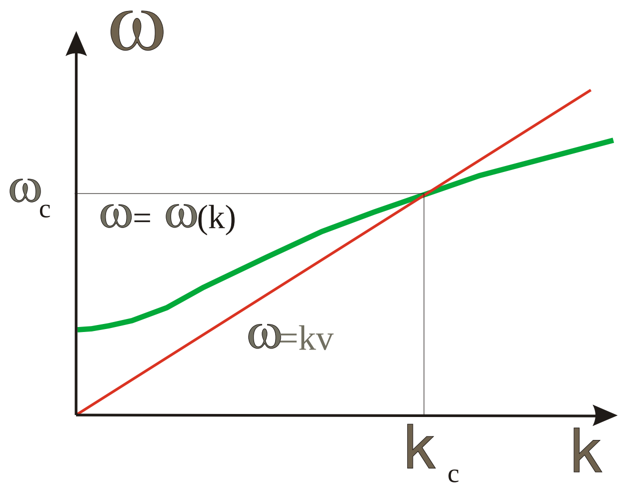
$$\frac{\Phi_0}{2\pi}\left\{C(\vec{\rho})\frac{\partial^2\phi}{\partial t^2}+G(\vec{\rho})\frac{\partial\phi}{\partial t}-\mathrm{div}L^{-1}(\vec{\rho})\nabla\phi\right\}+j_c(\vec{\rho})\sin\phi = j_e$$

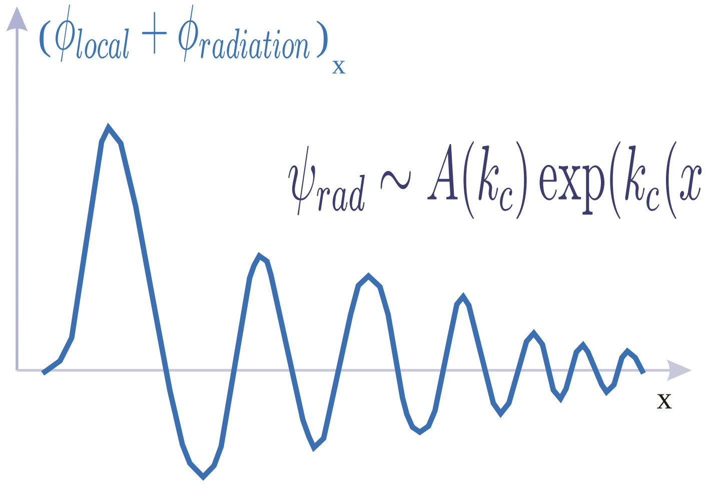
For narrow junction it may be reduced to
1D integral equation

$$\hat{D}\varphi+\sin\varphi = j_e,$$

Where $\hat{D}$ -linear operator

Common feature of such a system -radiation of linear waves by moving vortices due to Cherenkov effect





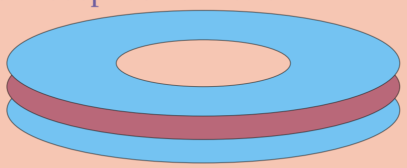
Taled Solitons (1)

$$\phi = \phi_{local}+\phi_{radiation}$$

$$\psi_{rad}\sim A(k_c)\exp(k_c(x-vt)+\Gamma(x-vt)/(v-v_g(k_c)))$$

results in:
long-range interaction and,
changing spectrum of vortex

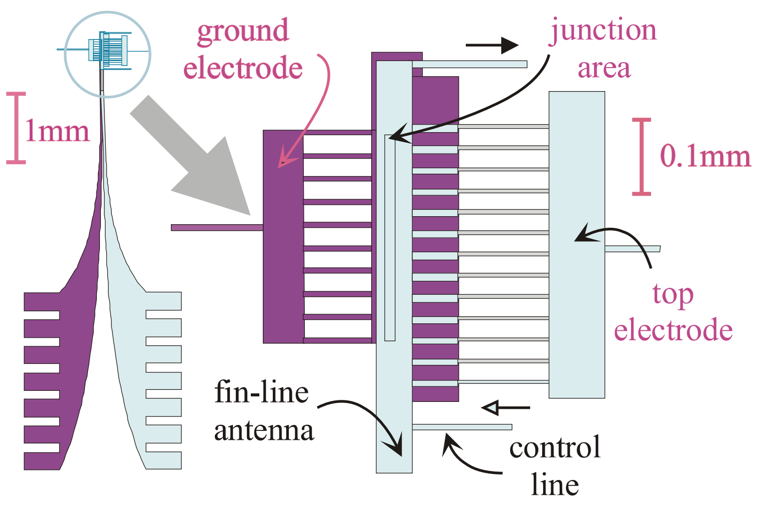
Annular Josephson Junction



$$\frac{\partial^2\phi}{\partial t^2}+\gamma\frac{\partial\phi}{\partial t}-\frac{1}{r}\frac{\partial}{\partial r}r\frac{\partial\phi}{\partial r}-\frac{\partial^2\phi}{\partial\theta^2}+\sin\phi = j_e$$

Experimental investigation of Long JJ built in space periodical slow-wave system

Appearance of the Sample



Parameters

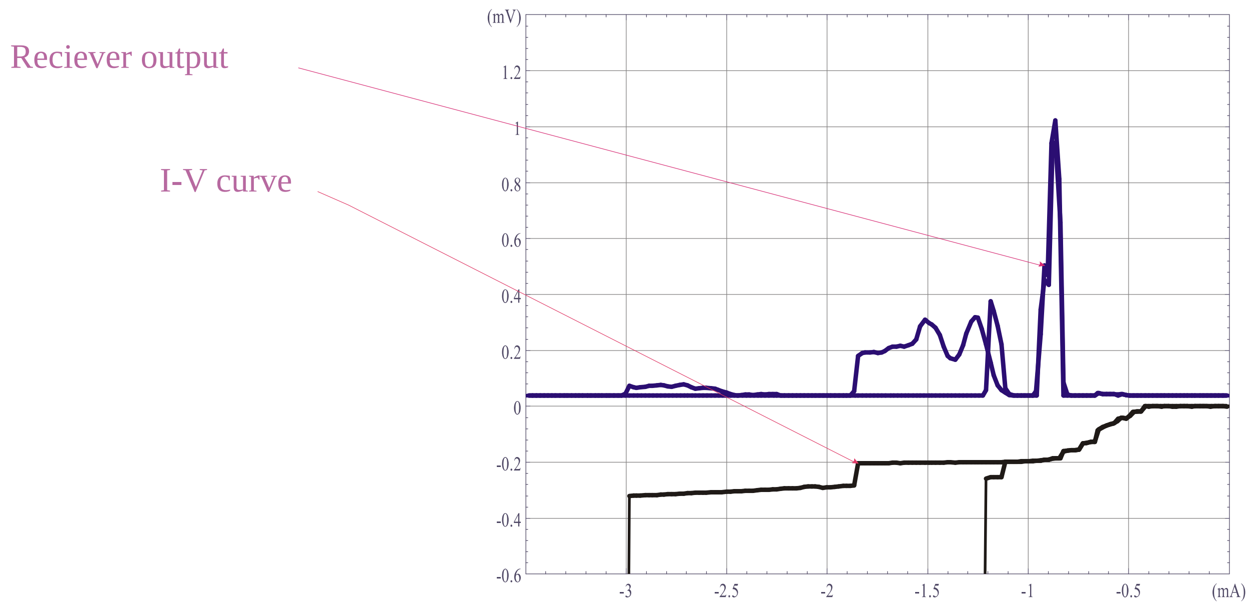
L=1-2 mm

$j_c=400A/cm^2$

$V_s=0.03c$

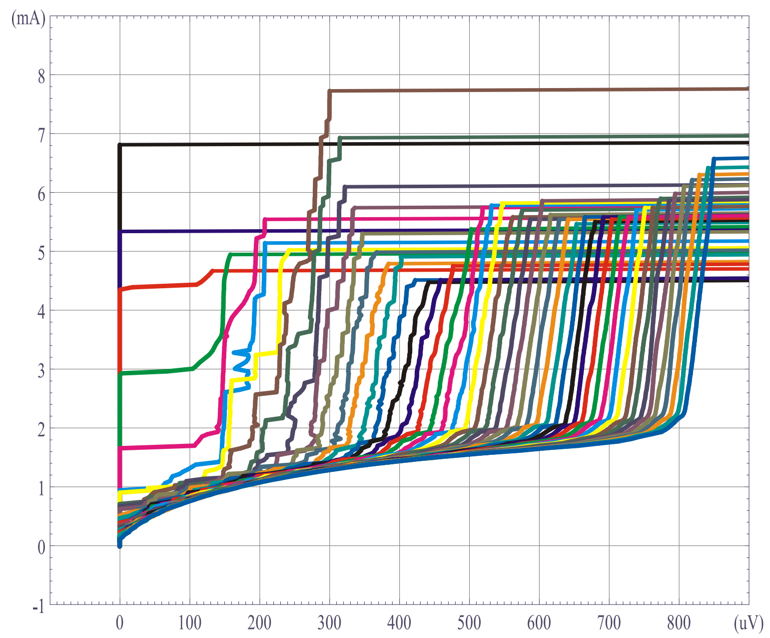
$lm_j=27m$

Intensity of radiation at 120GHz vs biasing current



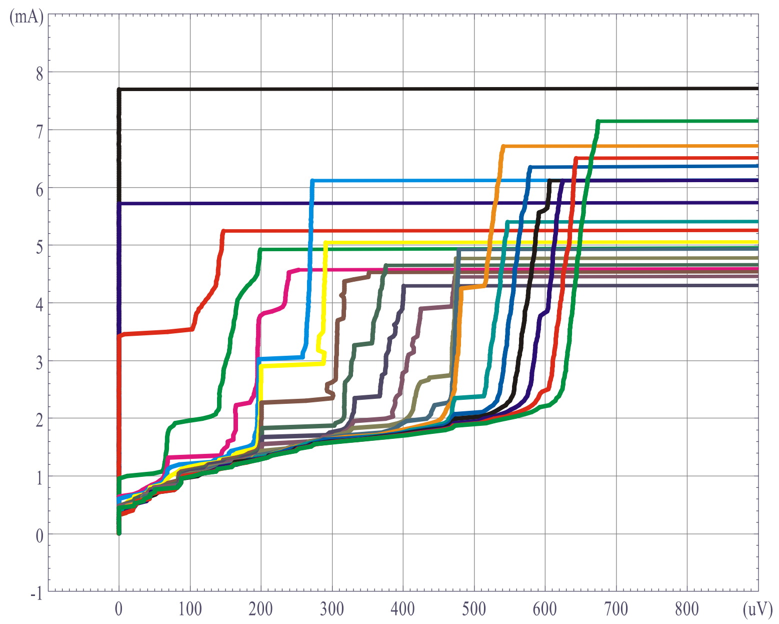
Set of I-V curves for test sample- without external waveguide system

Usual Fiske structure is seen

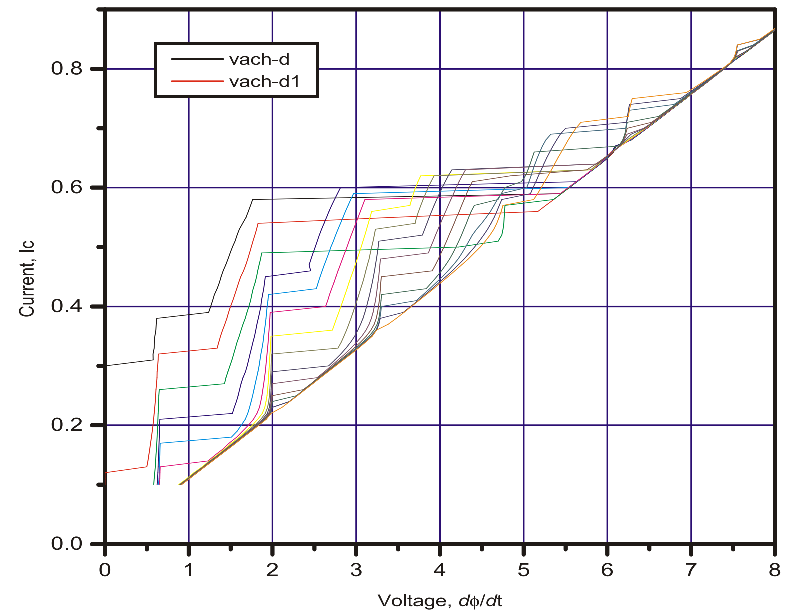


Set of I-V for LLJ coupled with space-periodical slow-line

Quantity of steps is reduced and band structure observable

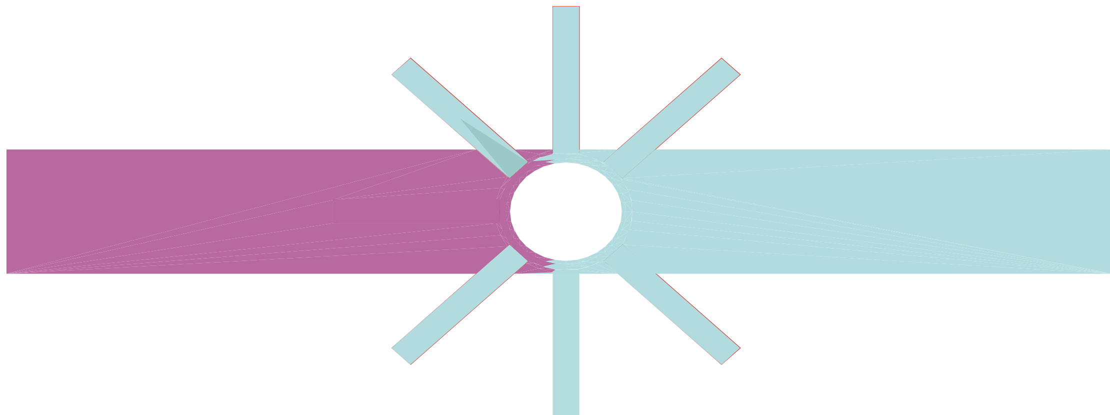


I-V simulated using RSJ 1D approach

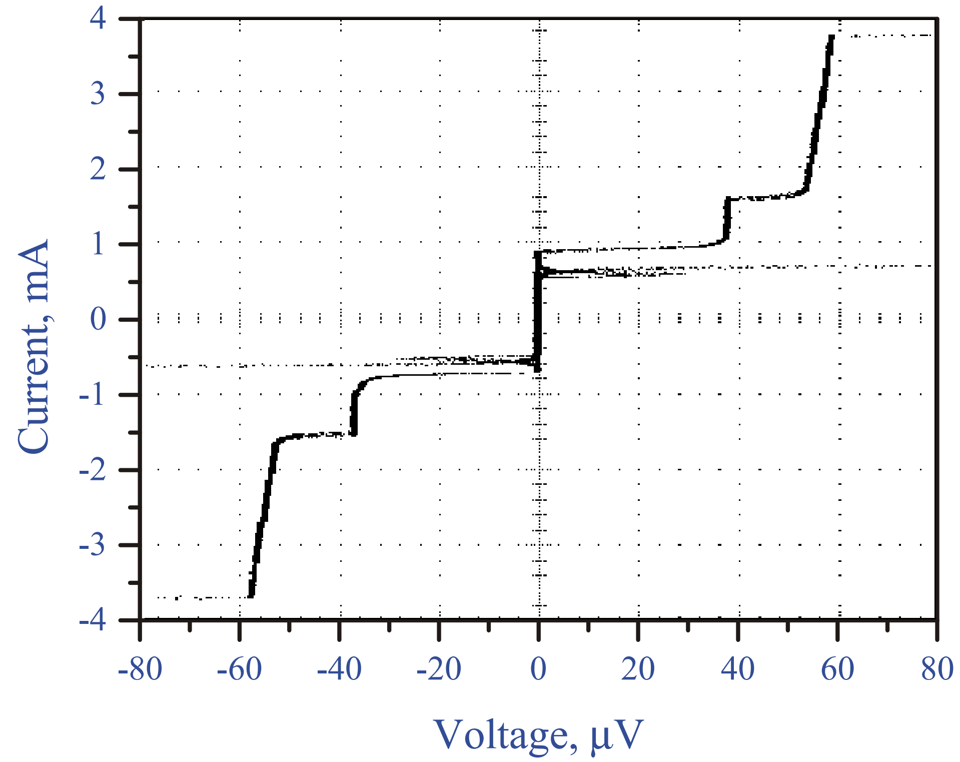


Cherenkov resonanses in the annular JJ with space-periodical slow-line (experiment)

Samples with different number and length of stubs are tested

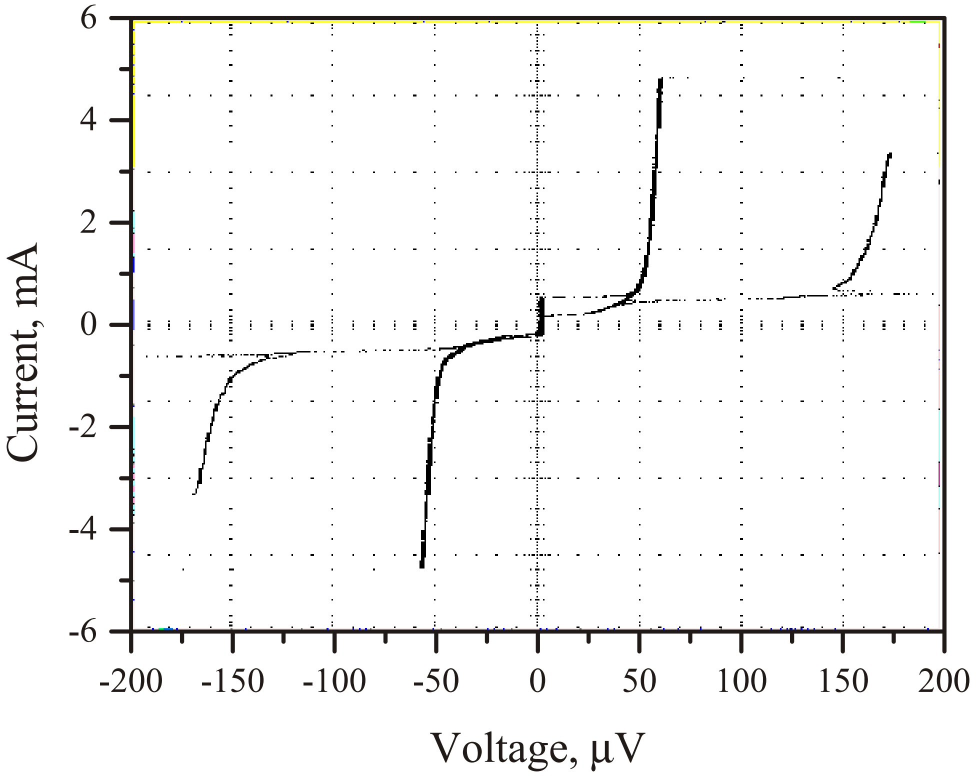


IV Steps for two temperatures,
one fluxon trapped



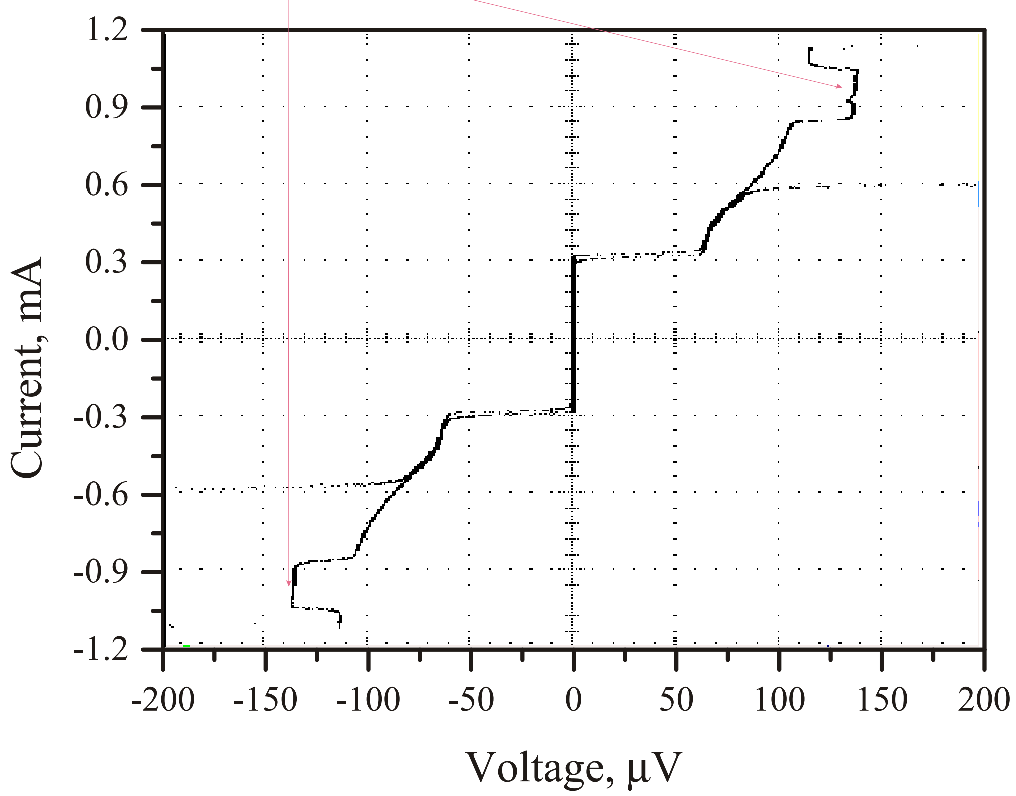
Test annular junction (no stubs)

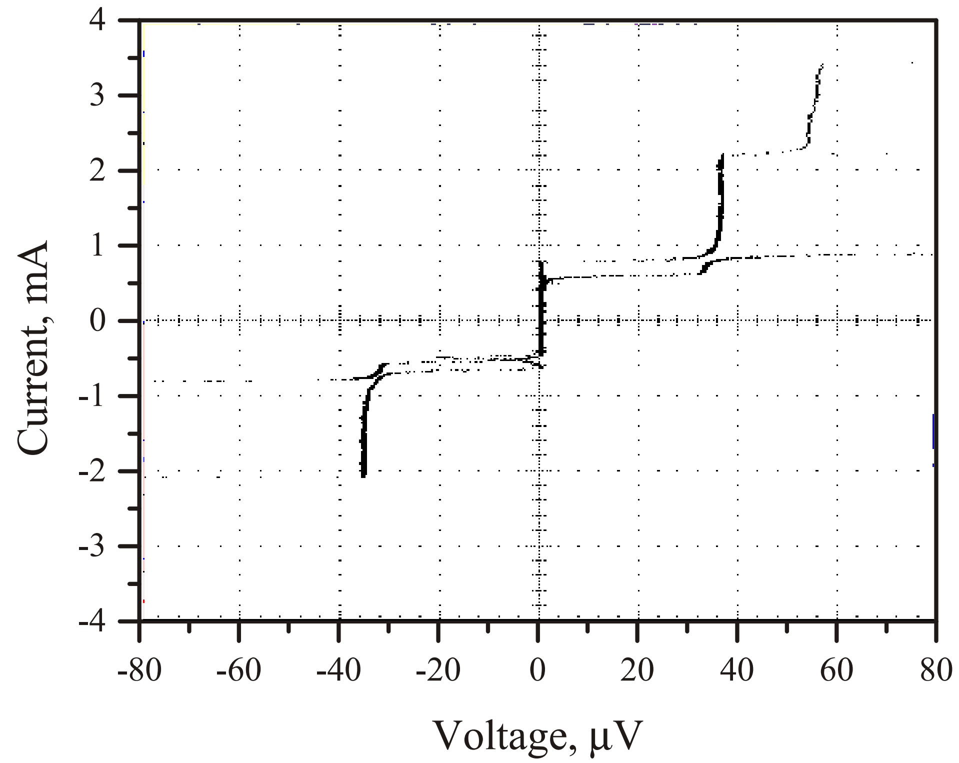
Different branches correspond to
N=1,2 trapped fluxons



I-V for two fluxons trapped

resonanse steps



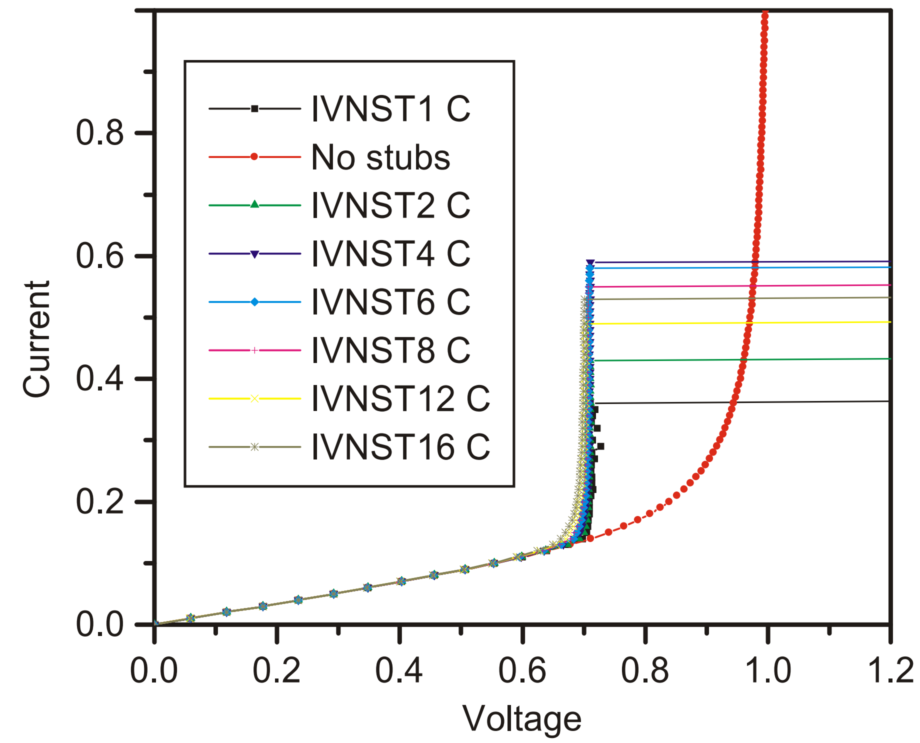


Cherenkov resonanses in the annular JJ with space-periodical slow-line (theory+simulation)

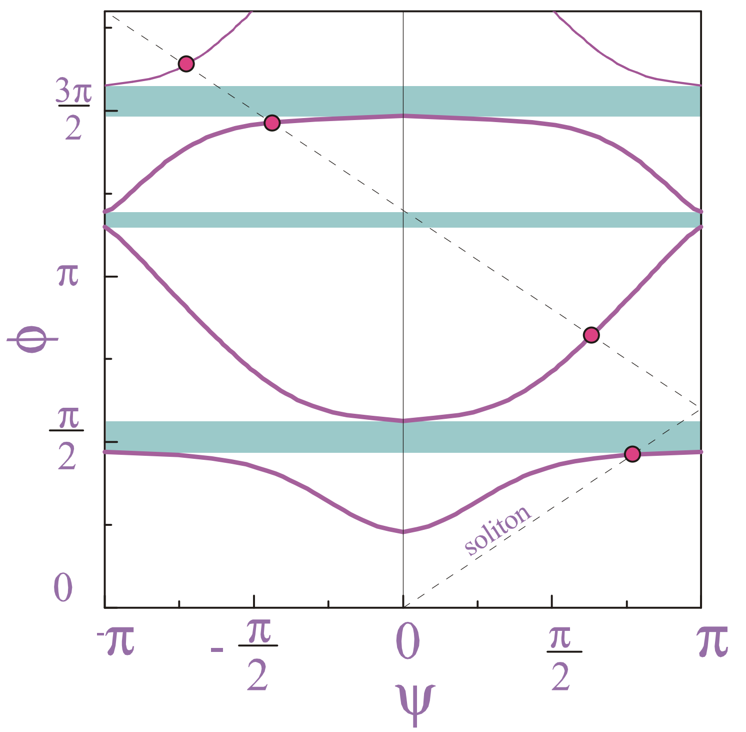
Theory and experiment for Cherenkov effect in smooth wide annular junctions

1. A. Wallraff, A. Ustinov, V. Kurin, I. Shereshevsky, N. Vdovicheva, Whispering Vortices, Phys.Rev.Lett., v.84, n.1, 151, (2000)
2. V. Kurin, A. Yulin, I. Shereshevskii, and N. Vdovicheva, Cherenkov Radiation of Vortices in a Two-dimensional Annular Josephson junction, Phys.Rev.Lett, 80, 15, 3372, 1998

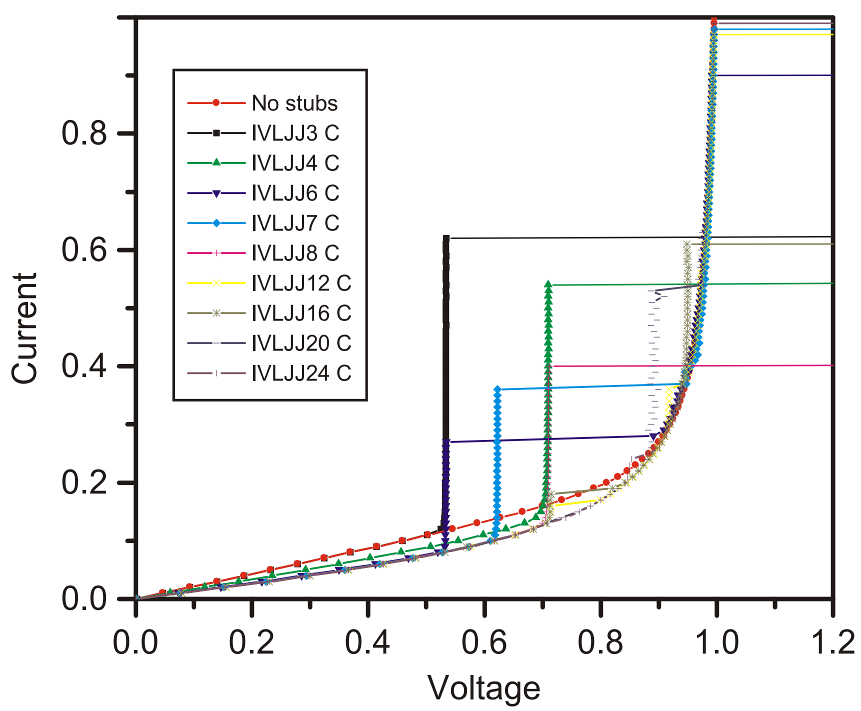
Steps for annular JJ with different number of stubs, one fluxon in JJ



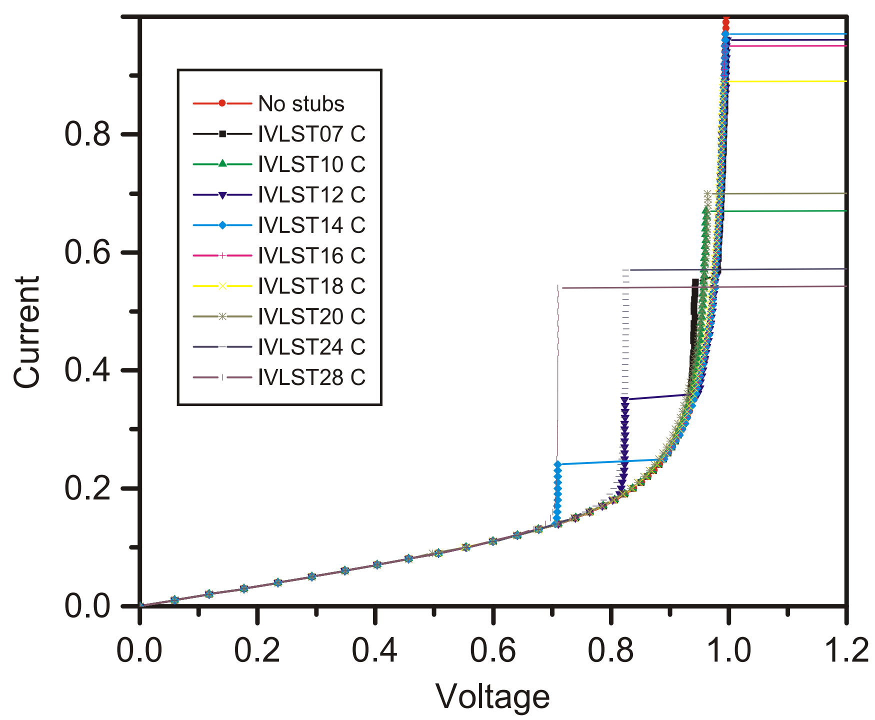
Dispersion of linear waves in space periodical line, red points-position of Cherenkov resonances



Different JJ length



Different stub length



Josephson Superlattice built-in Strip-Line

Equations i=1..N

j Ù

jgjjj+-+j(x)sin=G å j +j

itt it ixx c i i ext

G-linear operator of external impedance, originated from SL

Ù -iwt+ ikx 2

G f=G(k,w)f(w,k)e dkd/(2)

For smooth SL 1/2 1/2

G(w,k)=(a/w)(k2-w(w+iG)/v2)tanh(k2-w(w+iG)/v2)w

a-coupling, w-width of SL,

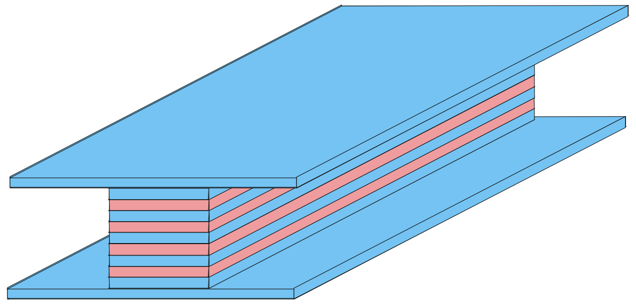
v-dimensionless wave velocity in SL

Stability of Symmetric Flux-Flow on condition that

bæ=(1-u2/v2)/(1-u2))<0

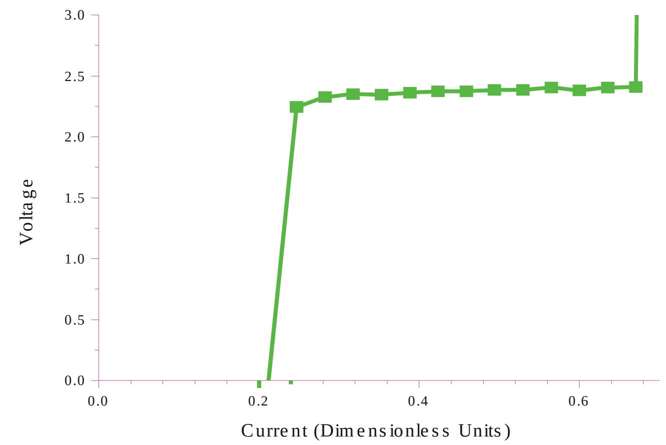
where is u vortex velocity, lying in the range -ve<u<ve,

ve=(1+)/(1+a/v2)- velocity of fully symmetric mode



Stack with artificial commensurable pinning,

jump from superconducting to flux-flow symmetric state



Computer Simulation for N=2

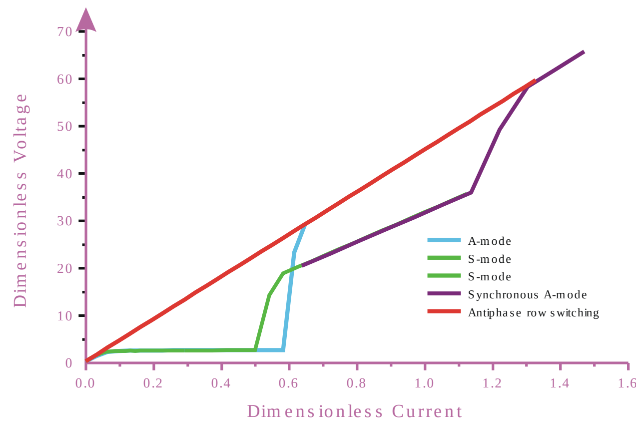
subSwihart SL, v=0.9,

a =2, w=0.2

periodical boundary condition,

two trapped vortices

I-V curves for different dynamic states



Flux-Flow branches zoomed