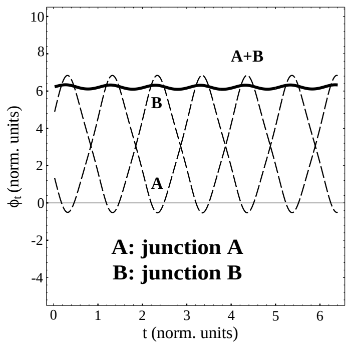
Out–Of–Phase Mode

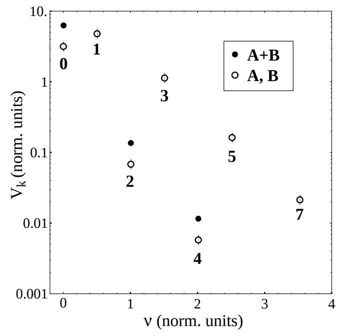
Equal Junction Parameters

c₋ mode

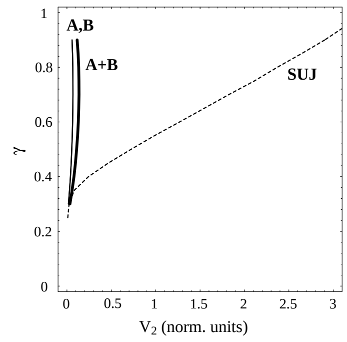
- suppression of even harmonics by magnetic images
- reduced frequency
- performance of single uncoupled junction is better than that of a stack in c₋ mode



The time dependent voltages $V^A(x_0,t)$, $V^B(x_0,t)$ and $V^\Sigma(x_0,t)$ at the arbitarily chosen coordinate x_0 in a stack with equal junction parameters at $\gamma = 0.5$.



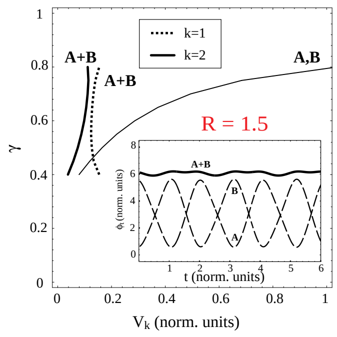
Spectrum of the voltage oscillations with harmonic amplitudes shown by open circles ($V_k^{A,B}$) and small solid circles (total voltage V_k^Σ) at $\gamma = 0.7$. Numbers indicate the harmonic index k.



The amplitudes of the second harmonic V_2 *vs.* bias current γ of the stack of identical junctions synchronized in out–of–phase mode. The dashed line shows V_2 of the single uncoupled junction (SUJ) for comparison.

Spread in Junction Parameters

Spread in resistances: $R = R^A/R^B$



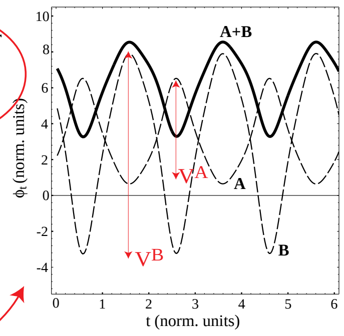
- phase shifts in harmonics occur
- amplitudes remain constant
- even harmonics almost cancel
- odd harmonics grow

also see frame on **Harmonic Amplitudes**

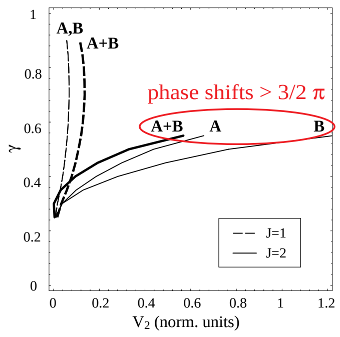
- amplitudes change **$V^A/V^B \approx 1/J$**
- phase shift $\delta\varphi_k$ appears

Solid lines show V_2^A, V_2^B (thin line) and V_2^Σ (thick line) as a function of γ. V_1^Σ (dotted line) is plotted for reference. The voltage profiles $V^A(x_0,t)$, $V^B(x_0,t)$ and $V^\Sigma(x_0,t)$ at $\gamma = 0.5$ are shown in the inset.

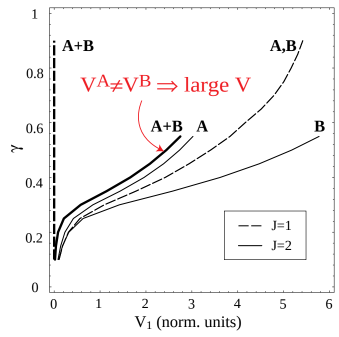
Spread in critical currents: $J = j^A/j^B \neq 1$



The evolution of $V^{A,B}(x_0,t)$ and $V^\Sigma(x_0,t)$ in time for $J = j_c^A/j_c^B = 2$ at $\gamma = 0.5$.



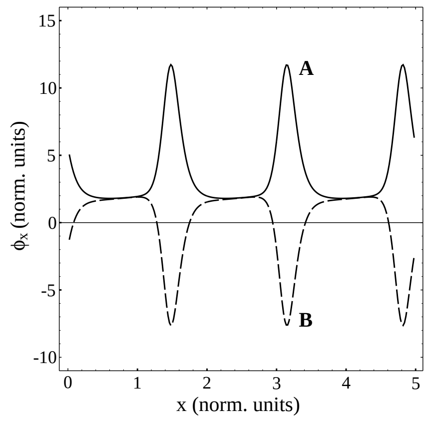
The second harmonic amplitudes $V_2^{A,B}$ and V_2^Σ plotted *vs.* γ for $J = 1$ (dashed lines) and $J = 2$ (solid lines).



The first harmonic amplitudes $V_1^{A,B}$ and V_1^Σ plotted *vs.* γ for $J = 2$ (solid lines) and $J = 1$ (dashed lines).

Magnetic Images

a) Out–of–phase, $N^A = 3$, $N^B = 0$, $S = -0.5$



The strong supression of even harmonic amplitudes in the out–of–phase mode can be explained by considering the interaction of the junctions via the magnetic coupling. Fluxons moving in JJ^A, with magnetic field profile $\bar{\phi}_x^A(x)$, create the image profile $\hat{\phi}_x^A(x)$ in JJ^B, as can be seen in plot a). The image profile in good approximation is given by

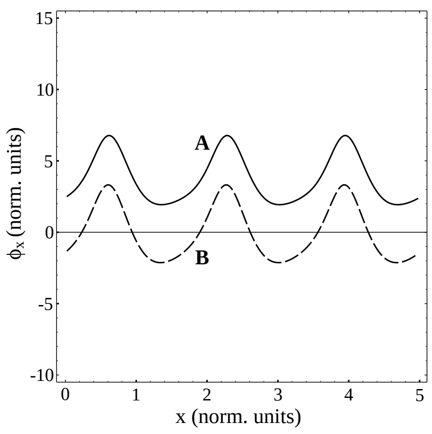
$$\hat{\phi}_x^A(x) \approx \mathrm{const} - \epsilon\bar{\phi}_x^A(x)\,, \qquad (1)$$

where ϵ is a constant close unity, for the values of S examined. Supposing existance of fluxons in JJ^B we get

$$\phi_x^B(x) \approx \bar{\phi}_x^B(x) + \hat{\phi}_x^A(x) \approx \bar{\phi}_x^B(x) - \epsilon\bar{\phi}_x^A(x) + \mathrm{const} \qquad (2)$$

For the out–of–phase mode $\bar{\phi}_x^B(x) = \bar{\phi}_x^A(x - T/2)$. Fourier expansion of $\phi_x^B(x)$ shows that all odd (even) harmonics of $\phi_x^B(x)$ increase (decrease) by a factor of $1 + \epsilon\,(1-\epsilon)$. Considering the addition of $\phi_x^B(x)$ and $\phi_x^A(x)$ with a phase shift of half a period results in vanishing odd and considerably reduced even harmonics as observed in the simulations of the out–of–phase mode.

b) In–phase, $N^A = 3$, $N^B = 0$, $S = -0.5$

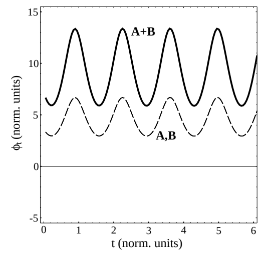


In–Phase Mode

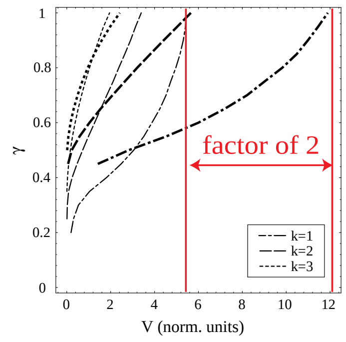
Equal Junction Parameters

c₊ mode

Local voltages at $\gamma = 0.5$



Harmonic amplitudes V_1, V_2, V_3 of the stack (thick lines) and of the single uncoupled junction

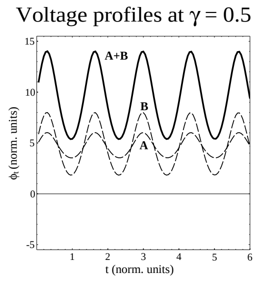


- gain in amplitude of V_1 is larger than 2
- increase of frequency

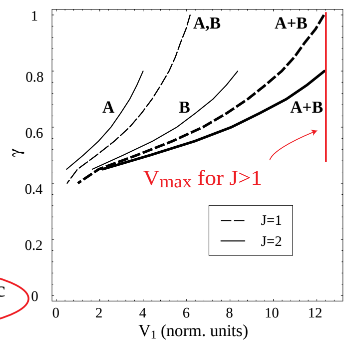
Spread in Junction Parameters

Spread in critical currents

Voltage profiles at $\gamma = 0.5$



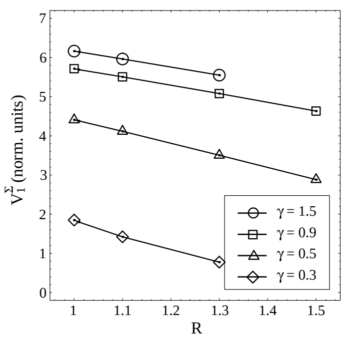
Harmonic amplitude V_1



- almost constant first harmonic amplitudes for J > 1

Spread in loss parameters

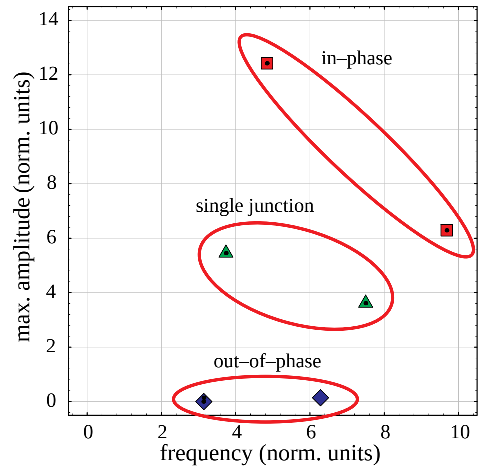
Harmonic amplitudes V_1 at γ = const.



- linear decrease of V_1 with R

Conlusions

- harmonic amplitudes are determined by magnetic images induced by the inductive coupling
- spread in junction parameters has strong influence on the harmonic amplitudes
- Feasibility of modes
  - In–phase
    - ∗ increase of power in low harmonics in comparison to single uncoupled junction
    - ∗ gain of more than a factor of 4 in the power of first harmonic
    - ∗ increased frequency
    - ∗ less stable with respect to parameter spread
  - Out–of–phase
    - ∗ less power in all harmonics than single uncoupled junction
    - ∗ reduced frequency



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