Superconducting Digital Circuits II

Outline

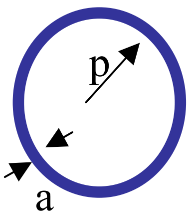
1. **Josephson Switches, Memories and Characteristic Times (see Lecture 15 also)**

2. **Voltage State Logic**

3. **Single Flux Quantum (SFQ) Logic**

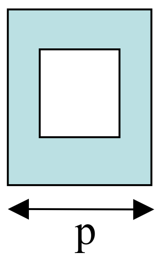
October 27, 2003

Superconducting Parameters



$$L[\mathrm{nH}] = p[\mu\mathrm{m}] \ln \frac{p}{a}$$

$$C_0 = 50\,\mathrm{fF}/\mu\mathrm{m}^2$$



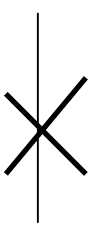
$$L[\mathrm{nH}] = 1.2\,p[\mu\mathrm{m}]$$

$$R_n[\Omega] = \frac{190}{A[\mu\mathrm{m}^2]\,J_c[k A\mathrm{cm}^2]}$$

$$L[\mathrm{nH}] = 1.2\,(2\lambda + d)[\mu\mathrm{m}]$$

$$\tau_J[\mathrm{ps}] = 0.15\left(\frac{R_n}{R_{sh}}\right)$$

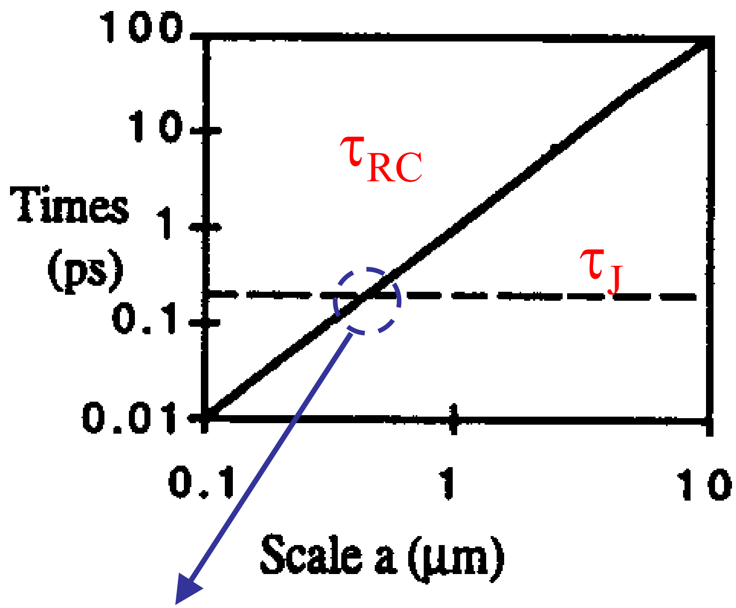
$$\tau_{\mathrm{RC}}[\mathrm{ps}] = \frac{7.5}{J_c[kA/cm^2]}\left(\frac{R_{sh}}{R_n}\right)$$



$$L_J[\mathrm{nH}] = \frac{300\mathrm{pH}}{I_c[\mu\mathrm{A}]}$$

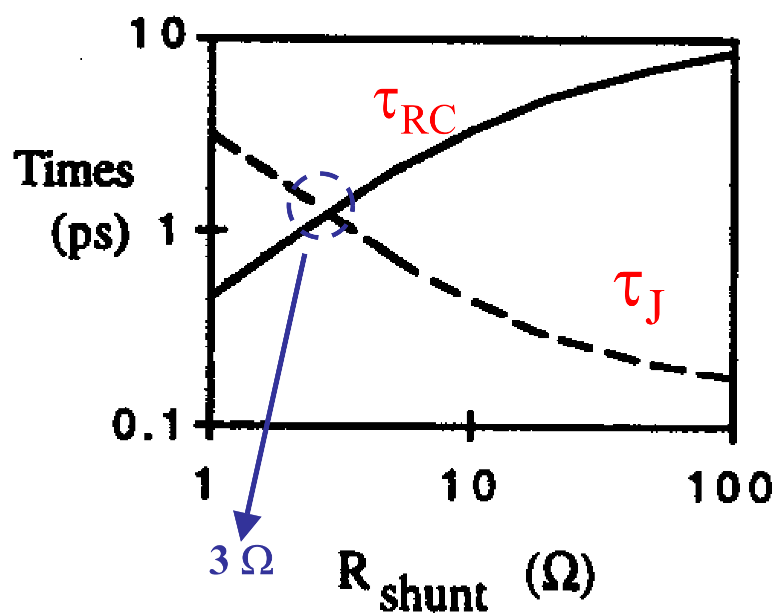
$$\beta_c = \frac{50}{J_c[kA/cm^2]}\left(\frac{R_{sh}}{R_n}\right)^2$$

Optimal Junction Size and Shunt Resistors



0.3 μm
Optimal for self-shunting junctions

For I_c = 100 μA



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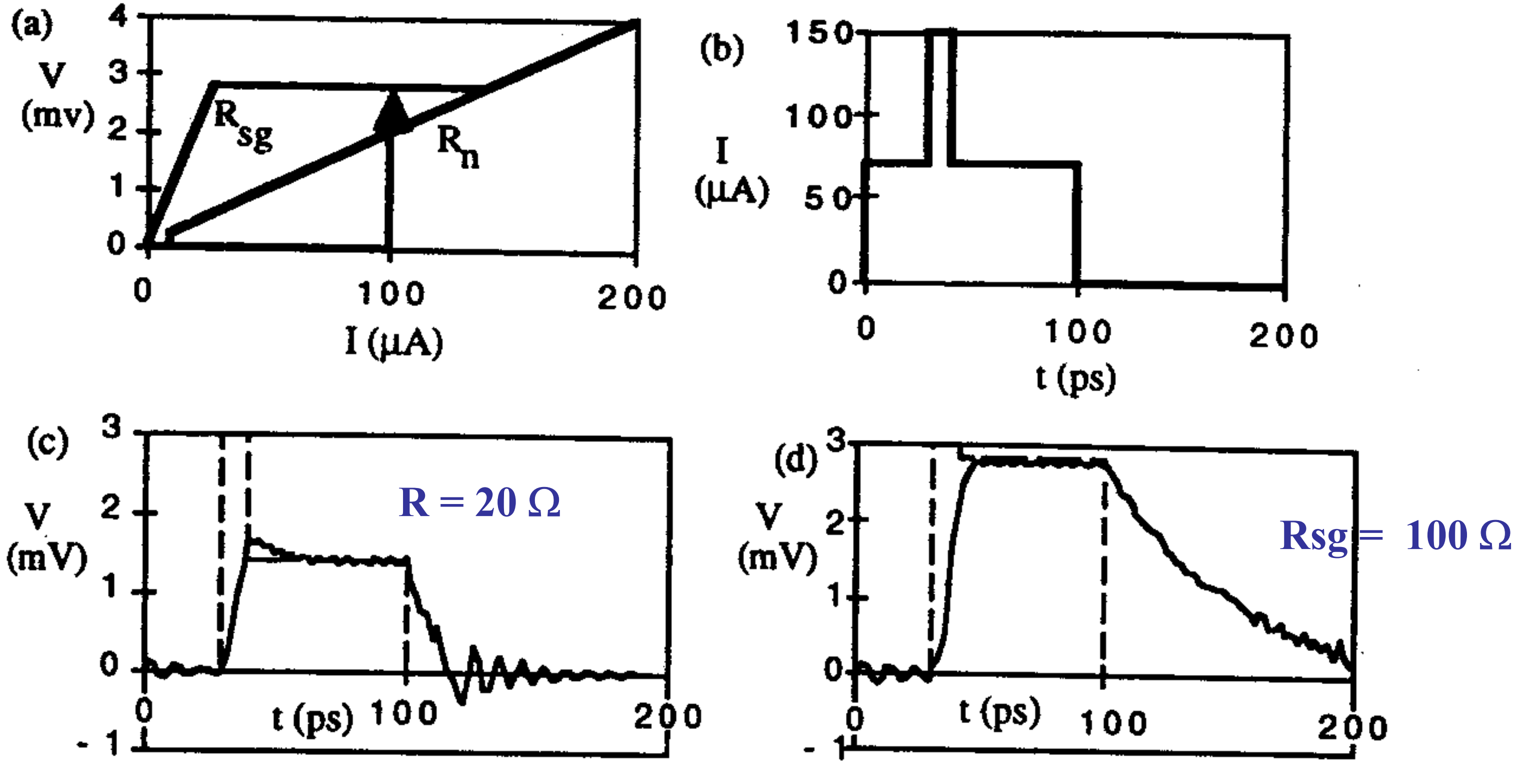
Transient Response for $\beta_c >> 1$



$I_c = 100\ \mu A$, $R_n = 20\ \Omega$,, Vg = 2.8 mV, and C=0.5 pF

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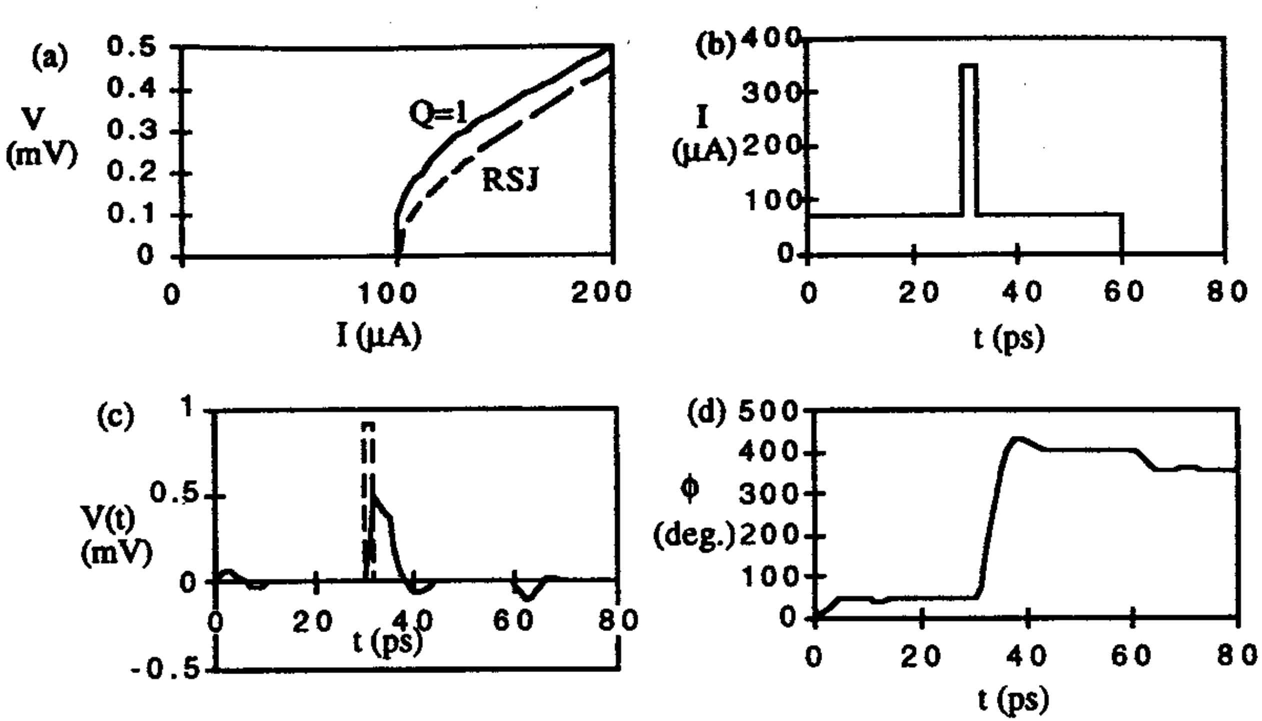
Transient Response for $\beta_c << 1$



$I_c = 100\ \mu A$, $R_{sh} = 2.6\ \Omega$, $Vg = 2.8$ mV, and $C=0.5$ pF

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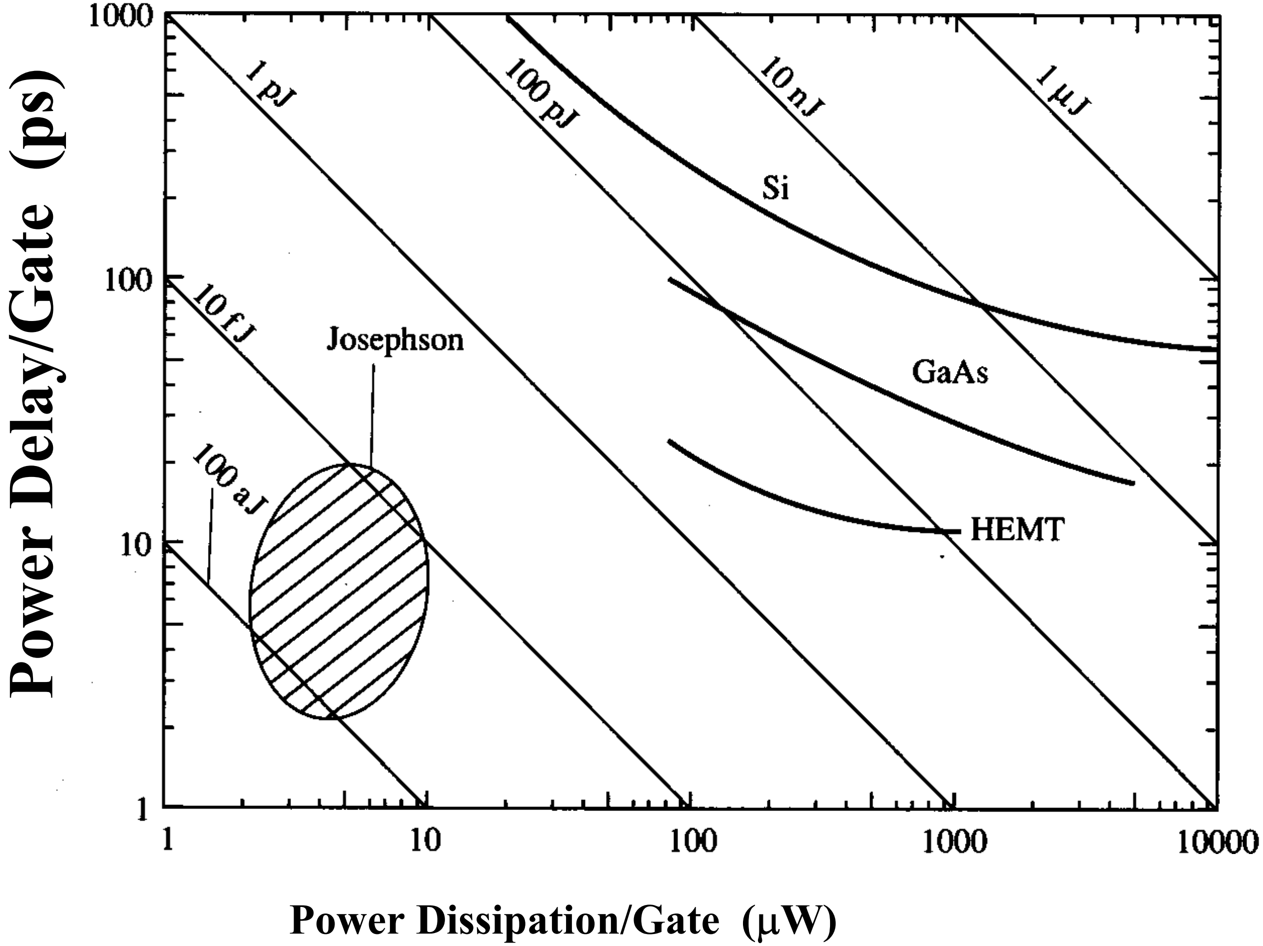
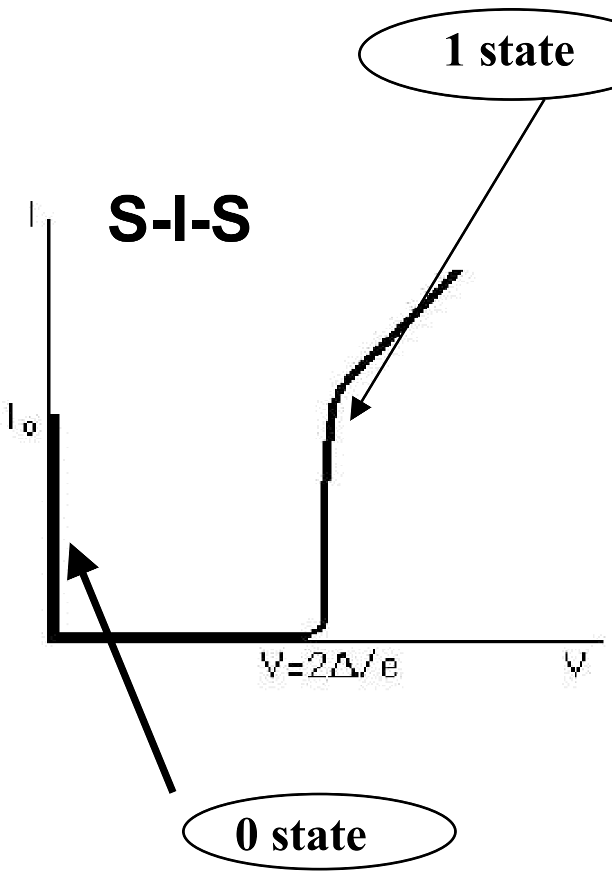
Delay-Power Graph

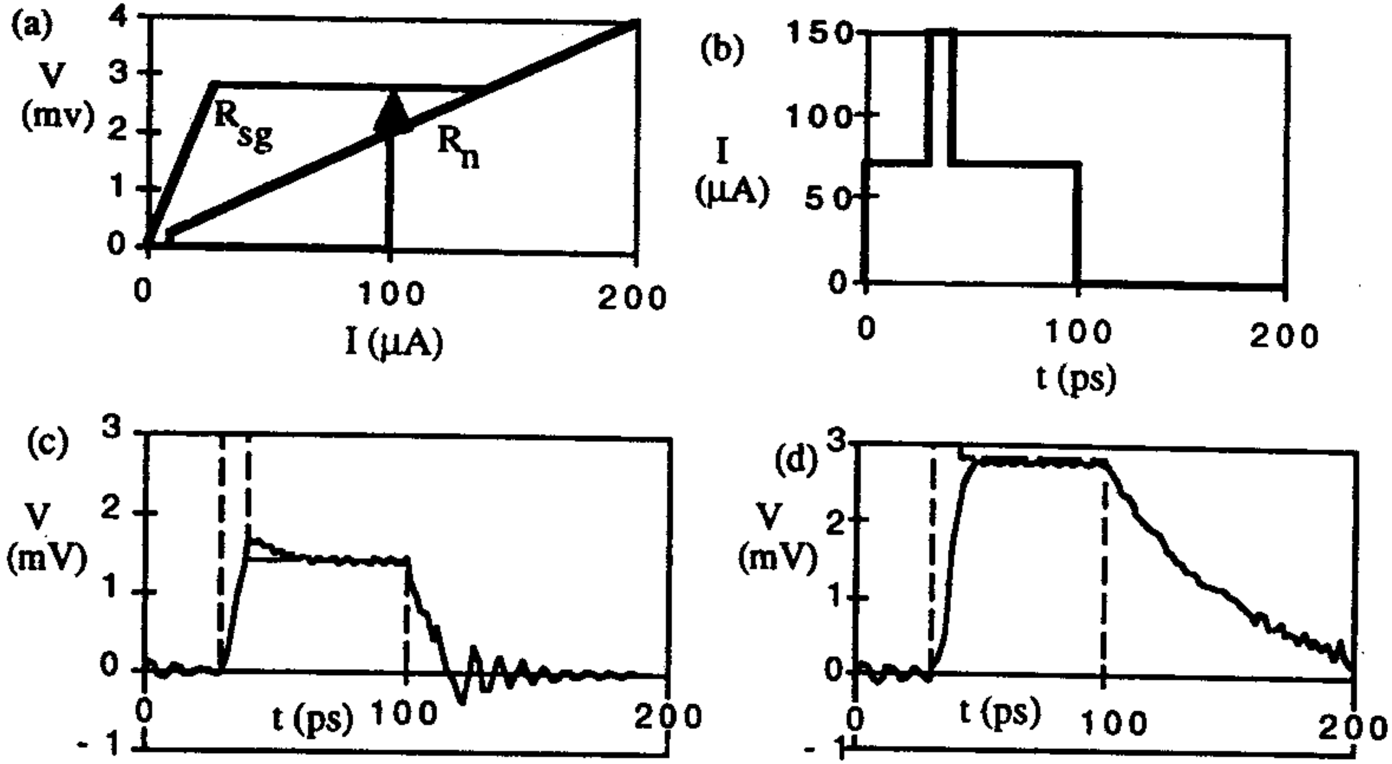


2. Voltage State Logic



1. Underdamped Junctions $\beta_c >> 1$
2. Can use unshunted junctions
3. Must induce a “switch” from 0 state to 1 state by changing the critical current
4. Once in the 1 state, must drive critical current to zero to reset

Transient Response for $\beta_c >> 1$



I_c = 100 µA, R_n = 20 Ω, Rsg = 100 Ω, Vg = 2.8 mV, and C=0.5 pF

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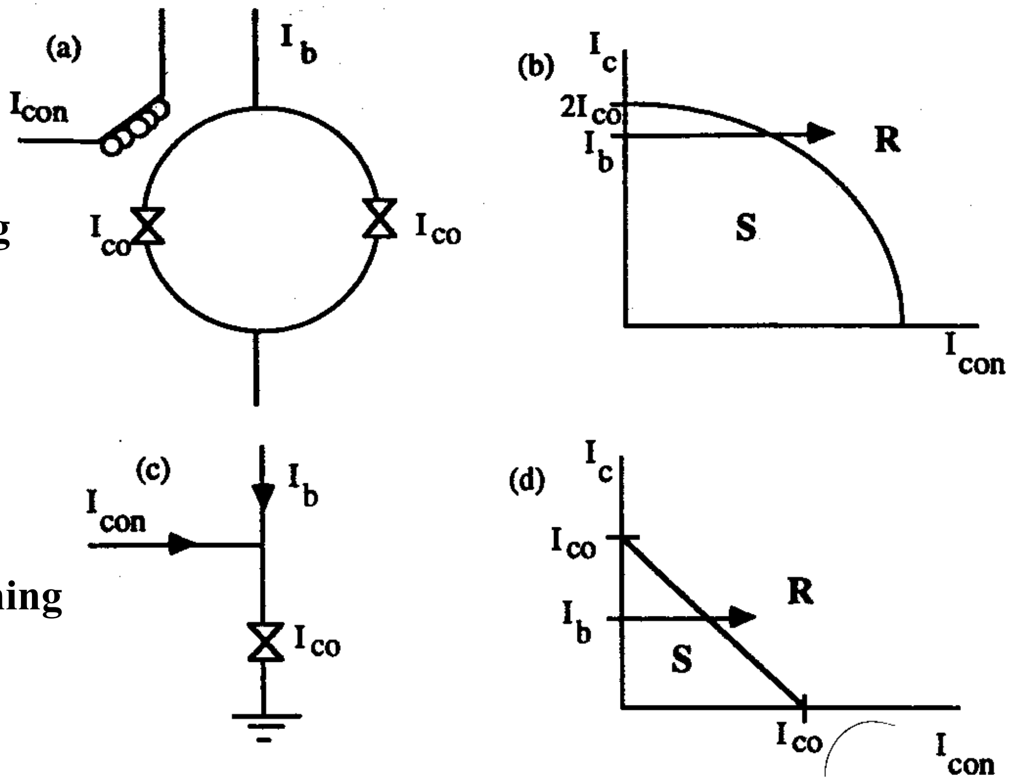
Voltage-State Switching

Magnetic field switching

Current Injection Switching



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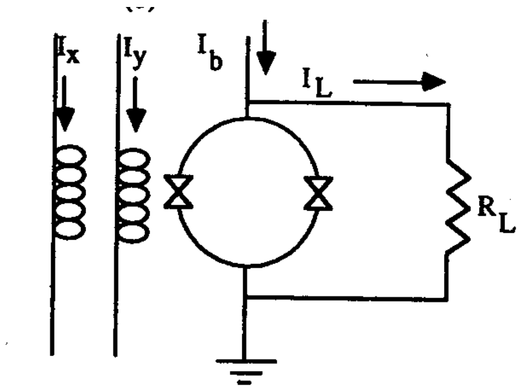
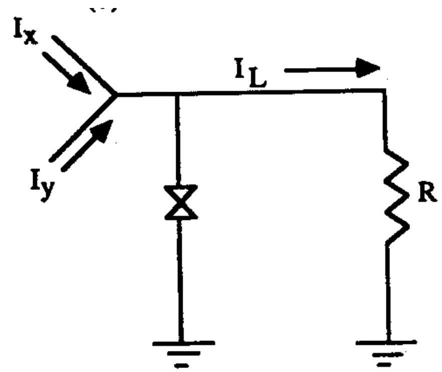
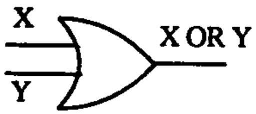
Voltage-State Logic Gates

Magnetic Coupling of signals

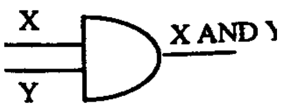


Current coupling of signals



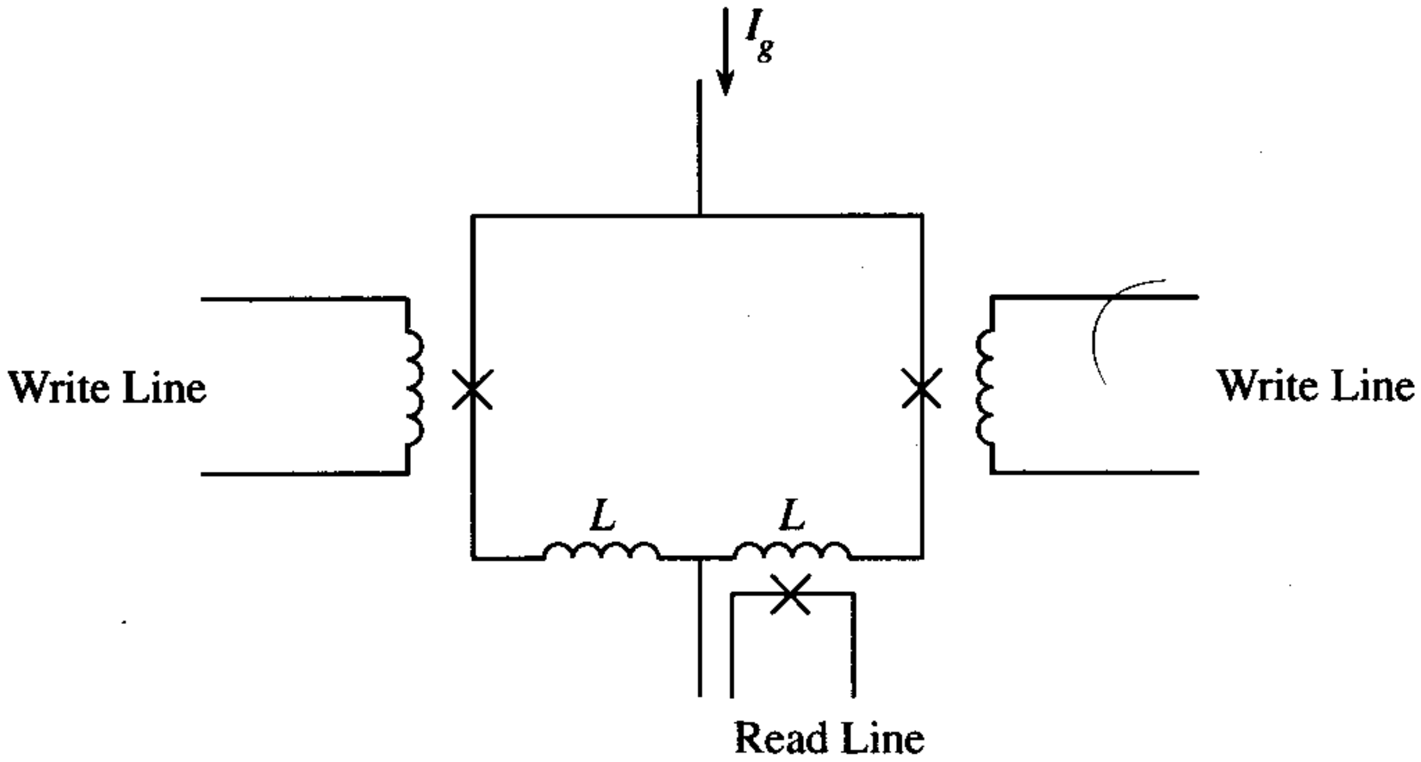


$$I_X + I_b > 2I_c \quad \text{or} \quad I_Y + I_b > 2I_c$$

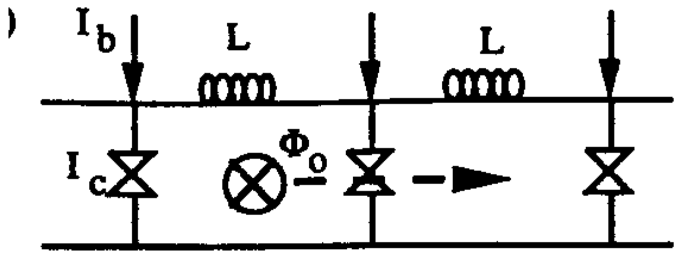


$$I_X + I_Y + I_b > 2I_c$$

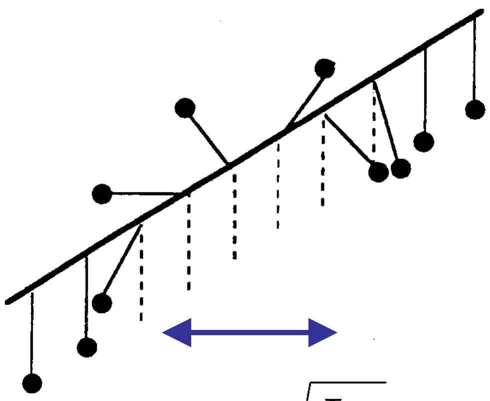
Voltage-State Memory



3. Single Flux Quantum (SFQ) Logic



SFQ Pulse (a vortex)

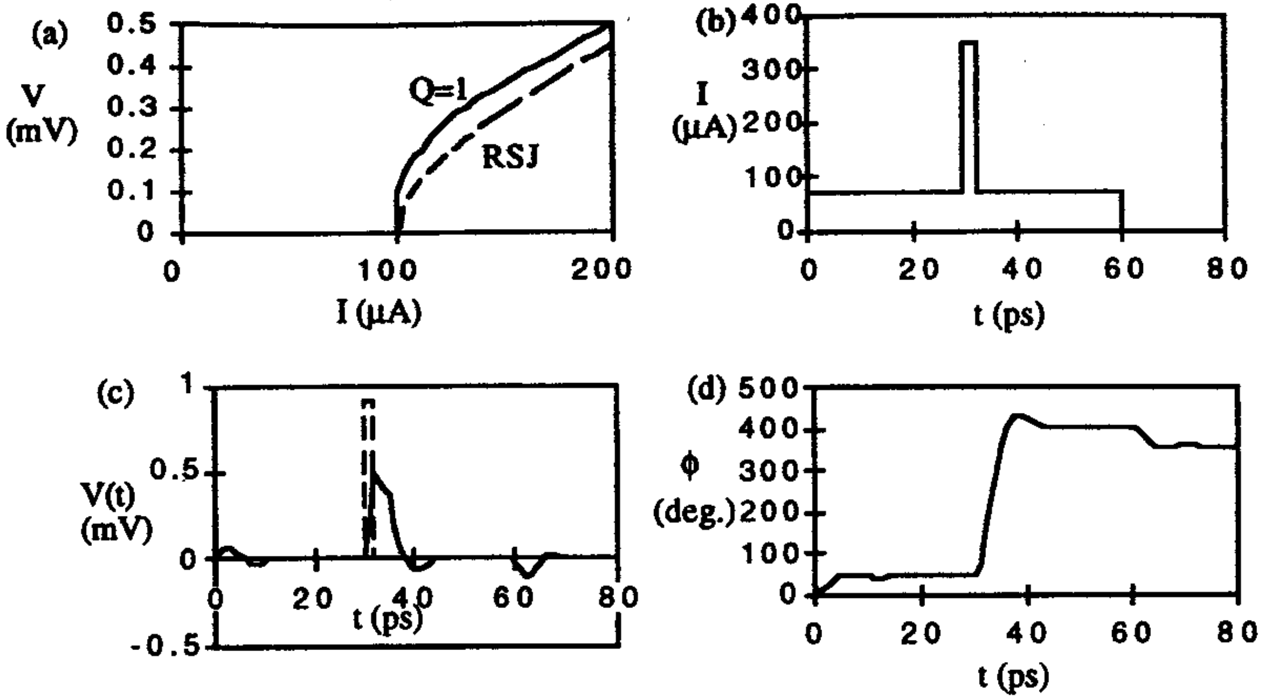


$$\Lambda = \sqrt{\frac{L_J}{L}}$$

Size of a vortex in a paralle array,

SFQ pulse confined to one cell $\Lambda = 1$

Transient Response for $\beta_c << 1$



$I_c = 100\ \mu A$, $R_{sh} = 2.6\ \Omega$, $Vg = 2.8$ mV, $C=0.5$ pF, and $L_J/L = 1$

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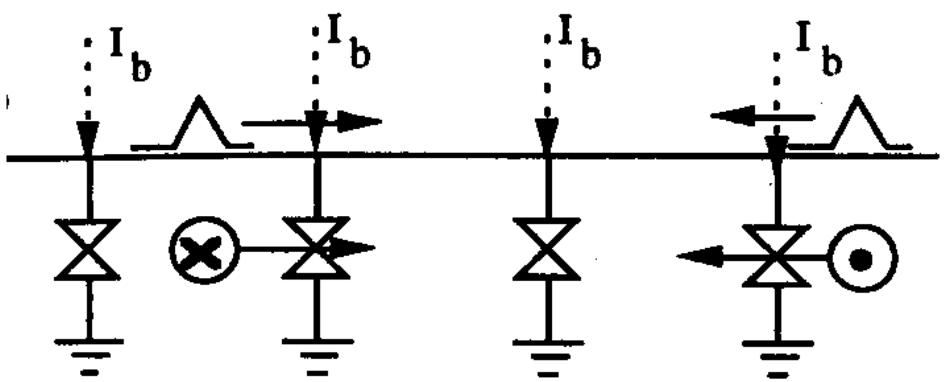
SFQ: The Josephson Transmission Line



Vortex (fluxon) moving to the right

Anit-Vortex (anti-fluxon) moving to the left

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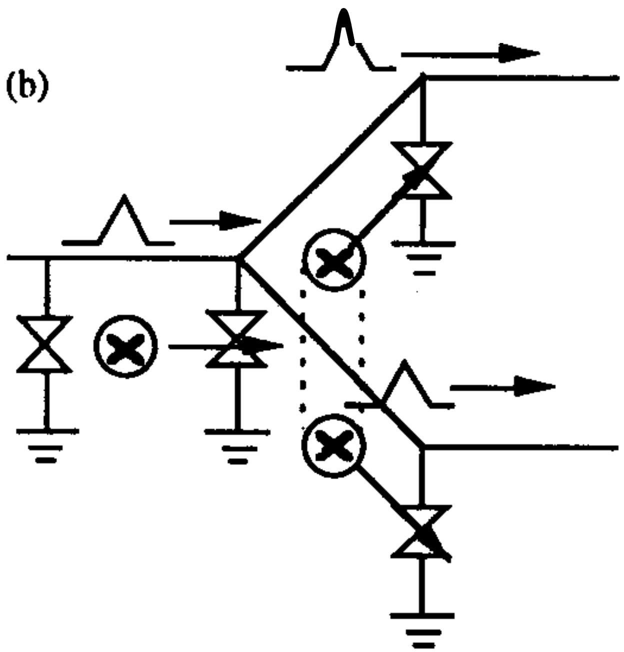
SFQ Splitter



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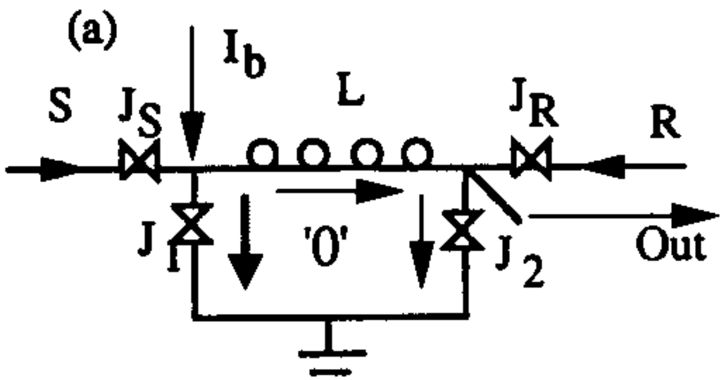
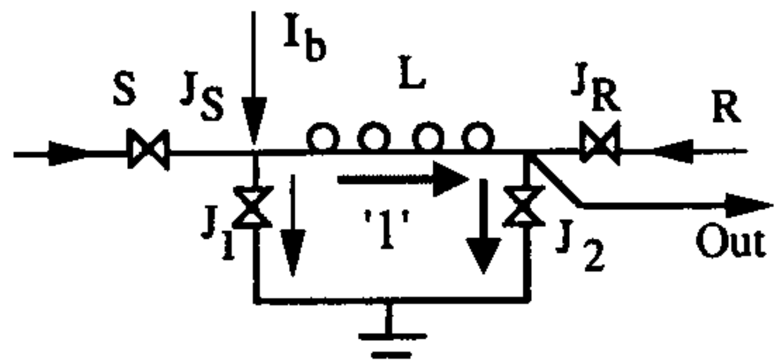
SFQ Memory Cell



0 = No flux stored



1 = flux stored

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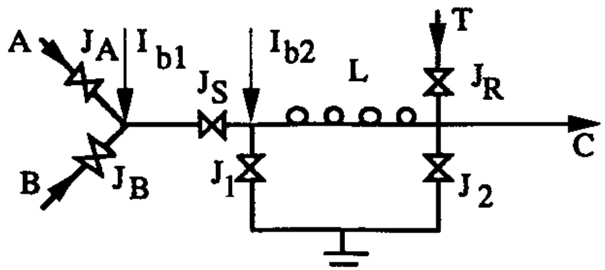
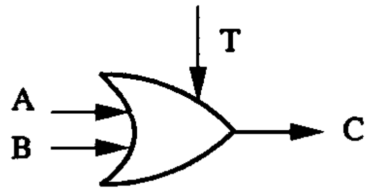
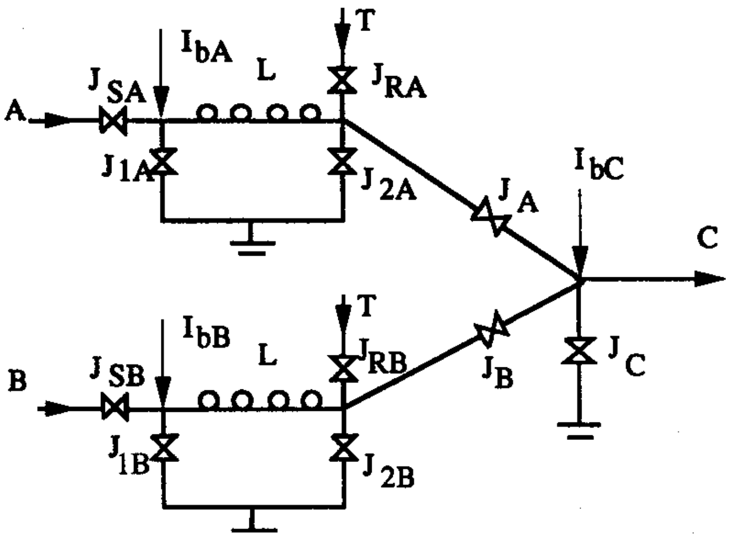
SFQ Logic Gates

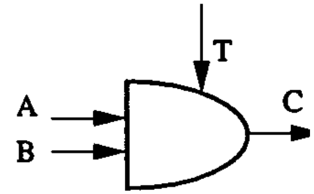
OR





AND





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