



Workshop on Physics & Engineering Issues in
Adiabatic/Reversible Classical Computing
October 5-9, 2020, Online

Reversible Quantum-Flux-Parametron

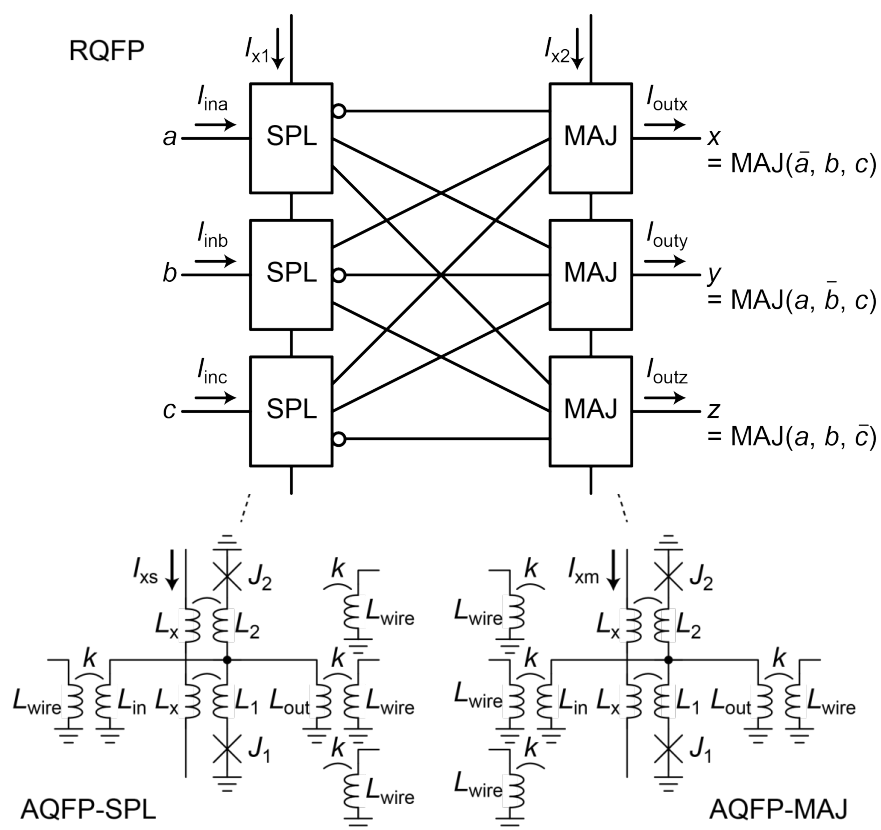
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Outline

- Bit Energy of an RQFP adder
- RQFP vs. AQFP
- Bit Energy of an RQFP Flip-Flop

Reversible QFP (RQFP)

Reversible majority QFP gate



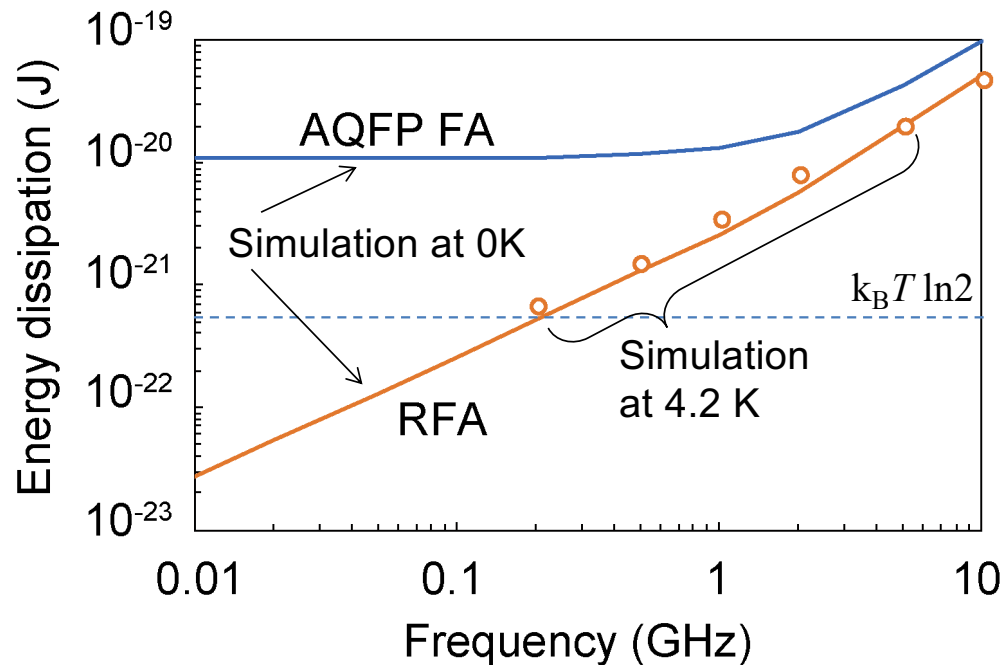
Truth table

Input			Output		
a	b	c	x	y	z
0	0	0	0	0	0
0	0	1	1	1	0
0	1	0	1	0	1
0	1	1	1	0	0
1	0	0	0	1	1
1	0	1	0	1	0
1	1	0	0	0	1
1	1	1	1	1	1

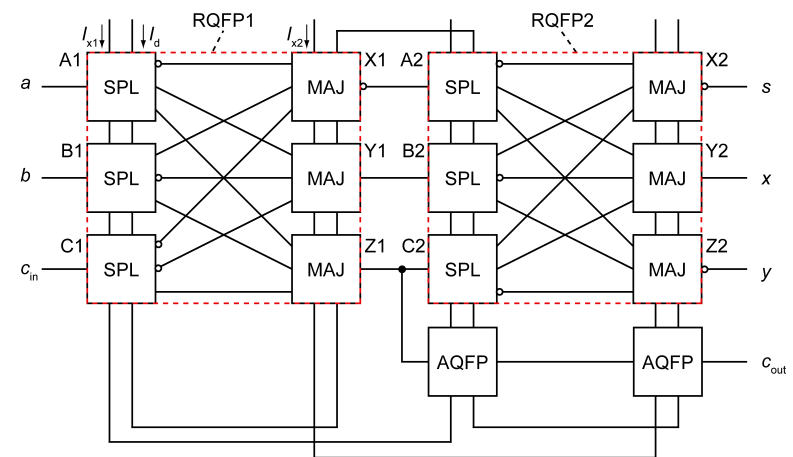
A logically and physically reversible gate

Reversible AQFP Adder

Calculated Energy dissipation of
1-bit full adder at $T = 4.2$ K



Schematic of 1-bit full adder

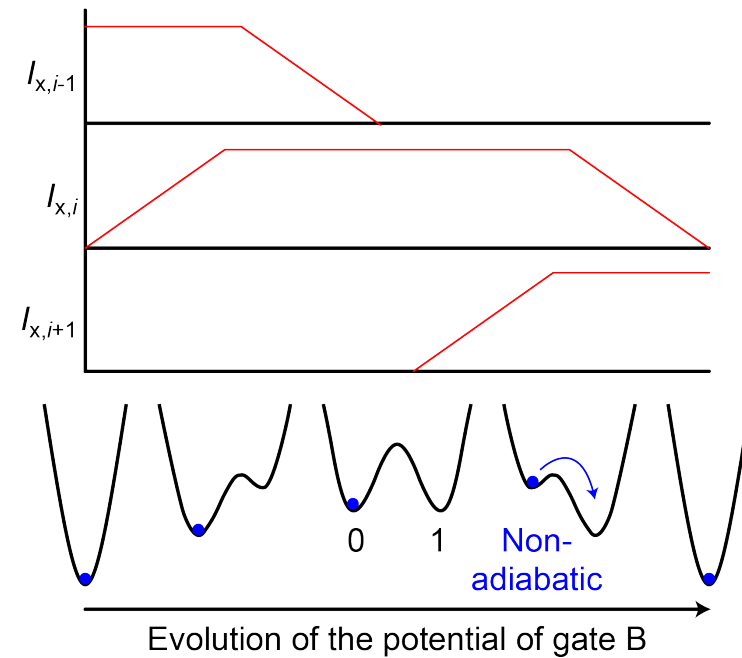
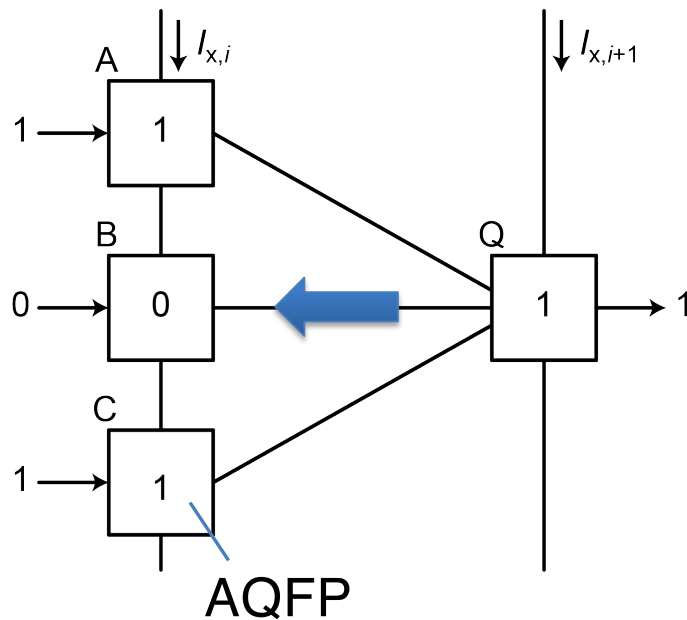


The total junction number: 28

Bit energy smaller than $k_B T \ln 2$ is possible in RQFP circuits.

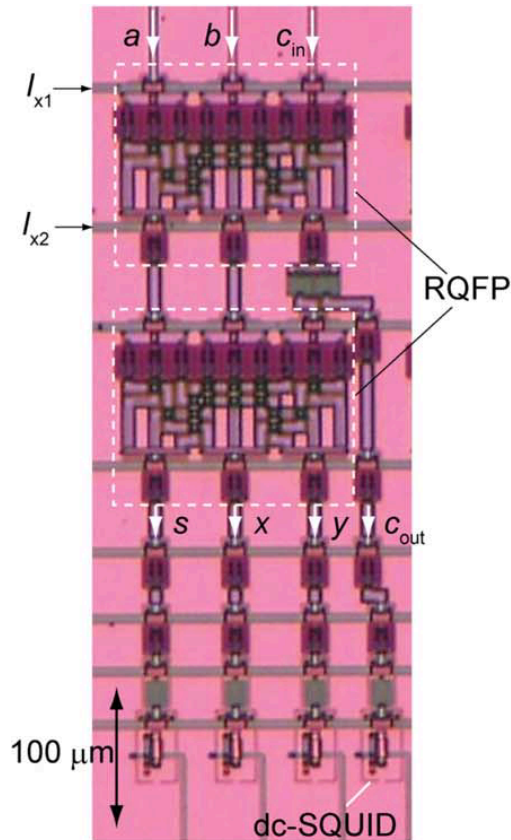
Irreversibility in AQFP

Irreversible case for a majority gate

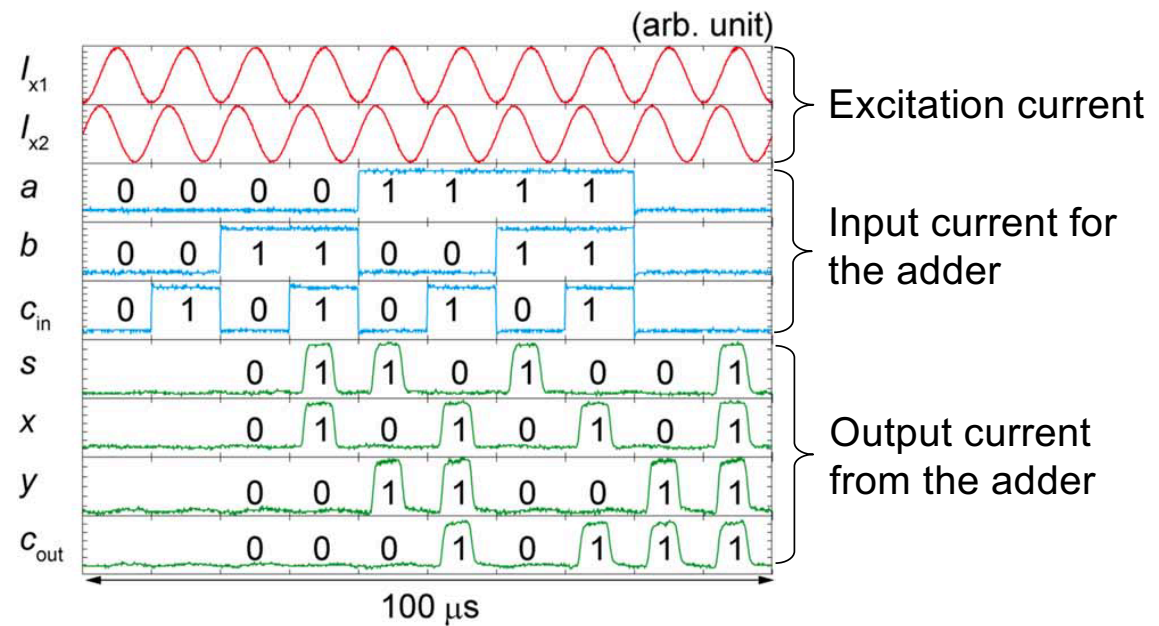


AQFP does not always operate adiabatically or reversibly.

Demonstration of 1-bit RQFP Full Adder



Measurement results of 1-bit RQFP Full Adder at 4.2 K

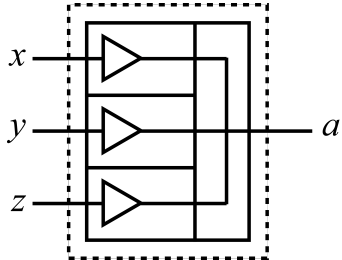
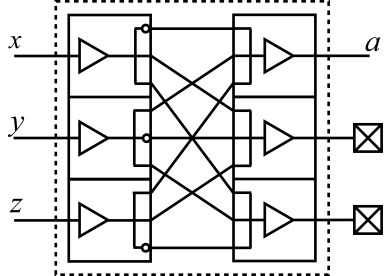
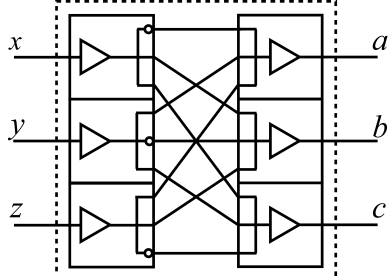


Excitation current margins:

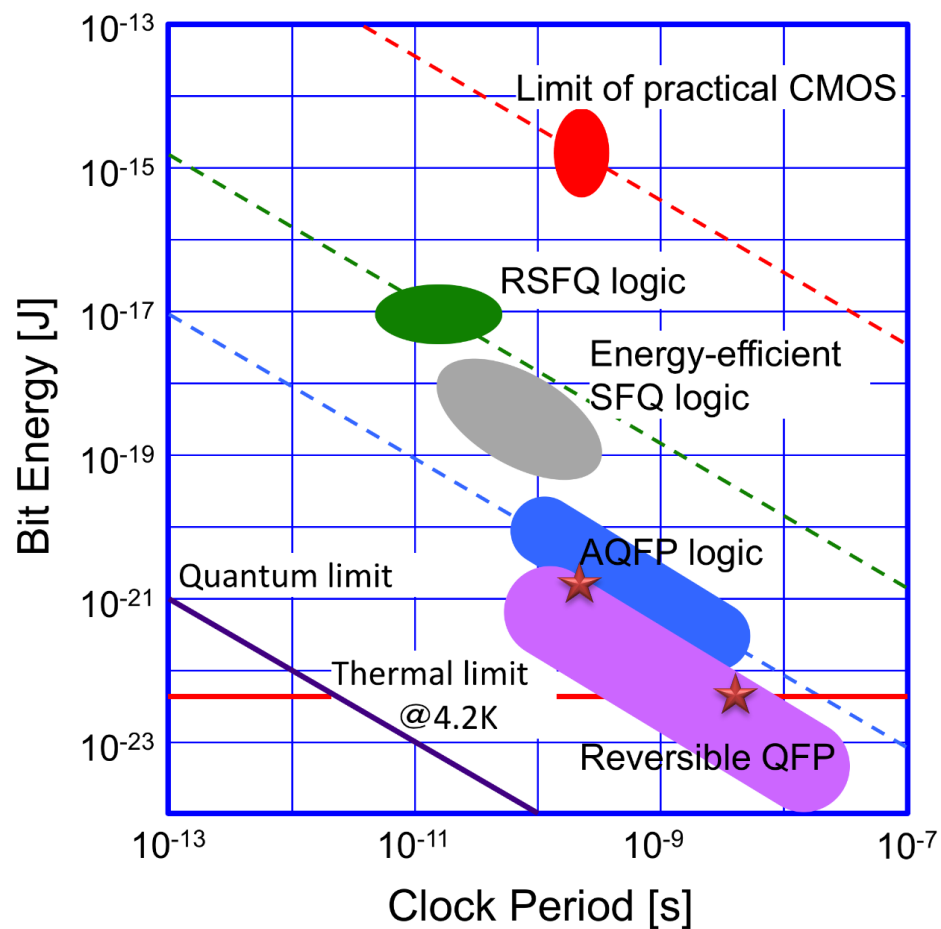
$$I_{x1} = 5.4 \text{ dB}, I_{x2} = 6.1 \text{ dB}$$

T. Yamae *et al.*, *SUST*, 32, 035005 (2019).

RQFP vs. AQFP

	Irreversible AQFP	Garbage erased RQFP	Complete RQFP
Structure	 $a = \text{MAJ}(x, y, z)$ $= xy + yz + xz$	 <p>Garbage is erased at every gates.</p>	 $a = \text{MAJ}(\bar{x}, y, z)$ $b = \text{MAJ}(x, \bar{y}, z)$ $c = \text{MAJ}(x, y, \bar{z})$
Reversibility	Small	↔	Large
Energy consumption	Large	↔	Small
Complexity	Small	↔	Large

Comparison of Energy and Delay of Superconductor Logic



Summary

- RQFP is a good practical device to investigate reversible logic.
- The following studies are under investigation:
 - Relationship between the bit energy and the erasure of information in practical circuits
 - Reduction of garbage bits by using the logic synthesis for RQFP logic
 - Measurement of bit energy in RQFP logic
 - Microprocessor using RQFP is under development.
 - All required components will be reported in ASC 2020.