Nano-Electronics using Quantum Circuits as Artificial Atoms on a Chip

Franco Nori [(1,2)]

(1) CEMS, RIKEN, Saitama, Japan. (2) University of Michigan, Ann Arbor, Michigan, USA.

Abstract: Recent technological advances have made it possible to implement atomic-physics and quantum-optics experiments on a chip using artificial atoms. These artificial atoms can be made from either semiconductor quantum dots and, more often, from superconducting circuits. Superconducting circuits based on Josephson junctions exhibit macroscopic quantum coherence and can behave like artificial atoms. Novel electronic devices are being explored with these type of superconducting (low-power-consumption) electronics. This talk presents a pedagogical (and, hopefully, entertaining) brief introduction to this rapidly advancing field. The references [1-13] provide a few overviews on various aspects of this subject and related topics.

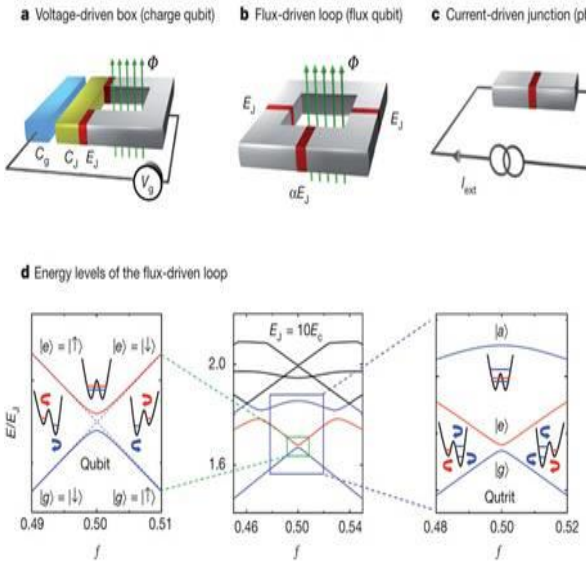

Fig. 1. Superconducting circuits as artificial atoms [1].

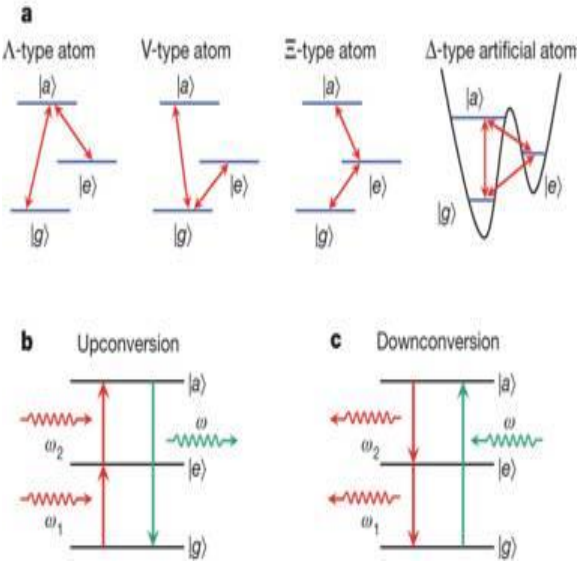

Fig. 2. Three-level atoms and frequency conversions [1].

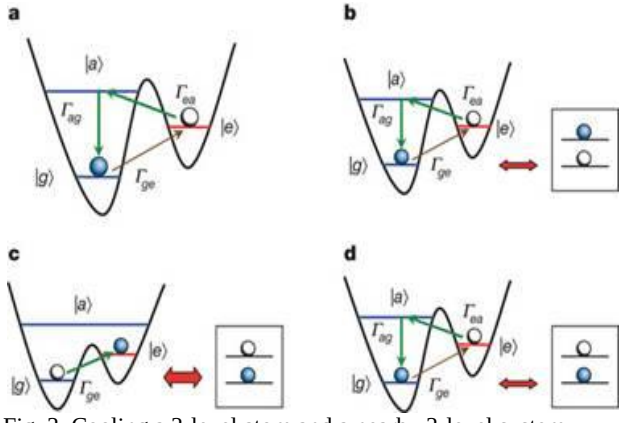

Fig. 3. Cooling a 3-level atom and a nearby 3-level system.

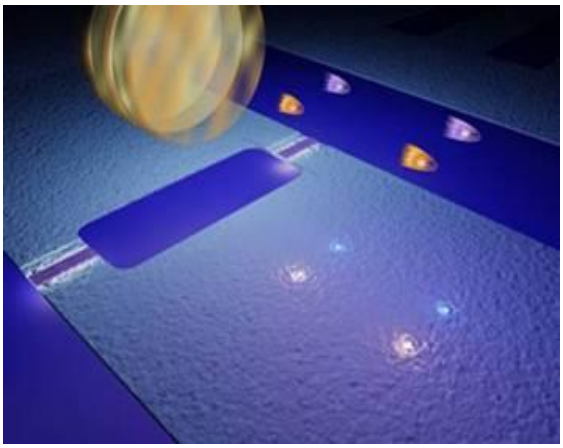

Fig. 4. Dynamical Casimir effect with superconducting circuits

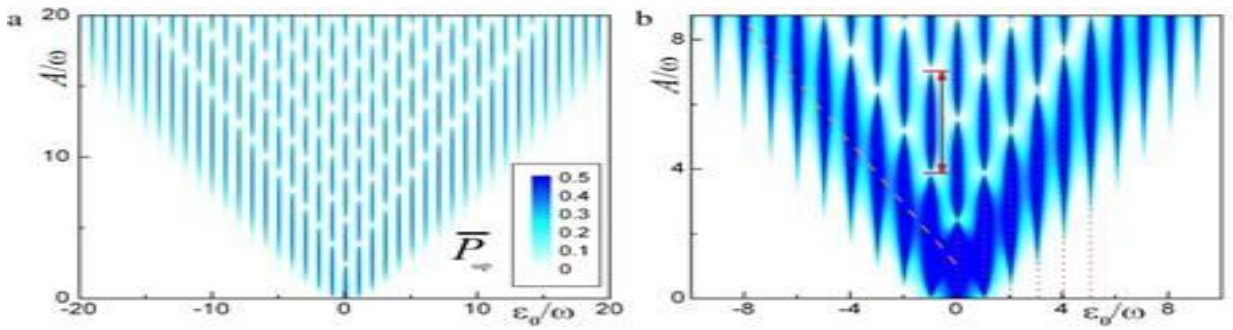

Fig. 5. Interference patterns from LZS interferometry using superconducting circuits. From Ref. [7]

[1] J.Q. You, F. Nori, *Atomic Physics and Quantum Optics using Superconducting Circuits*, Nature, **474**, 589 (2011). (a nine-pages overview of this field).

[2] J.Q. You, F. Nori, *Superconducting circuits and quantum information*, Physics Today **58** (11), 42-47 (2005).

[3] I. Buluta, F. Nori, *Quantum Simulators*, Science **326**, 108 (2009).

[4] I. Buluta, S. Ashhab, F. Nori, *Natural and artificial atoms for quantum computation*, Reports on Progress in Physics **74**, 104401 (2011).

[5] F. Nori, *Atomic physics with a circuit*, Nature Physics **4**, 589 (2008).

[6] F. Nori, *Quantum football,* Science **325**, 689 (2009).

[7] S.N. Shevchenko, S. Ashhab, F. Nori, *Landau-Zener-Stuckelberg interferometry*, Physics Reports **492**, 1 (2010). (about 50-50 split of review and original work)

[8] P.D. Nation, J.R. Johansson, M.P. Blencowe, F. Nori, *Stimulating uncertainty: Amplifying the quantum vacuum with superconducting circuits*, *Rev. Mod. Phys.*, **84**, 1-24 (2012).

[9] I. Georgescu, F. Nori, *Quantum technologies: an old new story,* Physics World **25**, 16-17 (2012). This two-page summary is non-technical.

[10] A.G. Kofman, S. Ashhab, F. Nori, *Weak pre- and post-selected measurements*, Physics Reports **520**, 43-133 (2012) (about 20 pages review, plus 70 pages of original work).

[11] Z.-L. Xiang, S. Ashhab, J.Q. You, F. Nori, *Hybrid quantum circuits: Superconducting circuits interacting with other quantum systems,* Rev. Mod. Phys. **85**, 623 (2013).

[12] C. Emary, N. Lambert, F. Nori, *Leggett-Garg Inequalities,* Reports on Progress in Physics **77**, 016001 (2014).

[13] I. Georgescu, S. Ashhab, F. Nori, *Quantum Simulation*, Rev. Mod. Phys. **86**, 153 (2014). Also the cover image.

PDF files of the above papers are available (free of charge) here:
http://dml.riken.jp/pub/nori/reviews.html