Сверхпроводящие кубиты

тонкости создания квантового компьютера

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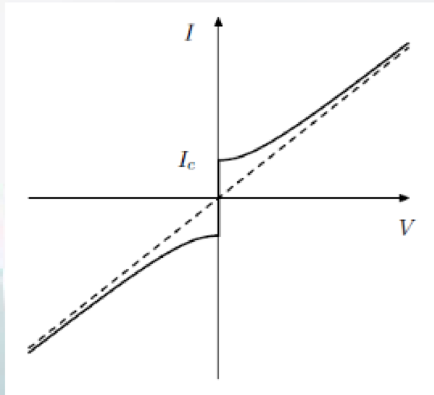
Семинар НУГ, 19 апреля 2016

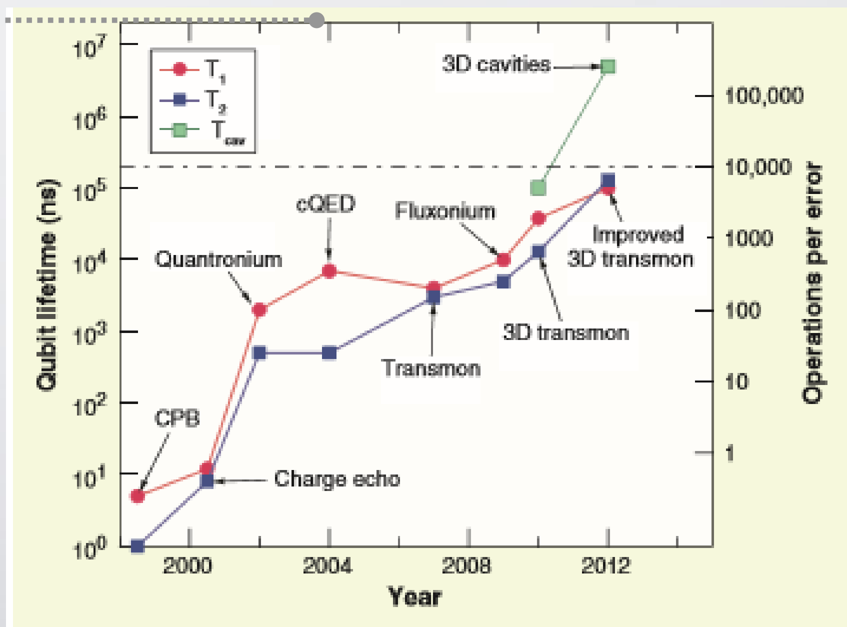
Виды сверхпроводящих кубитов



1 **Фазовые кубиты**

2 **Потоковые кубиты**

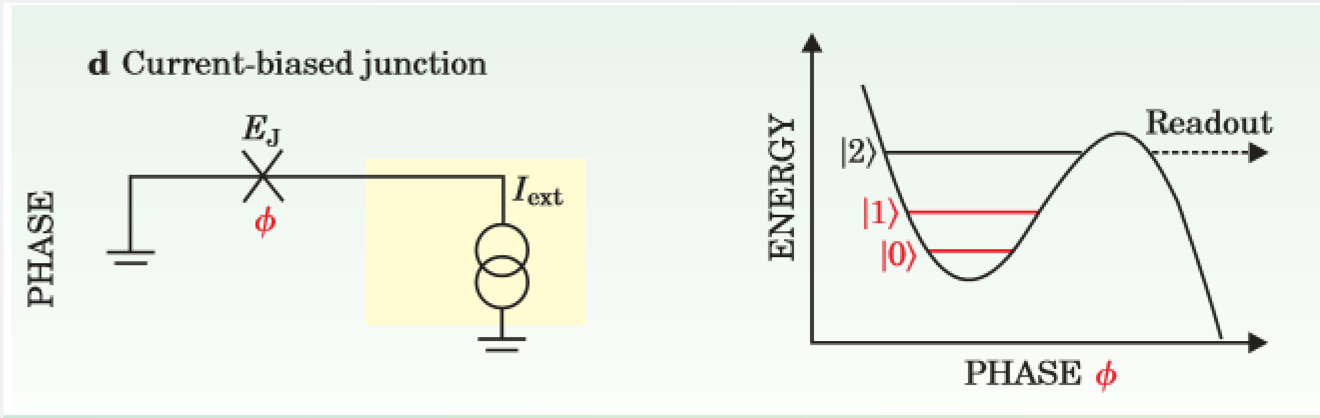
3 **Зарядовые кубиты**



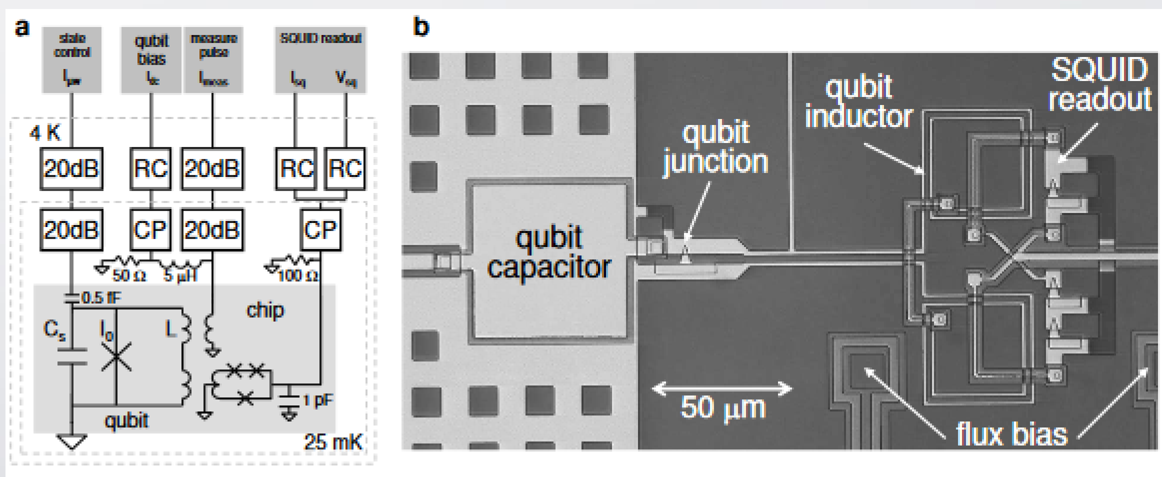
M. H. Devoret and R.J.SchoelkopfDOI:10.1126/science.1231930

Фазовый кубит

$$2eU = \hbar \frac{\partial \varphi}{\partial t} \quad (*)$$



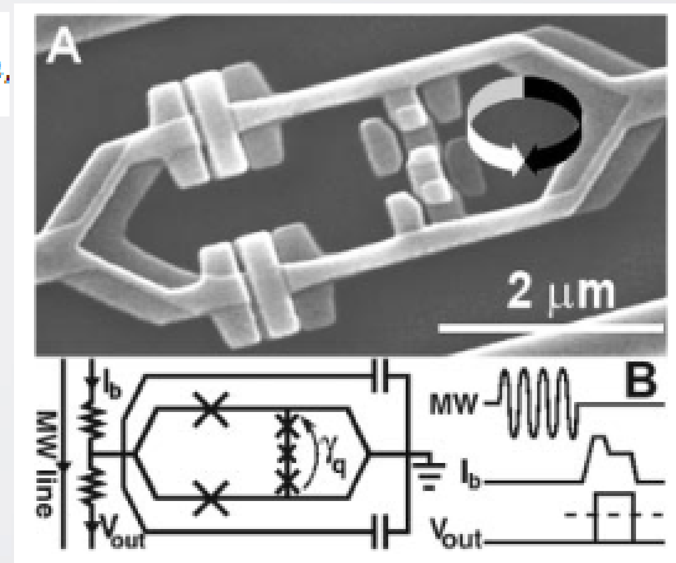
Physics Today 58(11), 42 (2005); doi:10.1063/1.2155757



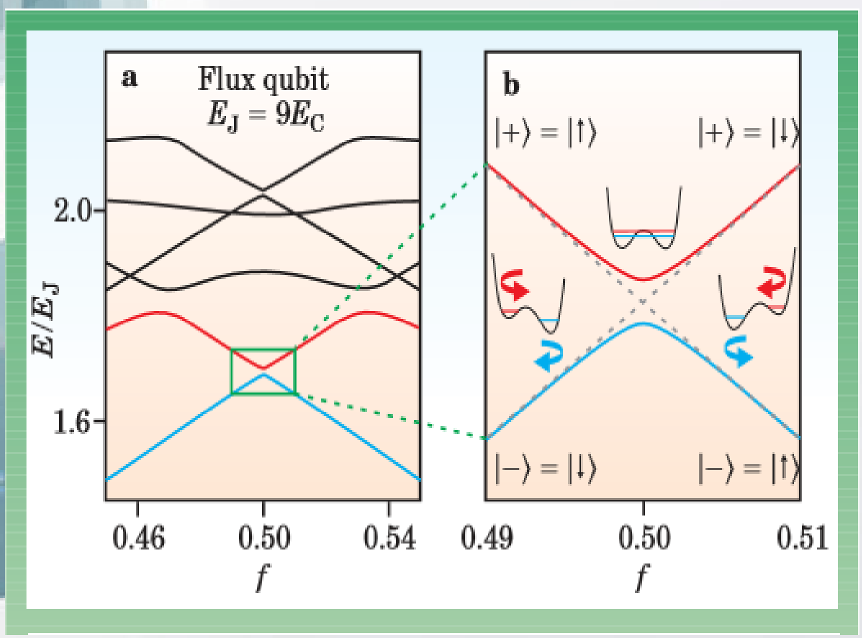
Superconducting Phase Qubits John M. Martinis

Потоковый кубит

$$\varphi_1 + \varphi_2 + \varphi_3 + 2\pi \frac{\phi}{\phi_0} = 2\pi n,$$



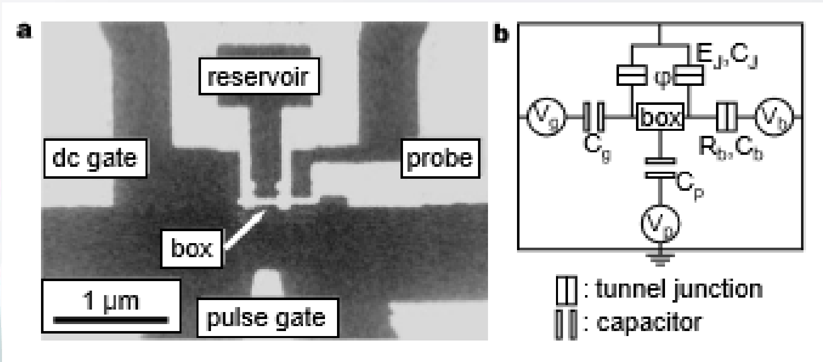
Chiorescu, Y. Nakamura, C.J.P.M. Harmans, J.E.Mooij
DOI:10.1126/science.1081045



Physics Today 58(11), 42 (2005); doi:10.1063/1.2155757

$$E_{C0} = (2e^2)/2C_\Sigma \qquad E_J = \Phi_0 I_c/2\pi$$

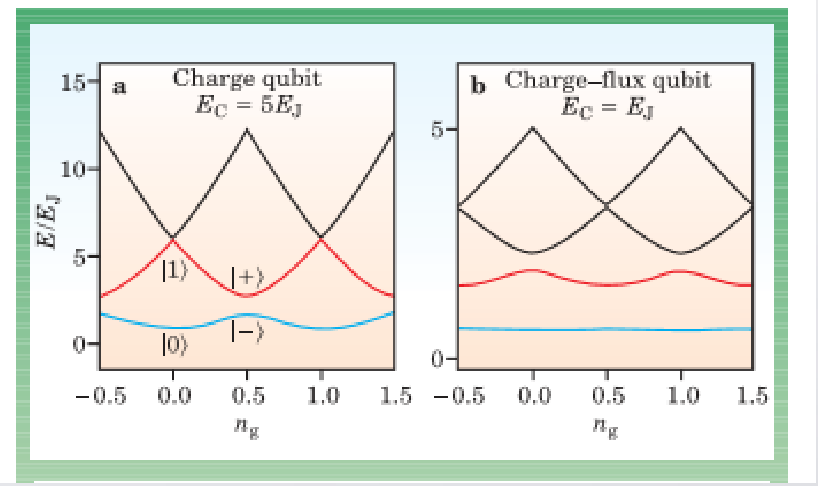
Зарядовый кубит



Y. Nakamura, Yu.A. Pashkin, and J.S. Tsai, Nature 398, 786 (1999)

Box 1. Parameters of Superconducting Qubits

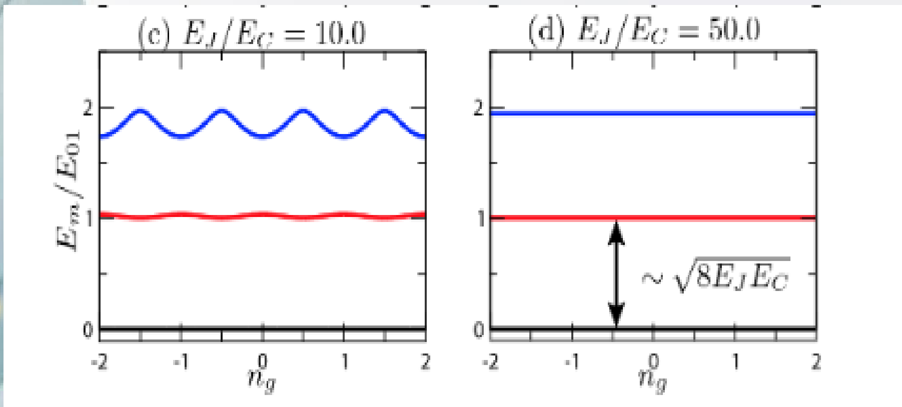
	Charge	Charge–flux	Flux	Phase
E_J/E_c	0.1	1	10	10^6
ν_{01}	10 GHz	20 GHz	10 GHz	10 GHz
T_1	1–10 μs	1–10 μs	1–10 μs	1–10 μs
T_2	0.1–1 μs	0.1–1 μs	1–10 μs	0.1–1 μs



Physics Today 58(11), 42 (2005); doi:10.1063/1.2155757

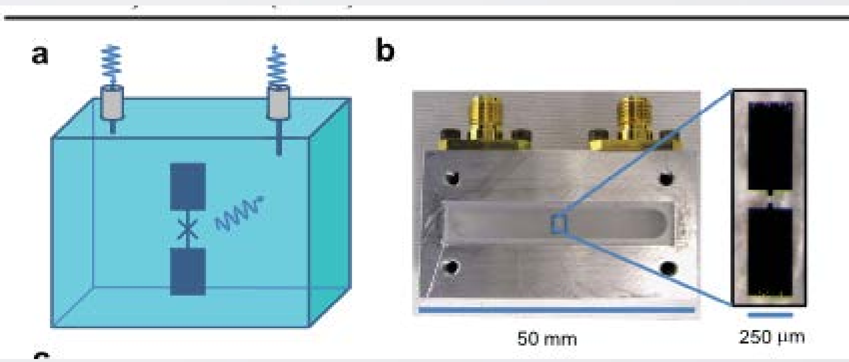
$E_{C0} = (2e^2)/2C_\Sigma$ $\qquad$ $E_J = \Phi_0 I_c/2\pi$

Улучшенный зарядовый кубит - Transmon

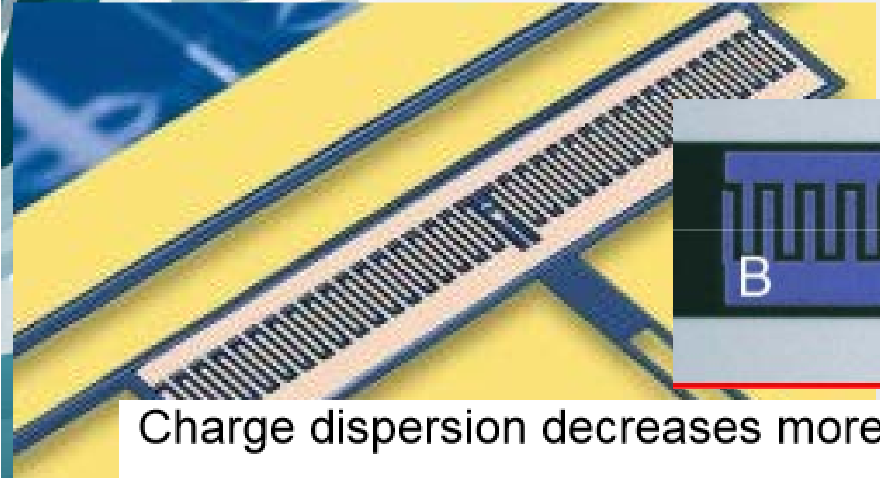


J. Koch et al., PRA76,042319(2007)

3D Transmon



H. Paik et al., Phys. Rev. Lett. 107, 240501 (2011)



Charge dispersion decreases more rapidly than anharmonicity:

$$\epsilon_m \equiv E_m(n_g = 1/2) - E_m(n_g = 0)$$
$$\simeq (-1)^m E_C \frac{2^{4m+5}}{m!}\sqrt{\frac{2}{\pi}}\left(\frac{E_J}{2E_C}\right)^{\frac{m}{2}+\frac{3}{4}} e^{-\sqrt{8E_J/E_C}}$$

$$\alpha_r(n_g = 1/2) \equiv (E_{12} - E_{01})/E_{01}$$
$$\simeq -(8E_J/E_C)^{-1/2}$$

Некоторые особенности разработки квантового компьютера.

- Наличие однокубитовых и двукубитовых квантовых вентилей.
- Возможность инициализировать регистр кубитов (например, ввести в состояние |00…0>).
- Считывание информации с отдельных кубитов.
- Большие времена когерентности.
- Транспортирование кубитов и передача запутанности между различными когерентными системами, то есть создание quantum-quantum interface.
- Создание классическо-квантовых интерфейсов для управления, считывания и хранения информации.

Заключение

- Значительный прогресс за последние 15 лет
- Зарядовые кубиты(Трансмоны)- лучшее на данный момент

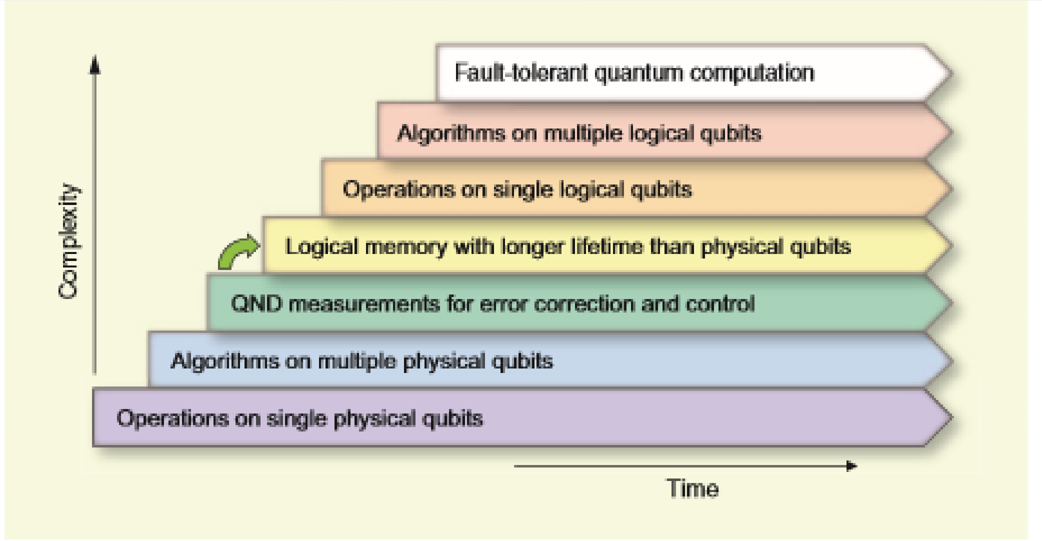


Fig. 1. Seven stages in the development of quantum information processing. Each advancement requires mastery of the preceding stages, but each also represents a continuing task that must be perfected in parallel with the others. Superconducting qubits are the only solid-state implementation at the third stage, and they now aim at reaching the fourth stage (green arrow). In the domain of atomic physics and quantum optics, the third stage had been previously attained by trapped ions and by Rydberg atoms. No implementation has yet reached the fourth stage, where a logical qubit can be stored, via error correction, for a time substantially longer than the decoherence time of its physical qubit components.

M. H. Devoret and R.J.SchoelkopfDOI:10.1126/science.1231930

БЛАГОДАРЮ ЗА ВНИМАНИЕ!

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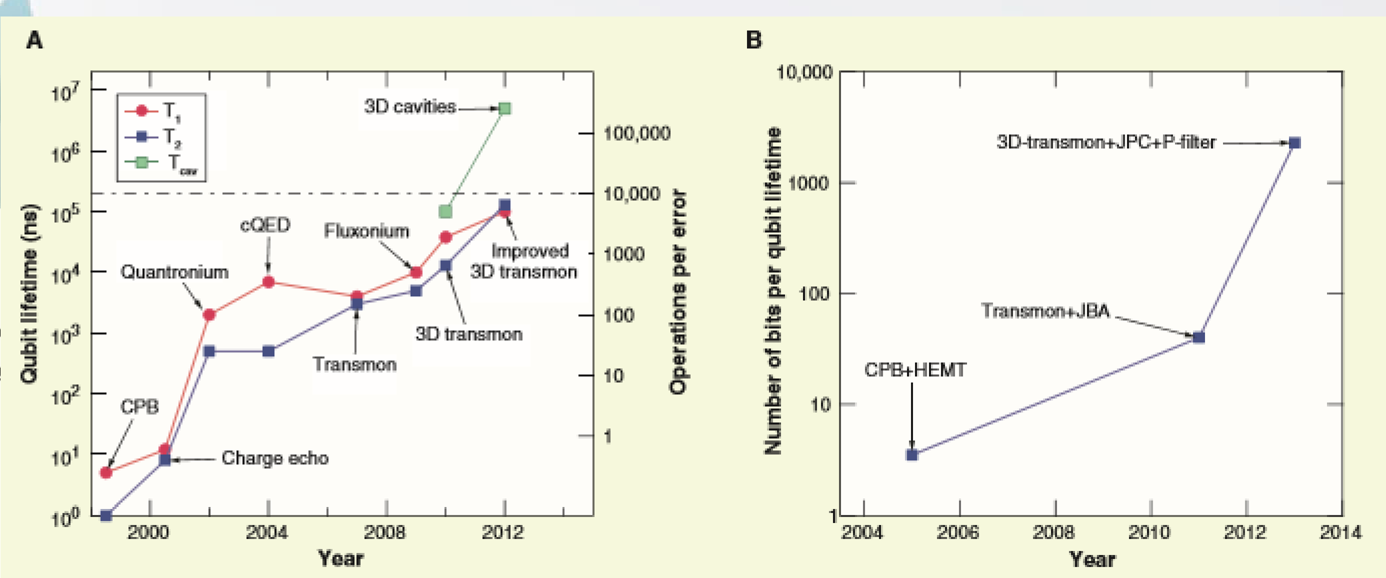

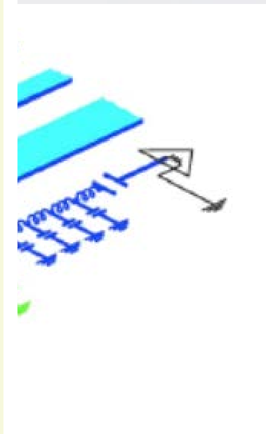

Rev. A, 2004

Fig. 3. Examples of the "Moore's law" type of exponential scaling in performance of superconducting qubits during recent years. All types have progressed, but we focus here only on those in the leftmost part of Fig. 2C. **(A)** Improvement of coherence times for the "typical best" results associated with the first versions of major design changes. The blue, red, and green symbols refer to qubit relaxation, qubit decoherence, and cavity lifetimes, respectively. Innovations were introduced to avoid the dominant decoherence channel found in earlier generations. So far an ultimate limit on coherence seems not to have been encountered. Devices other than those in Fig. 2C: charge echo (*63*), circuit QED (*44*), 3D transmon (*43*), and improved 3D transmon (*64*, *65*). For comparison, superconducting cavity lifetimes are given for a 3D transmon and separate 3D cavities (*66*). Even longer times in excess of 0.1 s have been achieved in similar 3D cavities for Rydberg atom experiments [e.g., (*67*)]. **(B)** Evolution of superconducting qubit QND readout. We plot versus time the main figure of merit, the number of bits that can be extracted from the qubit during its T1 lifetime (this number combines signal-to-noise ratio and speed). This quantity can also be understood as the number of measurements, each with one bit of precision, that would be possible before an error occurs. Data points correspond to the following innovations in design: a Cooper-pair box read by off-resonance coupling to a cavity whose frequency is monitored by a microwave pulse analyzed using a semiconductor high–electron mobility transistor amplifier (CPB+HEMT) [also called dispersive circuit QED (*68*)], an improved amplification chain reading a transmon using a superconductor preamplifier derived from the Josephson bifurcation amplifier (transmon+JBA) (*49*), and further improvement with another superconductor preamplifier derived from the Josephson parametric converter (*51*) combined with filter in 3D transmon cavity eliminating Purcell effect (3D-transmon+JPC+P-filter). Better amplifier efficiency, optimal signal processing, and longer qubit lifetimes are expected to maintain the rapid upward trend.