Comment on: “Charge-insensitive qubit design derived from the Cooper pair box”

J. Q. You,1, 2 Xuedong Hu,3 S. Ashhab,2, 4 and Franco Nori2, 4

1 Department of Physics and Surface Physics Laboratory (National Key Laboratory), Fudan University, Shanghai 200433, China
2 Advanced Science Institute, The Institute of Physical and Chemical Research (RIKEN), Wako-shi 351-0198, Japan
3 Department of Physics, University at Buffalo, SUNY, Buffalo, NY 14260-1500, USA
4 Center for Theoretical Physics, Physics Department, University of Michigan, Ann Arbor, MI 48109-1040, USA

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In a recent paper [1], Koch et al. stated that they “introduce a new type of superconducting qubit called the transmon.” In this comment we point out that the arguments used in Ref. [1] to establish the novelty of the “transmon” qubit are flawed.

The different types of superconducting qubits share a similar design, but use different values of the ratio $E_J/E_c$, where $E_J$ is the Josephson coupling energy of the Josephson junctions (JJ) and $E_c$ is the charging energy of the superconducting islands [2]. This ratio is typically $\sim 0.1$ for charge qubits, $\sim 10-100$ for flux qubits and larger than that for phase qubits. This difference in parameters, as well as differences in biasing conditions, cause the computational states of the qubit to take different properties in terms of the charge and phase degrees of freedom. Deep in the charge regime, the computational basis of the qubit is spanned by two quantum states differing by a single cooper pair that can tunnel into and out of a superconducting island. The states of flux and phase qubits are best described in terms of the motion of a fictitious particle (that corresponds to the phase variable) in a potential well: traditionally the basis of the flux qubit is spanned by two (at least partially) localized wavefunctions in a double-well potential, whereas the states of the phase qubit are the two lowest states in an anharmonic single-well potential.

Recently, Ref. [1] appeared and introduced the “transmon”. The authors used completely different arguments at different junctures to argue that the qubit design analyzed there is a new one. Here we show that none of those arguments is valid.

First, the authors state that the “transmon” is

“a transmission-line shunted plasma oscillation qubit.”

However, when they analyze the qubit properties and its advantages over the conventional Cooper-pair box, the transmission line is clearly irrelevant. The transmission line serves the same purposes (e.g. control and readout) for the modified design as it did for the conventional Cooper-pair box, and are not new to Ref. [1]. Therefore, the presence of the transmission line does not constitute any novelty.

Soon afterwards, the authors of Ref. [1] state that the design of their qubit is

“closely related to the Cooper pair box qubit...

However, the transmon is operated at a significantly different ratio of Josephson energy to charging energy.”

They also explain that this change in the ratio $E_J/E_c$ is the main reason for the improved coherence properties. They emphasized this argument further in their response to this comment by stating that the prefix “trans” (Latin for “over,” “beyond”) indicates that the device is operated in the regime $E_J/E_c \gg 1$. However, this argument again does not imply any novelty in the design. This parameter regime is exactly the one that has been used for years in flux and phase qubits, as well as in one experiment using a Cooper-pair box [3]. Therefore, a more appropriate interpretation of this change of circuit parameters would be that the circuit falls within the flux or phase regime of superconducting qubits, which are known to have superior coherence properties to the charge qubit.

In order to determine with which regime to associate the design of Ref. [1], the properties of the qubit’s quantum states must be analyzed in terms of the charge and phase variables. As explained above, these properties are the standard criterion for distinguishing between different superconducting qubits. No such comparison between the qubit states and those of other superconducting qubits was given in Ref. [1]. The smallness of the anharmonicity found in [1] suggests that the circuit is a phase qubit (this view is also taken in Ref. [4]).

The authors of Ref. [1] state that there is a topological difference between the transmon and the phase qubit and that

“this topological difference makes it impossible to establish a continuous mapping between the transmon and the phase qubit via adiabatic changes of $E_J/E_c$.”

However, in this argument they compare the phase within the qubit’s split-junction loop for the former and the biasing loop for the latter. This topological difference in the designs of the transmon and the phase qubit is simply a matter of splitting a Josephson junction into two junctions connected in parallel. It is the same difference as the one that exists between two well-known types of charge qubits, both of which were used on one sample in Ref. [5].

At a different point in Ref. [1], the authors state that

“the crucial modification distinguishing the transmon from the Cooper-pair box is a
shunting connection of the two superconductors via a large capacitance $C_B$, accompanied by a similar increase in the gate capacitance $C_g$.

This is precisely the crucial ingredient introduced in [6] to the conventional flux-qubit design in order to reduce its sensitivity to charge noise. Therefore, the addition of a shunt capacitance in order to modify the ratio $E_J/E_c$ for some junctions in the circuit and consequently reduce the sensitivity to charge noise is not new to Ref. [1]. An earlier experiment [7] had also used a shunt capacitor to improve the performance of the phase qubit, although the mechanism by which the shunt capacitor resulted in better qubit performance was quite different in that experiment.

The authors of Ref. [1] also use the fact that they find an exponential reduction in the qubit’s sensitivity to charge noise as an indication of novelty. This calculation of the functional dependence of the qubit’s sensitivity to (low-frequency) charge noise is a welcome contribution to the field. However, it is far from being an argument for novelty in the design. It is already well known that flux and phase qubits are insensitive to low-frequency charge noise. In the parameter regime where the authors of Ref. [1] find a huge reduction in the sensitivity to charge noise (e.g. an improvement by a factor $\sim 10^9$ for $E_J/E_c = 50$), low-frequency charge noise cannot be expected to be the limiting factor for qubit coherence. In contrast to Ref. [1], Ref. [6] considered both charge and flux noises with both low- and high-frequency components and compared the results with the best available coherence times for a superconducting qubit [8]. The fact that a more careful calculation was performed in Ref. [6] explains the more modest improvement found there, as compared with the huge improvement predicted in Ref. [1].

In conclusion, in order to give a proper description of the qubit design analyzed in Ref. [1], it would have been very useful to analyze the properties of the quantum states of the circuit and compare them with the physically defined states of flux and phase qubits. If such analysis reveals that the quantum states of the design under consideration have different properties from the three main superconducting-qubit types, novelty (assuming that one can speak of different types of superconducting qubits) would be established. The weak, disjoint arguments used in Ref. [1], on the other hand, do not lead to the stated conclusion of novelty. Finally, with numerous previous studies using some of what are stated in Ref. [1] to be defining characteristics of the “transmon”, e.g. Refs. [3, 6, 7] to name a few, one is left with the question: exactly what is it that makes a given circuit a “transmon” circuit?

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