Erratum: Micromachined Integrated Quantum Circuit Containing a Superconducting Qubit [Phys. Rev. Applied 7, 044018 (2017)]

T. Brecht, Y. Chu, C. Axline, W. Pfaff, J. Z. Blumoff, K. Chou, L. Krayzman, L. Frunzio, and R. J. Schoelkopf

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We identified a typographical error in the calculation script used to estimate the In-Au-Al seam loss of the multilayer microwave-integrated quantum circuit (MMIQC) devices modes appearing in Table S1. The reported value of the Al-Au-In seam conductivity per unit length used in calculations, $g_{\text{seam}} = 4.2 \times 10^5\ \Omega^{-1}\,\text{m}^{-1}$, exceeded the intended value by a factor of 10. However, we found that more accurately accounting for several simplifying assumptions in this first calculation with exact electromagnetic simulations reduced this error somewhat, to approximately a factor of 3.5. These errors alter the values presented in Sec. V of the main text, para. 2, as well as the discussion in Sec. V of the Supplemental Material.

TABLE S1. Limits on qubit and storage cavity lifetimes derived from seam admittances. The qubit and storage modes' y_{seam} values are found from HFSS simulation of the design featured in this work. The inferred lifetime limits are $T_1^{q,\mu} < g_{\text{seam}}/y_{\text{seam}}\omega_{q,\mu}$, assuming $g_{\text{Al-Au-In}} = 1.2 \times 10^5\ \Omega^{-1}\ \text{m}^{-1}$, and using $\omega_q/2\pi = 7.35$ GHz, and $\omega_\mu/2\pi = 9.38$ GHz. The last line computes limits imposed by the indium-to-indium bond around the perimeter of the micromachined cavity using $g_{\text{In-In}} = 1 \times 10^8\ \Omega^{-1}\,\text{m}^{-1}$.

Seam	y^q_{seam} ($\Omega^{-1}\,\text{m}^{-1}$)	y^μ_{seam} ($\Omega^{-1}\,\text{m}^{-1}$)	max T_1^q (μs)	max T_1^μ (μs)
In-Au-Al circle, $r = 1.00$ mm	7.86	0.0048	0.32	412
In-Au-Al circle, $r = 1.25$ mm	2.73	0.0269	0.92	73.6
In-Au-Al circle, $r = 1.75$ mm	0.823	0.0948	3.1	20.9
In-Au-Al square, 3×3 mm	1.044	0.0756	2.27	26.3
In-Au-Al square, 4×4 mm	0.460	0.187	5.49	10.6
In-Au-Al square, 5×5 mm	0.264	0.363	9.55	5.49
In-In, cavity perimeter	0.0239	15.96	91 000	108

First, we recalculate the value of seam conductivity using exact numerical methods. We use the measured internal quality factors of the stripline resonators in Fig. S5, recalculating their values of y_{seam}, in order to calibrate g_{seam}. The analytical methods previously used to calculate y_{seam} made several simplifying approximations regarding the geometry and field distribution. We perform finite-element simulations using Ansys HFSS to represent the electromagnetic field within the full geometry as accurately as possible and at frequencies matching the measured devices. We present the recalculated results, replacing Fig. S5(d), below.

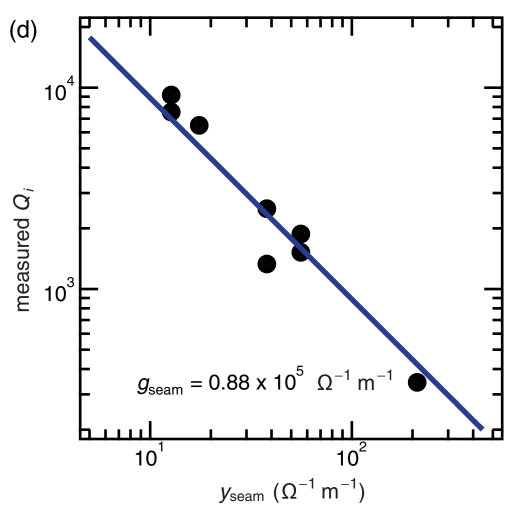

FIG. S5. Stripline resonators were used to measure the conductance of the seam in question. (d) Measured internal quality factors of the several devices of varying seam admittances. The blue line is the best fit of the data to $Q_i = g_{\text{seam}}/y_{\text{seam}}$ using linear least-squares regression in the log-log domain, which yields $g_{\text{seam}} = (0.88 \pm 0.09) \times 10^5\ \Omega^{-1}\,\text{m}^{-1}$.

The data in Fig. S5(d) are used to establish a bound on the value of g_{seam} according to

$$Q_{\mathrm{seam}} = g_{\mathrm{seam}}/y_{\mathrm{seam}}, \tag{1}$$

where we select the highest calculated value of Q_{seam} to set the strictest bound on g_{seam}, thus resulting in $g_{\mathrm{seam}} = (1.2 \pm 0.2) \times 10^5\,\Omega^{-1}\,\mathrm{m}^{-1}$, using the standard deviation from all the measurements. However, this value likely underrepresents the error, since g_{seam} calculated on a point-by-point basis ranges from $0.5 \times 10^5\ \Omega^{-1}\,\mathrm{m}^{-1}$ to $1.2 \times 10^5\ \Omega^{-1}\,\mathrm{m}^{-1}$.

Using this new value of g_{seam} in Eq. (1), we can revise our predictions of the T_1 and Q values at which the transmon and micromachined cavity modes for the device presented in the main text could be limited. We also recalculate values of y_{seam} for these two modes using exact numerical methods. Table S1 is reproduced below with corrected values.

The revised values remain close to the measured T_1 values of these two modes, although the predicted bounds are now lower. The apparent discrepancy of the value of this rough lower bound is not perhaps unexpected for several reasons. First, the significant spread in the values of Q_i measured in the stripline experiment leads to error in the calculated value of g_{seam}. Furthermore, the stripline devices and MMIQC devices were fabricated in different instances and on different wafers, so run-to-run variations in g_{seam} may exist between them. While g_{seam} appears to accurately model data from each device type, seam quality variations between wafers could add to the uncertainty of a g_{seam} calibrated from another device type.

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