SAND2018-12271C

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Poster Instructions

Title font: Gill Sans MT

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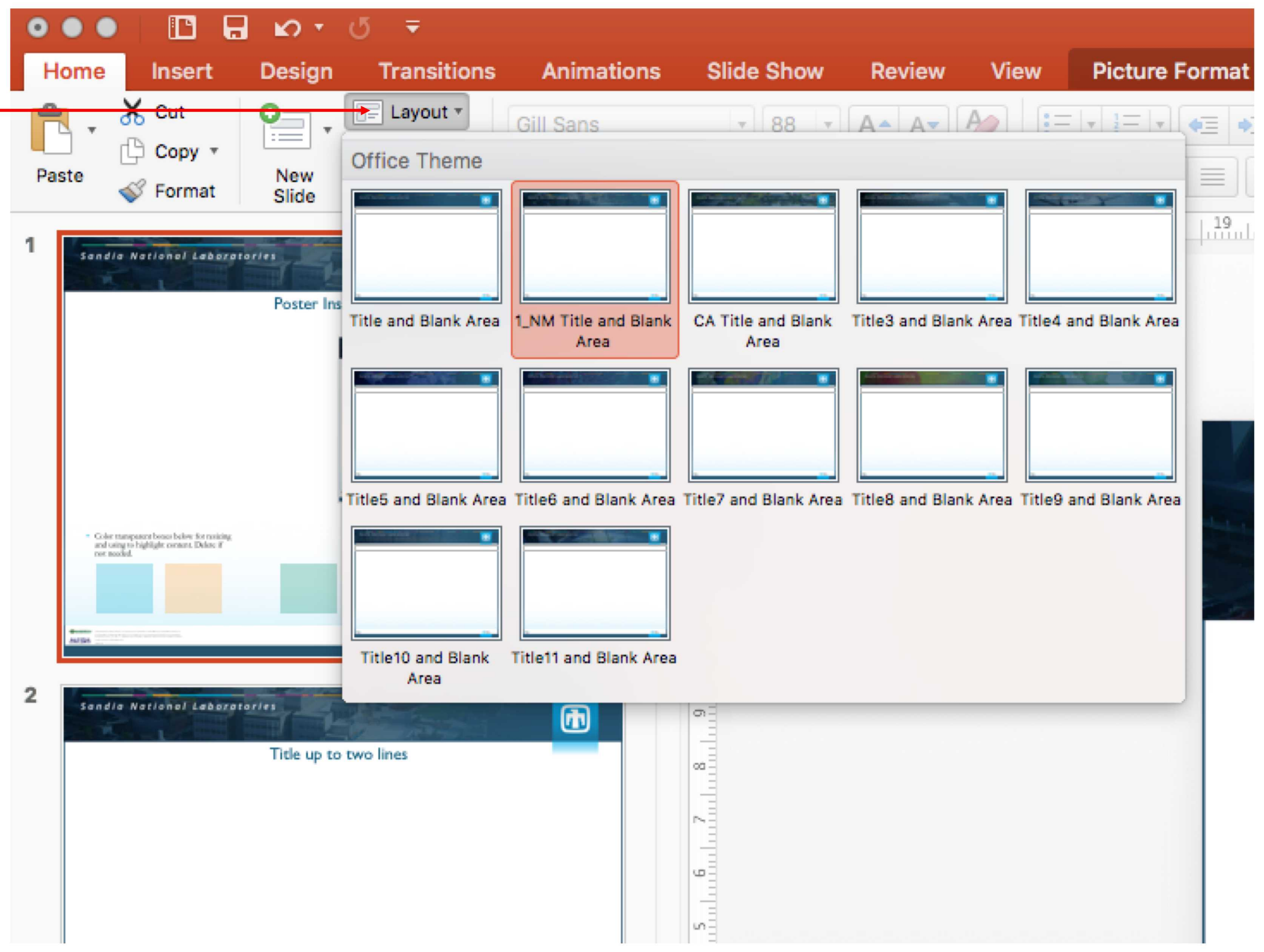

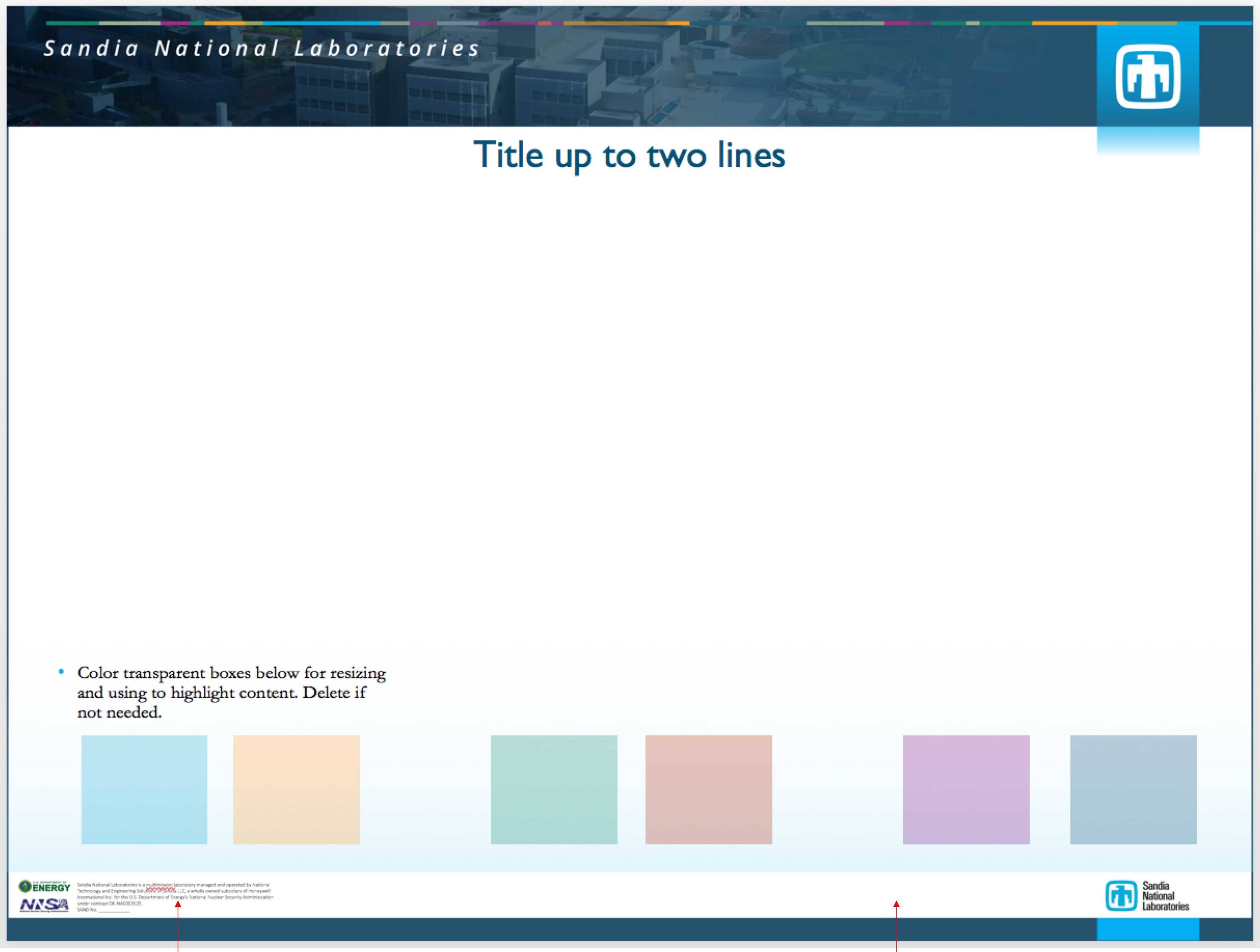

Body text/ support font: Garamond MT

Add Sand Number to the funding statement within the Master Title slide

Additional program/partner logos can be added here

- Color transparent boxes below are for resizing and using to highlight content. Delete if not needed.

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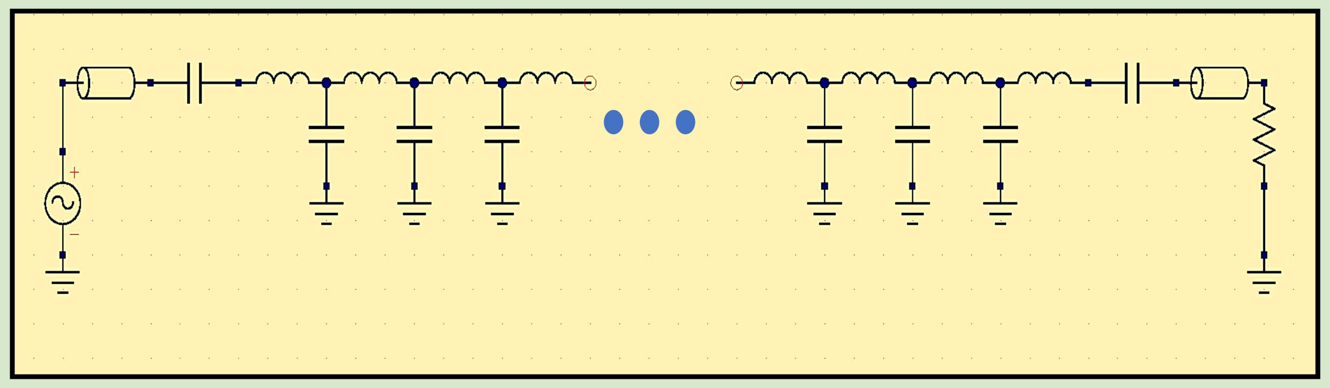
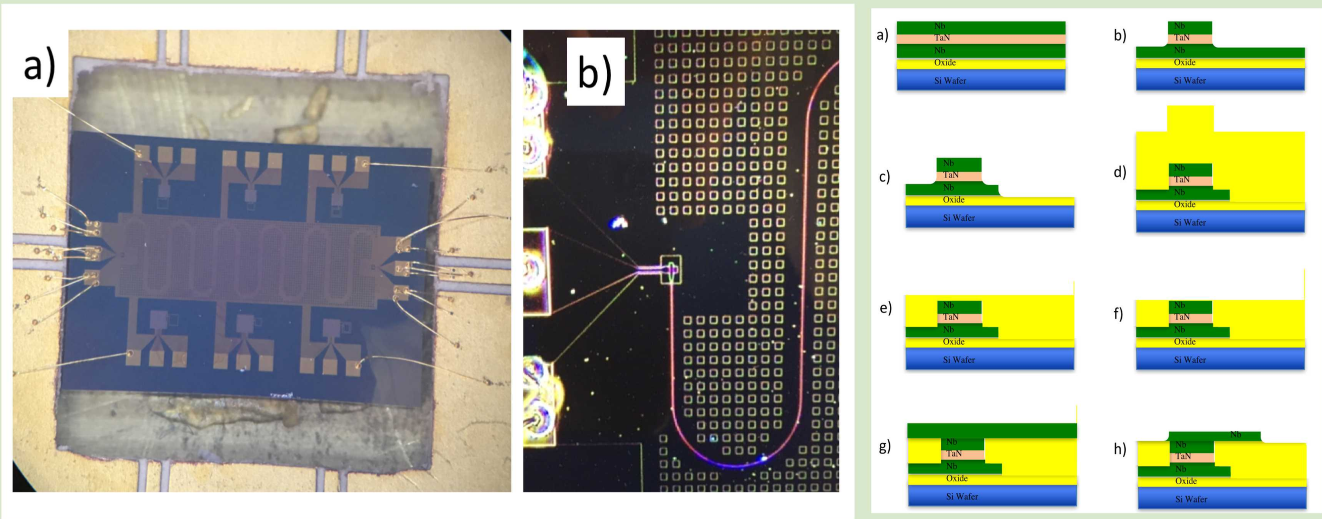
Measuring changes in inductance with microstrip resonators

R. M. Lewis, M. D. Henry, T. Young, M. Wolak, M. P. Frank, and N. Missert

Measure inductance with microstrip resonators



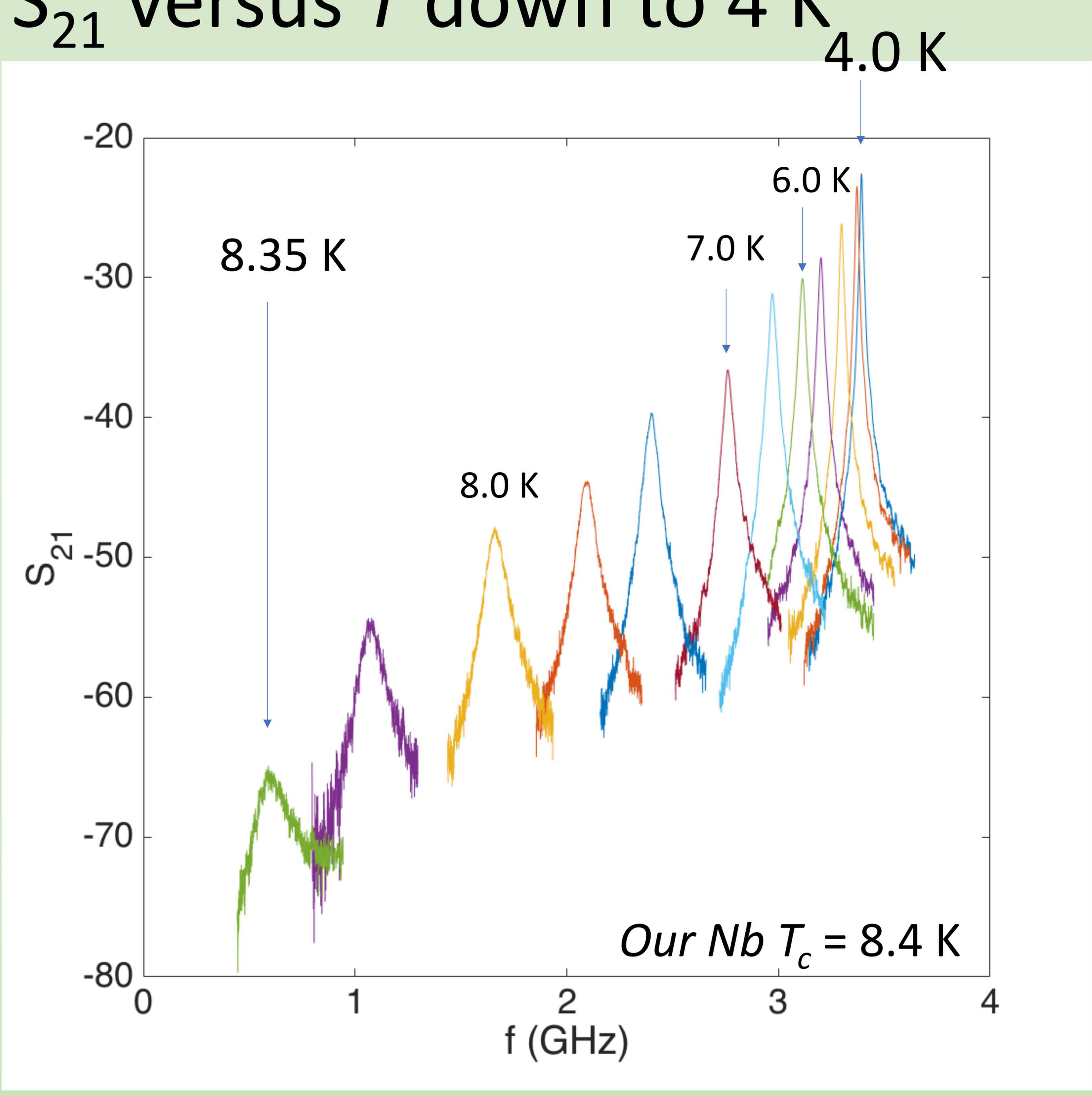
Devices:



- Nb JJ fab process, no JJs
- Measure transmission (S_{21}) using VNA
- Resonator: 15.7 mm long, 2 um wide
- Fit for f_{pk}, Q_{in}

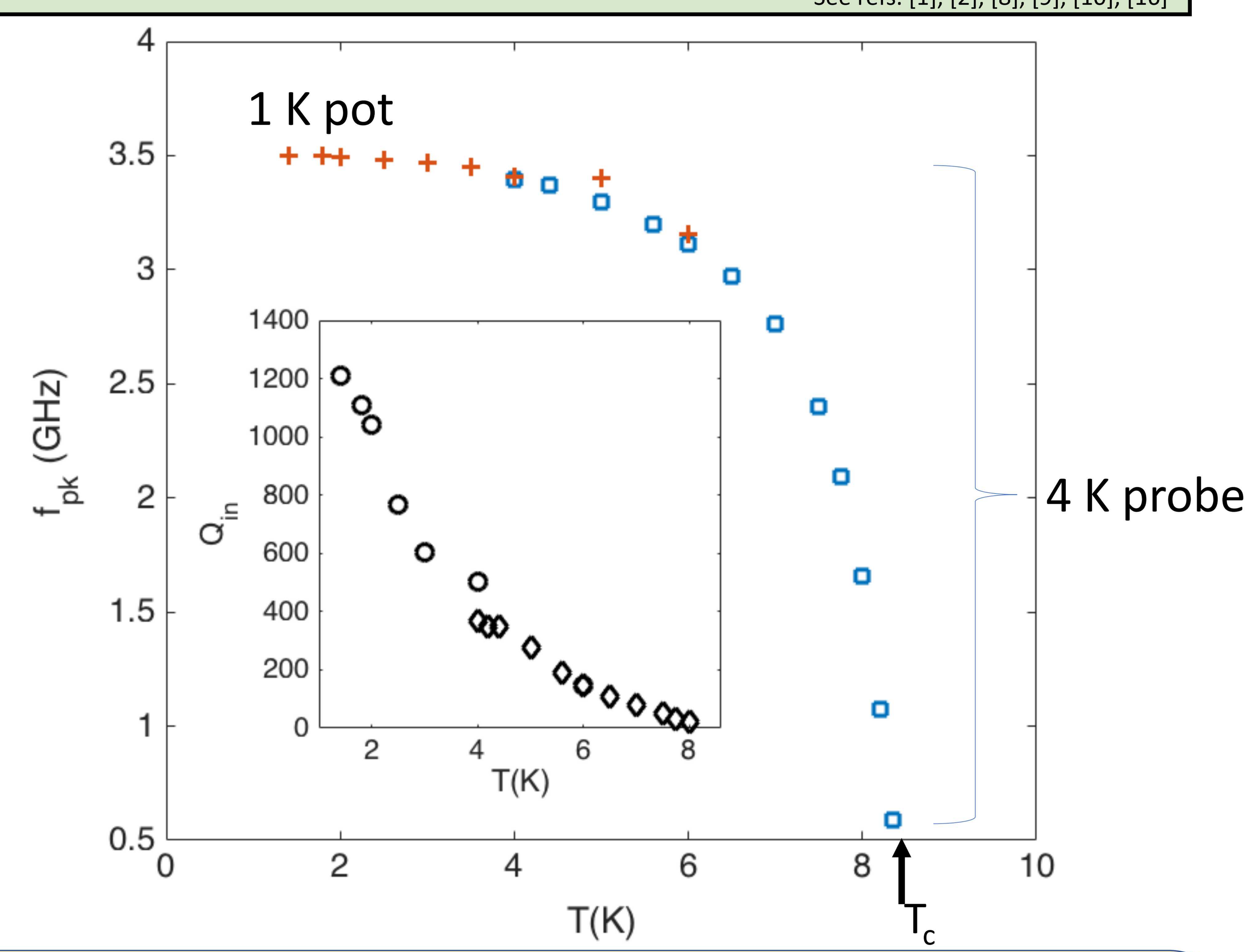
Further info refs. Measuring L: [3], PTLs [4,5,6,7], fab: [11,12]

S_{21} versus T down to 4 K



Inductance is a crucial parameter in superconducting electronics (SCE) circuit design. Understanding inductance variations with temperature enables more robust designs with wider margins.

See refs. [1], [2], [8], [9], [10], [16]



$$S_{21} = \frac{-Q_T}{2Q_L} - \frac{Q_T}{2Q_L}\,\frac{\left(\left(\frac{1}{Q_T}\right)^2 - \left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)^2 - 2i\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)\frac{1}{Q_T}\right)}{\left(\frac{1}{Q_T}\right)^2 + \left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)^2}$$

See for example refs [13], [14]

- $Q_{in} \approx 400$ @ 4 K
- Al etch stop layer may reduce Q—investigating further
- Helps quantify losses in Clock/AC bias lines
- Extrapolate to SFQ pulses at ~ 100 GHz Passive SFQ transmission lines (PTLs) < 4 mm OK!

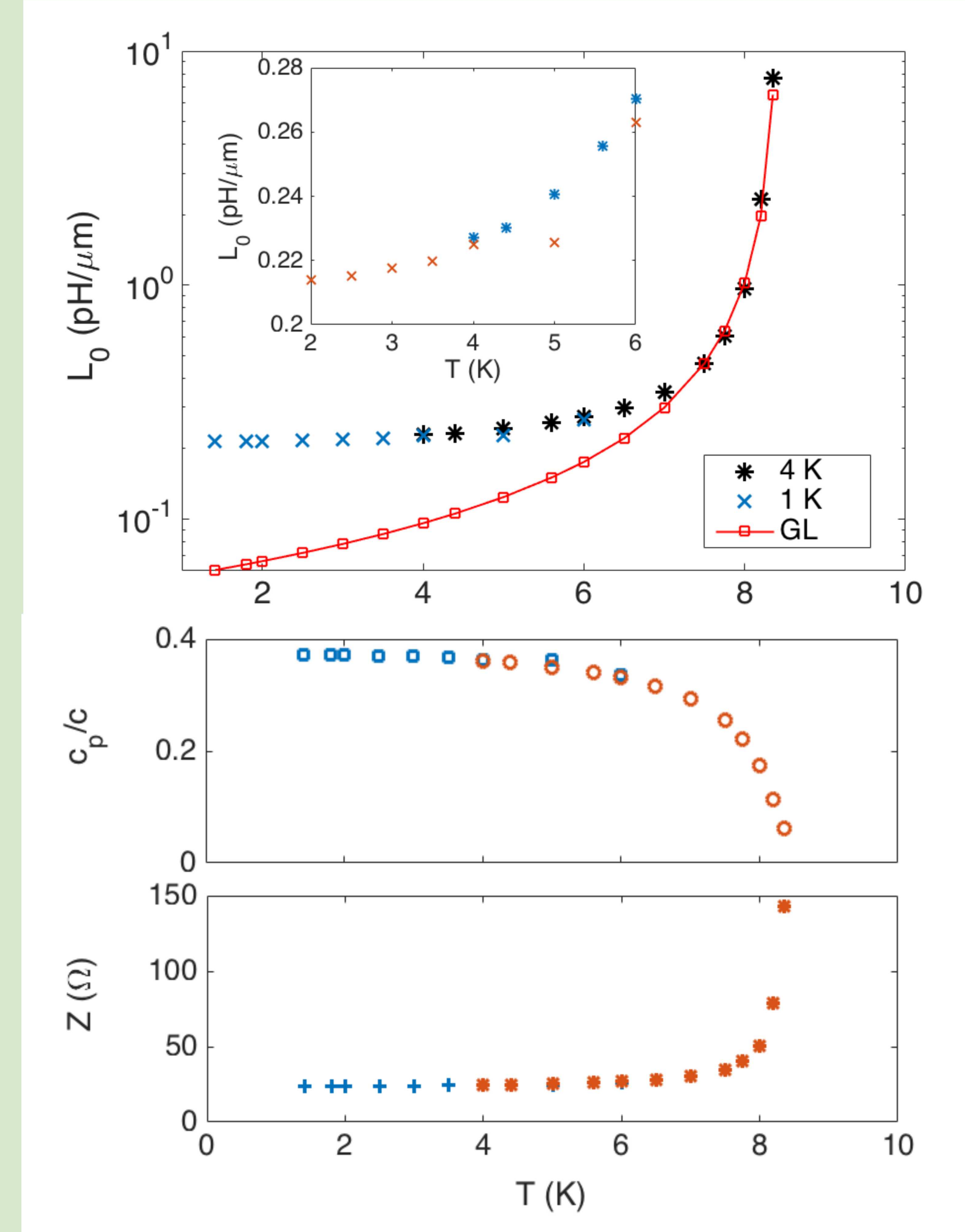
See refs. PTL losses: [4,5,6,7], low power Logic: [8,9.10]

Results:

$v_p = f_{pk} 2 l_{res}$

C_0=0.188 fF

$L_0 = 1/v_p^2 C_0$



- Inductance, L_0, shows 19 % increase between 2 and 6 K
- Impedance, Z, shows 11 % increase
- Phase velocity, v_p, shows 11 % decrease

GL, kinetic inductance: refs. [13,14,15]; Compare refs. [16], [17]

References:

[1] K. K. Likharev and V. K. Semenov, "RSFQ Logic/Memory Family: A New Josephson-Junction Technology for Sub-Terahertz-Clock-Frequency Digital Systems", IEEE Trans. Appl. Supercon. Vol. 1, No. **1**, 3 (1991). **[2]** See IARPA's SuperTools program: https://www.iarpa.gov/index.php/newsroom/iarpa-in-the-news/2018/1085-iarpa-launches-supertools-program-to-develop-superconducting-circuit-design-tools **[3]** B. W. Langley, S. M. Anlage, R. F. W. Pease, and M. R. Beasley, 'Magnetic penetration depth measurements of superconducting thin films by a microstrip resonator technique', Rev. Sci. Instrum. **62**, 1801 (1991). **[4]** R. L. Kautz, 'Miniaturization of Normal-State and Superconducting Striplines', Journal of Research of the National Bureau of Standards, Vol. **84**, No. 3, 247 (1979). **[5]** R. L. Kautz, 'Picosecond pulses on superconducting striplines', Journal of Applied Physics **49**, 308 (1978); doi: 10.1063/1.324387 **[6]** S. V. Polonsky, V. K. Semenov, and D. F. Schneider, 'Transmission of Single-Flux-Quantum Pulses Along Superconducting Microstrip Lines', IEEE Trans. Appl. Supercond. Vol. **3**, No. 1, 2598 (1993). **[7]** Kasumi Takagi, Masamisu Tanaka, Shingo Iwasaki, Ryo Kasagi, Irina Kataeva, Shuichi Nagasawa, Tesuro Satoh, Hiroyuki Akaike, and Akira Fujimaki, 'SFQ Propagation Properties in Passive Transmission Lines Based on a 10-Nb-Layer Structure', IEEE Trans. Appl. Supercond. Vol. **19**, No. 3, 617 (2009). **[8]** [D. E. Kirichenko, S. Sarwana, and A. F. Kirichenko, 'Zero Static Power Dissipation Biasing of RSFQ Circuits', IEEE Trans. Appl. Supercond. IEEE Trans. Appl. Supercond., vol. **21**, no. 3, pp. 776-779, (2011). **[9]** Quentin P. Herr, Anna Y. Herr, Oliver T. Olberg, and Alexander G. Ioannidis, "Ultra-low-power Superconductor Logic", J. Appl. Phys. **109**, 103903 (2011); doi: 10.1063/1.3585849 **[10]** Naoki Takeuchi, Dan Ozawa, Yuki Yamanashi and Nobuyuki Yoshikawa, 'An adiabatic quantum flux parametron as an ultra-low-power logic device', Supercond. Sci. Technol. **26**, 035010 (2013); doi:10.1088/0953-2048/26/3/035010 **[11]** M. D. Henry, S. Wolfley, T. Monson, B. G. Clark, E. Shaner, and R. Jarecki, "Stress dependent oxidation of sputtered niobium and effects on superconductivity," *Journal of Applied Physics,* Vol. **115**, no. 8, pp. 083903, (2014). **[12]** N. Missert, L. Brunke, M. D. Henry, S. Wolfley, S. Howell, J. Mudrick, and R. M. Lewis, 'Materials Study of NbN and TaxN Thin Films for SNS Josephson Junctions', IEEE Trans. Appl. Supercond. Vol. **27** , No. 4, 1100904 (2017); DOI: 10.1109/TASC.2017.2669582 **[13]** B. A. Mazin, Ph.D. dissertation, California Institute of Technology, 2004. [**14**] J. Gao, J. Zmuidzinas, B. A. Mazin, P. K. Day, and H. G. Leduc, "Experimental study of the kinetic inductance fraction of superconducting coplanar waveguide", Physics Research A **559**, 585-587 (2006). **[15]** Michael Tinkham, 'Introduction to Superconductivity, 2nd Ed.', Dover Publications, Inc., Mineola, NY, (1996). **[16]** Sergey K. Tolpygo, Vladimir Bolkhovsky, T. J. Weir, C. J. Galbraith, Leonard M. Johnson, Mark A. Gouker, and Vasili K. Semenov, 'Inductance of Circuit Structures for MIT LL Superconductor Electronics Fabrication Process With 8 Niobium Layers', IEEE Trans. Appli. Supercond. Vol. **25**, No. 3, 1100905 (2015); DOI: 10.1109/TASC.2014.2369213 **[17]** W. H. Chang, 'The inductance of a superconducting strip transmission line', Journal of Applied Physics **50**, 8129 (1979); doi: 10.1063/1.325953

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