CSQ Community Standard Resonators

Danielle A. Braje, Matthew Neeley, and William D. Oliver
MIT Lincoln Laboratory

CPW Reproducibility Device

The reproducibility device is a frequency multiplexed design that contains five quarter-wave CPW resonators with nominal resonant frequencies ranging from 5 GHz to 6 GHz. The resonators are capacitively coupled to a single 50 Ω center line. Transmission through the center line is essentially unity, except at the resonance frequencies of each resonator. At these frequencies, the resonators cause a dip (a notch) in the transmission frequency spectrum. One advantage of this approach is that the unloaded quality factor Q_i can be extracted without the additional calibration that is necessary when measuring transmission resonators. The coupling of the reproducibility device should be chosen to match approximately the expected material Q. CPW reproducibility designs are provided for six nominal coupling values (Q_c) ranging from 15,000 to 1,200,000 as shown in Table 2.

CAD File Name	**Target Coupling [Q_c]** (= 10)
Reproducibility Strong	15,000 – 25,000
Reproducibility Medium 1	40,000 – 60,000
Reproducibility Medium 2	100,000 – 150,000
Reproducibility Weak	200,000 – 300,000
Reproducibility Weaker	400,000 – 600,000
Reproducibility Weakest	800,000 – 1,200,000

Table 2: Target coupling Q (Q_c) of the CPW reproducibility resonator designs. Values based on Sonnet simulation with a substrate dielectric constant of ε = 10. File names correspond to the GDSII files. Other Q_c values are available upon request.

An image of the 5 × 5 mm^2 chip design is shown in Fig. 1. For wirebonding to the feedline and to package ground, 250 × 250 μm^2 bonding pads are centered along opposite chip edges, and a 250 μm-wide grounding strip is provided around the perimeter of the chip.

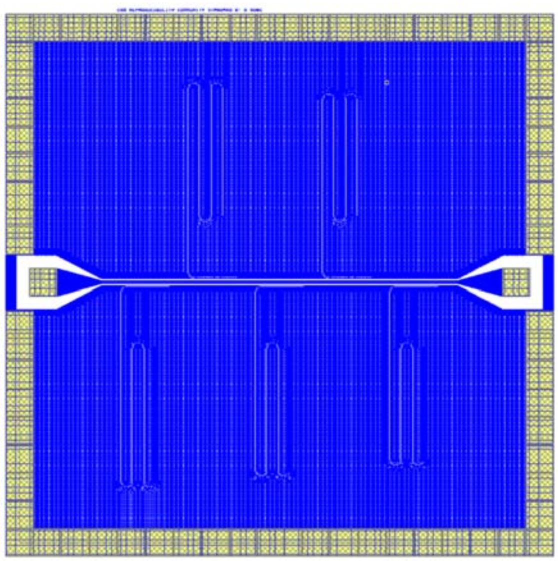

Figure 1: CPW reproducibility resonator design consists of five resonators capacitively coupled to a common feedline. Each quarter-wave resonators capacitively couples to the feedline with an elbow-shaped coupler at the open end while the opposite end is shorted to the ground plane. To accommodate their long length,

resonators are meandered with the spacing between adjacent CPW traces of 100 μm, nearly an order of magnitude larger than center width + 2×gap.

Several variables govern the overall geometry of the resonators. The coplanar waveguide and couplers are designed assuming a dielectric constant of ε = 10 and metal with negligible kinetic inductance. The nominally 50 Ω feedline width-to-gap ratio as well as the coupling parameters can be adjusted for other substrates or metals if necessary. The feedline width of 31 μm center conductor and 14 μm gap lessens resonator coupling

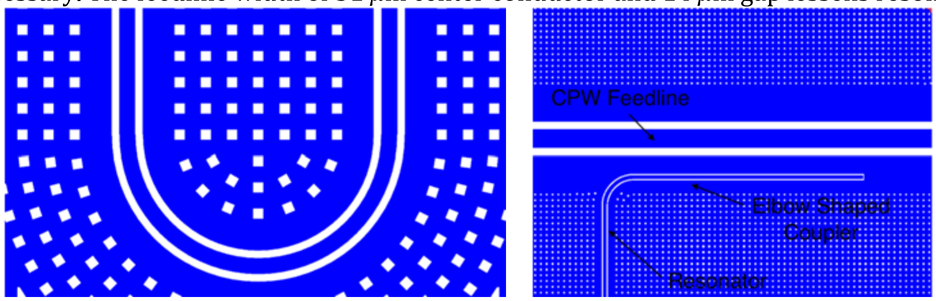

Figure 2: Design details for the reproducibility CPW resonator. (Left) Detailed view of the resonator ground perforation comprised of 4 μm square holes separated by 6 μm metal lines. The perforation follows the curve of the center trace lined with a solid ground plane region of twice the center width. (Right) The elbow shaped coupler capacitively couples to the feedline.

sensitivity to fabrication variations such as over-etching. The narrower width of the resonator at 6 μm center with 3 μm gap reduces the probability of trapping flux [4] while increasing sensitivity to TLS loss. The ground perforation spans the width of the chip, except in the bonding pads and adjacent to the transmission line center conductor. Figure 2 shows the perforated ground detail around the curved portion of the resonator. Square holes measuring 4 μm per side are separated by 6 μm metal lines. To keep the solid portion of the ground plane a constant spacing from the resonator, the perforation pattern follows the meander of the center trace.

Multiplexed Resonator #	**Resonator Length**
1	6195 μm
2	5995 μm
3	5795 μm
4	5595 μm
5	5395 μm

Table 3: Length for each of the multiplexed resonators in the CPW reproducibility device.

The resonator length (l) is 6195 μm for the first multiplexed resonator, with each resonator successively shorter by 200 μm as shown in Table 3. Neglecting kinetic inductance (KI), the multiplexed resonators span 5 GHz to 6 GHz, spaced by ~200 MHz. For a material of known KI, the resonant frequency will be shifted accordingly: $f_o = \left(4l\sqrt{(L_l + L_k)C_l}\right)^{-1}$ where f_o is the resonant frequency, L_k is the kinetic inductance per unit length, L_l and C_l are the geometric capacitance and inductance per unit length, respectively. Analytic expressions for the capacitance [1] and inductances [2] can be obtained by conformal mapping techniques or through simulation.

The resonators are coupled capacitively to the feedline near the open end by running a part of the resonator center line alongside the feedline while keeping the ground plane uninterrupted. Lengthening the coupler or decreasing the distance to the feedline increases the capacitive coupling. For each of the coupling designs, the desired coupling is achieved with a coupler length in the range of 300 μm to 500 μm while adjusting the separation to the feedline in 5 μm increments. Although the geometric coupling structure is identical for all the multiplexed resonators, Q_c varies with f_o, resulting in a range of coupling values.

References

[1] Spartak Gevorgian , L. J . Peter Linner, and Erik L. Kollberg. “CAD Models for Shielded Multilayered CPW” IEEE Trans. Microwave Theory Tech. **43**, 772 (1995).

[2] Koki Watanabe, Keiji Yoshida, Takeshi Aoki and Satoshi Kohjiro “Kinetic Inductance of Superconducting Coplanar Waveguides” Jpn. J. Appl. Phys. **33** 5708 (1994).