Modeling and Simulation of Mechanically Coupled MEMS Resonators Using COMSOL Multiphysics®

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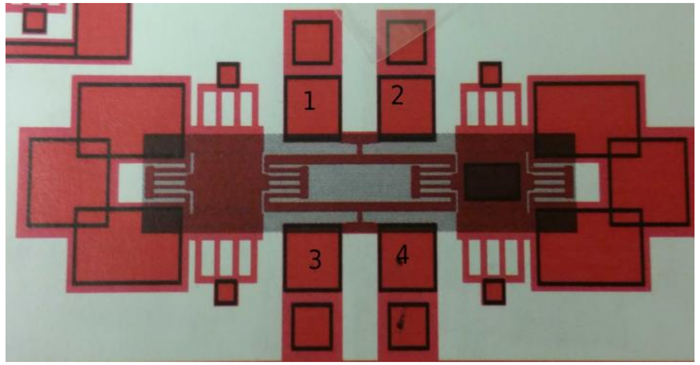
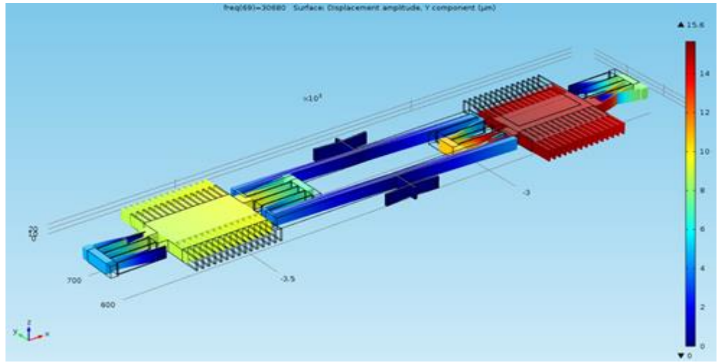
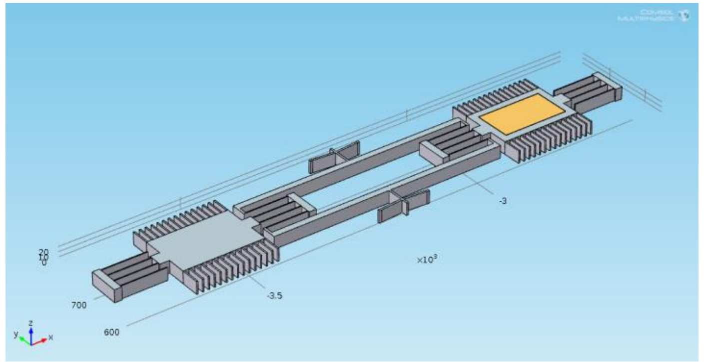
Purpose

- Create a COMSOL Multiphysics® model that represents the previously designed and fabricated coupled MEMS resonators
- Investigate the effect of altering mass loadings
- Compare Eigenfrequency analysis results with frequency sweep results for possible reduced simulation time





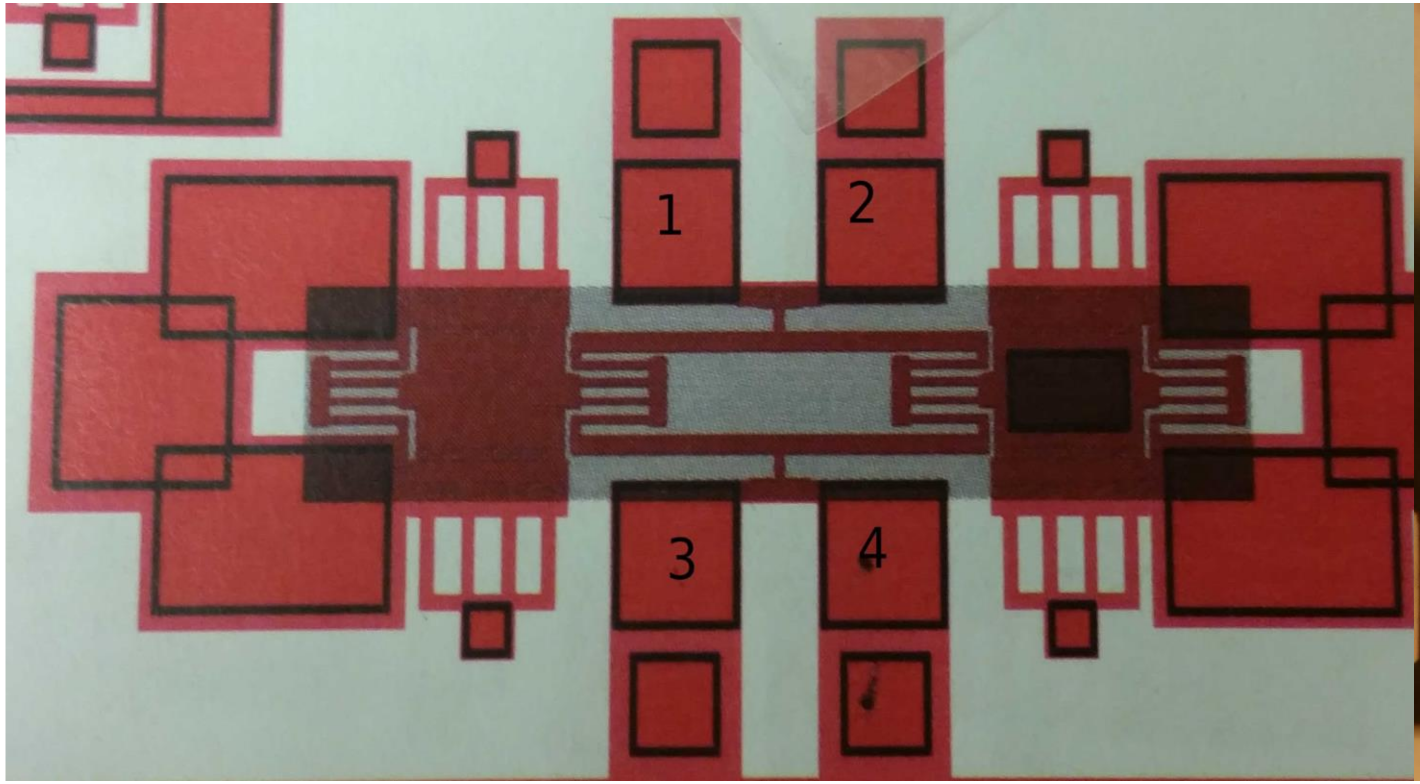


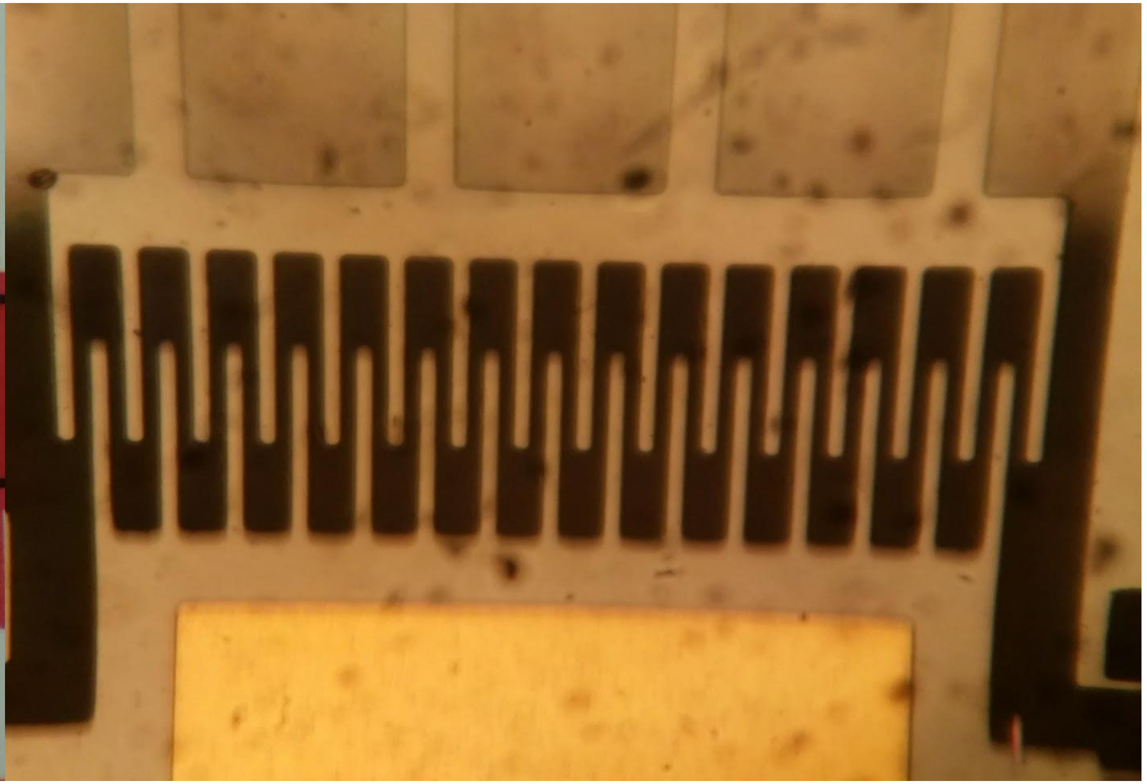
What are MEMS Resonators and What are Some Possible Applications?

- Microelectromechanical System Resonators
- Resonate at specific frequencies based on mass and spring constant $f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$
- Used in gas sensors for their sensitivity to mass
  - Two resonators - one with thin film to capture specific gas molecules-other as a reference
  - A change in resonance will indicate the presence and amount of the gas absorbed
- Response can be measured electrically through induced current from the mechanical motion

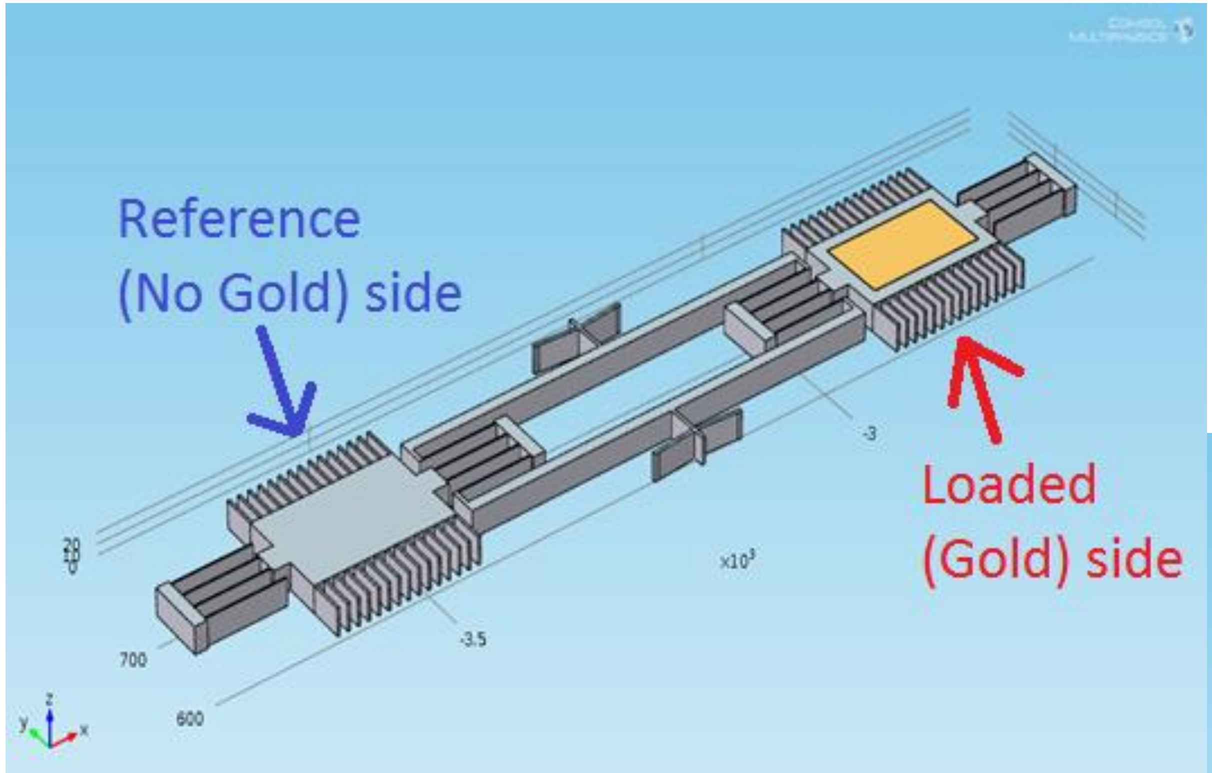
Fabricated Device

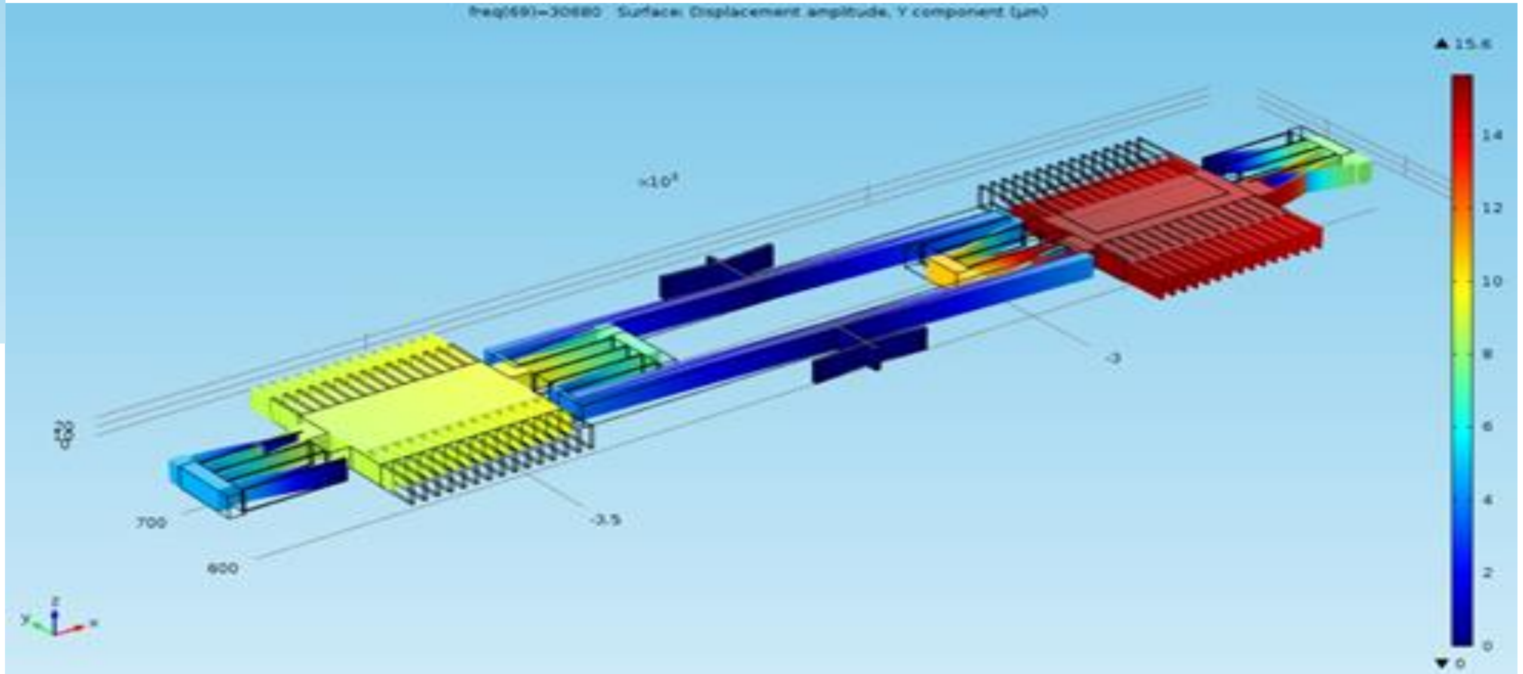
$$C = \frac{A\varepsilon}{d} \qquad I(t) = \frac{d(C \cdot V)}{dt}$$



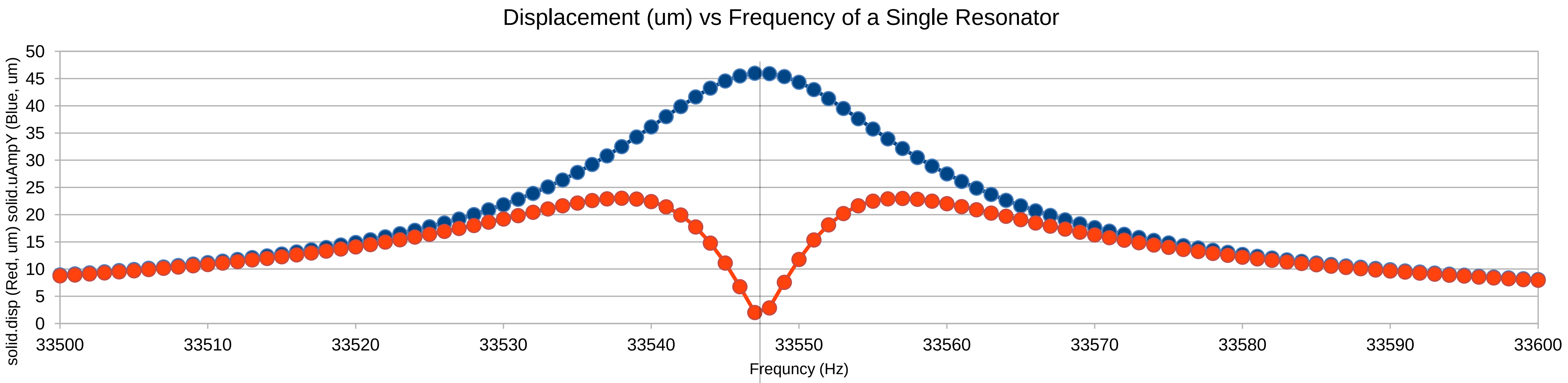


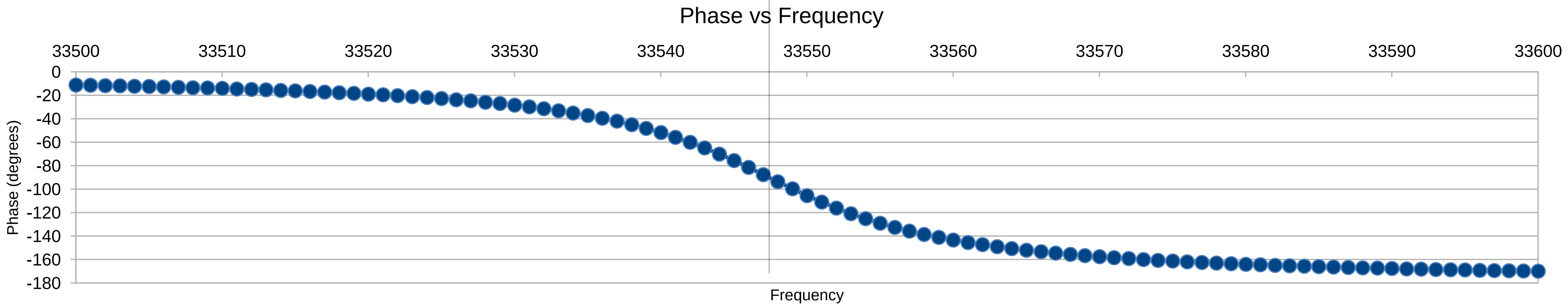
Model used for Simulations



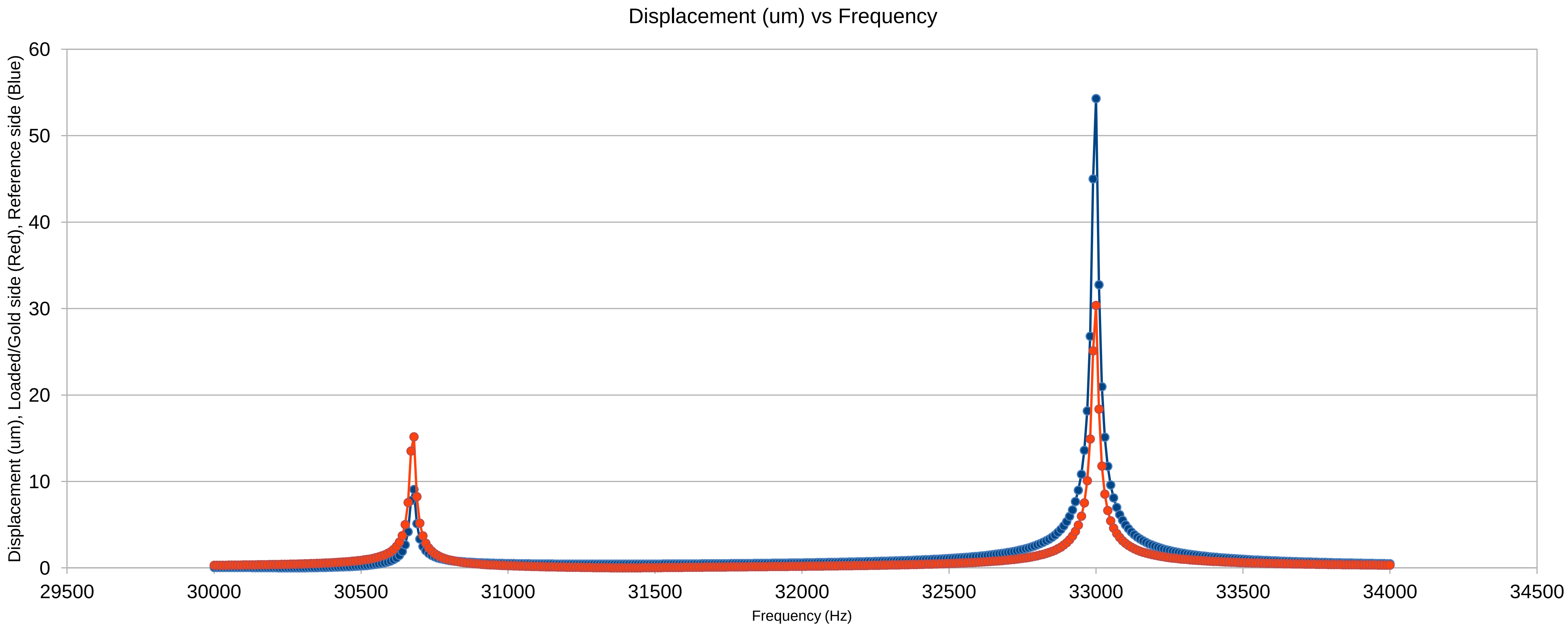


Magnitude and Phase of Single (Non Coupled) Resonator



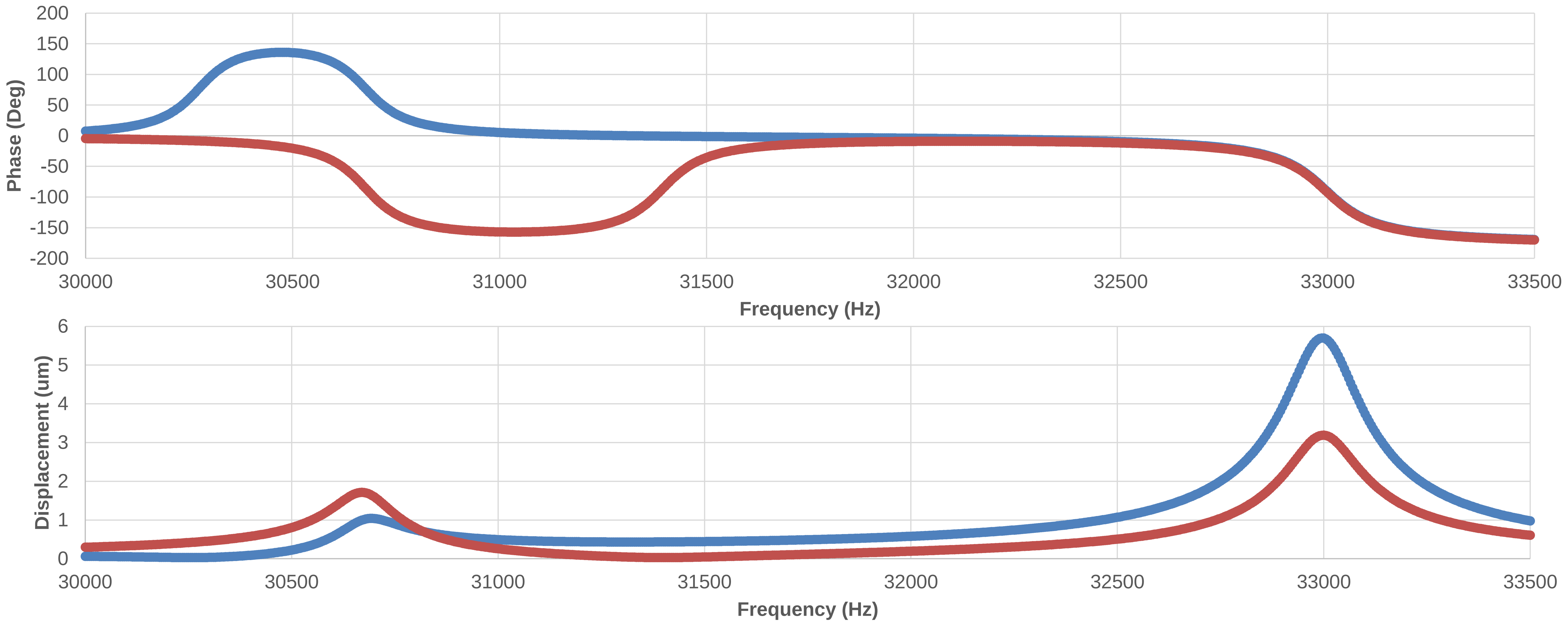


Simulated Coupled Resonator Frequency Response



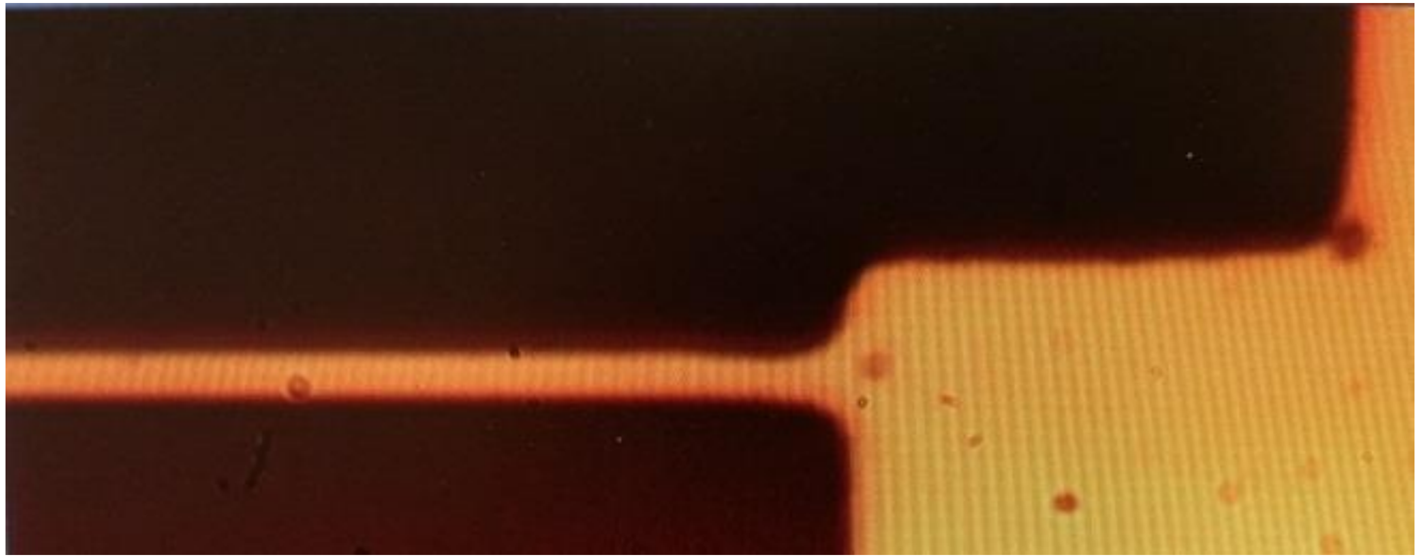
Reference Side is Blue and Loaded (Gold) side is Red

Coupled Resonators Frequency Response



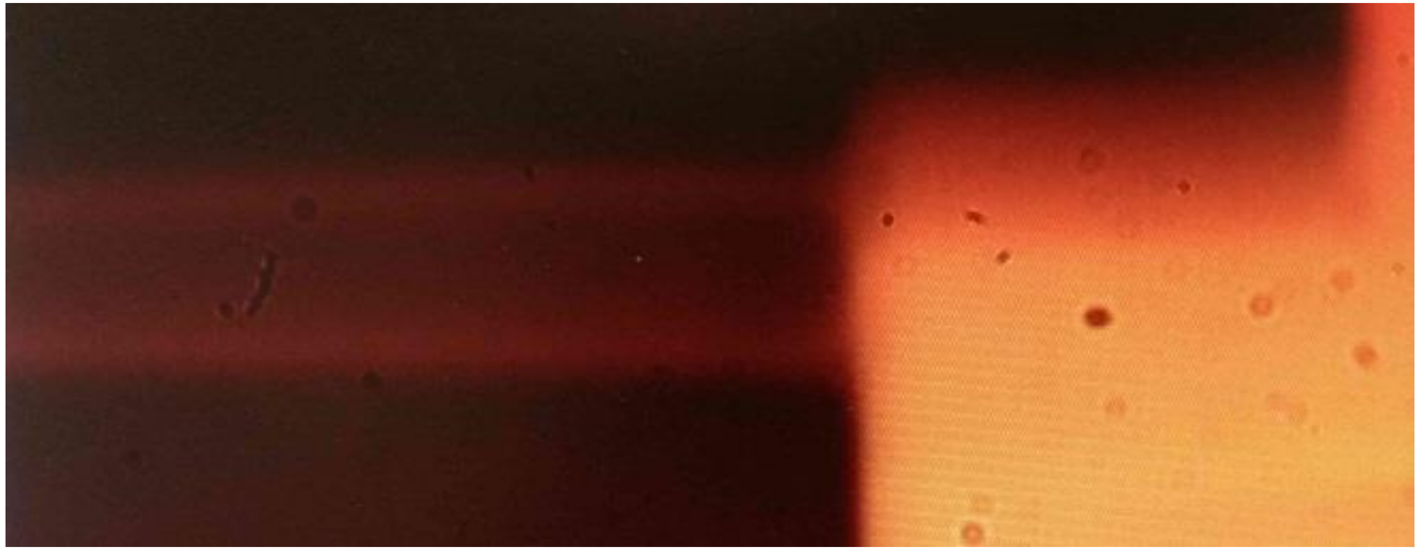
Reference Side is Blue and Loaded (Gold) side is Red

Resonance



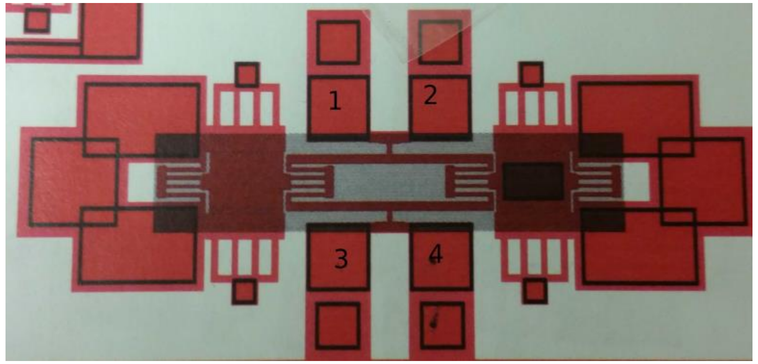
Reference Side not at Resonance

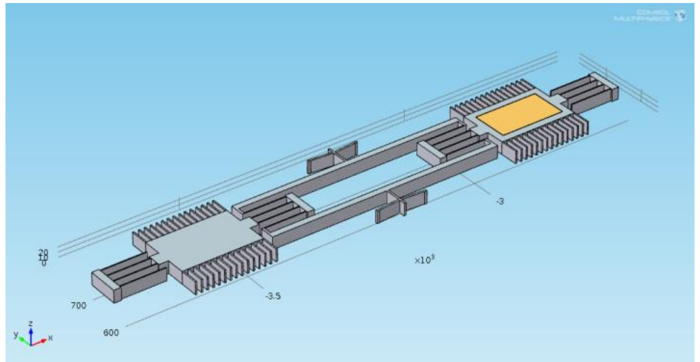
Reference Side at 31.964kHz (Resonance)



Real vs. Simulated

	Actual	Simulated
Loaded Side Resonant Frequency	29,650 Hz	30,680 Hz
Reference Side Resonant Frequency	31,964 Hz	33,000Hz
Displacement At Resonant Frequency (Loaded)	≈1 μm	15.16 μm
Displacement At Resonant Frequency (Reference)	≈4 μm	54.30 μm





Real vs. Simulated

	Resonant Frequency Difference (Simulated - Actual)	% Difference
Loaded Side (30,680-29,650)	1,030 Hz	3.41%
Reference Side (33,000-31,964)	1,036 Hz	3.19%
Difference between the peaks	6 Hz	0.58%

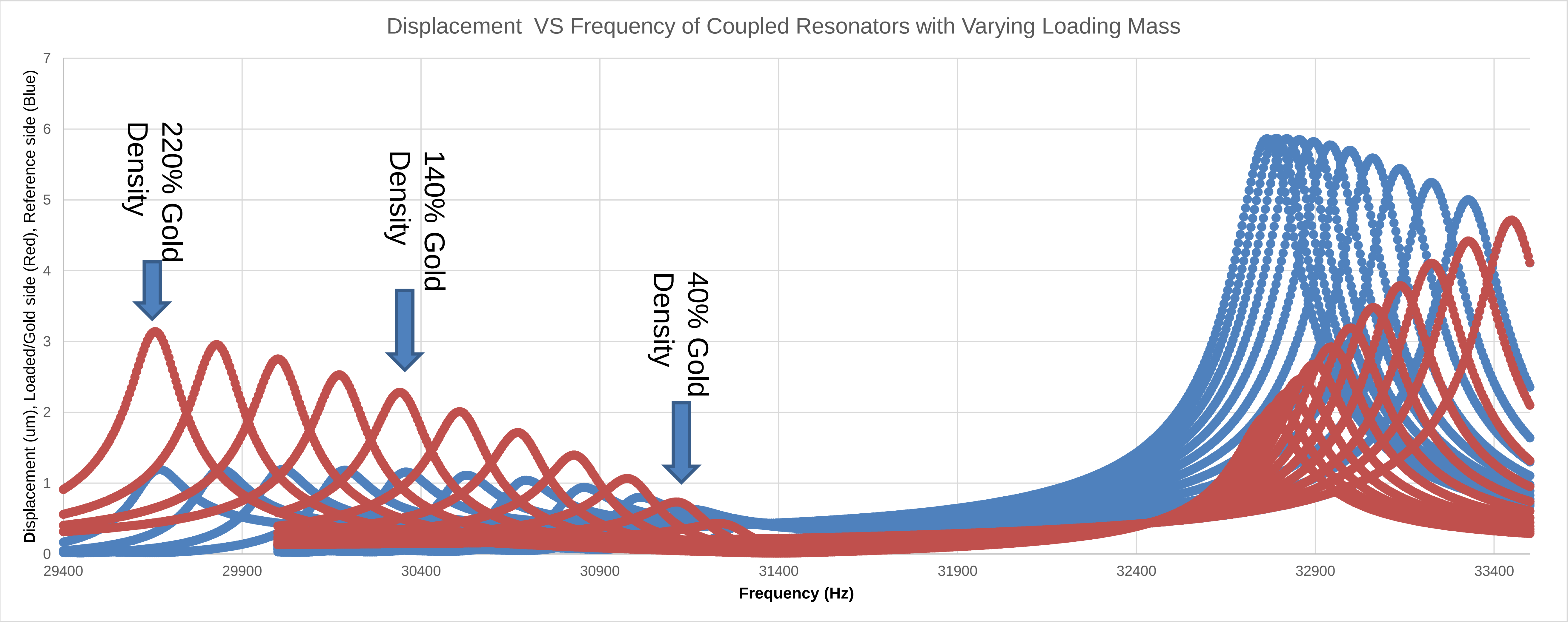
- Both resonant frequencies are shifted to the right by about 1kHz
- Frequency difference between two resonant frequencies is less than 1% and is likely lower due to observational error.
- Frequency shift could be caused by slight differences between this model and the original model, and manufacturing imperfections in the fabricated device

Varying Mass Simulation Setup

- Start with single model shown
- Define variable to sweep, increasing or decreasing density
- Multiply variable by default density
- Setup parameter sweep in frequency sweep study

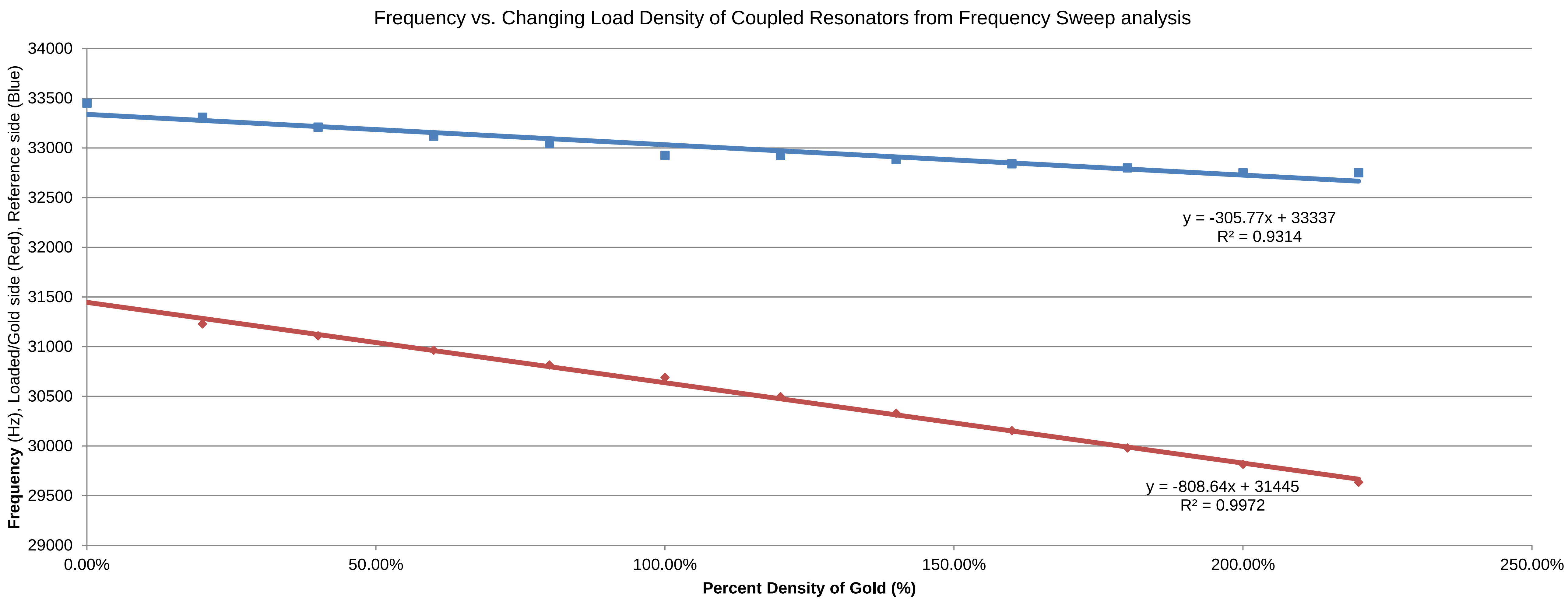
	Property	Name	Value	Unit	Property group
✓	Density	rho	PD*19300[kg/m^3]	kg/m³	Basic
✓	Young's modulus	E	70e9[Pa]	Pa	Young's modulus and Poisson's ratio
✓	Poisson's ratio	nu	0.44	1	Young's modulus and Poisson's ratio
	Electrical conductivity	sigma	45.6e6[S/m]	S/m	Basic
	Coefficient of thermal expar	alpha	14.2e-6[1/K]	1/K	Basic
	Heat capacity at constant p	Cp	129[J/(kg*K)]	J/(kg·K	Basic
	Thermal conductivity	k	317[W/(m*K)]	W/(m·k	Basic

Magnitude vs. Frequency for Coupled Resonator as Mass Increases

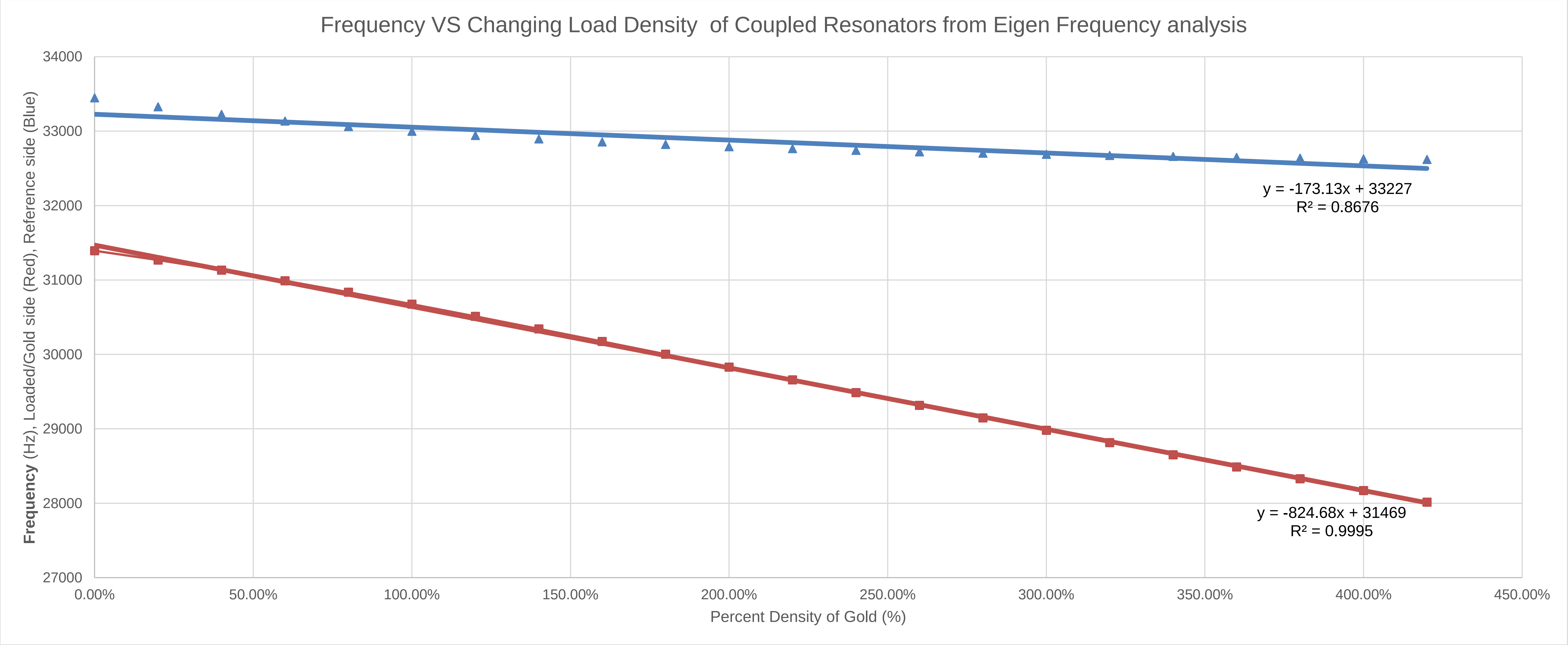


Reference Side is Blue and Loaded (Gold) side is Red

Coupled Resonators Resonant Frequency Plot



Coupled Resonators Resonant Frequency Plot from Eigen Frequencies



Conclusion

- Simulation produced by COMSOL Multiphysics® was shown to be an accurate representation of the characteristics of the real device.
- The simulation shows a mostly linear trend in the resonant frequency on the mass-loaded side of the coupled resonator as indicated by the R-squared value.
- Although mostly consistent in determining resonant frequencies, the eigenfrequencies for the coupled resonators showed a misleading result when the masses of the two similar, but not identical, resonators are equal.

Acknowledgements

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Thank You

Questions?