Study of Dissipative Losses in AC-Biased Mo/Au Bilayer Transition-Edge Sensors

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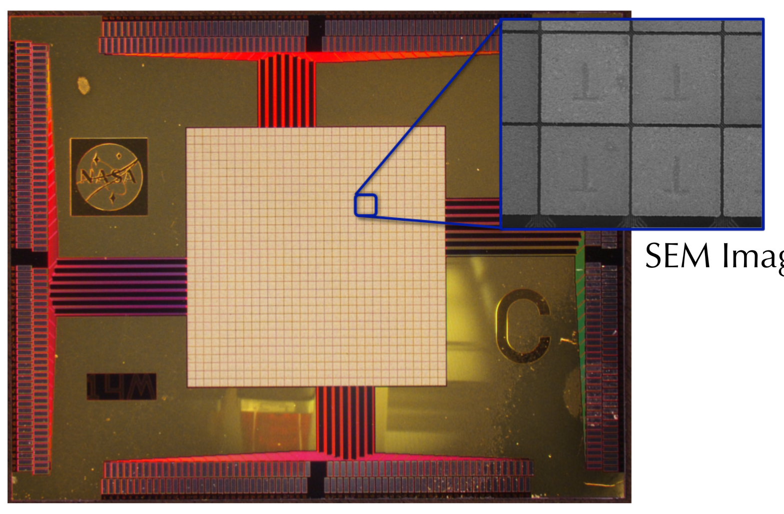
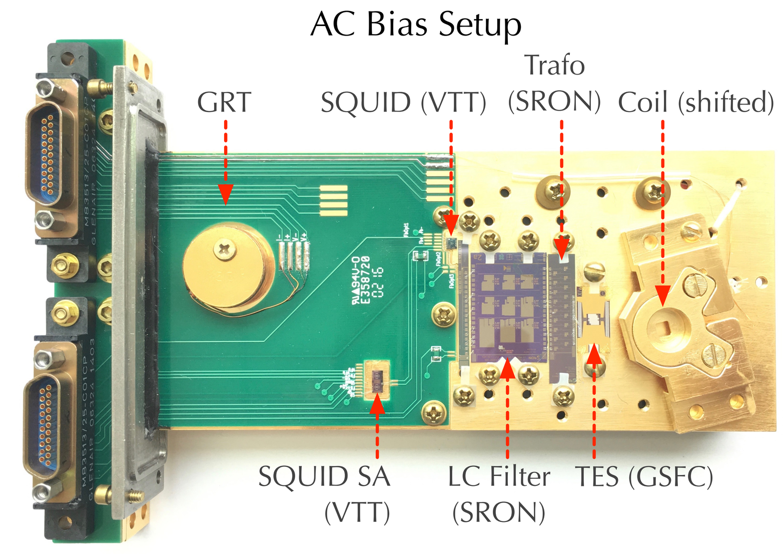
We are developing a kilo-pixel array of transition-edge sensor (TES) microcalorimeters for the X-Ray Integral Field Unit of the future European X-Ray Observatory Athena. Recent measurements of AC-biased Mo/Au bilayer TESs imply a dissipative loss at the TES. These measurements are made using a resonant circuit in the frequency range of 1-5 MHz. In this paper, we present the results of our measurements and discuss the cause of the AC losses. The AC bias currents used in these measurements are so low that under DC-bias, with the same nominal Joule power heating, the TESs would remain in the superconducting state. However under AC bias there is loss at MHz frequencies, which is frequency dependent and can be non-negligible even when biasing within the TES transition. The dissipation behaves as a series resistance within the TES, and therefore alters the transition shape, lowering the steepness of the transition, particularly low in the transition. This will affect the key properties that determine the microcalorimeter energy resolution. We measured AC losses and transition properties on various TES geometries. We looked at TESs with different sizes, TESs with different numbers of stripes, TESs with different sheet resistances, and TESs with different geometries for the contact area between the TES and the absorber. We also modeled the TES using a finite element method (FEM) and simulated the AC loss. The loss measurements on various TES devices and the FEM simulation results indicate a causal relationship between the loss and the normal metal area exposed to the self-induced magnetic field, implying that the loss is due to Eddy current heating.

1. Introduction

We are…
- ✓ developing a TES array for Athena
- ✓ optimizing the design to use under AC bias using SRON FDM warm electronics (Ravera+ 2014)



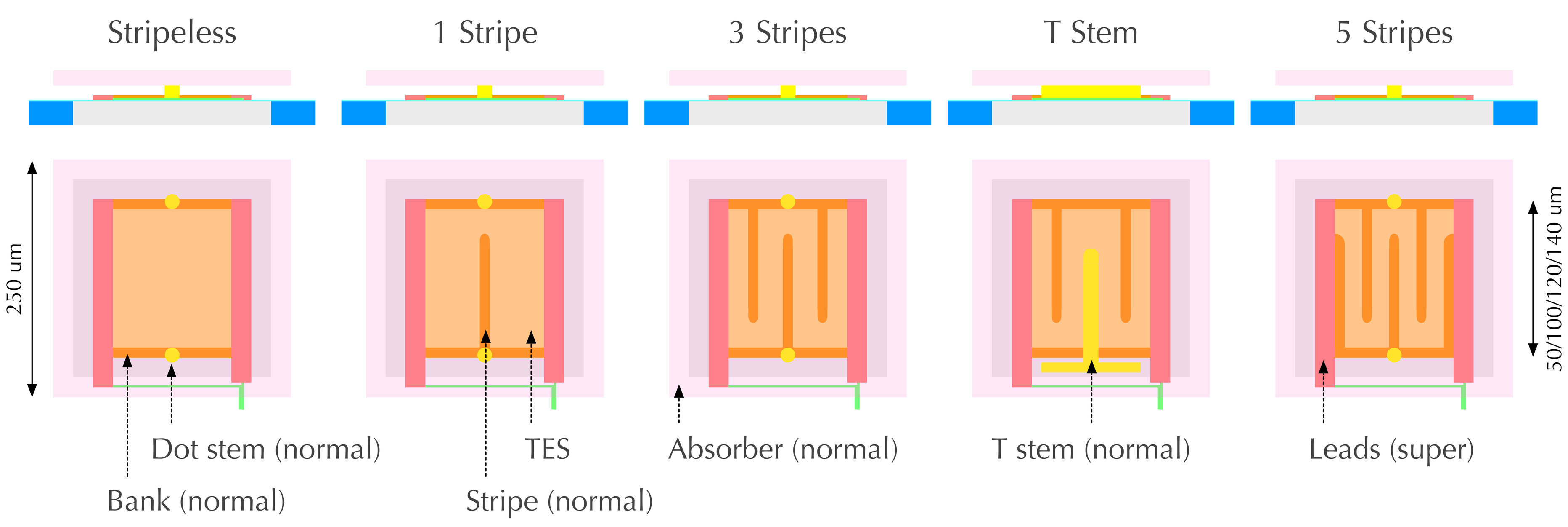
32×32 GSFC Mo/Au TES w/ Bi/Au Absorbers (Smith+ 2016)



Observations under AC bias:
- ✓ Dissipative losses are seen even with very low AC-bias currents
- ✓ Losses behave as series resistance
- ✓ It is comparable to resistance of low-impedance Mo/Au TES and affects transition properties

2. TES Types and Geometries

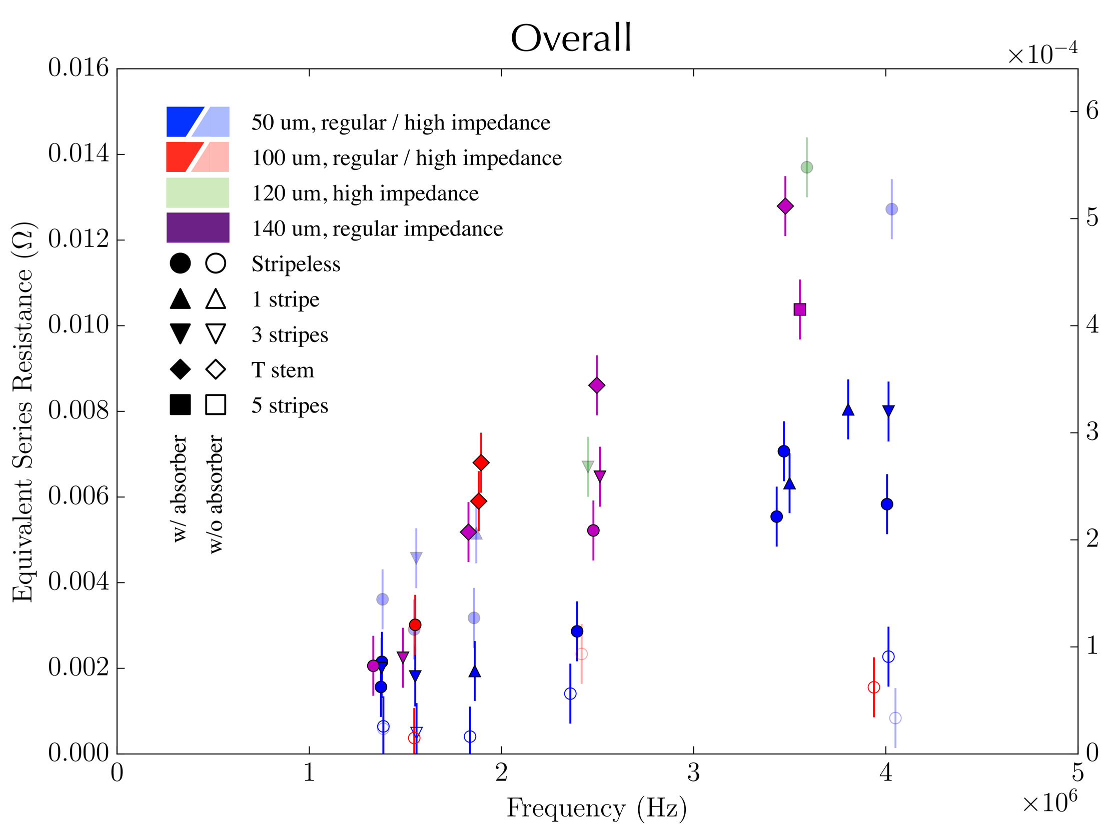
We measured dissipative losses for…
- ✓ 4 TES sizes: 50, 100, 120, and 140 um
- ✓ 2 wafers with different sheet resistances: regular and high TES impedance
- ✓ 5 different geometries: stripeless, 1 stripe, 3 stripe, T stem, and 5 stripes

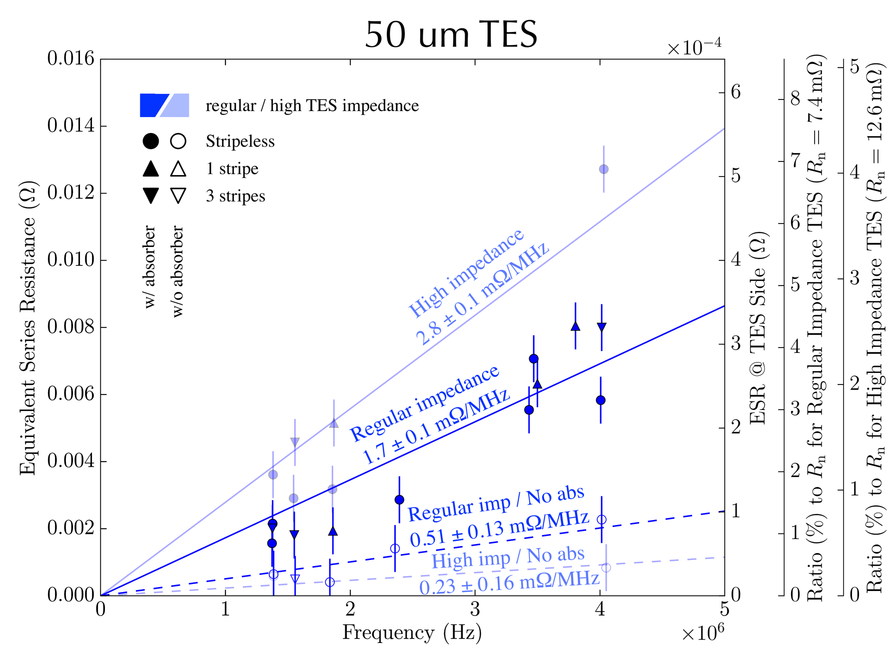


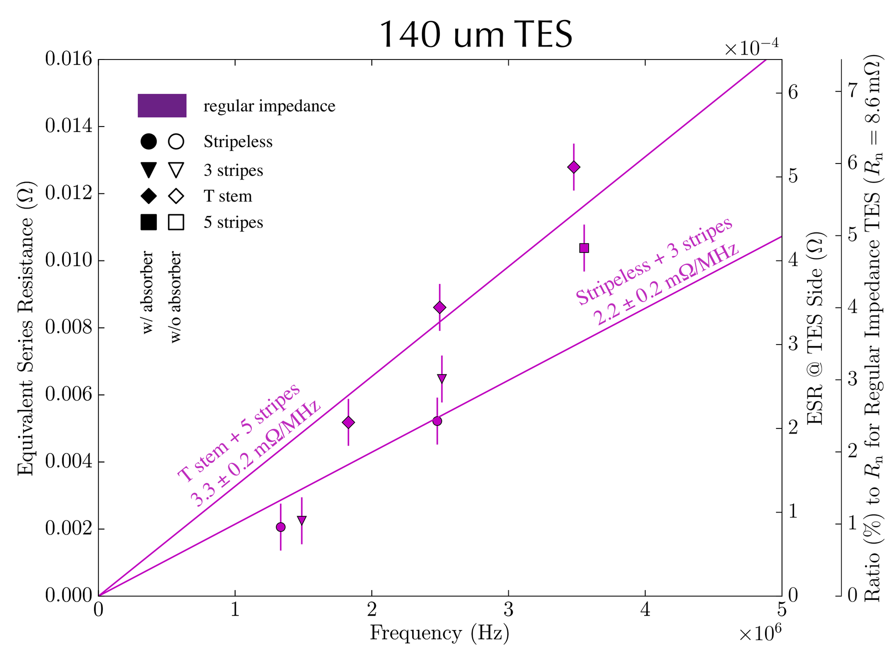
3. Measured Dissipative Losses

Resonance lines are fitted and dissipative losses are calculated as equivalent series resistances (ESR)
- ✓ Larger losses for higher frequencies
- ✓ Larger losses for TESs with larger volume of normal metals (e.g. larger TES size / more stripes)

Implies losses are due to **Eddy currents!**





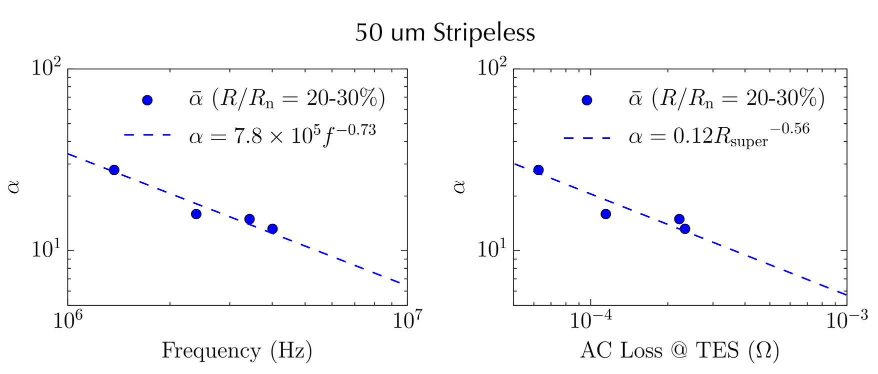


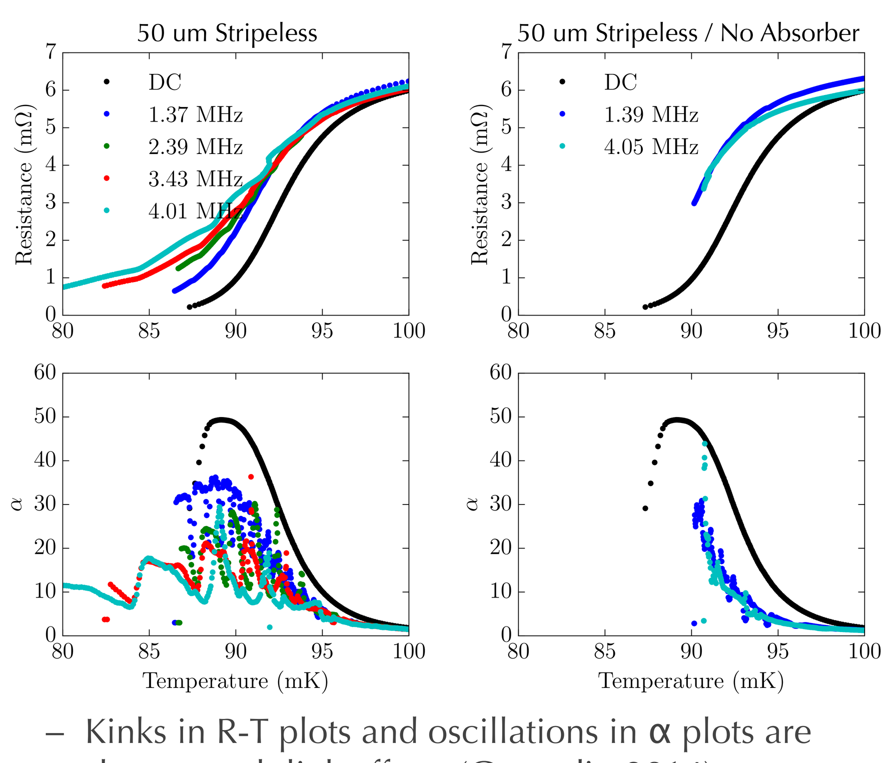
- Significantly larger losses for high impedance TESs with absorbers
- Losses for TESs w/o absorbers are very small and no significant difference between regular/high impedances
- Larger losses for TESs with T stem or 5 stripes than TESs with stripeless or 3 stripes

→ Higher losses for high impedance TESs are possibly due to lower resistance at absorber

4. Impact of Losses toward R-T and alpha

- ✓ Loss behaves as a series resistance and broadens transitions
- ✓ Loss also makes α frequency dependent
- ✓ No significant transition broadening for TESs without absorbers
- ✓ Goal: ESR@5MHz < 2% of R_n

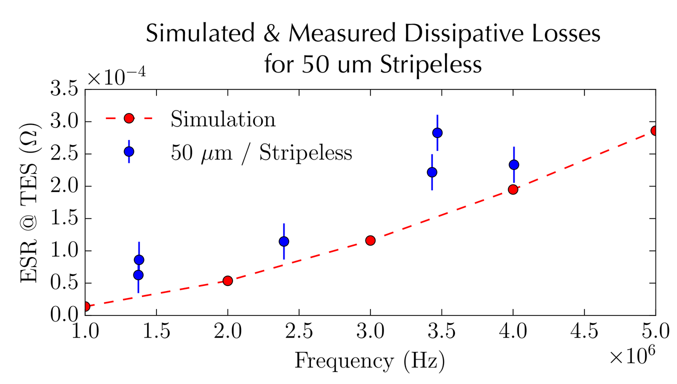


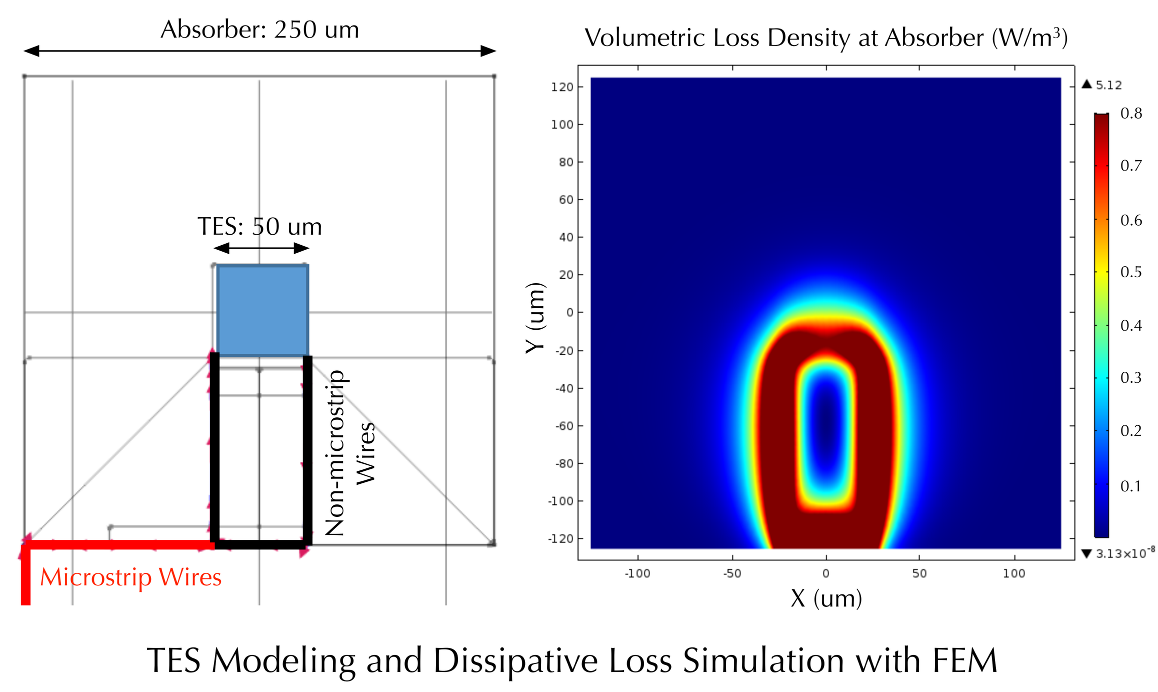


- Kinks in R-T plots and oscillations in α plots are due to weak-link effects (Gottardi+ 2014)

5. FEM Simulation on Dissipative Losses

We modeled our TES with FEM (COMSOL) and simulated dissipative losses
- ✓ Frequency dependance was reproduced
- ✓ Losses are mainly attributed to EM fields induced from wires

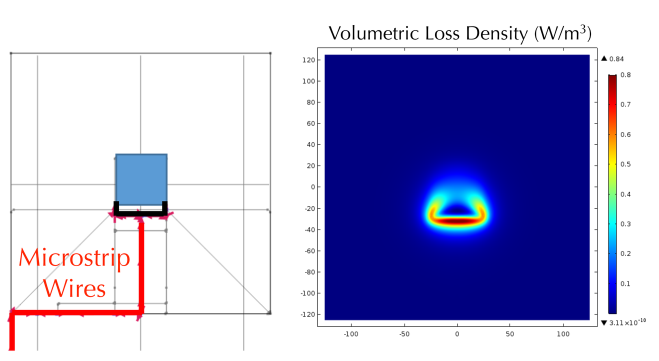




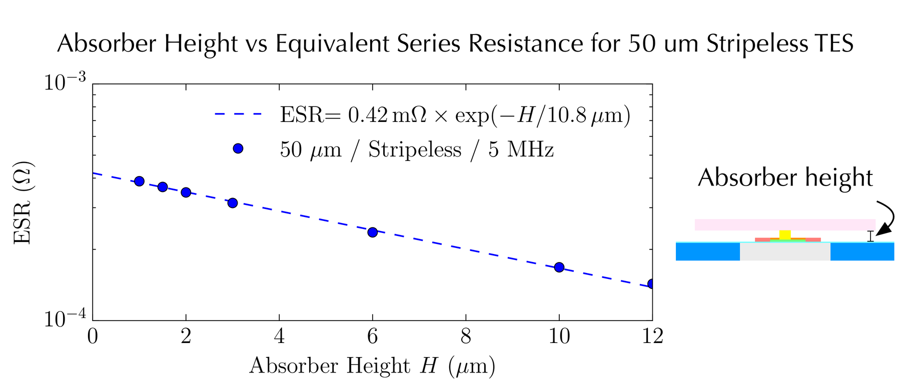
TES Modeling and Dissipative Loss Simulation with FEM

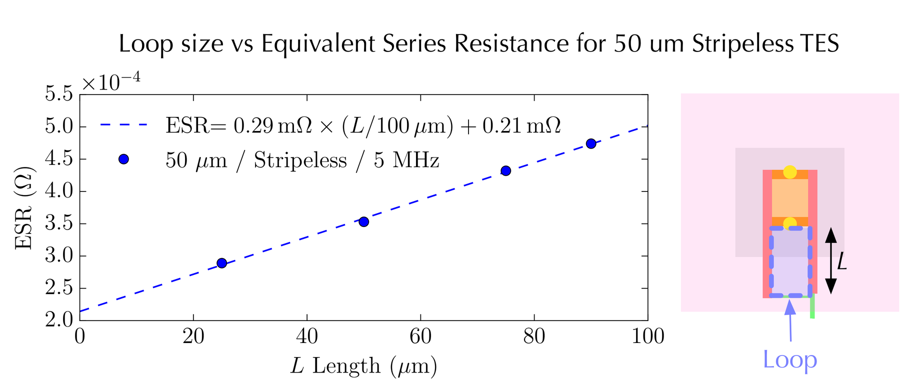
6. Mitigation to Dissipative Losses

Simulation shows…
- ✓ taller absorber heights make losses smaller
- ✓ smaller "loop" sizes make losses smaller
- ✓ keeping wires as microstrips closer to TES as much as possible minimizes losses



Wire geometry to minimize losses





7. Summary & Conclusion

- ✓ Dissipative losses were measured for different TES sizes, different TES impedances, and different TES geometries
- ✓ TESs with larger volume of normal metals show larger dissipative losses implying dissipative losses are due to Eddy currents
- ✓ Dissipative losses broaden TES transitions and degrade α and energy resolution
- ✓ To minimize losses - microstrip as close to the TES as possible and increase absorber height

References

Smith et al. 2016, Proc. SPIE, 9905, 99052H
Ravera et al. 2014, SPIE Proc., 9144, 91445T
Gottardi et al. 2014, JLTP, 176, 279