Controlling a mechanical oscillator with a tunable coherent feedback network

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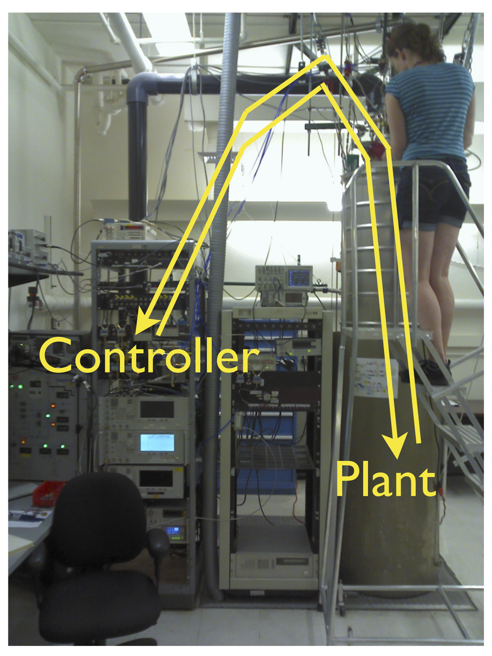
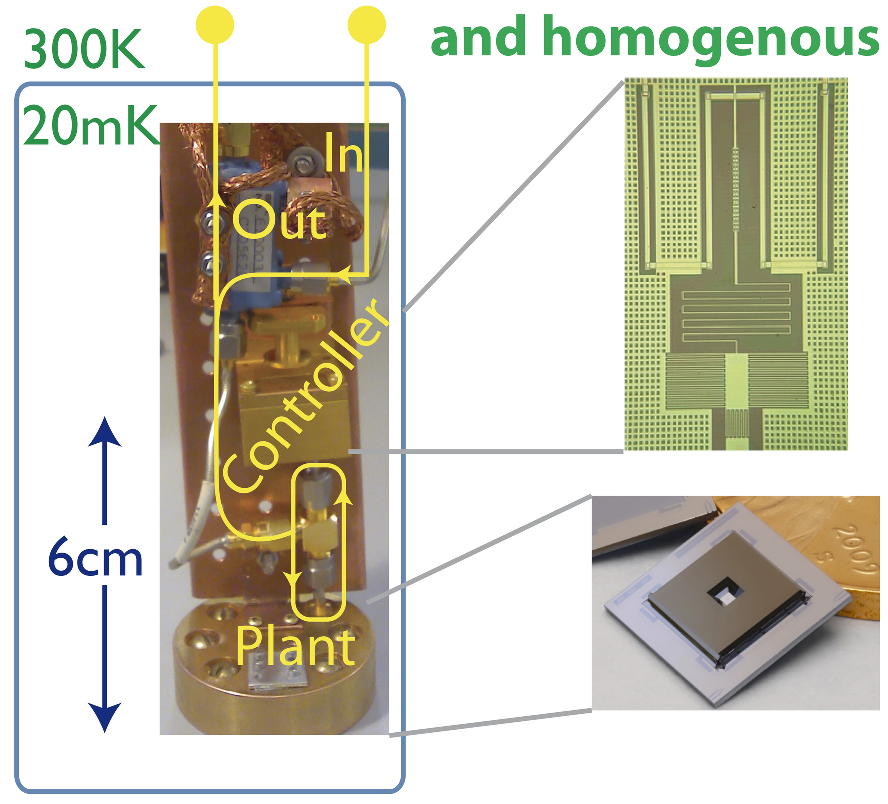
We demonstrate a **fully cryogenic microwave feedback network** composed of modular superconducting devices interconnected by waveguides and **designed to control a mechanical oscillator** coupled to one of the devices. The network is partitioned into an electromechanical device and a dynamically tunable controller that coherently receives, processes and feeds back continuous microwave signals that **modify the dynamics and readout of the mechanical state**. While previous electromechanical systems represent some compromise between efficient control and efficient readout of the mechanical state, as set by the electromagnetic decay rate, this flexible controller yields a closed-loop network that can be dynamically and continuously tuned between both extremes much faster than the mechanical response time. We demonstrate that **the microwave decay rate may be modulated by at least a factor of 10 at a rate greater than 10^4 times the mechanical response rate.** See arXiv: 1211.1950

Coherent feedback networks (i.e. feedback without measurement) yield novel dynamics between modular, coherent devices with little hardware overhead.

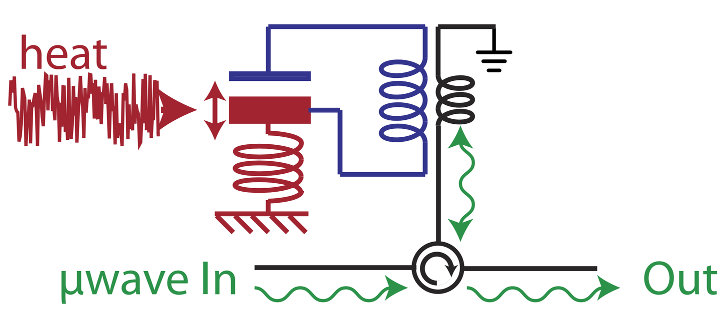
measurement-based feedback is cumbersome and slow



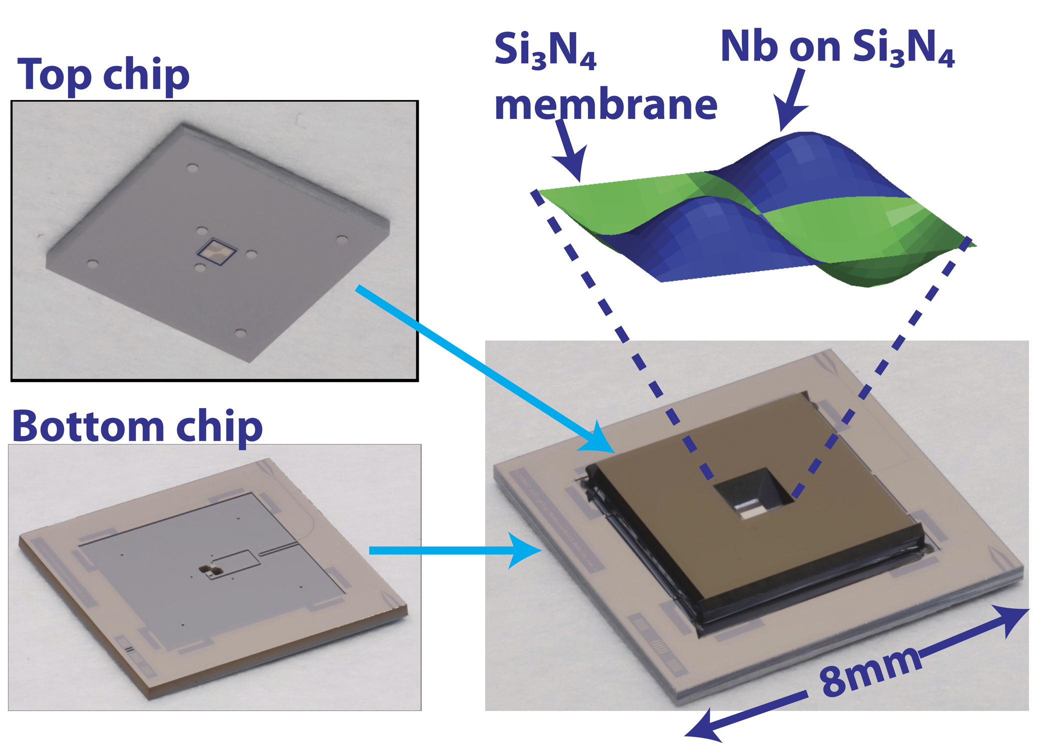
coherent feedback is compact and homogenous



The plant (i.e. the device to be controlled) is a superconducting microwave **electromechanical circuit.** This device encodes the motion of a micromechanical mass onto microwave probes.

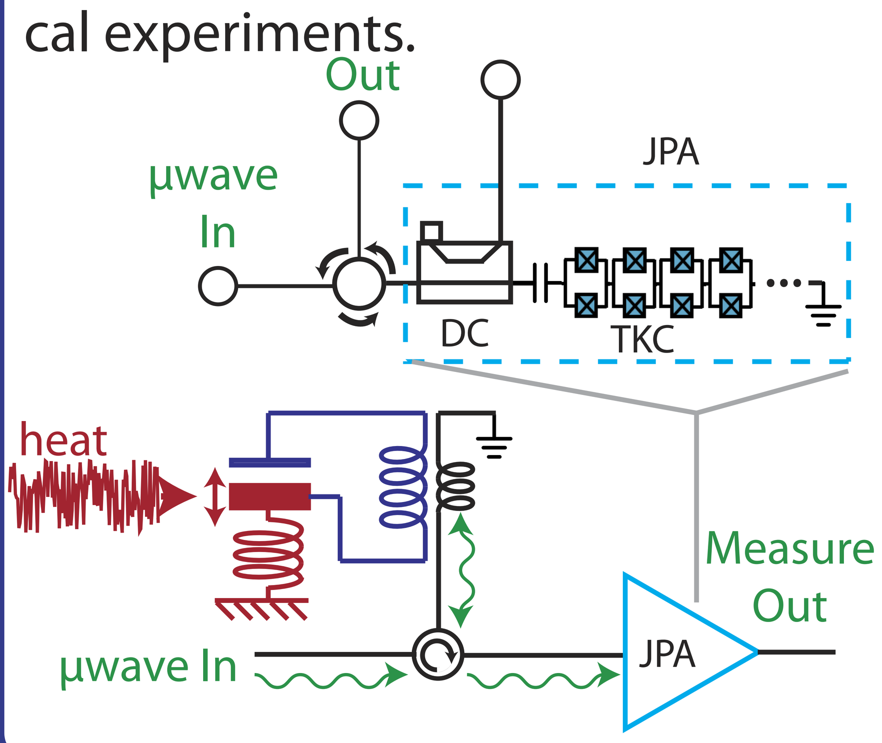


The mass is a drumhead mode of a metalized, Si_3N_4 membrane ($Q \sim 10^6$).

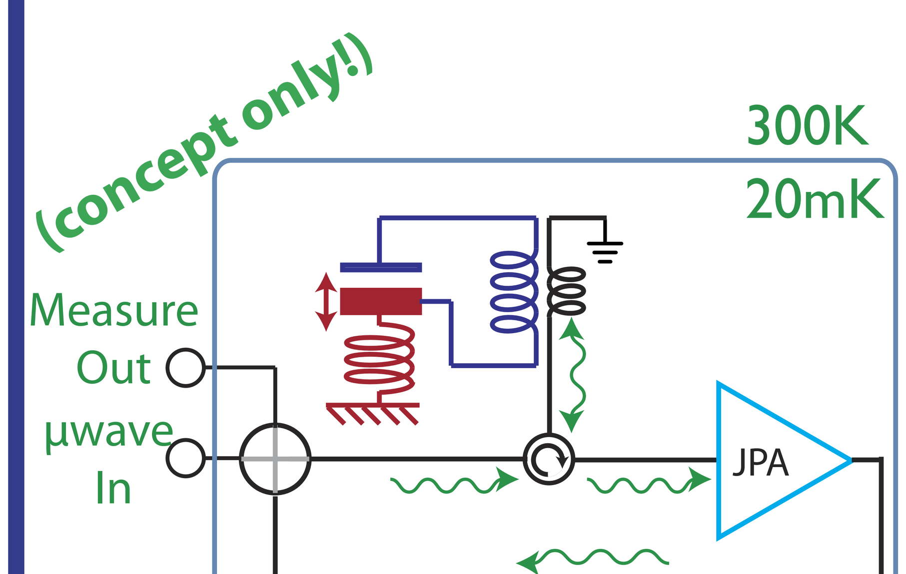


While this device works very well for many applications, **many important characteristics (e.g. microwave center frequency and linewidth) are completely fixed at the time of construction.**

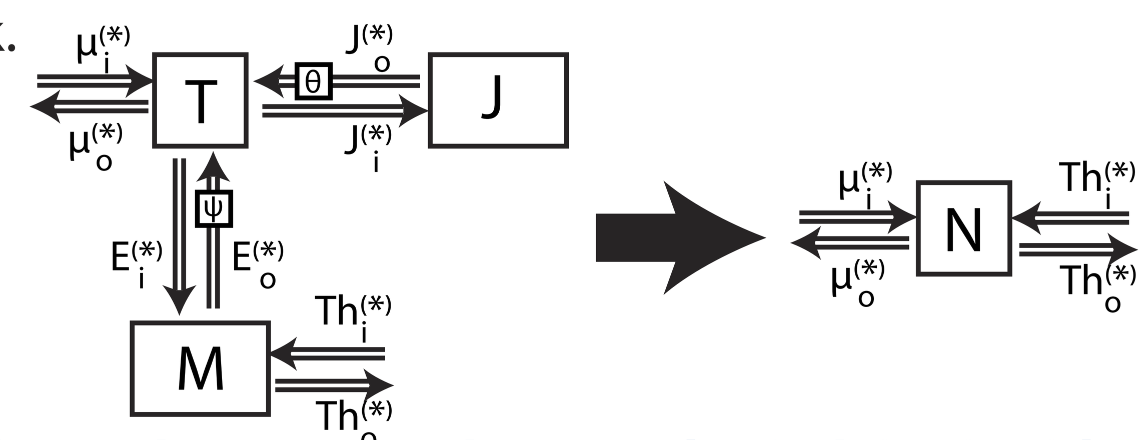
The controller is a near quantum-limited, Josephson parametric microwave amplifier (**JPA**). This **flux-tunable device** has already enabled many "open-loop" electromechanical experiments.



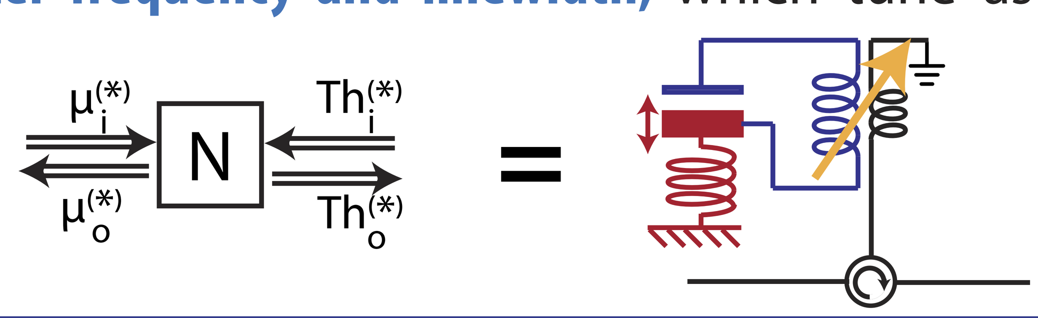
Conceptually, **this work closes the loop inside the cryostat** using low-loss SMA cables.



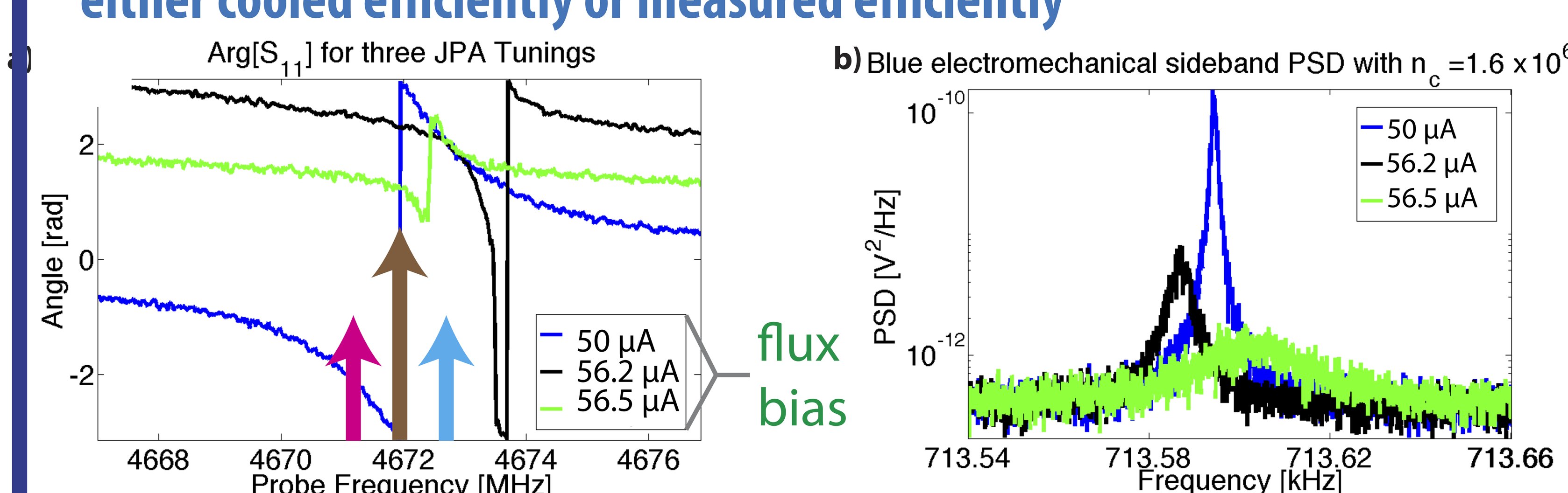
Modeling uses a network systems approach. Each device admits a linear, input-output, state space representation. After defining the device models and interconnections, **off-the-shelf software automates the derivation** of an effective state space representation of the entire network.



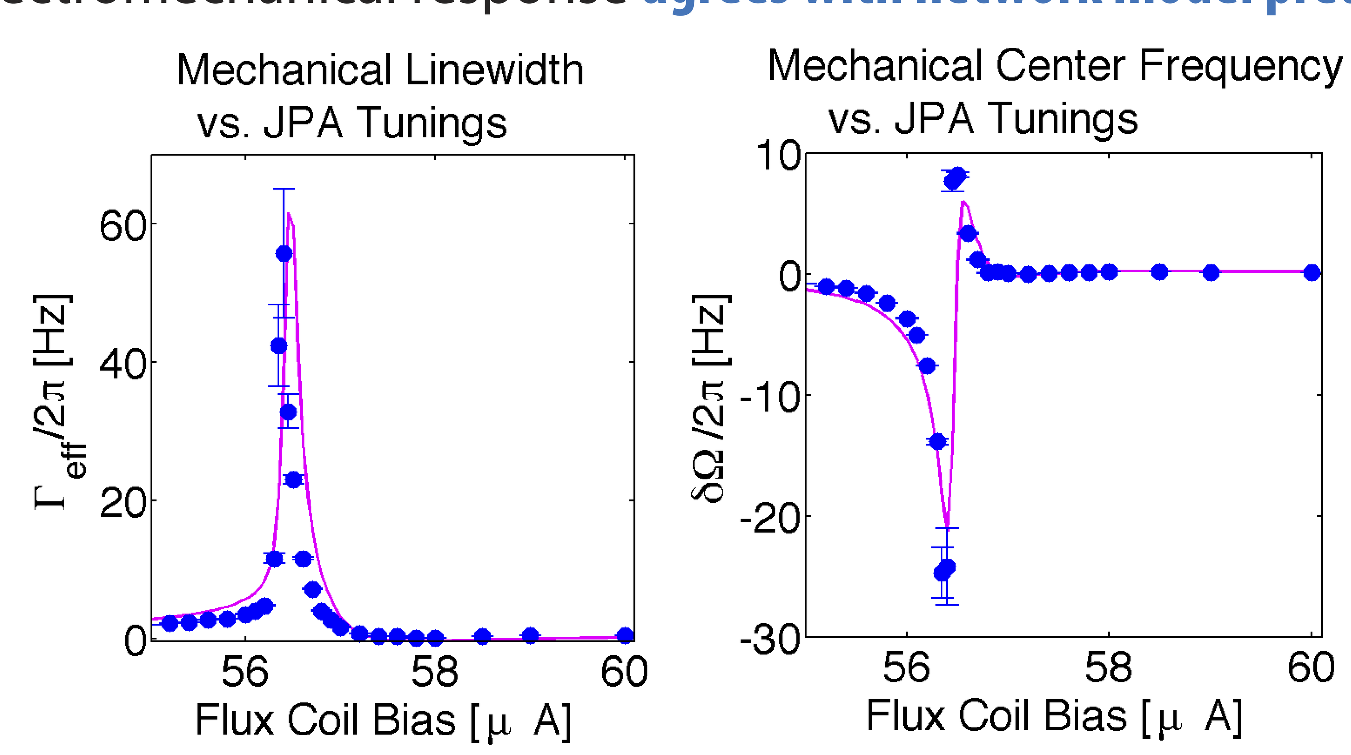
The entire network is analogous to an electromechanical circuit with a tunable center frequency and linewidth, which tune as the JPA tunes.



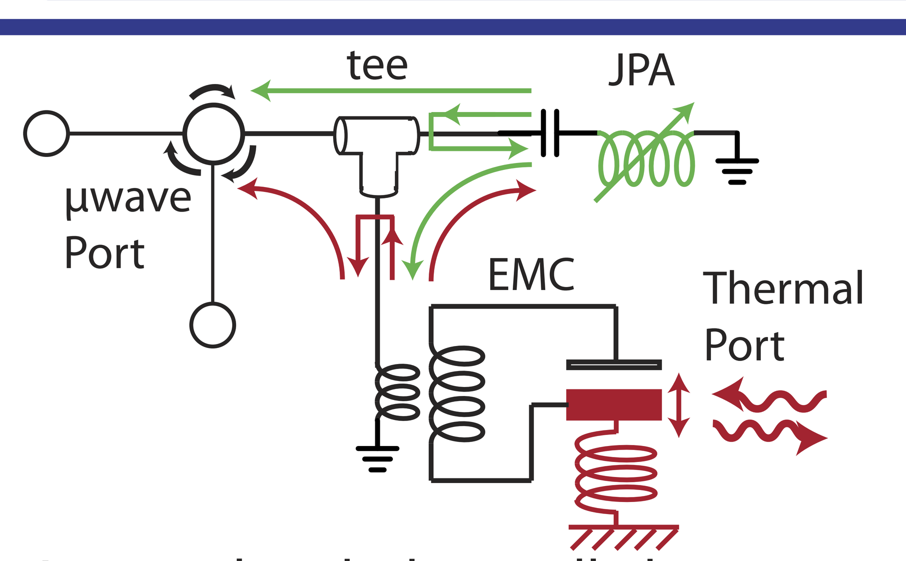
As the network is probed and tuned, **the mechanical oscillator is either cooled efficiently or measured efficiently**



Electromechanical response **agrees with network model predictions**

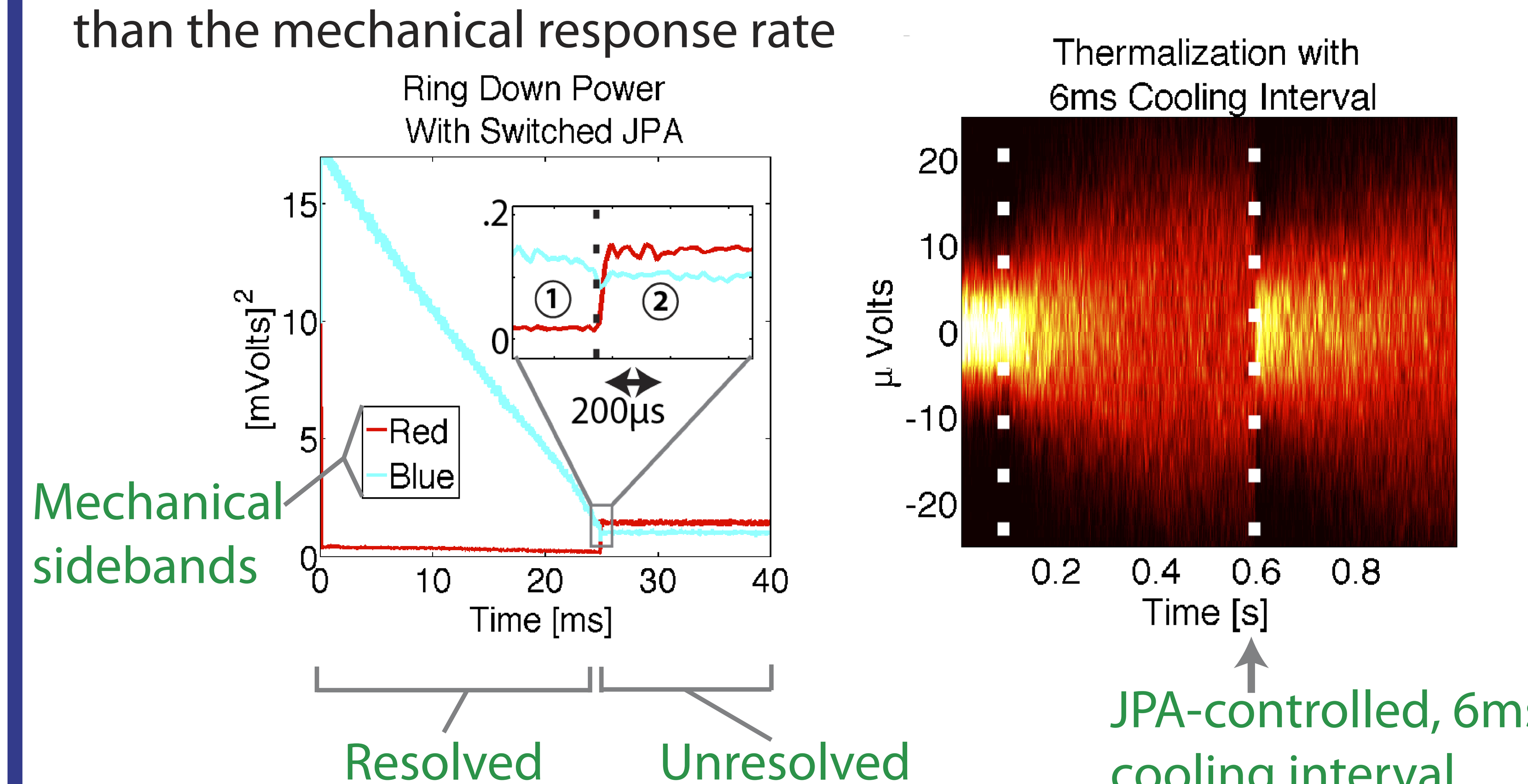


The actual network connects the plant and controller with an SMA tee. **The two devices exchange continuous coherent signals** and modify each other's microwave decay rate through interference. But because the JPA is dynamically tunable, **these interactions are tunable.**



As we already have all the parts, this is **easier to build than to model!**

The network may be **dynamically switched between resolved and unresolved mechanical sideband regimes** at least 10^4 times faster than the mechanical response rate



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