Integrated Magnonic Transducer for Advanced Magnetic Sensors

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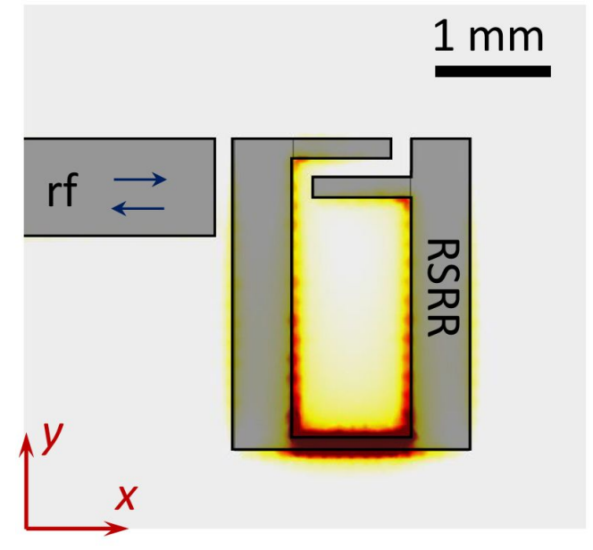
Abstract

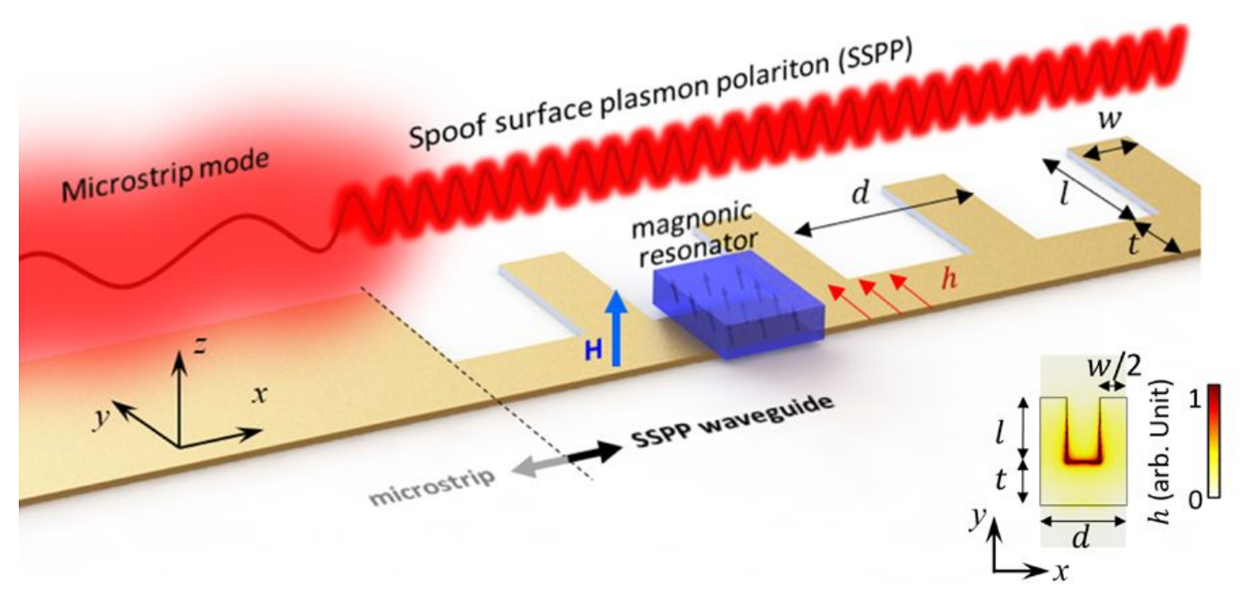
Magnons are quasiparticles that represent collective spin excitations in magnetic materials. Cavity magnonics, in particular, is an important hybrid magnonic platform for coherent interactions between magnons, photons, and phonons within resonant structures, which enables fast information exchange across physical systems. These interactions have the potential to allow for energy-efficient signal processing, quantum transduction, and hybrid computing technologies. Our research focuses on developing hybrid magnonic devices that leverage light-matter interactions in the slow-wave regime, where electromagnetic (EM) waves are significantly slowed down compared to conventional EM waves to enhance interaction strength.

In this work, we introduce a novel waveguide structure consisting of an array of coupled rectangular split-ring resonators (RSRR), allowing for compact designs and improved field confinement while maintaining slow-wave capabilities. By leveraging the unique properties of slow-wave hybrid systems, our new structure promises great potential for both fundamental research and practical applications. Additionally, the concept of this device can be extended to other systems, such as optomagnonics (involving optical photons rather than microwave photons) and magnomechanics (involving mechanical vibrations), paving the way for coherent information science.

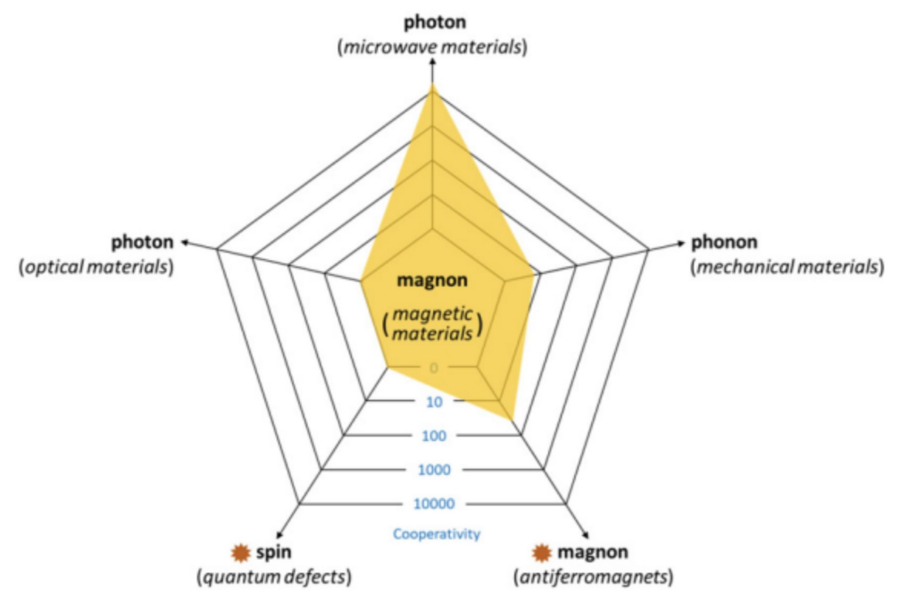
Background



RSRR



SSPP



Hybridization

We aim to develop high-efficiency spin-wave transducers that can convert signals between magnonic and photonic domains with minimal loss. However, detecting lower frequencies requires larger structures, posing a challenge for device minimization.

We currently have a device with a resonance frequency of around 2 GHz, a relatively low GHz frequency. However, the spoof surface plasmon polariton (SSPP) waveguide used to detect it is too large (16 mm) and must be reduced to be integrated into future compact devices. Our work focuses on creating a device consisting of rectangular split-ring resonators (RSRR) in series to resonate at low GHz frequencies similar to the SSPP waveguide. The resonance frequencies of the RSRR structure are determined by its gaps and loops, as opposed to the length of the grooves used in SSPP waveguides, allowing us to study lower frequencies without depending on vertical dimension.

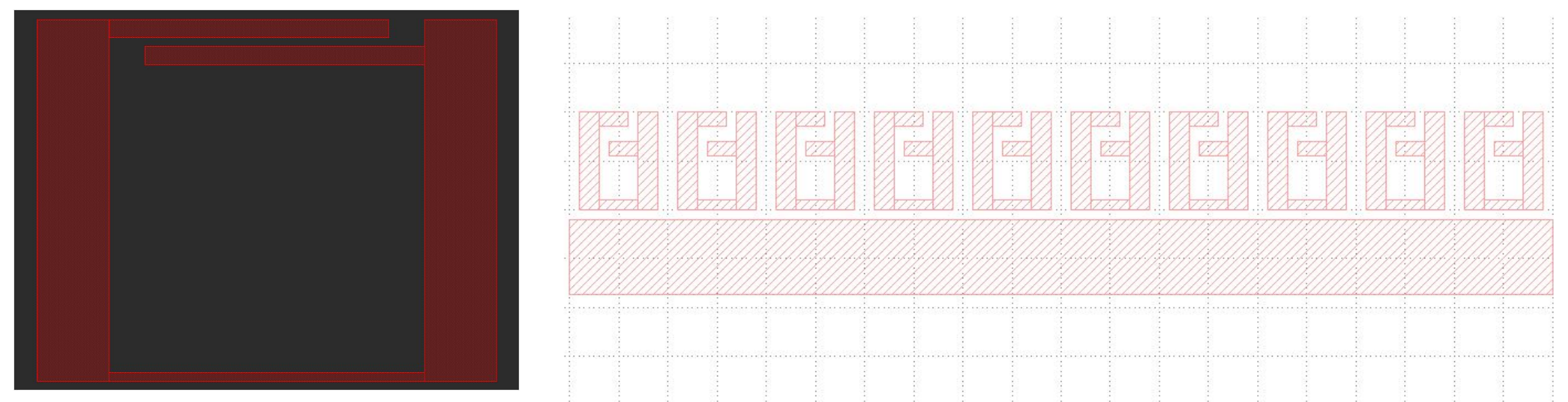
By creating an array of resonators in series, we aim to drastically reduce to overall device size while preserving the high interaction efficiency that SSPP waveguides offer. This approach is a step towards miniaturized hybrid magnonic systems, where magnons and EM waves can coherently exchange information within compact devices.

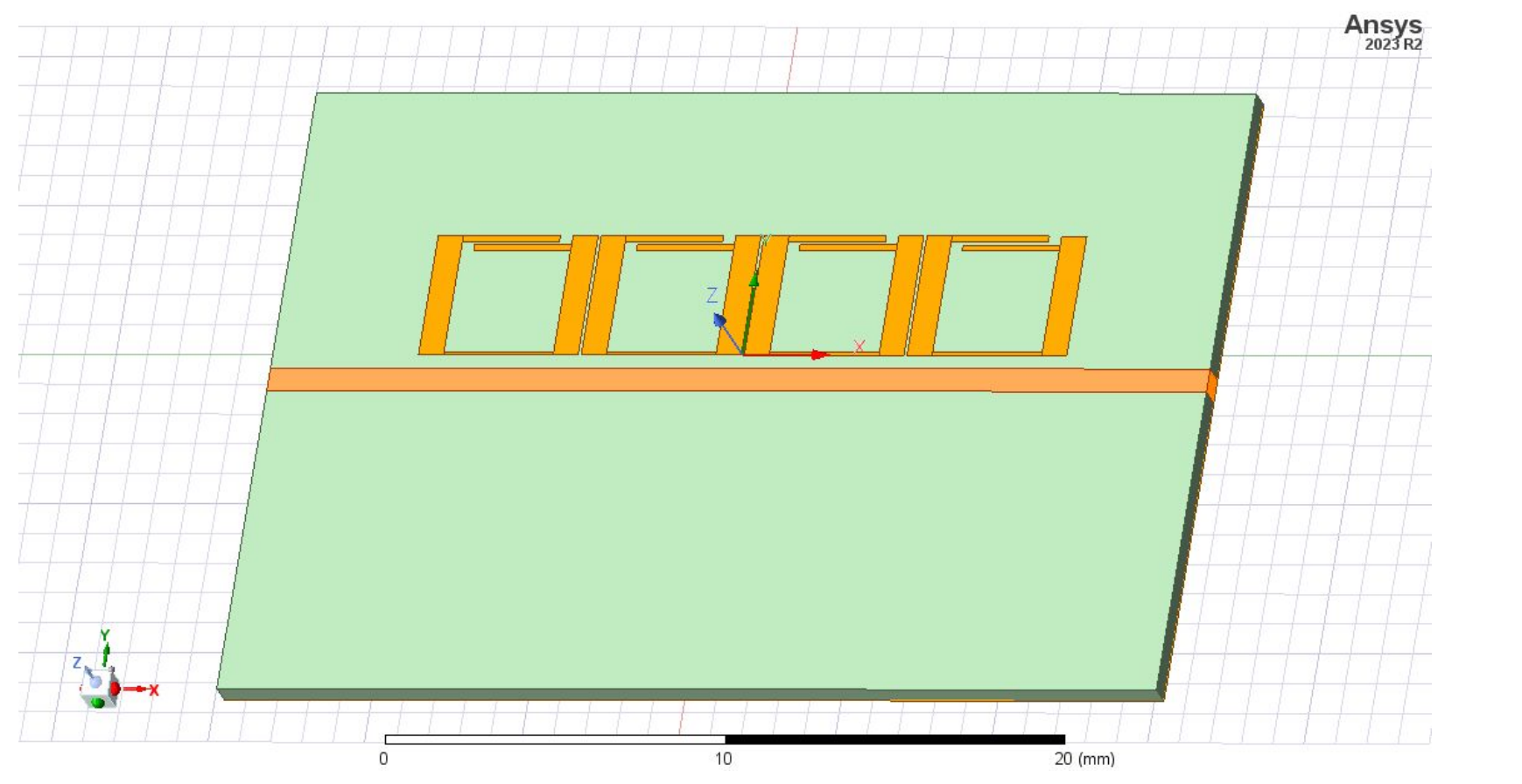
Experimental Methods

Goal: *Create a RSRR array no bigger than 5mm with a cut-off frequency around 2 GHz and localized E and H fields.*

Step 1:

- We designed the pattern of a basic RSRR using Python, assigning specific parameters obtained from simulations which will be used in the fabrication process.
- We expanded on this by coding a array of rectangular split-ring resonators along a microstrip.



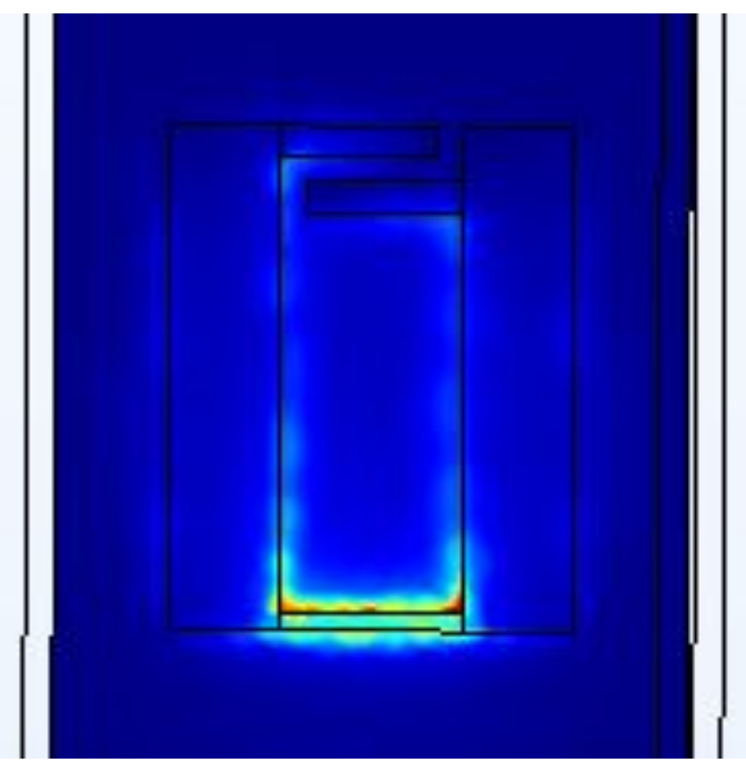


Step 2:

- Using Ansys HFSS, we built a magnonic device, assigning specific materials, parameters, and properties.
- We simulated the microwave response, testing 501 frequencies ranging from 1 GHz to 10 GHz to find the transmission of the structure.
  - We ran this multiple times, modifying our parameters to achieve the target resonance frequencies.
- Analyzed the transmission spectrum and the H-field and E-field distributions.

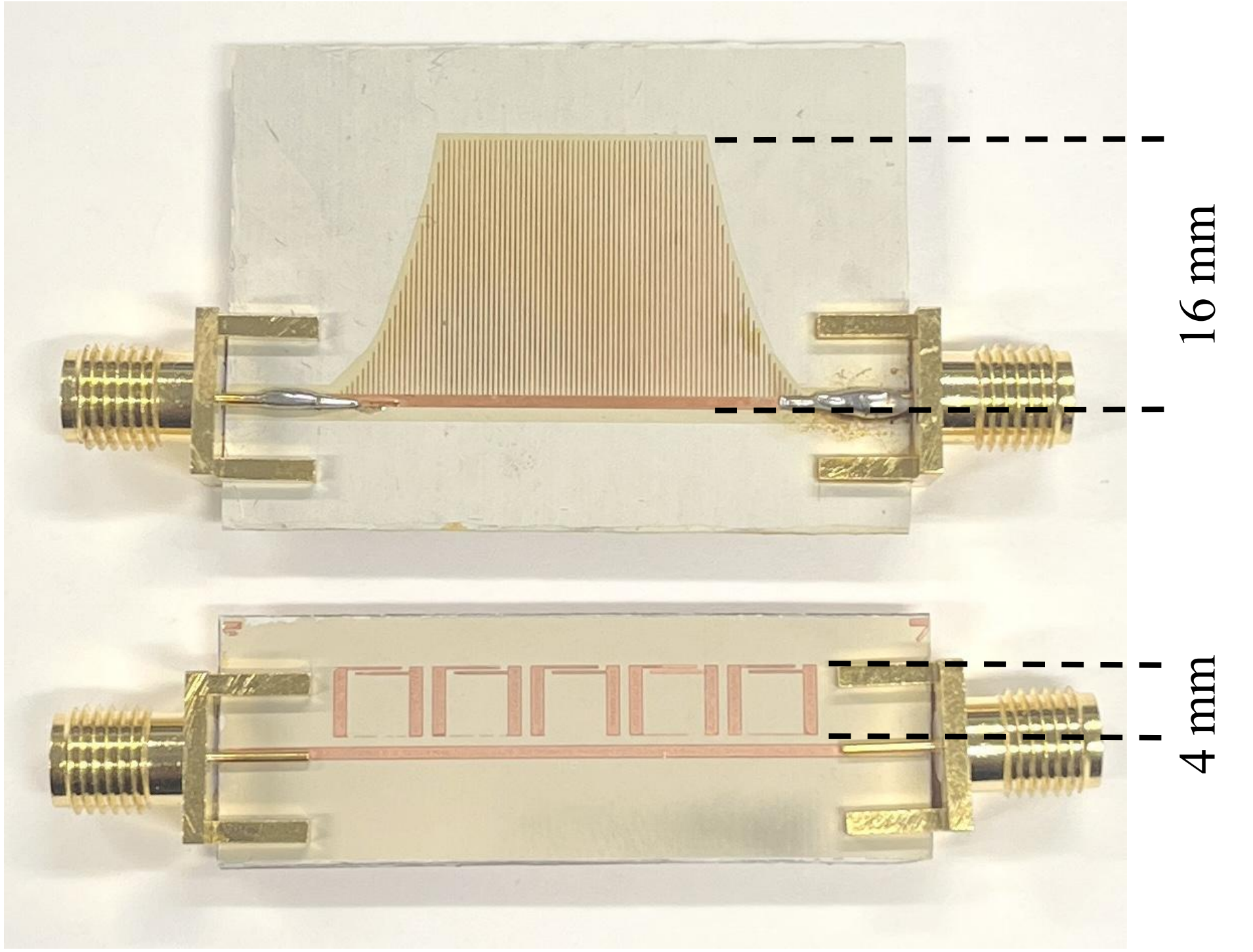
Step 3:

- Built a single unit cell to reduce simulation run time on COMSOL Multiphysics.
- Swept various parameters to evaluate how changing the size of the resonator affects its eigenfrequencies.
  - Worked on increasing the size of the resonator to achieve lower GHz frequencies.
- Plotted a dispersion curve, showing an asymptotic frequency.
  - Anticrossing: when magnons and photons at similar resonance frequencies hybridize and deviate from each other.

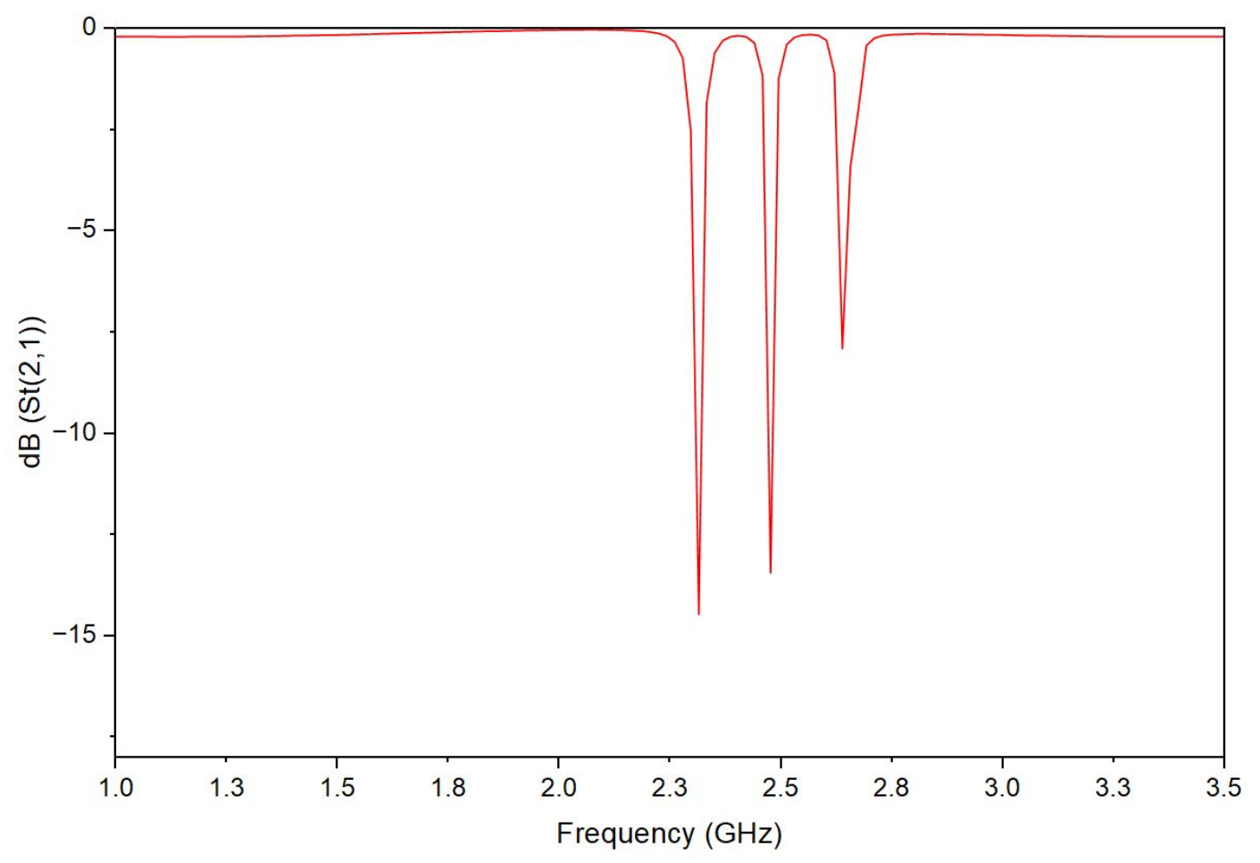


Results

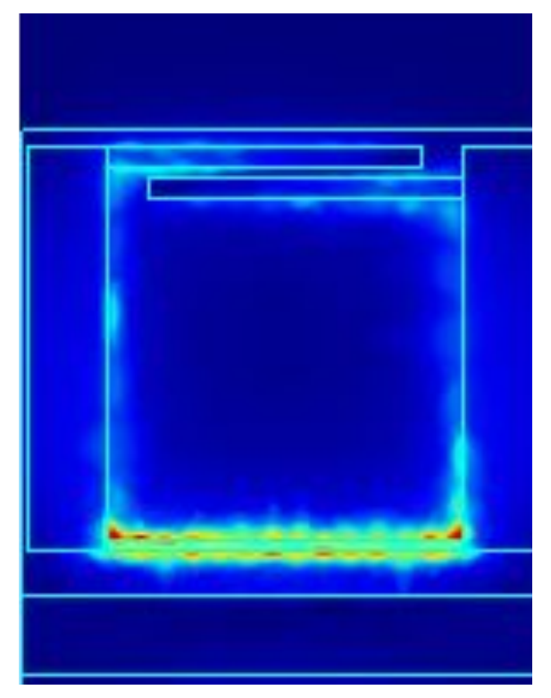
- The dispersion curve of the 4mm x 4mm RSRR device shows anticrossing around 2.67 GHz.
- Stronger deviation from the asymptote of the dispersion curve indicates stronger formation of the SSPP, which is the lower branch.
- H-field and E-field were both localized and concentrated in their respective regions.
- The simulated spectrum indicates a transmission cutoff at around 2 GHz frequencies as well.



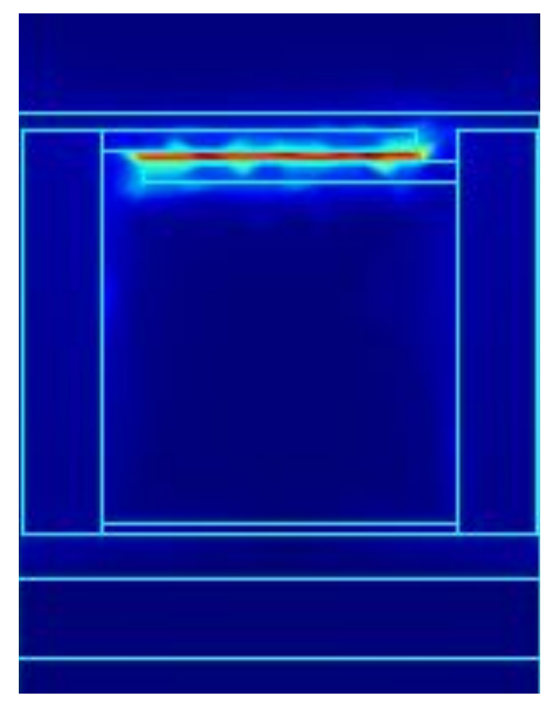
SSPP waveguide compared to 5 RSRRs in series
Both resonate around 2 GHz.



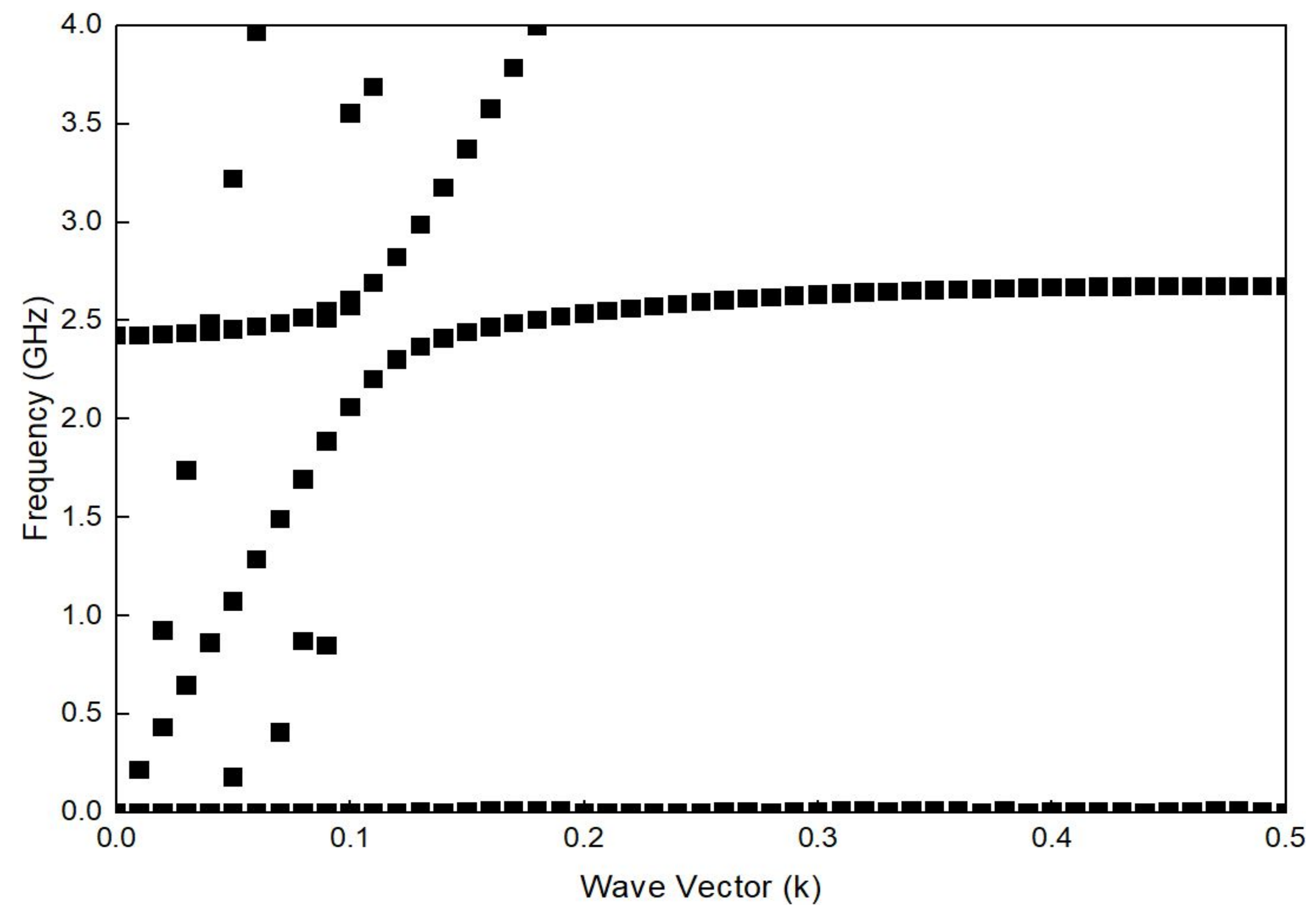
Simulated Transmission Spectrum (S21)



H-field



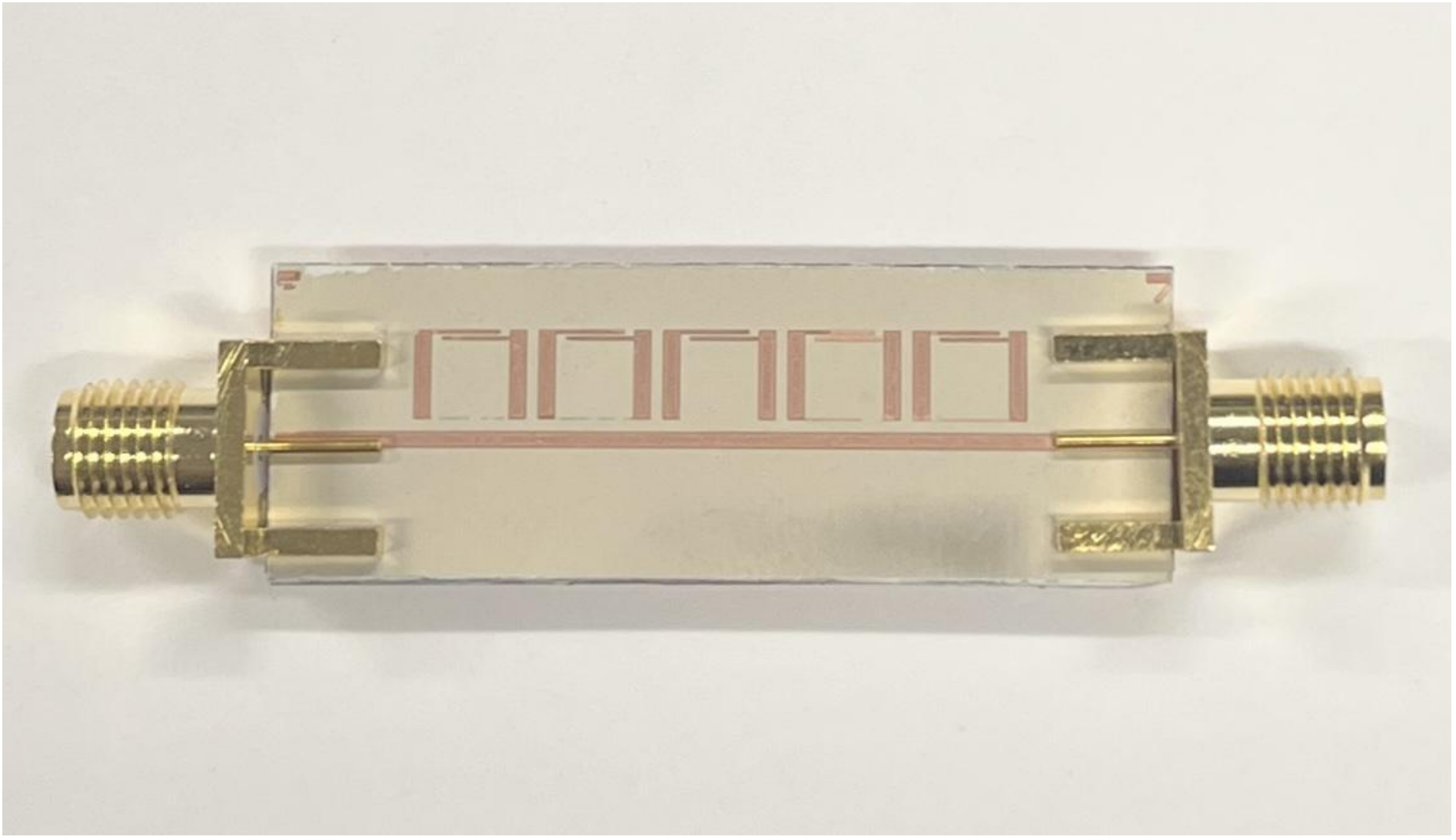
E-field



Dispersion Curve

Conclusion and Future Steps

Our results indicate that our RSRR series device successfully achieves our goal of having magnon-photon hybridization in low GHz frequencies while also maintaining a small size. With further optimization, this device can assist in ongoing hybrid magnonics research. Developing these systems using hybrid quasiparticle interactions will help us attain faster and efficient processing speeds and assist in the development of advanced technology such as integrated quantum magnonic circuits.



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