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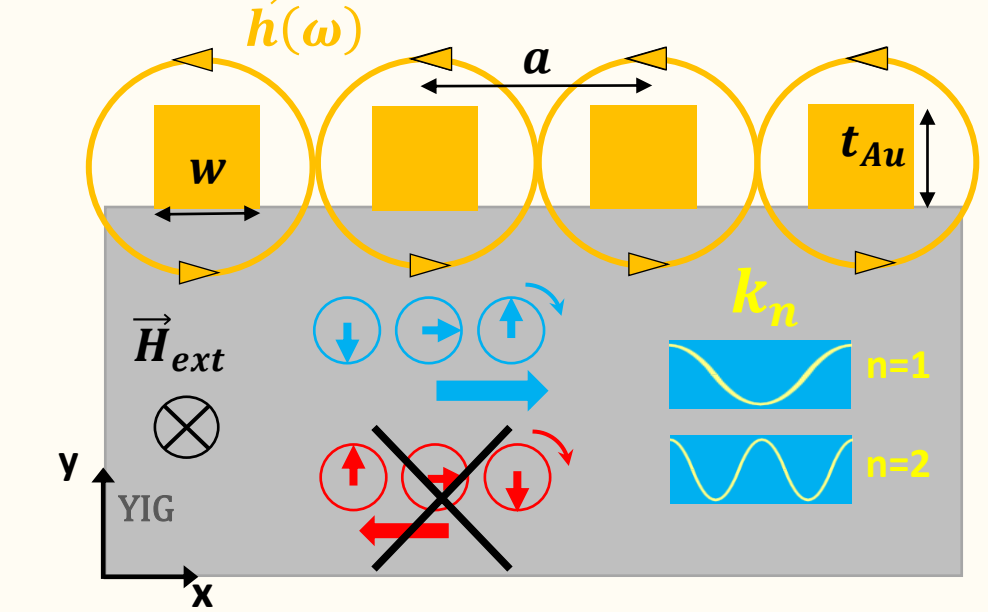
IMT Atlantique
Bretagne-Pays de la Loire
École Mines-Télécom

Micron-sized magnonic 3-port rectilinear circulator

Motivations

- ❖ **Need for miniaturized Circulator**
Breaking the "Ferrite Limit", which rely on bulky ferrite components, which are hard to integrate on the on-chip demands [1]
- ❖ **Need for high frequency communication**
Meet the bandwidth demands of the next generation wireless networks such as 6G [2]
- ❖ **Ultra low Power Signal Processing**
Spin waves enable charge-free information routing, drastically reducing power consumption and thermal dissipation.

Chiral excitation of spin-waves



- Matching of the distribution of the **microwave excited fields** with the **spin wave phase profile** [3]
- According to right hand rule: $\frac{\vec{k}}{\|\vec{k}\|} \times \frac{\vec{M}}{M_s} = \vec{u}_y$

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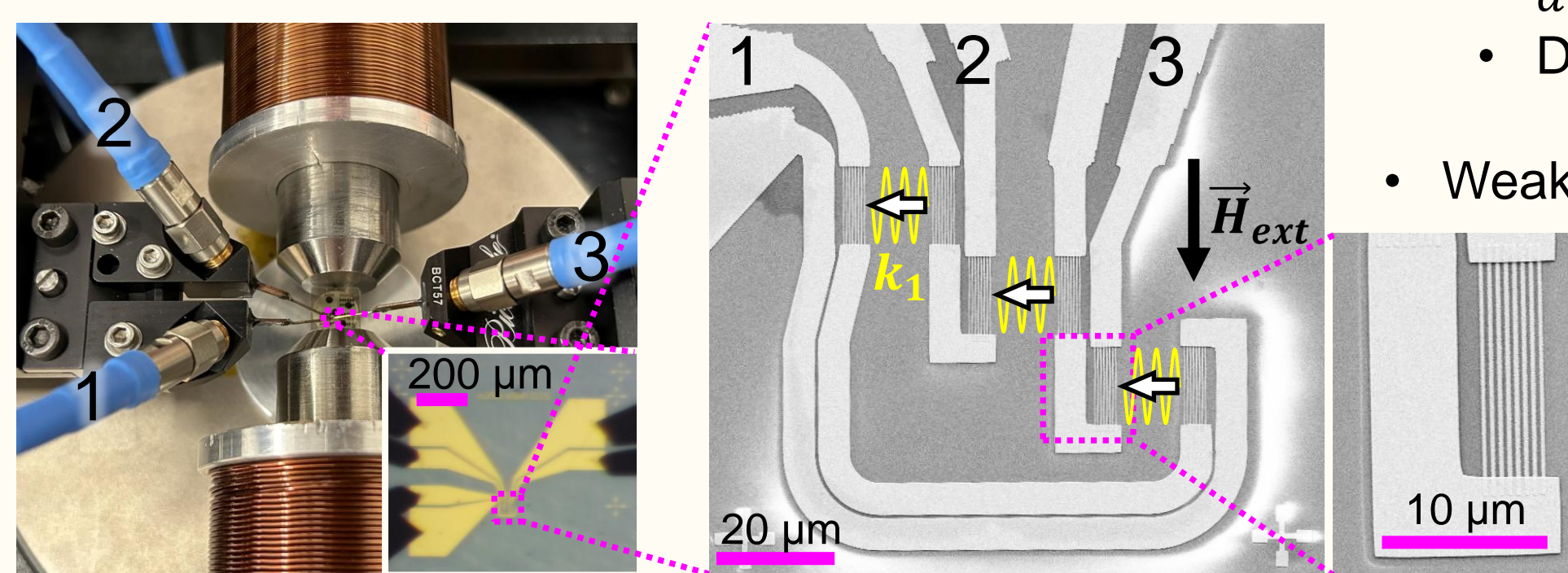
References

- [1] V. G. Harris, IEEE Trans. Magn. 48, 1075 (2012).
- [2] L. Ranzani & J. Aumentado, IEEE Microw. Mag. 20, 112 (2019).
- [3] D. Wagle et al., Phys. Rev. B 113, L060405 (2026).
- [4] K. Davidkova et al., Phys. Rev. Appl. 23, 034026 (2025).

Circulator Design

Three-port measurement Setup

- Three-port spin-wave spectroscopy using a Rhode&Schwarz-ZNA43 vector network analyzer



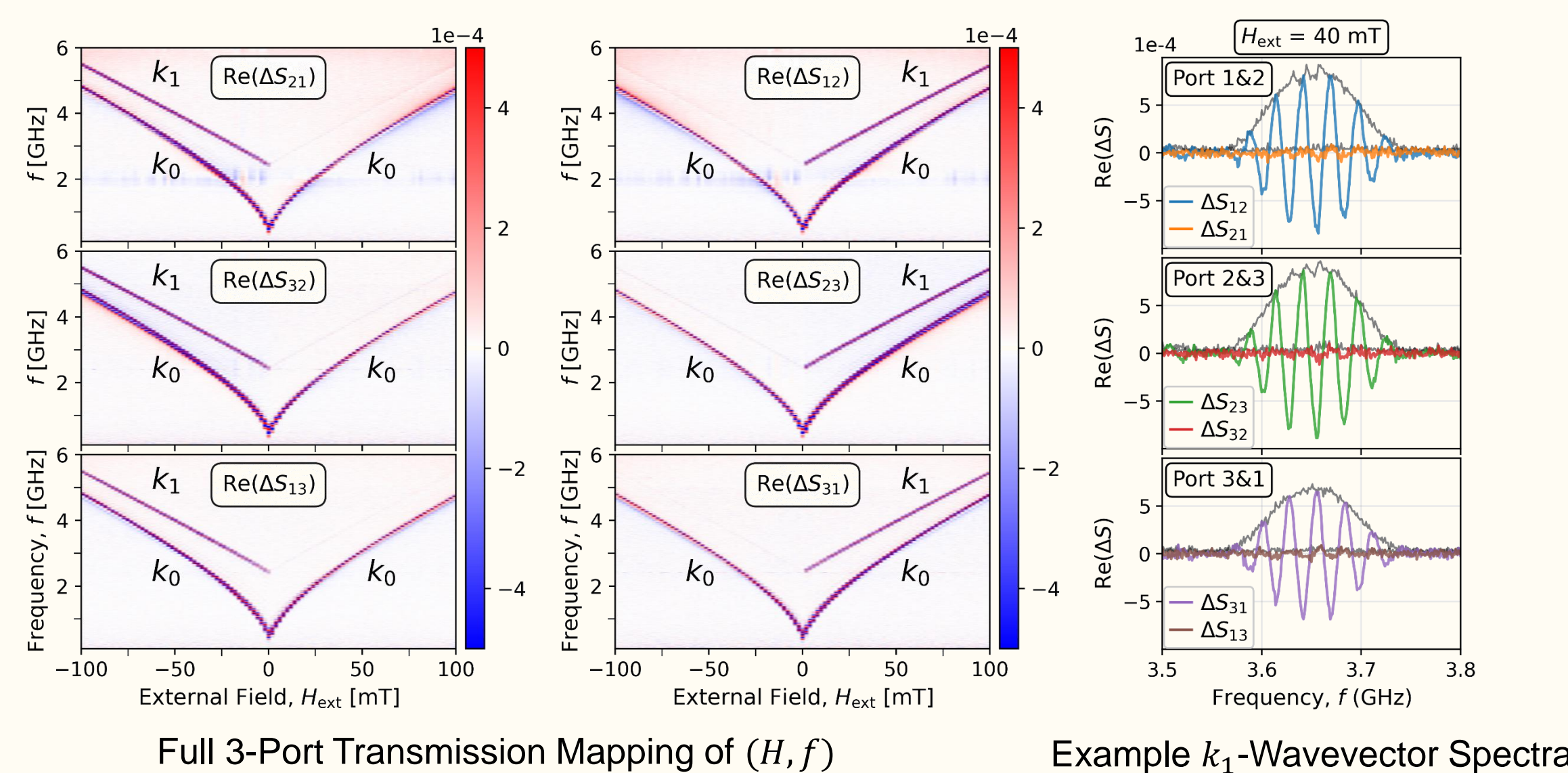
- Rectilinear design with three geometrically separated spin wave channels
 - Active Area: $100 \times 100 \mu\text{m}^2$
 - 55nm thick YIG film
 - Nanobar dimensions: $w = 200\text{nm}$, $a = 500\text{nm}$, $t_{Au} = 40\text{nm}$, $d = 15\mu\text{m}$
 - Damon-Eschbach modes

- Weak Inductive Coupling
 - High insertion losses and weak transmission signal
 - -60dBm for k_1
 - We chose to remove parasitic baseline by: $\Delta S = S_{meas} - S_{ref}$

Spin Wave Circulation

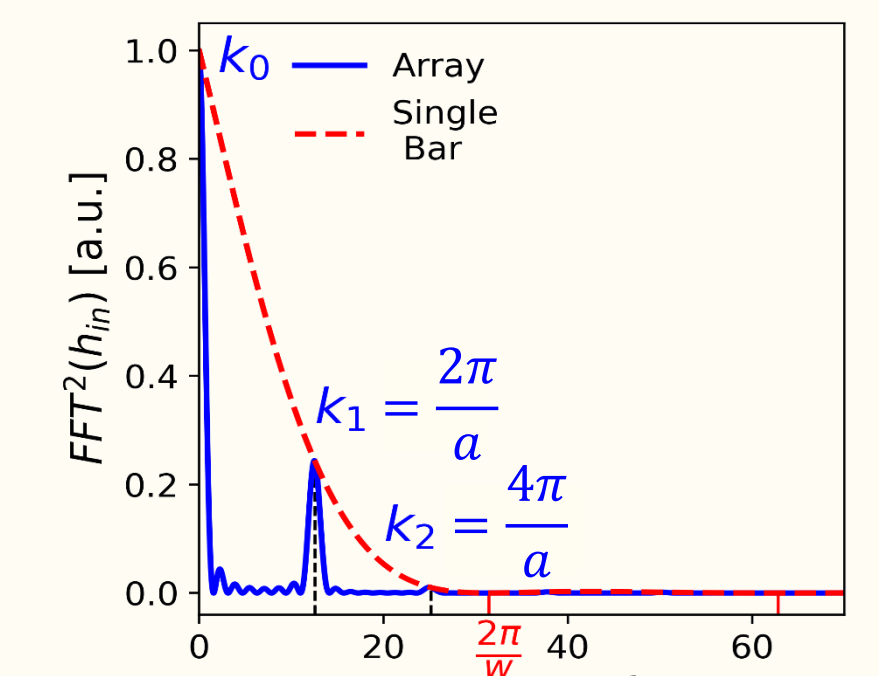
Full 3-Port Transmission Mapping of (H, f)

- Shows a symmetric k_0 branch
- Unidirectional k_1 branch with respect to the external field H_{ext} orientation
 - Exhibits strong isolation
- Quasi-even level of circulation transmission



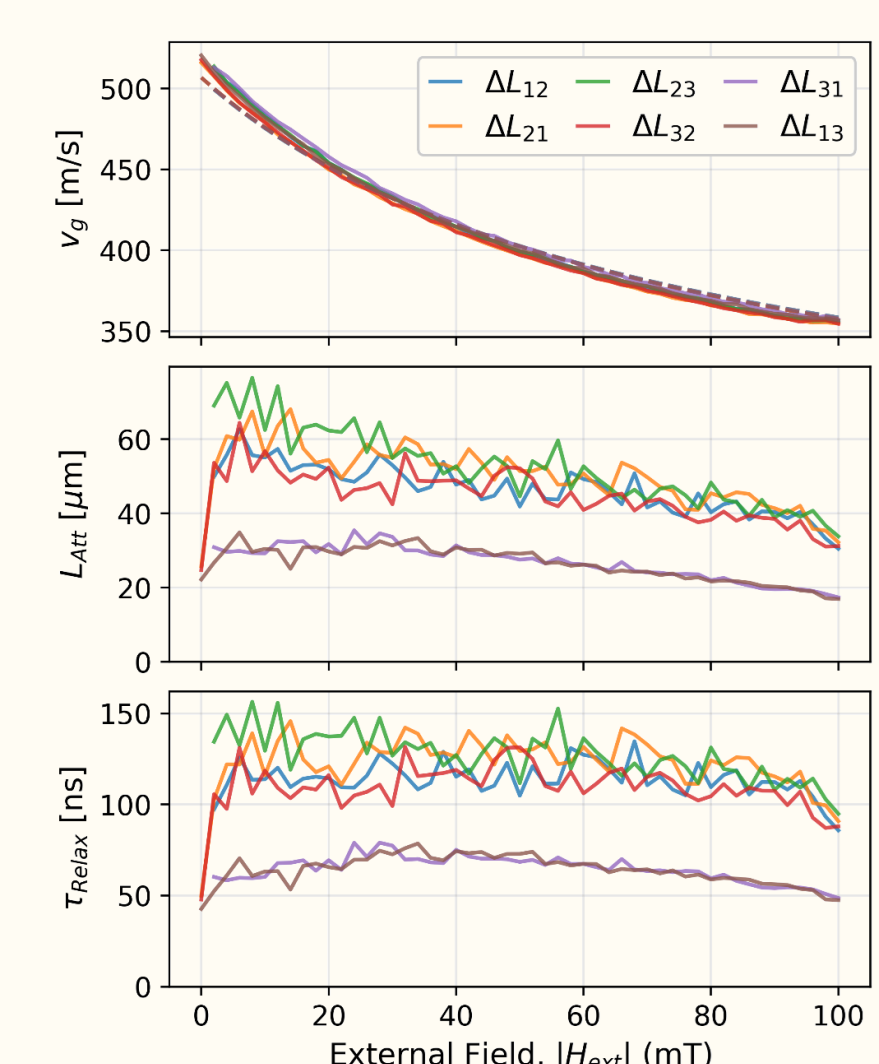
Fourier Transform of the Excitation Field

- Depending on the excitation antenna configuration
- Shows a strong $k_0 = 0$ branch
- Shows a sufficient excitation of $k_1 = \frac{2\pi}{a} \approx 12.6 \text{ rad}/\mu\text{m}$
- Higher wavevectors $k_n = \frac{2n\pi}{a}$ are effectively suppressed



Group Velocity v_g of k_1 Branch

- (only passing mode are compared and flipped in field sign for the complementary channel directions)
- Identical monotonic decrease over all channels
- Matches the theoretical curve



Attenuation Length L_{Att}

- Channel 1 & 2 and 2 & 3 fairly identical
- Channel 1 & 3 has reduced attenuation length
 - Likely due to the longer shape of the port 1 determination, that couples with port 3

Relaxation Time τ_{Relax}

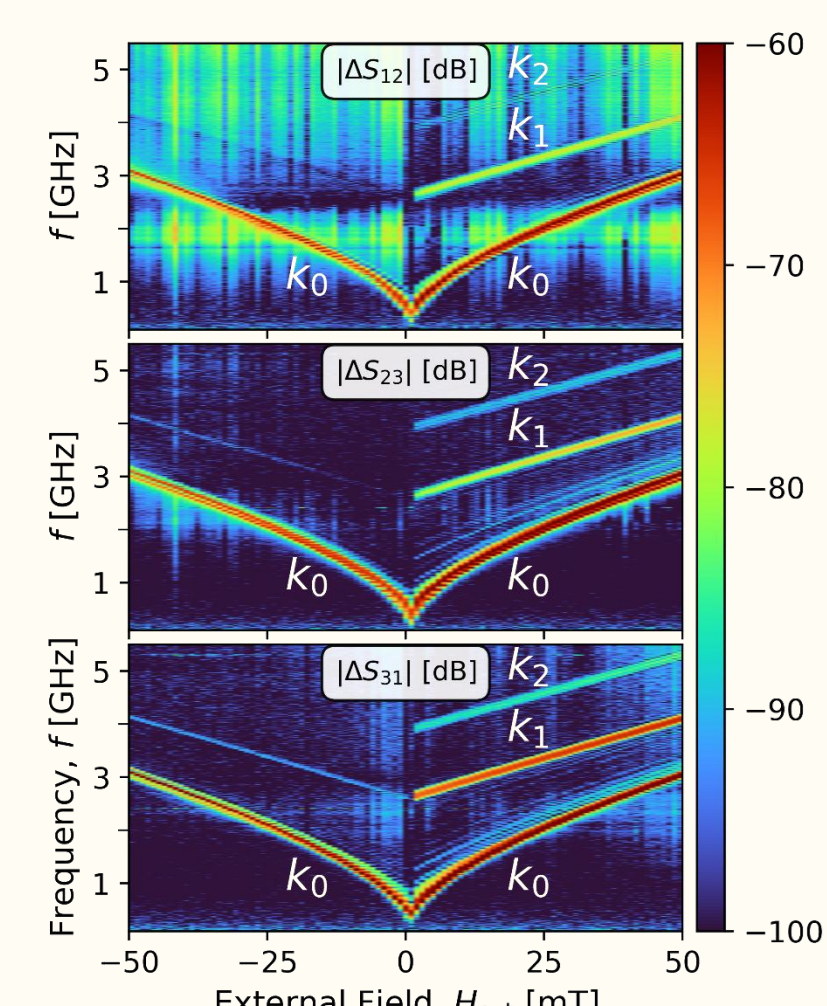
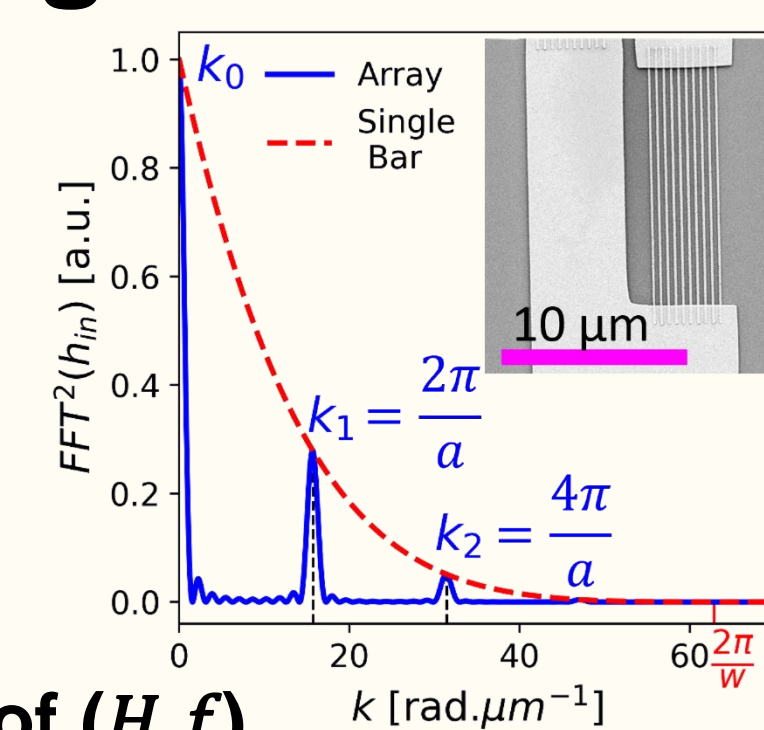
- Similar decreased relaxation times for the channel 1 & 3

Higher Wavevector Engineering

Fouriertransform of the Excitation Field

- Different antenna dimension
- $w = 100\text{nm}$, $a = 400\text{nm}$, $d = 10\mu\text{m}$
- Increased ratio $\frac{a}{w} = 4$
 - effectively enhances excitation strength of

$$k_1 = \frac{2\pi}{a} \approx 15.7 \text{ rad}/\mu\text{m} \quad \& \quad k_2 = \frac{4\pi}{a} \approx 31.4 \text{ rad}/\mu\text{m}$$

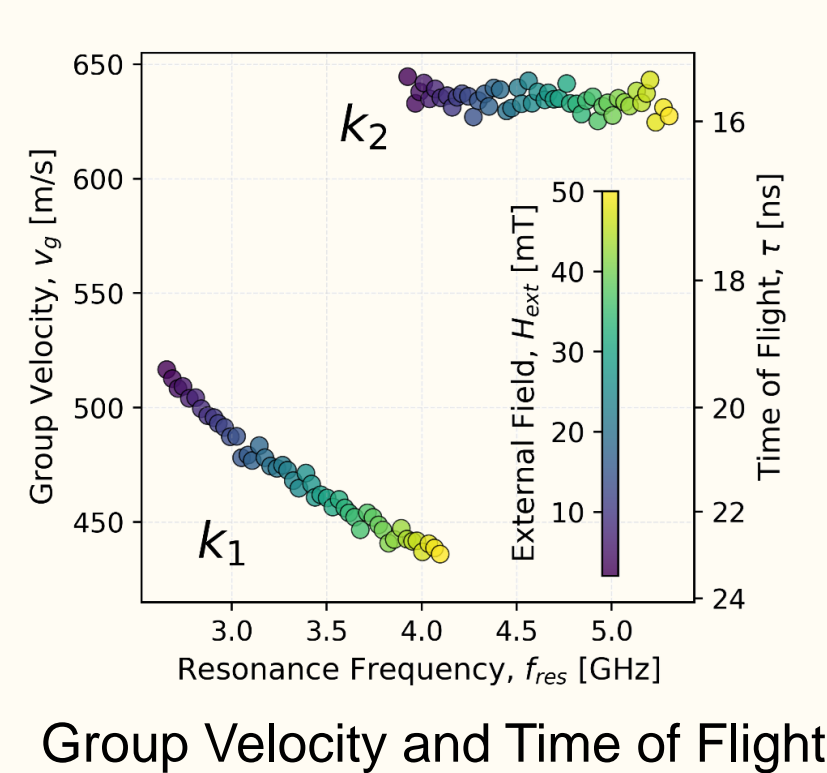
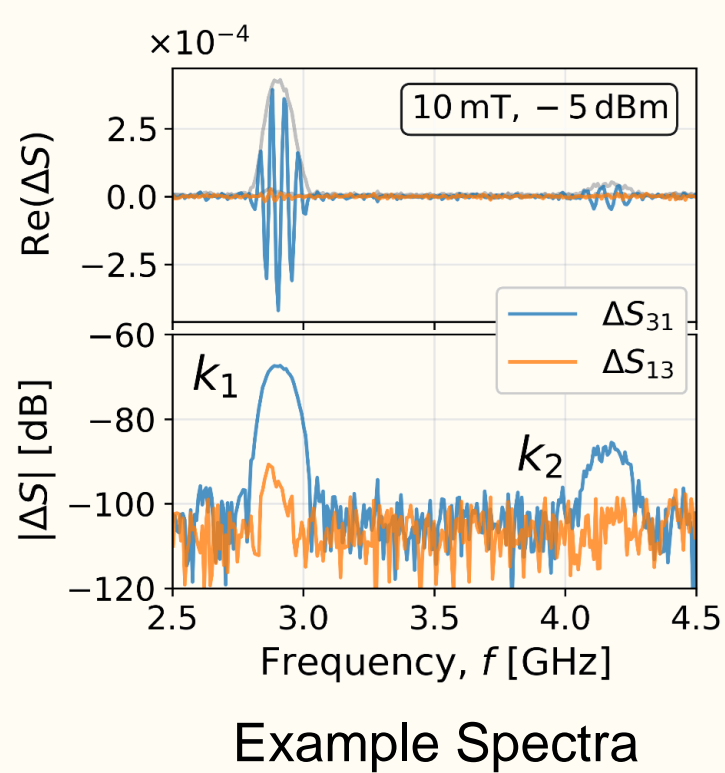
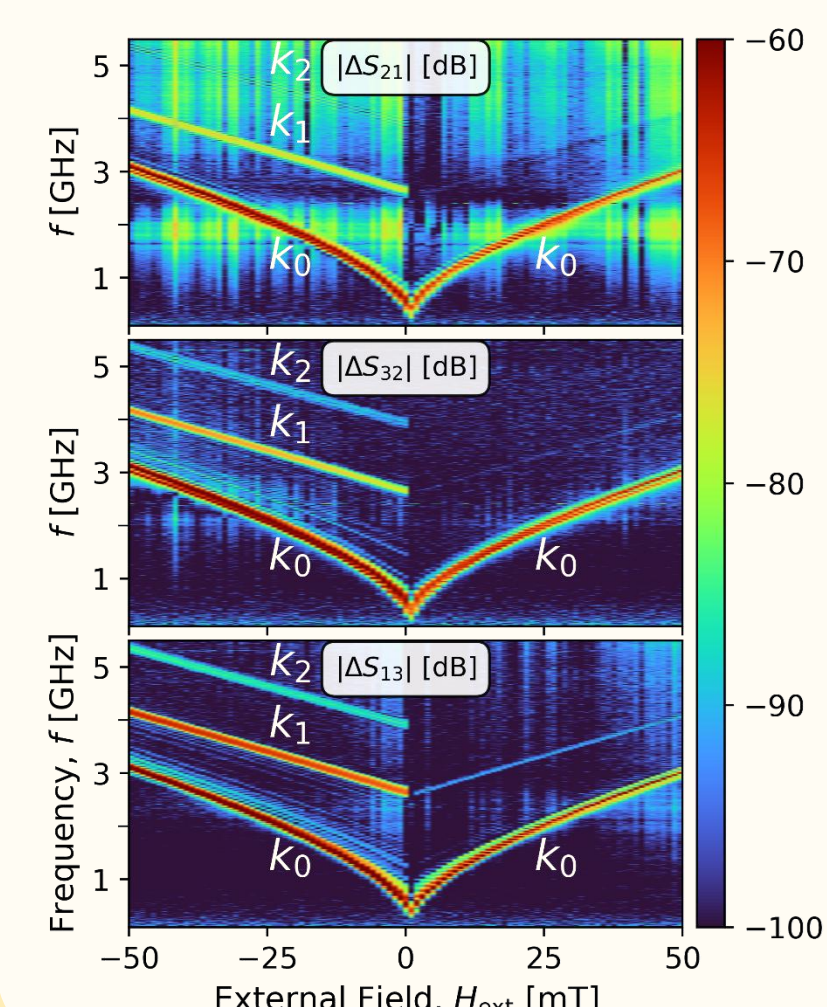


Transmission Mapping of (H, f)

- Shows symmetric k_0 branch
- Shows unidirectional k_1 branch
- Reveals additional unidirectional higher wavevector branch k_2

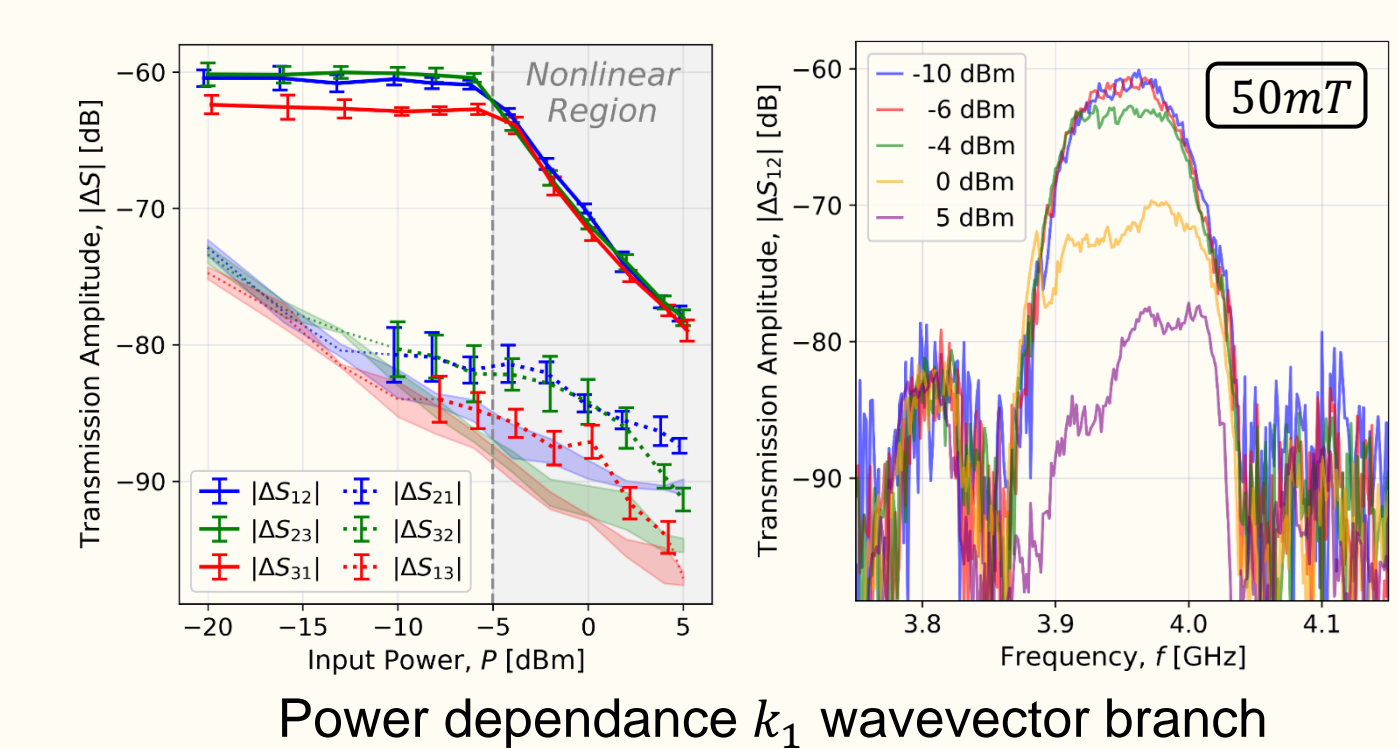
Group Velocity v_g (from Port 1 to 3)

- Decreasing v_g for k_1
- Remarkably invariant and higher v_g for k_2
- Routed in the Dispersion Relation
 - k_1 (Dipolar Regime): High sensitivity to the Zeeman. Dominated by the quadratic exchange term ($\propto k^2$)
 - k_2 (Exchange Regime):
- Versatile Platform for exploiting different timing characteristic



Power Dependance of k_1

- Achieves isolation bigger than 20dB over all channels
- Shows nonlinear threshold ($\approx -5\text{dBm}$ @ 50mT)
- Can act as a power limiter [4]



Conclusions

- ▶ **Demonstrated prototype of micron scale ($100 \times 100 \mu\text{m}^2$) three-port-spin-wave circulator**
- ▶ **Implemented a comprehensive three-port spin-wave spectroscopy**
- ▶ **Quasi-even level transmission amplitude with an isolation greater of 20dB**
- ▶ **Further engineering of the nanobar grating's dimensions**
→ possible excitation of additional higher wavevector branches