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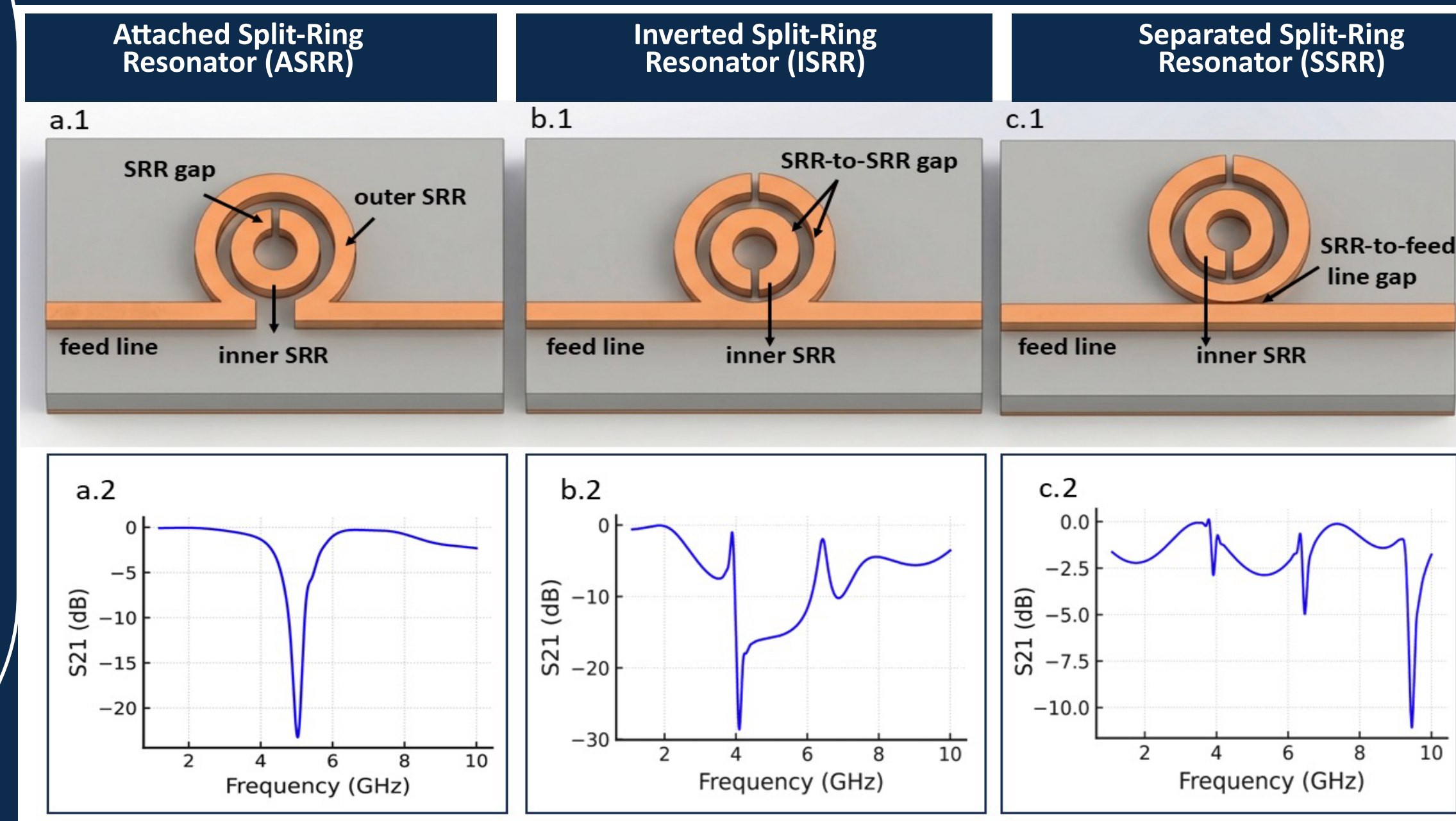
1- ABSTRACT

In this research, we develop a compact planar Attached Split-Ring Resonator (ASRR) cavity designed to support strong magnon–photon coupling (MPC) through enhanced microwave magnetic-field confinement and improved quality factor. We further investigate how the geometry of the magnetic element influences the coupling by comparing three yttrium iron garnet (YIG) structures: a full ring, a half ring, and a disk. Our goal is to establish a scalable planar platform for cavity magnonics and to understand the role of magnetic geometry in determining coupling strength and cooperativity.

2- MOTIVATION

- * Strong MPC enables coherent magnon–photon interaction for hybrid quantum technologies.
- * Conventional 3D cavities limit scalability and integration.
- * Planar resonators provide a compact alternative but require optimized coupling.
- * This work investigates how resonator and YIG geometry affect coupling performance.

3- DEVELOP COMPACT PLANAR

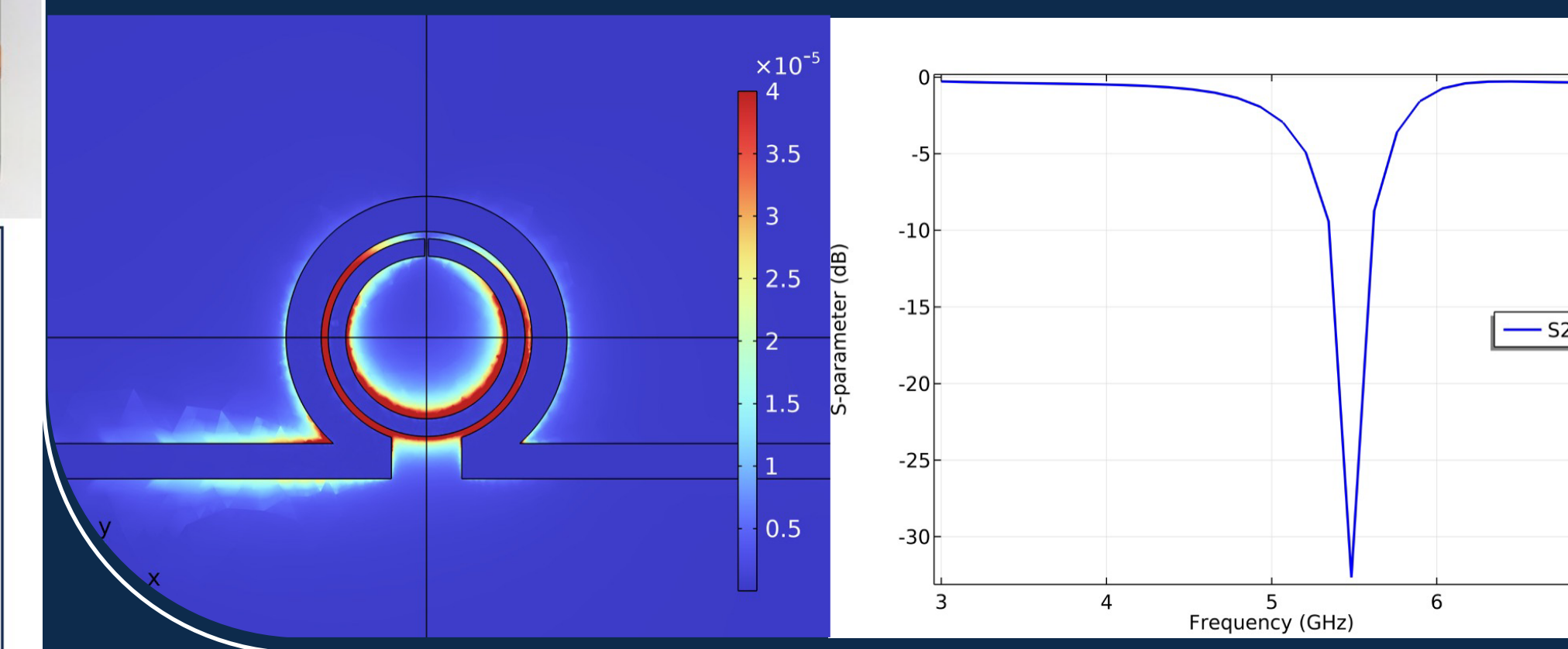


4- OPTIMIZED ASRR

Achieved Q = 190 at 5.48 GHz, providing strong magnetic-field confinement for efficient magnon–photon coupling.

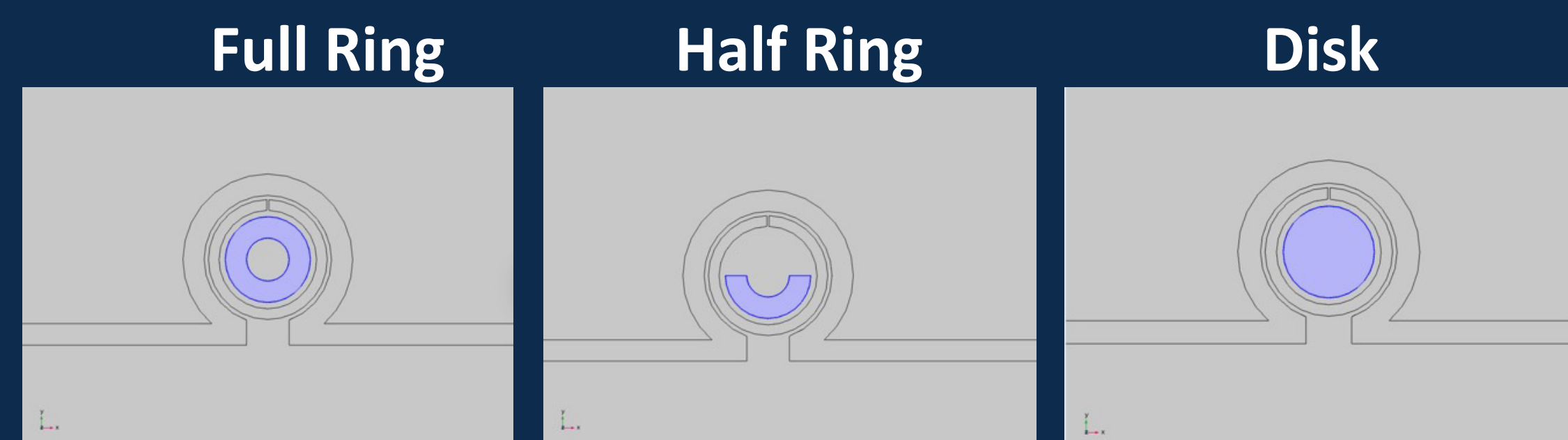
Inter-ring spacing = 0.275 mm
SRR slit gap width = 0.1mm
Substrate thickness = 0.5mm

Substrate permittivity (ϵ_r) = 3.48
Inner-ring width = 0.5mm



5- THREE YIG GEOMETRIES ADDED

YIG structures were introduced into the region of maximum microwave magnetic-field intensity to investigate the influence of magnetic geometry on magnon–photon coupling.



These geometries show how magnetic shape influences the coupling strength, linewidths, and cooperativity of the hybrid magnon–photon system.

6- MODELING APPROACH

The cavity response was calculated by solving the electromagnetic wave equation derived from Maxwell's equations, providing the

$$\nabla \times \mu_r^{-1} (\nabla \times E) - k_0^2 \epsilon_r E = 0$$

resonance frequency, quality factor, and microwave magnetic-field distribution of the resonator.

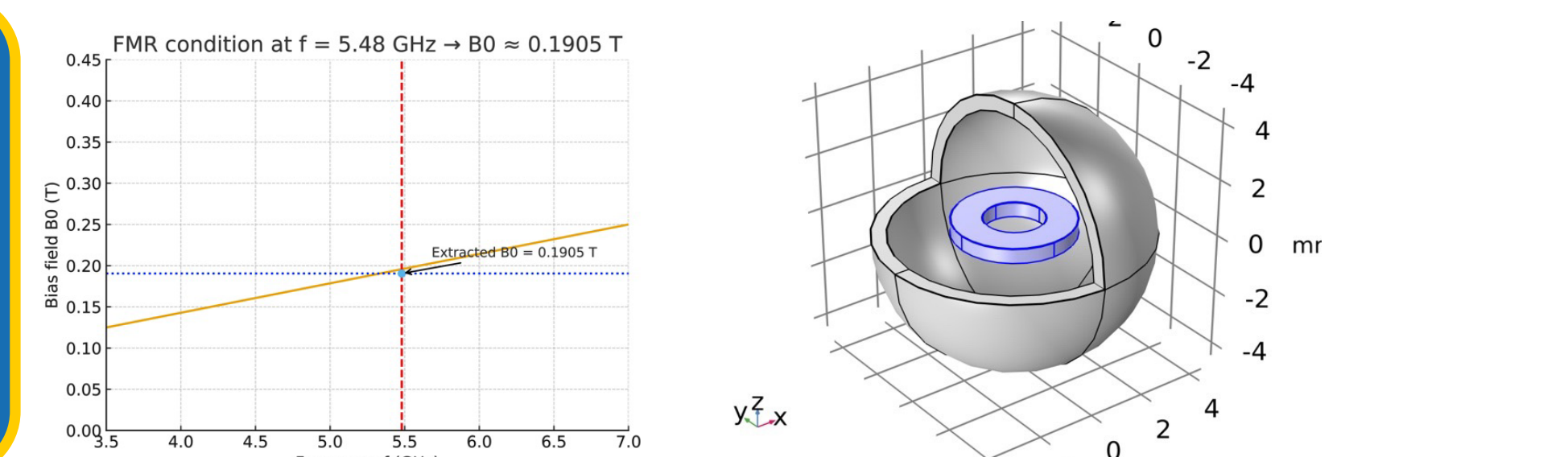
For the full-ring and half-ring geometries, the FMR field was determined by solving the linearized LLG equation, including both exchange and demagnetizing fields.

$$\frac{\partial \mathbf{M}}{\partial t} = -\gamma \mu_0 \mathbf{M} \times \mathbf{H}_{eff} + \alpha \mathbf{M} \times \frac{d\mathbf{M}}{dt}$$

COMSOL Multiphysics[®] was used to simulate the coupled electromagnetic and magnetic response of the optimized ASRR–YIG system.

$$\mu_r = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \mu & -ik \\ 0 & ik & \mu \end{pmatrix}$$

This enables the simulation of magnon–photon hybridization and the observation of avoided level crossings.



7- RESULTS

The coupling characteristics of the ASRR–YIG system were quantified from the simulated transmission spectra (S21).

The cavity linewidth was extracted from the full width at half maximum (FWHM) of the uncoupled cavity resonance.

The magnon linewidth was obtained from the FMR peak in the uncoupled region of the dispersion.

At the resonance condition, the avoided level crossing produces two hybridized modes separated by (2g), allowing direct extraction of the coupling strength (g).

These parameters provide a quantitative measure of the strength and efficiency of magnon–photon coupling.

Geometry	Volume $V(m^3)$	Spins $N = n_s V$	Coupling g (MHz)	Normalized coupling $g = g_0/\sqrt{N}$	YIG Geometry	B_0 [mT]	g [MHz]	κ_c [MHz]	κ_m [MHz]	C	Qualitative Coupling Efficiency
Full ring	4.712×10^{-9}	1.885×10^{19}	115	2.65×10^{-8}	Half Ring	186	70	32	10	20.4	Moderate, slightly reduced due to edge demagnetization
Half ring	2.356×10^{-9}	9.420×10^{18}	108	3.52×10^{-8}	Full Ring	188	50	28.8	3.4	25.2	Strong, well-balanced hybridization
Disk	6.283×10^{-9}	2.513×10^{19}	135	2.69×10^{-8}	Disk	134	145	24	18.7	47	Very strong, enhanced by field overlap and in-plane symmetry

$$\kappa_c = \frac{f_{SRR}}{Q}$$

κ_c is photon decay rate

$$\kappa_m = \pi \cdot \Delta f_m$$

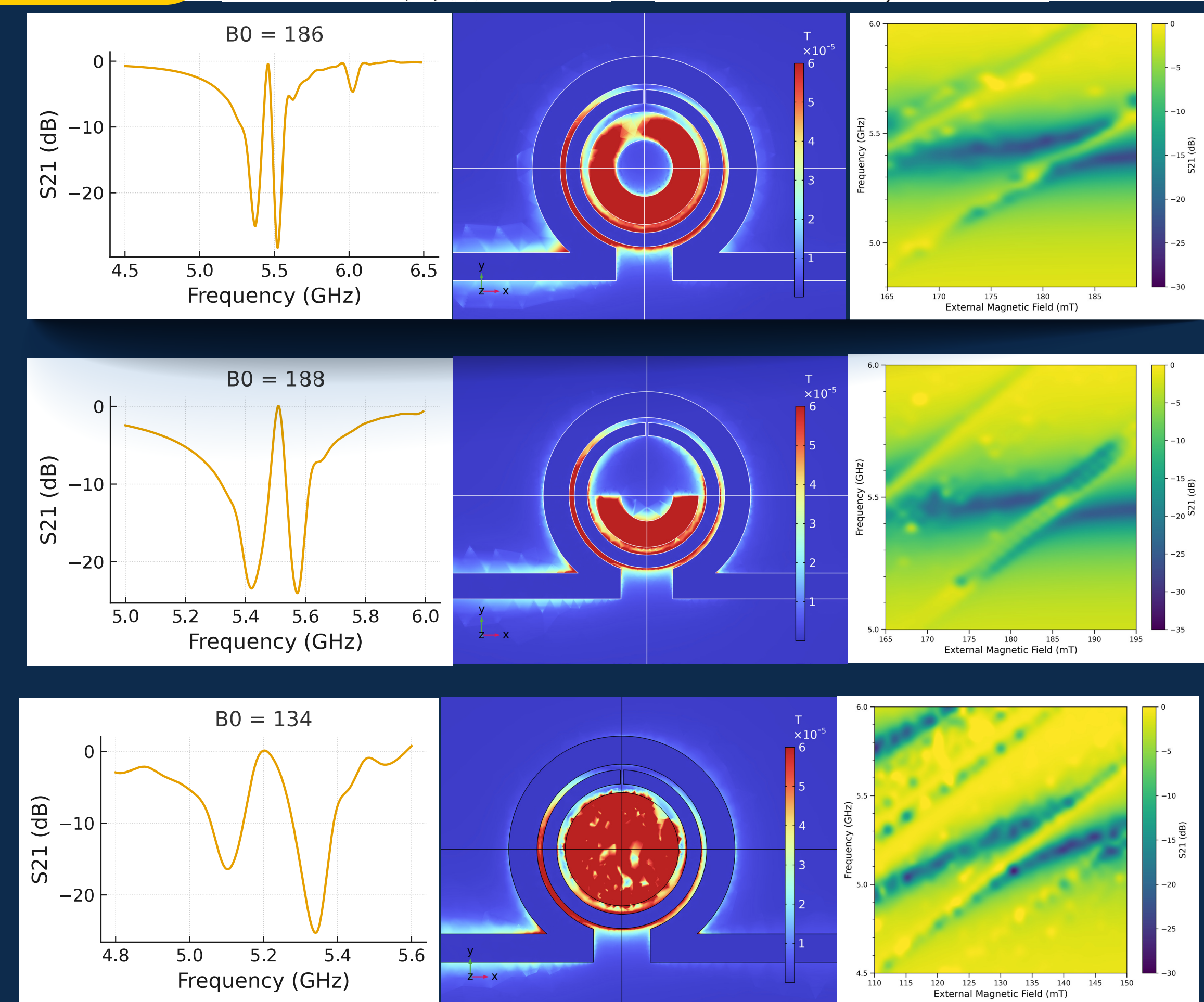
κ_m is magnon decay rate
 Δf_m is FWHM of the magnetic resonance

$$g = \frac{f_{upper} - f_{lower}}{2}$$

$g > \kappa_m \kappa_c$
condition for a strong magnon–photon coupling

$$C = \frac{g^2}{\kappa_m \kappa_c}$$

$C > 1$
coupling are in the strong regime



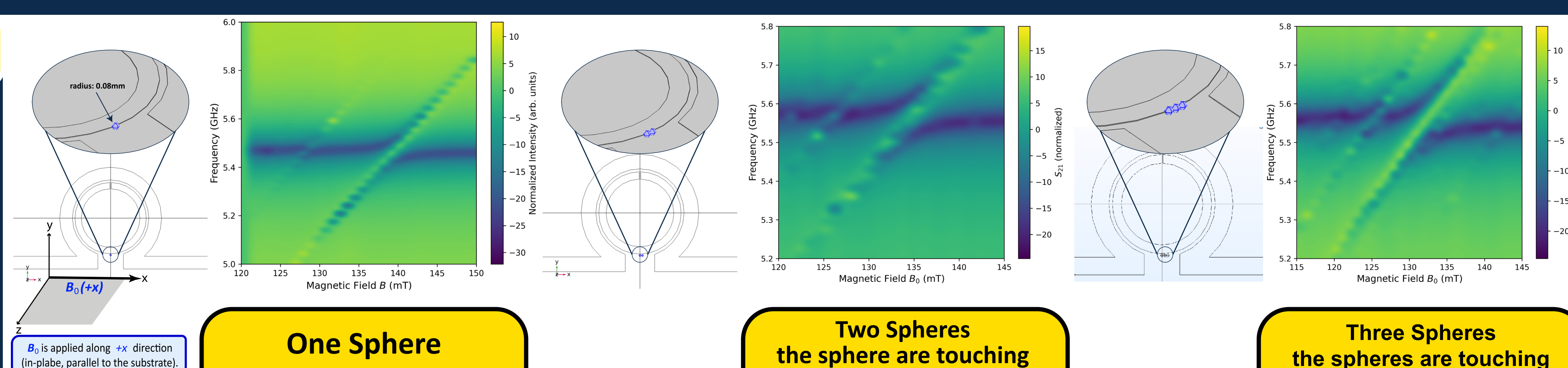
8- NEW RESEARCH DIRECTION

Develop a compact highly sensitive integrated platform for magnon-microwave photon coupling.

Introduce single and multiple micron-sized YIG elements for single- and multi-resonator architectures.

Investigate strong magnon–photon coupling.

Explore bandwidth enhancement through multi-mode interactions.



9- CONCLUSION

- Optimized ASRR achieved a high Q-factor (Q ≈ 190) with strong microwave magnetic-field confinement.
- Strong magnon–photon coupling was demonstrated for all YIG geometries.
- YIG geometry significantly influences coupling strength and cooperativity.
- The YIG disk exhibited the strongest coupling (g = 135 MHz) and highest cooperativity (C = 25.3).
- The optimized ASRR provides a promising platform for compact planar cavity magnonic devices.

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