# Magnonic full adder based on magnonic neurons

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When designing an artificial neural network based on a physical system, it is crucial to create a system characterized by nonlinearity, fading memory, and parameters for reprogrammability. The use of magnonic nanoresonators placed over a ferromagnetic layer or waveguide for this purpose is a promising direction in creating hardware artificial neural networks based on spin waves (SWs) [1]. Here, instead of using uniformly magnetized chiral magnonic resonators [1], we use non-uniformly magnetized bowtie-shaped resonators (see Fig. 1) and exploit the advantage of a noncolinear magnetic configuration that remains stable at low bias magnetic fields. The bowtie-shaped resonator is composed of two trapezoidal shapes joined at their short edges and is placed above Yttrium Iron Garnet (YIG) film (see Fig. 1). The trapezoidal shapes are designed to stabilize magnetic domain states with parallel or antiparallel relative magnetization orientation. This choice of resonator shape is intended to ensure their reprogrammability through the various possible magnetic textures that can be stabilized in them, and the presence of various low-frequency resonant modes that can easily couple to SWs with a wavelength of about 1 µm. In particular, we focus on the effects in the context of the resonator's applications as a nonlinear scatterer in magnonic-based artificial neural networks. Using micromagnetic simulations in the mumax3 environment [2], we design a mesh composed of two layers of resonators that scatter the incident waves. Subsequently, we show that such a system can act as a reservoir, performing neuromorphic computation. In a series of numerical simulations, we present the functionality of a full adder, where we exploit the nonlinear scattering to code binary information in the physical system. Our results demonstrate that magnonic structures can be used to develop energy-efficient building blocks for advanced analog and neuromorphic computing, moving beyond traditional CMOS technology.

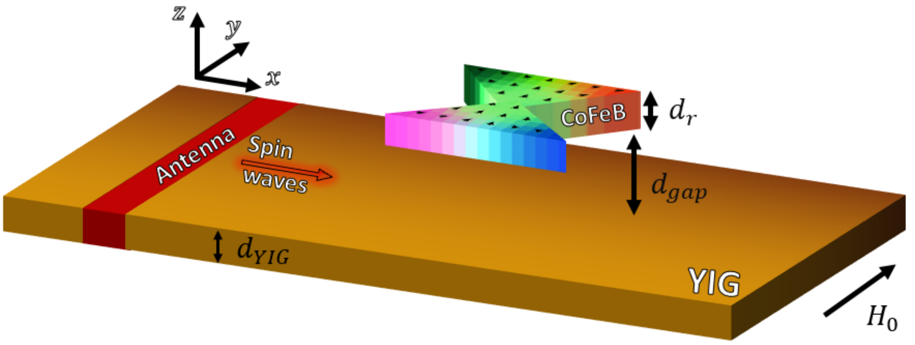


Fig. 1. Schematic picture of the studied system. A YIG thin film with thickness $d_{YIG} = 50$ nm. The bias field is applied in the $y$ direction. The bowtie-shaped resonator of thickness $d_r = 30$ nm is placed $d_{gap} = 5$ nm above the thin film. The resonator is non-collinearly magnetized. We detect SW-encoded information behind the resonator.

This project has received funding from the European Union's Horizon Europe research and innovation program under Grant Agreement No. 101070347-MANNGA. However, views and opinions expressed are those of the authors only and do not necessarily reflect those of the European Union or the European Health and Digital Executive Agency (HADEA). Neither the European Union nor the granting authority can be held responsible for them.

[1] K. G. Fripp, Y. Au, A. V. Shytov, V. V. Kruglyak; Nonlinear chiral magnonic resonators: Toward magnonic neurons. *Appl. Phys. Lett.* 24 April 2023; 122 (17): 172403.
[2] Vansteenkiste, A., Leliaert, J., Dvornik, M., Helsen, M., Garcia-Sanchez, F., & Van Waeyenberge, B. (2014). The design and verification of MuMax3. AIP Advances, 4(10), 107133.