INSTITUTE COLLOQUIUM

S. N. BOSE NATIONAL CENTRE FOR BASIC SCIENCES
(AN AUTONOMOUS RESEARCH ESTABLISHMENT UNDER DST, GOI)
Block-JD, Sector-III, Salt Lake, Kolkata-700 106

26th December 2025, 4.00 pm at FERMION

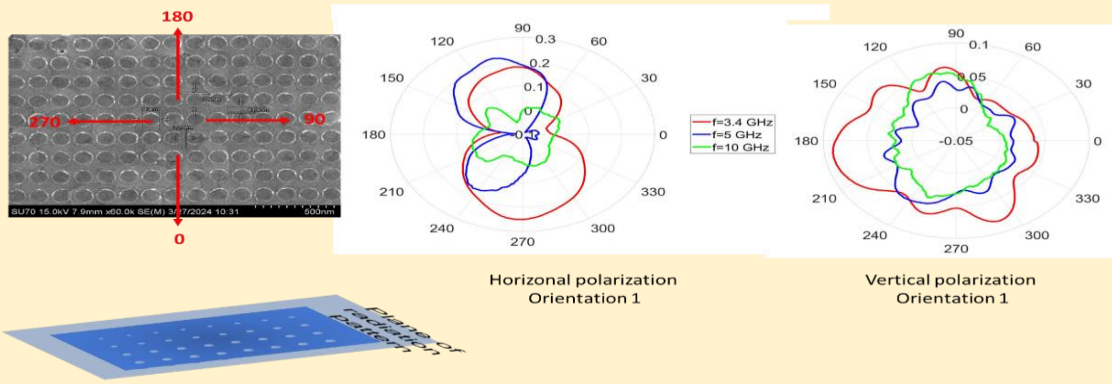
Colloquium Link for Online

* TITLE :: Topological Analog Electronics: Quantum micro-antenna and electromagnetic beam steering based on spin-momentum locking in the topological insulator $Bi_2 Se_3$

ABSTRACT: *Quantum materials* (topological insulators, Weyl semimetals, alter-magnets) are enabling new device functionalities that were hitherto inaccessible. A remarkable impact has been made in the field of analog electronics, specifically antennas, which have until now defied aggressive miniaturization because of the infamous Harrington limit. This limit postulates that the radiation efficiency of any traditional classical antenna will be limited to A/λ^2 where A is the radiating area and λ is the wavelength of radiation. Clearly, the efficiency will plummet if the antenna is made much smaller than the wavelength.

Recently, we were able to overcome this fundamental limit by embracing an unconventional antenna modality based on magnon-photon coupling in an artificial "magnonic crystal" comprising a periodic two-dimensional array of nanomagnets (made of cobalt) fabricated on a thin film of a topological insulator Bi_2Se_3. An alternating charge current of frequency 1-10 GHz flowing through the topological insulator (TI) injects a spin current of alternating spin polarization into the nanomagnets to excite spin waves (magnons) in them. The spin waves radiate electromagnetic waves in space via magnon-photon coupling, thereby implementing an antenna. The frequency of the emitted radiation is the same as the frequency of the current. The measured radiation efficiency exceeded the Harrington limit by more than 3 orders of magnitude.

Because its lateral dimension (~550 μm) is 0.6-1.8% of the free space wavelength (3-9 cm), the micro-antenna is effectively a "point source" and yet it radiates *anisotropically* because of the anisotropy of the spin wave patterns generated within them, which endows the "point source" with internal anisotropy. One can change the anisotropic radiation pattern by changing the direction of the injected alternating charge current, which changes the spin wave patterns within the nanomagnets because of **spin-momentum locking**, which is a property of the quantum material. This implements *beam steering* using a single antenna, orders of magnitude smaller than the radiated wavelength, by exploiting the spin-momentum locking property of a TI. Normally, beam steering will require a phased array with multiple antennas each much larger than the wavelength. Here, we can accomplish beam steering with a single antenna much smaller than the wavelength.



Scanning electron micrograph of the nanomagnet array on a TI and measured radiation patterns

SPEAKER: **Prof. Supriyo Bandyopadhyay is a Commonwealth Professor of Electrical and Computer Engineering at Virginia Commonwealth University (VCU) where he directs the Quantum Device Laboratory. Research in the laboratory has been frequently featured in national and international media (newspapers, internet blogs by media persons, magazines, journal highlights such as in Nature and Nanotechnology, CBS, NPR, and internet news portals). In 2016, he was named Virginia's Outstanding Scientist by the Governor and in 2018, he received the State Council of Higher Education for Virginia Outstanding Faculty Award which is the highest teaching award accorded to any faculty member in any college or university in Virginia. In 2012, he received the Distinguished Scholarship Award from VCU and in 2017 he received the University Award of Excellence – both given to one faculty member in the university in any year. His department gave him the Lifetime Achievement Award in 2015. In 2020, Prof. Bandyopadhyay was named the winner of the "Pioneer in Nanotechnology" award by the Institute of Electrical and Electronics Engineers IEEE), the world's largest professional organization. This is the highest honor given by IEEE in nanotechnology. In 2020-2021, he served as a Jefferson Science Fellow of the US National Academies of Science, Engineering and Medicine and acted as Senior Advisor to the USAID Bureau for Eastern Europe and Eurasia, Division of Energy and Infrastructure. Prof. Bandyopadhyay is a Fellow of IEEE, American Physical Society, Institute of Physics (UK), the Electrochemical Society, and the American Association for the Advancement of Science.**