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A Handheld Mechanical Antenna with Frequency Multiplication and Phase Modulation Capability

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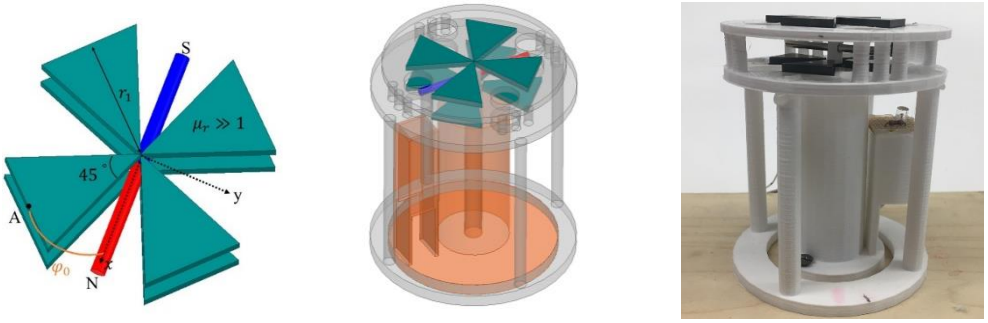
Among the RF communication bands, Super-Low Frequency band (SLF, 0.03-0.3 kHz) and Ultra-Low Frequency band (ULF, 0.3-3 kHz) are potential candidates for underwater and underground communication applications due to their capability to penetrate in lossy materials such as wet soil and sea water. The long signal wavelength (hundreds of km) is the key factor for the significant signal penetration into the seawater ($\sigma = 4$ S/m) and soil compared to higher frequencies.

Application of such low frequency communication links is usually hampered by the requirement in using giant-size transmitting and receiving antennas and the very small available bandwidth such systems can provide. Considering the extremely long wavelength at 1 kHz (300 km), design and fabrication of a reasonably small, portable, and efficient SLF/ULF antenna using the conventional miniaturization techniques is impossible. Hence, alternatives must be considered to realize such hand-held and low frequency antennas. In the past couple of years, the concept of mechanical antennas has been introduced and investigated extensively for this purpose. From the theory of electromagnetics, it is well-known that mechanical acceleration of charged particles induces electromagnetic radiation at the fundamental frequency of motion. The frequency of intended radiation (0.03-3 kHz) seems to be low enough to imagine the possibility of inducing it by mechanical rotation of charged particles or permanent magnets. As long as the rotation (acceleration) of charges is maintained mechanically, it is shown that the radiation efficiency of mechanical antennas is many orders of magnitude higher than conventional electrically small antennas.

Another important challenge associated with the communication at SLF/ULF bands is the small available bandwidth. We can take the advantage of different modulation schemes proposed to overcome such drawback. The common modulation techniques for mechanical antennas would be the frequency modulation (FM), amplitude modulation (AM) and phase modulation (PM). In frequency modulation, it is required to change the rotation frequency of the magnets mechanically and instantaneously. However, this approach is constrained by the moment of inertia of magnet (bulky) and hence is totally inefficient. A new amplitude modulation scheme has been also recently proposed in the literature. This modulation scheme is shown to provide much improved bandwidth compared to the frequency modulation, but the achieved modulation is less immune to the additive noise due to the small modulation depth (~30%) which may not be sufficient for long range communication applications.

To offer better performance in terms of noise for the signal modulation, in this paper, a novel phase modulation scheme is introduced for rotating permanent magnets. The idea here is actually based on rotating a permanent magnet sandwiched between two stationary pairs of orthogonal bow-tie shape layers made of a magnetic material (very high μ material) such as ferrites. Displacement of the initial position of these magnetic posts is shown to modulate the phase and amplitude of EM signal. The amplitude modulation is significant and this provides an additional important feature, which allows the antenna to generate higher signal harmonics of the rotation frequency and thereby it facilitates radiation at a much higher frequency than the rotational frequency of the motor. Hence, higher range and more radiated power can be achieved. Numerical simulations using ANSYS Maxwell along with the measurements are performed to verify the performance of proposed antenna and its unique features.



(a) (b) (c)

Figure.1 (a): The 3D view of proposed configuration for achieving phase modulation in mechanical antennas. (b): The CAD model of proposed mechanical antenna with all its plastic holders. (c): The fabricated antenna.