

Advancements in ULF Transmitter Design: Metglas Modulation and Magnetic Field Dynamics

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Abstract—This paper presents a novel Ultra Low-Frequency (ULF) transmitter that utilizes a static permanent magnet to produce a time-variant magnetic field. By controlling the reluctance of the surrounding magnetic material, the magnetic field can be modulated without any mechanical movement, making it an easily scalable option. The transmitter was successfully developed and tested using a vector induction coil magnetometer demonstrating a normalized field strength at the receiver that was 16.4 dB higher than the coil's leakage at an 800 Hz frequency. A biphasic sinusoidal signal modulated the magnet, operating at twice the source frequency.

I. INTRODUCTION

Very Low Frequency (VLF) and Ultra Low Frequency (ULF) transmitters are gaining popularity for their ability to transmit effectively in RF-challenged environments, especially underwater and underground. However, due to their large size and high loss, traditional antenna designs face difficulties requiring extensive power sources and unwieldy structures [1], which are impractical in certain scenarios. Researchers in [2] proposed low-frequency signal generation using rotating magnets. In [3], a field from a rotating magnet modulated by controlling the reluctance of the shield is proposed. To overcome the mechanical constraints of physical rotation [4] proposed a method to modulate the magnetic field based on variable material permeability. While the proposed U-shaped core eliminates mechanical motion, the leakage from the control coil is significant.

This paper presents a practical solution involving a static permanent magnet encased in magnetic material, acting as a shield and significantly reducing field leakage. By saturating the magnetic shield, the field lines of the permanent magnet extend outside of the shield. Alternating between the saturated and non-saturated states, the static magnetic field of the permanent magnet becomes time-variant.

II. ULF TRANSMITTER

A. Transmitter Geometry

Fig. 1 displays the specifications of a shield surrounding a cylindrical permanent magnet. The shield is a square loop of amorphous magnetic material, specifically Metglas-2605HB1M, measuring $18.05 \times 18.05 \times 9$ cm and 75 μ m thick. The primary function of this mechanism is to create a pathway for the magnetic flux generated by the permanent magnet, located at its core, to extend beyond the confines of its enclosure. The amorphous magnetic alloy has a saturation induction (B) of 1.63 T at a magnetic field strength (H) of 80 A/m.

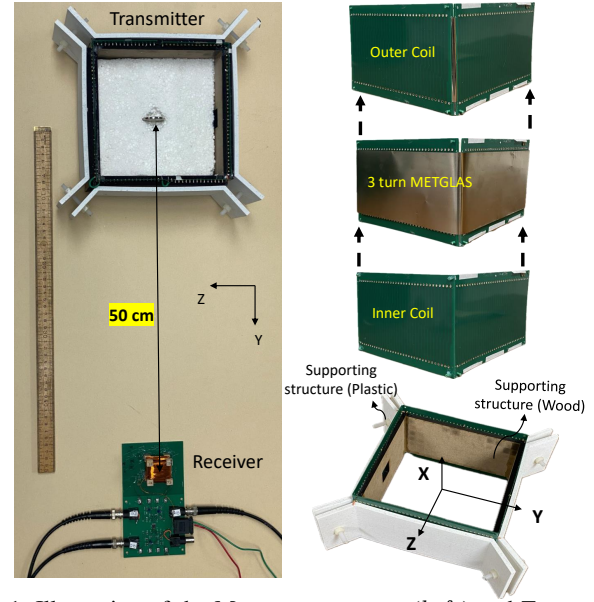


Fig. 1: Illustration of the Measurement setup (left) and Transmitter Internal Structure (right), Highlighting the Metglas and Coil on the Printed Circuit Board (PCB).

To receive the time-varying magnetic field, a baseband signal is fed to a 140-turn coil on a 0.4 mm thick PCB, loaded in series with a high-power resistor of 0.68 Ω as the current sensor. A calibrated inductive 3D magnetometer is used at the receiver, 50 cm away from the static permanent magnet. The cylindrical permanent magnet has a radius of 1.6 cm and a height of 0.32 cm.

B. Operating Principle

Metglas is a ferromagnetic material that a magnetic field can manipulate via a control coil. Its behavior can switch between saturation and unsaturation based on its B-H curve. This amorphous metallic shield surrounds a static permanent magnet, which generates a ULF signal and eliminates the need for a rotating permanent magnet. During each cycle, a biphasic baseband signal causes the Metglas to undergo dual saturation instances, which modulates the magnetic field emitted by the static permanent magnet at a frequency that is twice that of the baseband signal. When working with Metglas, it is crucial to consider factors such as its thickness, field strength, permanent magnet positioning, and baseband signal amplitude, as they significantly influence its saturation. Moreover, increased baseband signal amplitudes can reduce the permanent magnet's impact on the Metglas. Finally, a

calibrated multi-turn coil detects the dynamic signal across three dimensions.

III. MEASURED RESULT

A 400 Hz sinusoidal signal is applied to the transmitter. Subsequently, the voltage across three channels of the 3D magnetometer is measured and normalized to the transmitted power. This setup reveals that the coil produces a measurable voltage across the three orthogonal planes, as depicted in Fig. 2. Additionally, the nonlinearity of the magnetic material that contains the permanent magnet, the received signal exhibits higher harmonics.

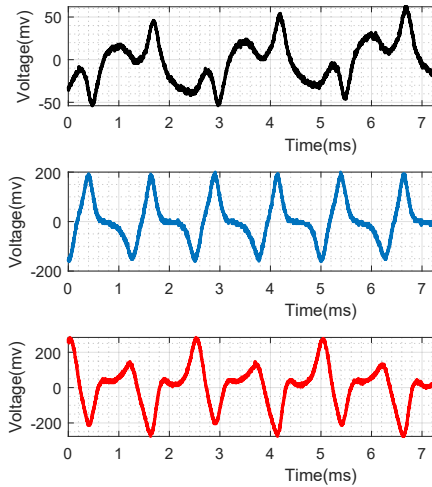


Fig. 2: Higher order harmonics received from the coil along the 3-orthogonal planes due to the nonlinearity of the magnetic material

In Fig. 3, we can observe the signal received from a stationary magnet placed at the center. The magnet is aligned along the X, Y, and Z axes. The remarkable improvement in efficiency, with a 1.5 times increase in the received signal, compared to the coil's leakage. It's worth noting that the received signal has been adjusted to account for a 1.5 times increase in frequency.

Fig. 4 depicts the time-varying magnetic fields across the 3D space with varying magnetic pole orientations. The decrease observed in the orthogonal channels for Y and Z-pole confirms that the signal received is due to the modulation of magnetic fields from a stationary permanent magnet, not the control coil. The preponderance of orthogonal fields in the X-pole orientation can be explained by the relatively short height of the magnetic shield.

IV. CONCLUSION

An innovative method has been developed to produce an Ultra-Low Frequency (ULF) signal. This process involves manipulating the magnetic field of a stationary permanent magnet. A magnetic loop is employed to reduce transmission loss, which is regulated by closely spaced coils printed on a slender PCB structure. The findings indicate that the receiver receives

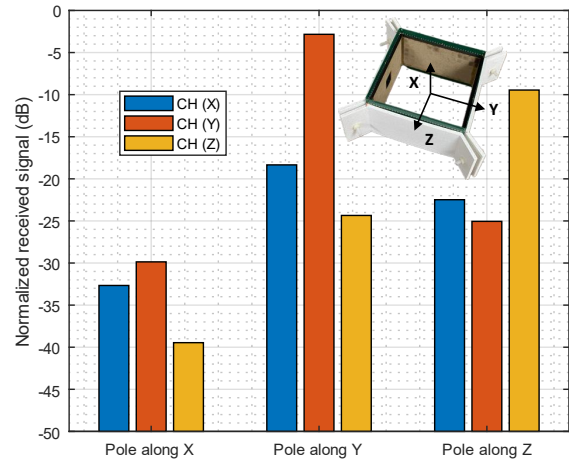
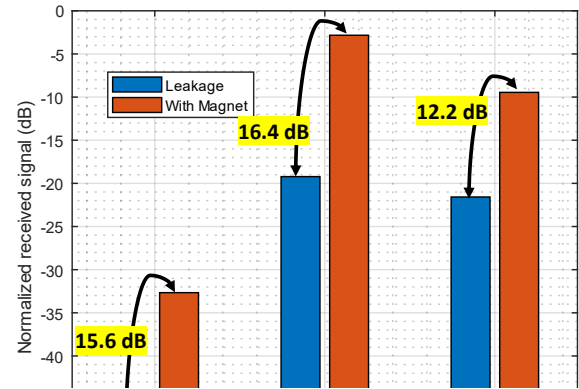


Fig. 4: Fields along the 3D space for magnet pole along X, Y and Z

a field that is 16.4 dB more potent than the transmission loss. The most substantial field strength is achieved when the magnet is perpendicular to the axis of the Metglas shield.

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