System Development

Creation of a Referencing Signal for 360 Degrees Angle Calculations

1. **A third signal** is sent by the source to define the 0 and 180 degrees of space as the peak field strength occurs twice in a rotation cycle.
2. While the third signal is **linearly polarized**, the phase of this signal can be used as a reference for angle calculations〔Fig. **7**〕.
3. The **phase** of rotating magnetic field signals is calculated to approximate the actual angle with respect to the defined 0 and 180 degrees.

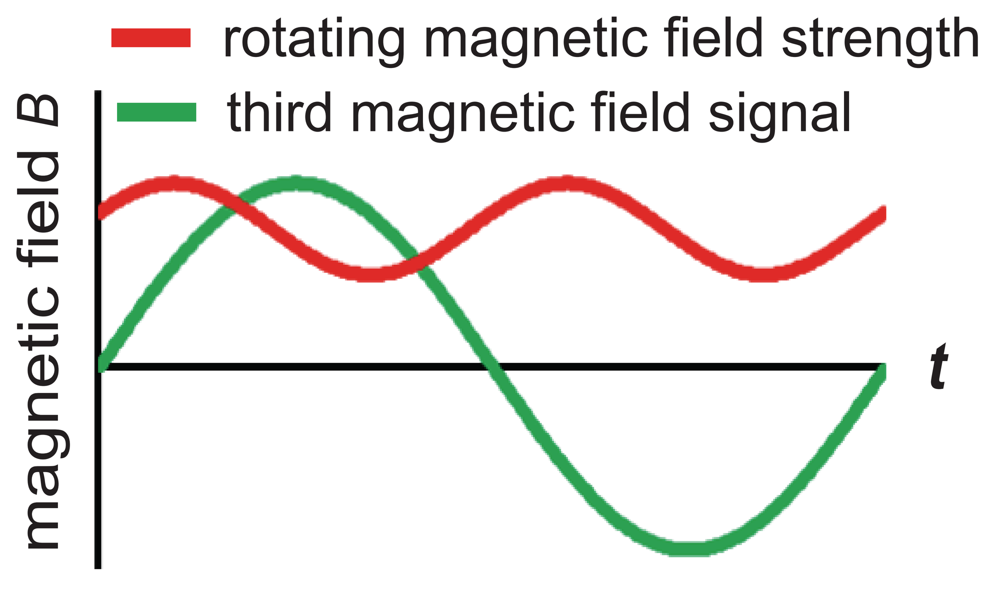

Fig. 7. Mechanism of a third signal

Introduction of the Magnetic Positioning Sphere (MPS)

1. MPS consists of three mutually orthogonal coils and an Arbitrary Waveform Generator (AWG)〔Fig. **8**〕.
2. The AWG sends phase-quadrature signals to the coils to simulate a rotating magnetic field.
3. The Frequency Division Multiplexing (FDM) allows an object to gather two rotating magnetic field signals at different frequencies simultaneously〔Fig. **9**〕.
4. A third signal is sent to the three coils, and it is converted into a magnetic field as a reference to calculate the elevation and the azimuth angles of the object.
5. Formula ***(3)*** reveals the field strength received by the MPS from an object at *(r, θ, φ)*, where

   N : turns of a coil

   I_0 : electric current sent into the MPS

   $\omega_{1\,\&\,2}$: angular frequencies of rotating magnetic fields

   A : area of a coil

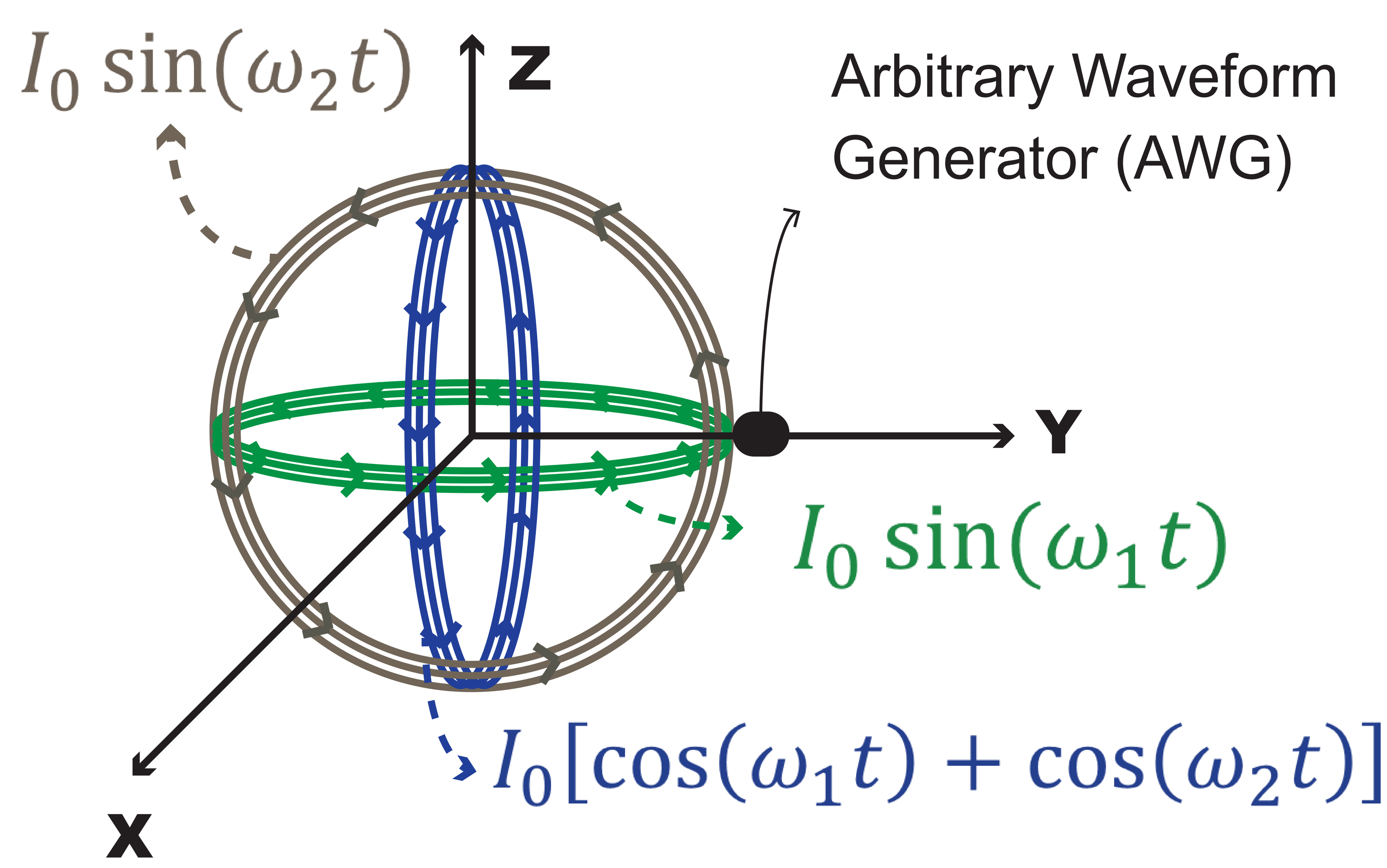

Fig. 8. Magnetic Positioning Sphere (MPS)

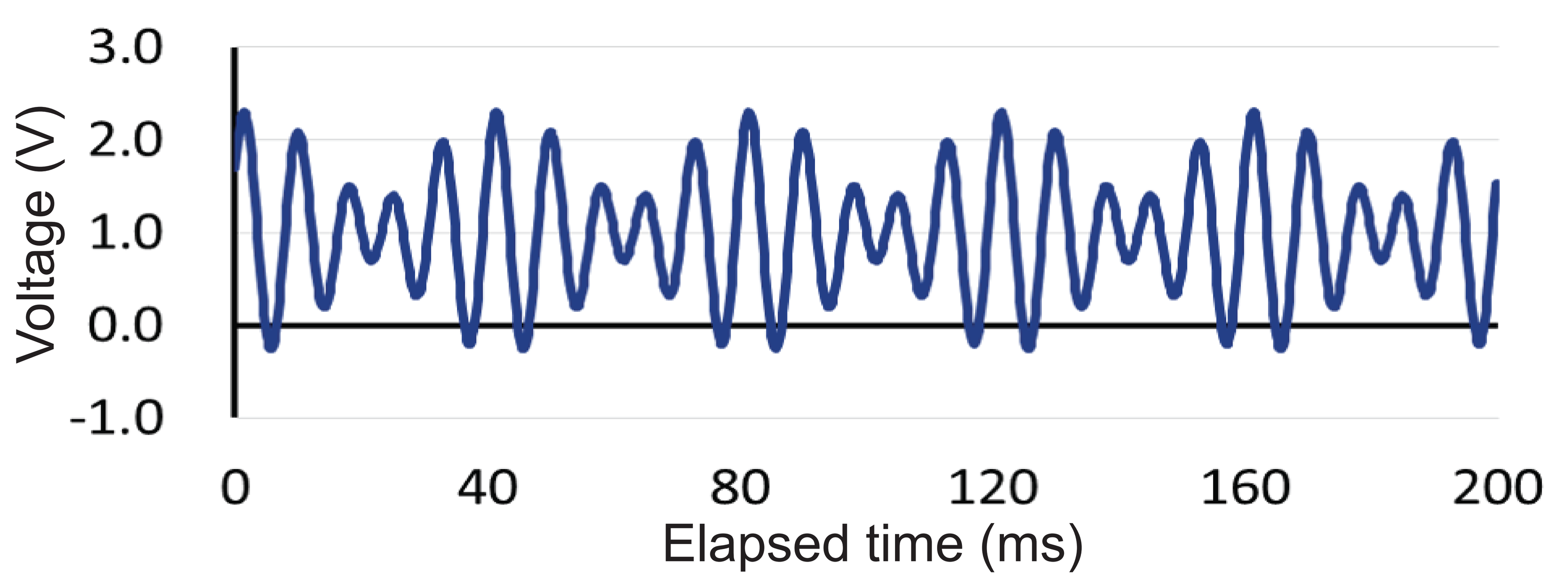

Fig. 9. Combination of two rotating magnetic field signals

$$|B| = \frac{\mu_0 N I_0 A}{4\sqrt{2}\pi r^3}\left\{\sqrt{3\cos[2(\theta - \omega_1 t)] + 5} + \sqrt{3\cos[2(\varphi - \omega_2 t)] + 5}\right\} \quad (3)$$

Signal Processing for MPS System

1. In this study, we considered **only two specific freqeuncies,** instead of the entire frequency range, in the Discrete Fourier Transform (DFT) to save computation time.
2. The amplitude and phase of each signal can be obtained by formula ***(4)*** and ***(5)***, where R_e and I_m are the real part and imaginary part of each Fourier coefficient supplied by DFT〔Fig. **10(a)** & **10(b)**〕.

$$amplitude = \sqrt{R_e^2 + I_m^2} \quad (4)$$

$$phase = \tan^{-1}\frac{I_m}{R_e} \quad (5)$$

3. The distance (r) can be derived from formula ***(3)*** and ***(4);*** and the elevation angle (θ) and azimuth angle (φ) can be derived from formula ***(2), (3)*** and ***(5).***

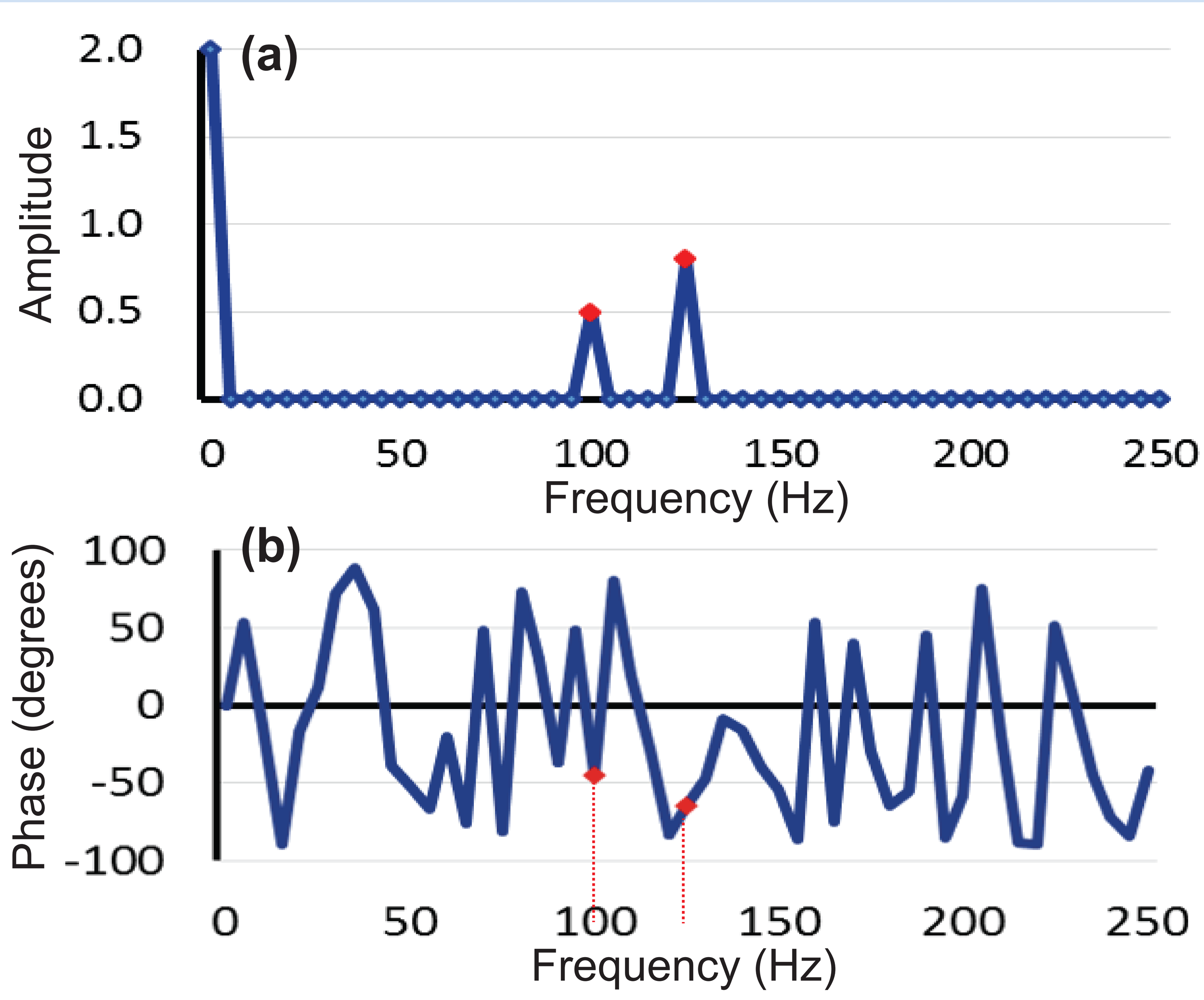

Fig. 10. Calculation processes after DFT

(a) Calculation of amplitudes

(b) Calculation of phases (Red dots indicate the only two frequencies that execute DFT)

Implementation

1. The MPS is composed of a signal source with three mutually orthogonal coils and an Arbitrary Waveform Generator (AWG), which is composed of amplifiers and an MCU to generate phase-quadrature signals〔Fig. **11**〕.
2. The object being detected uses a magnetometer to receive the rotating magnetic field strength signals.

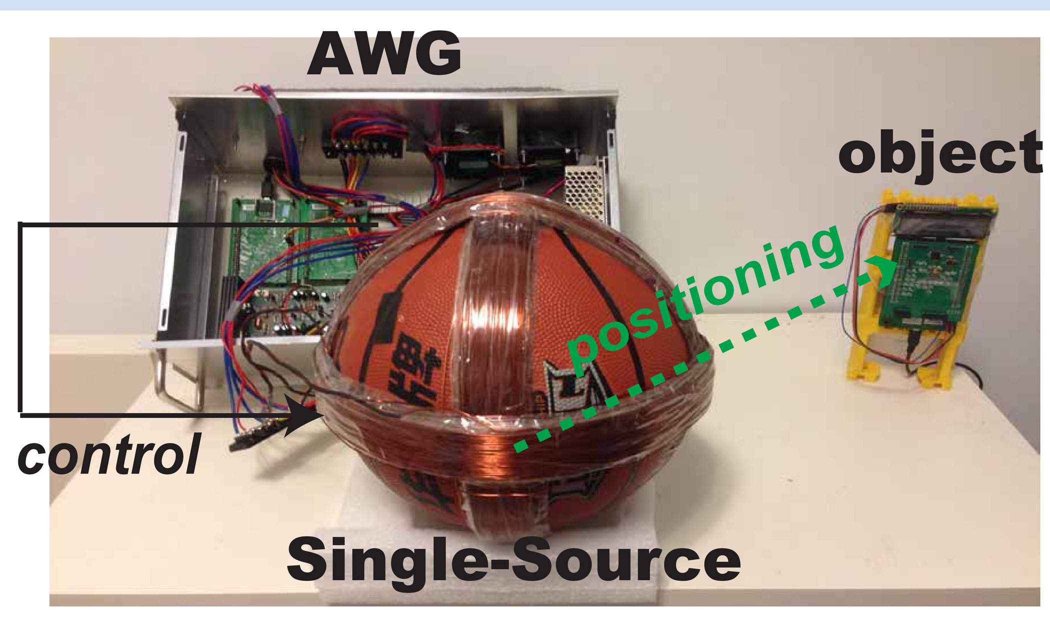

Fig. 11. MPS system prototype