UNIVERSITI TEKNOLOGI MARA

DESIGN AND ANALYSIS OF AXIAL MODE HELICAL ANTENNA FOR UNDERWATER COMMUNICATION SYSTEMS AT 433 MHZ IN FRESHWATER ENVIRONMENTS

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ABSTRACT

The underwater environment includes both seawater and freshwater areas, where reliable communication systems are essential for practical applications such as remote sensing, environmental monitoring, aquaculture, and surveillance operations in lakes and rivers. These applications demand dependable short-range communication systems, with antenna performance playing a critical role. However, previous studies have been limited to basic experimental data on propagation attenuation and low-gain antenna configurations. Practical implementations involving high-gain antennas and validated radio link design equations for underwater use, particularly in freshwater, remain unclear. Motivated by the need to enhance short-range underwater communication, this research investigates the development of high-gain antennas for freshwater applications. The study systematically examines the effects of signal reflection and refraction due to varying water conditions to understand propagation behaviour and signal attenuation. A radio link design equation, specifically developed and validated for freshwater environments, is proposed to serve as a reliable model for analysing and improving underwater signal transmission. In this research, freshwater is characterized by a conductivity of 0.06 S/m and a relative permittivity of 76, and these values were used during the antenna design calculations as they significantly influence electromagnetic wave propagation and antenna performance. The research focuses on improving communication in freshwater environments over distances ranging from 0.5 to 3 meters. A frequency of 433 MHz from the ISM band is selected. For a high gain antenna, an axial mode helical antenna of seven turns is used. It was chosen for its ability to provide directional radiation and circular polarization in underwater conditions. The use of directional antennas provides higher gain and circular polarization, improving link stability even when slight misalignments occur. The antenna is enclosed in a polyethylene terephthalate (PET) capsule to prevent direct contact with water and ensure mechanical stability. To minimize signal loss and detuning effects, the capsule is filled with distilled water, which has near-zero conductivity and provides a suitable low-loss medium. This design approach enables effective antenna gain, and results show a gain of 9 dBi with an end-fire radiation pattern, indicating strong performance for short-range underwater communication. The study compares the degradation in power density over distance between electromagnetic (EM) simulations and theoretical predictions. The radio wave propagation method, incorporating the Friis equation, is used to analyse signal attenuation and validate the link design equation under both deep and shallow freshwater conditions. Experimental measurements conducted in a 1.2-meter-deep swimming pool support the simulation findings, with water surface reflections identified as a contributing factor to signal variation. In conclusion, this study advances underwater communication by presenting a high-gain antenna design and a validated link design model adapted for freshwater environments, offering improved system performance, accuracy, and reliability.

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CHAPTER 1
INTRODUCTION

1.1 Research Background

Wireless transmission is important either in normal terrestrials or underwater network. It provides connection and allows the energy transmission to be more flexible, efficient, and convenient regardless of the obstacle surrounding the network. This technology can contribute to various benefits in terms of underwater environmental monitoring, oil and gas exploration, surveillance operation and military. Communication between submerged devices or sensors can be established without the use of physical cables. Underwater wireless communications refer to transmitting data in an unguided water environment by wireless carriers including acoustic, radio frequency (RF), and optical waves. However, it is crucial to carefully evaluate the primary challenges related to signal attenuation, multipath propagation, limited data rate, and other constraints during the design process.

Underwater wireless communication presents unique challenges due to the harsh environment and the distinct properties of water compared to terrestrial communication systems. The attenuation of electromagnetic energy intensity in water is primarily influenced by two physical processes, absorption, and scattering. Absorption occurs when electromagnetic waves interact with the water's molecules and dissolved substances, converting energy into heat. Scattering takes place when electromagnetic waves encounter particles, bubbles, or other irregularities in the water, causing the energy to be redirected in various directions. Both processes contribute to the reduction in signal strength as electromagnetic waves propagate through the water, with their impact varying based on water composition, salinity, and turbidity.

Underwater communication can be categorized into two primary classifications depending on the water type: seawater and freshwater. Seawater communication utilizes acoustic, optical, and radio wave technologies to transmit data and information underwater. Wireless technology in underwater communication can provide many advantages for the military, scientific mission, oceanographic observation, bioenvironmental studies, marine archaeology, and commercial mission such as in fishery and aquaculture activities [1]. Underwater communication requires intense