Experiments with Electrically Short Antennas and Low Power in the Low Frequency Band

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December 23, 2014

In Re: 0893-EX-PL-2014

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Abstract

This experiment examines the effectiveness of electrically short antennas using ground wave propagation, signal processing and digital communication techniques under low power conditions. Our objective is to determine how far a signal can propagate when a low power transmitter drives an inefficient antenna on the low frequency band.

Keywords: Radio, amateur, communication, LF

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Introduction

Delegates to the International Telecommunication Union's World Radiocommunication Conference (WRC-07) agreed to a secondary allocation of 135.7 kHz to 137.8 kHz (LF Band) to the Amateur Radio Service in 2007. Outside this allocation, the band 130 kHz to 148.5 kHz has primary users in the Maritime Mobile Service and the Fixed Service. The main users are naval one-way transmissions and radiolocation systems (Contributors, 2200-Meter Band, 2014).

Nations in all three ITU Regions have incorporated the WRC-07 agreement by allocating spectrum for amateur use, most notably European nations within the framework of CEPT/ERC Recommendation 62-01 E. In ITU Region 2, Canada granted privileges to amateurs in December 2009 while the Federal Communication Commission demonstrated intent to authorize the band to amateurs in the United States in November 2012 (Federal Communications Commission, 2012). The Commission has granted experimental licenses for both the LF Band and the MF Band allocation near 500 kHz in the interim.

This document is part of an application for an Experimental License Grant issued under Part 5 of the Federal Communication Commission's Rules. The application requests a 24-month grant to Brian S. McDaniel, an individual citizen of the United States, for purposes of radio propagation experimentation described herein.

Purpose of the Experiment

The purpose of this experiment is to examine the effectiveness and practicality of electrically short antennas using ground wave propagation, signal processing, and digital techniques and protocols under conditions of low effective radiated power. The experiment will investigate propagation of ground wave daytime mode conversion, ionosphere nighttime mode conversion, the effects of low power on ground dipoles, and the application of models to forecast radio propagation conditions in the LF Band. The applicant proposes the use of amplitude-shift keying and frequency-shift keying methods, horizontal electric dipole antennas, and Transmitter Power Output (TPO) below 5 watts.

Characteristics, Advantages and Uses

Professional propagation researchers generally agree that propagation between 50 kHz and 150 kHz is different than both the bands above and below that region (Craig & Melia, 2005). The lower frequencies, radio frequencies between 3 kHz and 30 kHz, propagate by Earth-ionosphere waveguide mode between the ground and the ionosphere, fading above 30 kHz and ending above 60 kHz (Thierry, 2003). The LF Band has a substantial ground wave service area, with the wave front being bent to follow the curvature of the Earth to some extent. In daytime, there is an absorbing ionized region, formed by the photo-dissociation, which corresponds to the D-layer between 50 km to 90 km above the Earth's surface (Craig & Melia, 2005). Ground waves are subject to less attenuation and sky waves are less affected by ionospheric conditions and disturbances. These characteristics make the region especially favorable for communication (Martin & Carter, 1961).

Experimentation

In his seminal work, *Extremely Low Frequency (ELF) Propagation Measurements Along a 4,900-km Path*, Lawrence Ginsberg measured the amplitude of a Continuous Wave signal transmitted from North Carolina to receiving sites located in New York State, Labrador, and Iceland (Ginsberg, 1974). Ginsberg designed his experiment to obtain the maximum amount of all-daylight path propagation data possible at that time of year. The ELF transmitters were on frequencies of 78 and 156 Hz, using high TPO into a pole line antenna array.

In Ginsberg's original experiment, transmitters emitted large amounts of power into an antenna supported by power poles similar to electric power lines. Ginsberg measured field strength at each of the three sites. His work later influenced Project Sanguine in 1969 where the United States Navy experimented with ELF systems near Clam Lake, Wisconsin (Coe, 1996). The first Sanguine experiment utilized a horizontal electric dipole, a specialized radio antenna that consists of two ground electrodes buried in the earth and separated by hundreds of kilometers (Contributors, Ground Dipole, 2014).

This experiment follows in Ginsberg's footsteps but with variations that take into account the advances in technology nearly 50 years later. The first variation will focus on transmitter power; the second on transmitter waveform.

Transmitter Power

The main disadvantages of the LF Band are the high cost and practical difficulties associated with the construction of radiators having dimensions appreciable with respect to the wavelength (Martin & Carter, 1961). A half-wave dipole for 136.75 kHz, for example, is over a kilometer long. The size of such an antenna dictates that the largest practical antennas for the LF Band are electrically short as a result. Because an electrically short antenna is smaller than the wavelength of the wave it radiates, antenna efficiency also drops. The final result is that an electrically short antenna only radiates a tiny fraction of the input power supplied by a transmitter.

To compensate for loss of antenna efficiency, both primary and experimental users employ techniques such as driving high TPO into an inefficient antenna. It is not uncommon to find experimental stations where TPO is in excess of 100 watts while Effective Radiated Power is near 5 watts. The purpose of these techniques is to achieve long distance communication during a variety of atmospheric conditions.

This experiment will take the opposite approach; driving low TPO into an antenna. Our objective is to determine how far a signal will propagate when we drive low TPO into inefficient antennas such as the horizontal electric dipole, spiral top-loaded antenna, and the helical antenna. We will examine signal strength at various locations within a 50 km zone surrounding the fixed transmitter location, accumulate data, and statistically analyze the data to determine practical methods to communicate using ground-wave techniques.

Transmitter Waveforms

As we continue to overcome the practical difficulties of the transmission system outlined above, our attention now turns to the information carried by the signal. Transmitter waveforms during the Ginsberg era overcame the signal-to-noise ratio with lower baud rates at higher power. Modern experimenters employ waveforms specifically designed to probe potential propagation paths with low-power transmission. In this experiment, we will employ two wave forms; the Ginsberg-era mode called *Amplitude-Shift Keying*, and a modern digital technique called *WSPR-15*.

Amplitude-Shift Keying

Ginsberg's original experiment employed a transmission technique similar to the extremely slow Morse code technique QRSS used in the Amateur Radio Service today. Where Ginsberg's transmission cycle was one (1) hour with a carrier on and thirty (30) minutes with a carrier off, the QRSS technique sends Morse code where the speed of a single "dit" lasts between three (3) and one-hundred-and-twenty (120) seconds. In our base-line experiment, we will employ the QRSS technique using *Amplitude-Shift Keying (ASK)*.[1] Our goal is to recreate Ginsberg's experiment in a faithful manner yet under low power conditions.

ASK is a form of amplitude modulation (AM) that represents digital data as variations of a carrier wave. Like other AM waveforms, ASK is sensitive to atmospheric noise, distortions, and propagation conditions. We can compensate for these deficiencies by employing extremely slow switching rates between binary states in order to decrease signal-to-noise ratios in the LF Band. This Off-On Keying technique is more spectrally efficient than frequency-shift keying.

The entire message would consist of the call sign of the station as assigned by the Commission under this application. All signals are one-way transmissions.

WSPR-15

WSPR-15 is a data telemetry protocol designed for probing potential propagation paths with low-power transmissions. The protocol compresses information using a convolutional code with a long constraint length. The long constrain length makes undetected decoding errors less probable, thus allowing receiving stations to decode emissions with signal-to-noise ratios as low as -28 dB in a 2,500 Hz bandwidth.

The experiment will employ a fifteen (15) minute transmit and receive cycle.[2] This slow cycle should improve sensitivity over the traditional two (2) minute WSPR cycle used in the Amateur Radio Service on medium frequency and high frequency bands.

The entire message would contain the station's call sign as assigned under this application; the Maidenhead grid location[3] of the transmitter; and the transmitter power, stated in dBm. All signals are one-way transmissions.

[1] Emission Designations for this experiment are 1H67A1B, H600A1B, H200A1B, H100A1B, and H050A1B. Transmitter Power Output shall not exceed 5 watts in any ASK experiment.

[2] Emission Designators for this experiment are 6H00J7B and 6H00F1B. Transmitter Power Output shall not exceed 5 watts in any WSPR-15 experiment.

Equipment

Low frequency transmissions require specialized, usually custom-made, equipment. Because of the time frame of this application, we desire to maximize the amount of time available for over-the-air experimentation. As a result, we will utilize the Raspberry Pi, a credit-card sized computer, as the transmitter; custom low-pass filters to regulate transmitter operating frequency; and software to produce and manage the waveforms in this experiment. This transmission system allows us to focus on the development of our antenna network.

Horizontal Electric Dipole

A ground dipole consists of two grounded electrodes buried in the earth, separated by a distance, and linked by overhead transmission lines to the transmitter. We will experiment with a variety of designs, materials, and configurations; focusing on practical uses for this impractical and electrically short antenna.

Spiral Top-Loaded Antenna

Alan Melina and Finbar O'Connor developed an efficient LF Band antenna for use in a limited space. The top-load of the antenna has both an inductive and capacitive component. Despite the limited dimensions of the antenna, Melina and O'Connor successfully brought it to resonance on 136 kHz with a relatively small loading coil (Strobbe, 2009). In correspondences with O'Connor, the applicant discussed methods to improve performance with various material and design techniques.

Helical Antenna

A helical antenna consists of a conducting wire wound in the form of a helix and mounted over a ground plane. The feed line is connected between the bottom of the helix and the ground plane with part of a loading coil mounted in the vertical section of the antenna.

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[3] Maidenhead grid location is a geographic co-ordinate system used in the Amateur Radio Service.

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