MEDIUM FREQUENCY PROPAGATION PREDICTION TECHNIQUES AND ANTENNA MODELING FOR INTELLIGENT TRANSPORTATION SYSTEMS (ITS) BROADCAST APPLICATIONS

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This paper discusses the basic aspects of radio-wave propagation and antenna modeling in the medium frequency (MF) band. This band covers the frequencies of 300 to 3000 kHz. More specifically, we are concerned with the ground wave and the sky wave in the 300 kHz to 1705 kHz band. The sky wave models described in this paper are valid from 150 kHz to 1705 kHz. The ground wave models described in this paper are valid from 10 kHz to 30 MHz. The AM Broadcast band of 535 to 1605 kHz is in this band and is planned to be used in the Advanced Traveler Information Systems (ATIS) of Intelligent Transportation Systems (ITS) for rural travelers. This system would provide information such as road conditions, road hazards, weather, and incident reporting. The 285 kHz to 325 kHz band is presently being used for a differential correction signal in another application of ITS called the Differential Global Positioning System (DGPS) that will be used for precision location of vehicles. The propagation of radio waves in this band depends on both a ground wave and a sky wave and is quite different from propagation at any other frequency. Antenna modeling in this band is also quite unlike that in other bands. This paper describes radio wave propagation together with antenna modeling in this frequency band so that a better understanding of the phenomena can be obtained for use in design and application of ITS subsystems. The models described here can be used for designing systems and making performance predictions for both of these ITS applications and any other systems that operate in this band. The paper contains descriptions of both sky-wave and ground-wave propagation models in addition to the methodology used to analyze antennas that operate in this band. A method of calculating and normalizing antenna gain for MF systems computations is also discussed. Some comparisons of measured and predicted data are also contained in the descriptions.

Keywords: radio-wave propagation, antennas, communications, intelligent transportation systems

1. INTRODUCTION

This paper contains discussions about radio-wave propagation and antenna analysis in the medium frequency (MF) band and how analysis methods differ from those used in other frequency bands. The MF band covers the frequencies of 300 to 3000 kHz. Actually the sky-wave propagation models are also valid down to 150 kHz, and the ground-wave model is valid down to 10 kHz. The paper specifically addresses two applications of Intelligent Transportation Systems, but this material is

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useful for other systems that operate in this band. Radio-wave propagation prediction models, that can be used for engineering analyses of communication systems, determine the basic transmission loss between a communications transmitter and receiver. This knowledge is necessary for the prediction of the behavior of separate functional communication subsystems of the Intelligent Transportation System (ITS) and other systems operating in this band. This knowledge can be used for planning, architectural evaluation, system performance prediction, system design and testing, interference resolution, and standards development. The AM Broadcast band of 535 to 1605 kHz is in this band and is planned to be used in the Advanced Traveler Information Systems (ATIS) of ITS for rural travelers. This system would provide information like road conditions, road hazards, weather, and incident reporting. The subsystems of ITS use computer and telecommunications technology to provide information to travelers about road and transit travel conditions and also provide information to monitor, guide, and control the operation of vehicles. ITS can improve safety, reduce congestion, enhance mobility, minimize environmental impact, save energy, and promote economic productivity on the Nation's transportation system. The 285 kHz to 325 kHz band is presently being used for a differential correction signal in another application of ITS called the Differential Global Positioning System (DGPS) that will be used for precision location of vehicles. The DGPS signals in this band are used to differentially correct the location determined by the Global Positioning System (GPS) navigation system. Each DGPS site processes information from the GPS satellite signal to calculate the location. The DGPS site then compares this location to its exact fixed location and sends out a correction signal at 300 kHz for others to obtain a more precise location calculation than originally available from the L-band GPS satellite signals.

Propagation models that are used to analyze radio communication systems require sound engineering judgement in their use for a particular analysis. For the MF band of 300 kHz to 3000 kHz both the ground wave and the sky wave must be considered. The propagation of radio waves in this band depends on both a ground wave and a sky wave and is quite different from propagation at any other frequency. Antenna modeling in this band is also quite unlike that in other bands. The expected sky-wave signal combined with the ground-wave signal may be compared with the expected radio noise environment (consisting of atmospheric, galactic, and man-made noise components) to predict the likelihood that the communication link will operate satisfactorily. The presence of the sky wave at night could create potential interference problems between distant stations on the same frequency or frequencies that are near each other. The sky-wave models provide some means of estimating the expected field strengths of signals to assist in frequency allocation and to avoid potential interference problems. Free space loss cannot be used to characterize radio-wave propagation at these frequencies. Other propagation models must be used to predict radio-wave propagation correctly. The ground-wave prediction methods presented here are valid from 10 kHz to 30 MHz.

The sky-wave propagation loss prediction methods discussed in this paper are valid from 150 kHz to 1705 kHz. Above 1705 kHz and below 150 kHz there are different sky-wave propagation phenomena that take place and other methods must be used which are not included in this paper, since our current attention focuses on frequencies around 300 kHz and the AM broadcast band.

This paper will describe analysis techniques and propagation models used in this frequency band and will give examples of comparisons of predictions and measurements. Use of the appropriate antenna gains with the propagation models is also essential to accurate performance prediction. This paper will also explain how antenna gains are determined at these MF frequencies to predict system performance correctly. A method of calculating and normalizing antenna gain for systems computations has been proposed. Antenna modeling examples will be presented for the average frequency of 300 kHz used for DGPS, and the 760 kHz test frequency used for the AM subcarrier Advanced Traveler Information Systems (ATIS) test program.

2. BASIC CONCEPTS IN RADIO-WAVE PROPAGATION

In all of the radio-wave propagation concepts that are discussed, it is assumed that the propagation is taking place in the far field of the transmitter and receiver antennas. If a point source radiates power with a transmitter antenna that has a directional gain, then the received power for a receiver antenna is given by the following [1-4]:

$$P_r = P_t + G_t + G_r - L_{fsb} \qquad (dBm) \tag{1}$$

where P_r and P_t are the received and transmitted powers respectively in dBm, and G_r and G_t are the receiver and transmitter antenna gains respectively in dB. L_{fsb} is the free-space basic transmission loss in dB and is given by the following [5]:

$$L_{fsb} = 32.45 + 20\ \log(f_{GHz}) + 20\ \log(r) \qquad (dB) \tag{2}$$

where f_{GHz} is the frequency of the radio wave in GHz and r is the distance between the transmitter and receiver in meters. Free-space loss is a theoretical reference or limit, against which the actual basic transmission loss L_b can be compared or expressed as a ratio.

Equation (1) can be used to calculate the received power for a transmitter and receiver located in free space. Free space is a highly idealized environment and is not the situation for ITS propagation channels. In the ITS environment there is at least a conducting ground to consider and in many situations the wave may have to propagate through a very complicated environment. For example, the energy may have to propagate: through or be reflected from precipitation, through an atmosphere with oxygen and water vapor, through buildings, around corners, down side streets, into and around wooded areas, and over rough terrain. For radio-wave propagation at MF the loss due to precipitation or atmospheric absorption by water vapor or oxygen is negligible, but the signal must still diffract around obstacles in the environment. Radio-wave propagation at frequencies between 150 kHz and 1705 kHz depends on both a ground wave and a sky wave. Neither of these two wave-propagation phenomena behave like free-space loss. In this type of environment the received signal can be expressed by the simple equation given in (1) if the free-space basic transmission loss L_{fsb}