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}

were replaced by the basic transmission loss L_b computed by propagation models that take all of these propagation effects into account. Basic transmission loss is the transmission loss that would occur if the transmitter and receiver antennas were replaced by ideal isotropic loss-free antennas with the same polarization as the real antennas [3,4].

This paper describes the different types of radio-wave propagation phenomena and antenna behavior that must be considered for general radio-wave propagation models in the roadway environment in the MF band. Radio-wave propagation prediction models generally compute basic transmission loss L_b which is combined with antenna gains and transmitter power to perform engineering analyses of communication systems.

3. GROUND-WAVE PROPAGATION

The ground-wave signal can be determined using one of several models [6,7] that specifically address the propagation phenomena at these frequencies. One general ground-wave model [6] computes propagation loss, electric field strength, received power, noise, received signal-to-noise power ratio, and antenna factors over lossy Earth. The smooth-Earth and irregular-Earth (terrain dependent) propagation loss prediction methods within this model can be used over either homogeneous or mixed paths. This model combines three propagation loss prediction methods for both smooth and irregular Earth, and an antenna algorithm into a single analysis tool. The propagation loss prediction methods for the ground-wave model compute basic transmission loss and are valid from 10 kHz to 30 MHz. A model that incorporates the sky wave with the ground wave [7] specifically addresses the 150 kHz to 1705 kHz frequency range. The frequency limits of this model have been set by the valid frequency range of the sky-wave model. This model was previously available on a mainframe computer but now operates in a Windows environment on a PC.

The ground wave includes the direct line-of-sight space wave, the ground-reflected wave, and the Norton surface wave that diffracts around the curved Earth. The Norton surface wave will hereafter be referred to as a surface wave in this paper. Propagation of the ground wave depends on the relative geometry of the transmitter and receiver location and antenna heights. The radio wave propagates primarily as a surface wave when both the transmitter and receiver are near the Earth in wavelengths, because the direct and ground-reflected waves in the space wave cancel each other and as a result the surface wave is the only wave that is left. This cancellation is a result of the fact that the elevation angle is zero and the two waves (direct and reflected) are equal amplitude and opposite in phase. This is the condition that exists for the MF band. The surface wave is predominantly vertically polarized, since the ground conductivity effectively shorts out most of the horizontal electric field component. What is left of the horizontal component is attenuated at a rate many times that for the vertical component of the field. When one or both antennas are elevated above the ground to a significant height with respect to a wavelength, the space wave predominates.

The ground-wave propagation phenomena at these frequencies are basically deterministic processes. The noise, however, is a stochastic process. The surface wave propagates along and is guided by the Earth's surface. This is similar to the way that an electromagnetic wave is guided along a