Optimal Receiver for Polarization Based Estimation of Angle of Arrival at HF band

Mani Kashanianfard*[1], Kamal Sarabandi[1]
University of Michigan, Ann Arbor, MI 48105

Short dipole and small loop antennas are the oldest radiating elements that have appeared in myriads of different configurations for many applications. One such application has been in source tracking and direction finding. In the receiving mode, these elements can be used as electric and magnetic field probes. That is, under high impedance termination, the voltage at the antenna terminal can be used to determine the intensity of the field components at a given orientation. Neglecting the multi-path effects, five independent field components (e.g. three components of the electric field and two components of the magnetic field) are required to uniquely determine the field direction of arrival; however, in multi-path environments, more field components will be needed. Small loops and dipoles are commonly used for direction finding in the HF band within the frequency range of 1MHz to 10MHz. At these frequencies, the size of the probes is relatively large (1m-5m). Therefore, placing multiple dipoles and loop antennas close to each other would require a large space. In addition, accurate direction finding requires all field components to be measured at the same point which means the probes need be co-located. Due to physical constraints and interference effects, co-locating loops and dipoles that are oriented in different directions is impractical. To mitigate the aforementioned problems, two-port loop antenna configuration is proposed. This antenna is configured to have two ports and is capable of simultaneously measuring one component of electric and magnetic fields. Three such probes are sufficient to measure all six field components provided that the two-port loops are placed orthogonal to each other at the same location.

Recently, a circuit model for the two-port loop antenna was introduced (M. Kashanianfard and K. Sarabandi, IEEE Trans. Antennas Propag, vol. 65, pp. 114-120, Jan. 2017). The model was shown to be capable of estimating the received voltages at the antenna terminals for an arbitrary incident field. However, the ohmic losses and the mutual coupling between the orthogonal antennas were neglected. It was shown that as the size of the antenna increases, the accuracy of direction of arrival estimation decreases due to the high-order effects related to derivatives of the incoming fields. On the other hand, decreasing the size of the antenna reduces the received voltages for the same incident field and in turn, reduces the sensitivity and noise tolerance of the system. In this paper, an optimal range for the size of the loop antenna based on a compromise between the sources of inaccuracies is proposed. The noise performance of two-port loop antennas for matched and open-circuit terminations is evaluated and it is shown that the signal to noise ratio of an impedance matched antenna with the radiation efficiency of η can be improved by a factor of $1/\eta$ if a high-impedance termination is used. A number of high-impedance amplifier configurations based on high-speed op-amps are considered and compared with designs based on RF amplifiers. Expressions for the received voltages at the terminals of three orthogonal and co-located two-port loop antennas are derived for an incident filed with an arbitrary polarization and angle of arrival. The high-order effects, as well as the mutual coupling between the antennas, are considered and an iterative method for estimating the angle of arrival and the polarization of the incident field based on the received voltages is proposed.