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Calibration of antenna arrays for aeronautical vehicles on ground

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ABSTRACT

Antenna pattern and characteristics change significantly when antenna arrays are placed on platforms like aeronautical vehicles. Calibration of antenna arrays is an important and costly process for such cases. In this paper, a method is proposed for the offline calibration of a direction finding antenna array mounted on a UH-60 helicopter. The calibration is done on an open-field test area with a flat ground plane. Ground reflections are the main sources of error corrupting the calibration data. The proposed method eliminates the ground reflections by employing a time-gating technique. Calibration data is generated by considering the platform effects. Complete calibration scenario is simulated by using numerical electromagnetic simulation tools. It is shown that the proposed approach is very effective and can be used to calibrate direction finding algorithms like the MUSIC algorithm.

1. Introduction

Calibration of antennas mounted on aircrafts is a challenging task. Antenna arrays for direction finding (DF) are usually designed and tested in isolated environments such as the anechoic chambers [5]. When these arrays are placed on platforms like UAVs (Unmanned Aerial Vehicles), planes or helicopters, scattering, reflection and diffraction from the platform change the response of the antenna array for the incoming source signal [16]. Therefore antenna array should be calibrated while it is mounted on the platform. This task is a nontrivial, time consuming, sensitive and costly process. The motivation of this paper is to propose a method to simplify this procedure decreasing the cost and time duration as well as increasing the accuracy.

There are two major ways of calibration for the antenna arrays mounted on aeronautical platforms. In the first approach, calibration is performed when the platform is on the air flying over a predetermined course [17]. The standard approach for on-the-air calibration is to fly the vehicle in a circle above a transmitting antenna with a low depression angle and collect the calibration data for every five degrees and for a range of frequencies. This process has several limitations since the airplane cannot keep a steady depression angle and flying course due to several factors such as meteorological conditions and dynamics of the flight. This is also a very costly and time consuming process.

The second approach for calibration is to use an anechoic chamber where the aircraft is placed together with a transmitting antenna positioned away from the aircraft as far as possible [5]. This approach has also serious limitations. It is costly and difficult to build such an anechoic chamber which should have a large volume to take an aircraft inside. In fact, there are only a few examples of such chambers. Furthermore, these sites cannot be used for accurate characterization of platform effects on the antenna array especially for low frequencies. An alternative to anechoic chamber is to use an open-field test area [3]. In this case, there is a strong multipath from the ground plane. Electromagnetic absorbers can be used to decrease ground reflections [22]. This also has limitations since absorbers designed for a large frequency span (i.e. 50 MHz–1 GHz) are difficult to construct and they are costly.

An alternative approach to inside the anechoic chamber calibration is to use a scaled mock-up for the aircraft and install the antenna array on this structure [10]. This approach has certain limitations as well. The antenna array mounted to the mock-up should also be scaled appropriately and manufactured with high precision. Otherwise, the measurements do not completely reflect the practical case. One of the most convenient and cost effective analysis technique for installed antenna performance prediction is to use numerical electromagnetic simulation tools [6].

Calibration of antenna arrays for direction finding purpose is investigated for airborne platforms in the literature. The performance of the DF antennas is investigated in [8] and [4] without considering the multipath from the ground which causes large errors. In [8], DF performance is evaluated for antenna array mounted on a UAV. In [4], calibration is directly performed by using the comparison of the measured data and the simulation results which include

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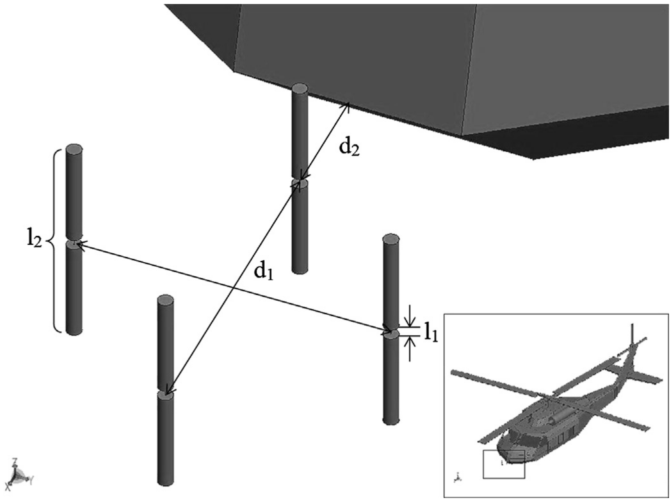

Fig. 1. The antenna array is composed of four dipoles mounted in front of a UH-60 helicopter.

the platform effects and mutual coupling. Ground reflection is an important source of error in calibration. The effect of ground plane is investigated in [1] for monopole antenna arrays.

In this paper, a new method is proposed to calibrate the DF antenna arrays on ground for the aeronautical vehicles. Ground reflections are removed from the calibration data using a time-gating approach. While time-gating is a well-known method for antenna measurements [11], it has not been used for DF array calibration mounted on aeronautical vehicles before. Calibration process is implemented on a facility where the vehicle is elevated over the ground plane and the transmitting antenna is placed on an appropriate distance from the vehicle. The selection of this distance and vehicle height becomes important factors as it is expressed in the following parts of this paper. The main problem of over-the-ground calibration is the ground reflections. These reflections alter the received signal significantly and the collected data is usually useless without appropriate corrections. When time-gating method is used, reflection-free calibration data is obtained for direction finding. The proposed method is evaluated when the DF array is mounted on a UH-60 helicopter, using a numerical electromagnetic simulation tool, FEKO [9]. The platform effects are considered and a composite calibration matrix is used for direction finding. The results show that the proposed approach is very effective. It presents several advantages compared to previous approaches. The cost of the proposed approach is significantly lower since the method is performed in an open field. The size of the aircraft does not pose a major problem in general. The time and manual labor involved is lower than the alternatives especially over-the-air calibration. The method also allows the correct characterization of platform effects on the DF array since the transmit antenna can be positioned at a large distance. The method is essentially performed in time and the calibration data for any frequency can be obtained easily. Overall accuracy of the method is good which leads to an effective calibration technique in practice.

2. Test setup and problem description

In this paper, offline calibration of a DF antenna array mounted on an aeronautical vehicle is considered. More specifically, a UH-60 helicopter is selected as the platform. A four element dipole antenna array is mounted in front of the helicopter as shown in Fig. 1. The array is a uniform circular array (UCA) with the antenna and array dimensions given in Table 1. The target is to obtain the calibration data for the antenna array so that the DF algorithms work with good accuracy.

Table 1
Antenna array dimensions.

Array diameter	d_1	0.4242 m
Distance from the platform	d_2	0.1 m
Length of the dipole	l_1	0.05 m
Gap for the dipole	l_2	0.3 m
UCA radius	r	0.2121 m

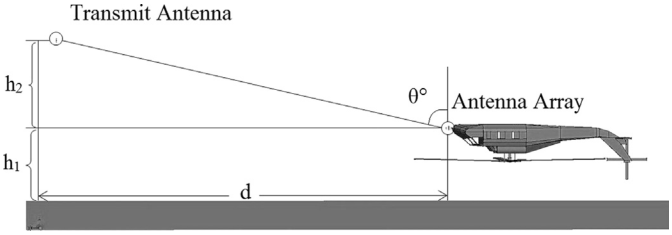

Fig. 2. The open-field test area and platform placement.

Table 2
Calibration and test setup parameters.

Height of the helicopter over the ground	h_1	16 m
Height of the transmitter	h_2	24 m
Horizontal distance of transmitter	d	100 m
Elevation angle	θ	76.5°

The open-field test area and platform placement is shown in Fig. 2. Test facility is considered as a 200 m × 200 m open-field with a flat ground plane. It is assumed that there is no obstacle in the near vicinity of the test field which may cause additional disturbances. The helicopter is elevated above the ground and flipped upside down so that a similar condition for a source emitting from the ground to the airborne vehicle is generated. The transmitting antenna is elevated to a height so that sufficient elevation for the calibration is obtained. The transmit antenna is identical to the array antennas and the parameters for the test field are given in Table 2.

2.1. Problem description and the model

The problem is the calibration of the DF system mounted on a UH-60 helicopter as shown in Figs. 1 and 2. MUSIC algorithm [18] is selected as the DF algorithm. It is known that MUSIC algorithm approaches to the optimum solution asymptotically [21].

There are two problems that should be solved for a satisfactory DF performance. The first and the most important problem is the ground reflections. Ground reflections corrupt the data collected by the DF antennas. The effect of these reflections decreases as the operating frequency increases. Nevertheless, ground reflections are the major sources of error especially in the VHF/UHF (30 MHz–1000 MHz) range. The second problem is the multipath components due to the platform as shown in Fig. 3. Reflections, scattering and diffraction from the platform affect the data collected by the antenna array. MUSIC algorithm does not perform well for antenna arrays mounted on platforms like the one in Fig. 3. In this paper, a method is proposed to eliminate the ground reflections and obtain calibration data to mitigate the platform effects for the MUSIC algorithm.

In the time domain, the output of the ith antenna, $y_i(t)$, can be expressed as the convolution of the antenna impulse response and the source signal, i.e.

$$y_i(t) = h_{i,eff}(p_i, t, \Theta) * x(t - \tau_i) + e_i(t) \tag{1}$$

$p_i = (x_i, y_i, z_i)$ is the antenna position and the direction of arrival (DOA) of the source is $\Theta = (\phi, \theta)$ where ϕ and θ denote the azimuth and elevation angles respectively. $x(t) = Re\{s(t)e^{j\omega_c t}\}$