Calibration of direction finding antennas in complex environment

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Abstract

This paper focus on the generation of calibration tables for direction finding antennas (DFA) using an electromagnetic software. Indeed, calibration table realization for DFA is generally a very long and complex manipulation, depending on angle's precision and number of frequencies. Moreover, in some cases, like DFA on complex carriers (boat, aircraft, helicopter…), it can be a very complex and expensive manipulation. Nevertheless, all interaction types with the carrier must be take into account into the calibration. In the case of an interferometer, this study compares differential phases obtained from simulations and the ones measured on a DFA in the frequency band at 329MHz. We estimate the accuracy of DFA using a simulated calibration table instead of a measured calibration table. The results show that the simulated calibration table permits obtaining results with a great efficiency and saving thus a lot of time, which is very interesting for industrial applications.

1. Introduction

Direction finding antenna (DFA) systems allow to compute the arrival angle of a polarized signal on an antenna array by using a direction finding algorithm. Figure 1 shows the principle of a DFA. According the antenna and/or the application, a DFA uses different algorithms based on signal amplitudes and/or signal phases. In most of the cases, it is necessary to have a calibration table to take into account disturbing elements or phase errors between cables or matching circuits. The environment of the DFA influence directly the direction finding performance [1].

For a differential phases system, the estimation of arrival angle is based on the comparison between the received differential phases and the one from calibration table. However, calibration table is generally constituted by measured phase values which are obtained from very long and expensive operation. For example, for a differential phases system of 5 antennas, 50 frequencies and 90 angles, 22500 measures of phase are needed to realize a calibration table. Nevertheless, these measured values are very difficult to perform in some cases, for example, when the antenna is on the top of a boat or on a aircraft. But the influence of the carrier is not inconsiderable, particularly when the DFA works in V/UHF frequency band.

Contrary to [2] and [3] which use coupling matrix concept or [4] which use near field measurement to calibrate a DFA, in this paper, we propose another way to realize calibration table and to avoid long, complex and expensive operations when the DFA is in a very complex environment. The DFA is modelled by using an electromagnetic software with the best accuracy as we can. This permits obtaining a simulated calibration table by a more simple operation than from measured values. [5] has shown the good results of this calibration's type for complex DFA on mast. In this paper, we focus on DFA on very complex carrier. To estimate the precision of using a simulated calibration table we consider in this study, a DFA constituted of 5 antennas working on the frequency band [200-500] MHz equipped under a helicopter (Fig. 2). Like DFA on vehicles or boats, there are a lot of interactions between the helicopter and the DFA like reflections, diffractions, creeping waves, masking effects or couplings which must be take into account during the calibration. All these parameters can't be take into account with classical computation methods, but an electromagnetic software can consider all of them.

2. Configuration of Simulation

We consider that the antennas are placed under a PUMA helicopter. The 5 antennas are simulated with an electromagnetic software while complex parts like dielectric and metallic parts of the helicopter was built by using

3D modelling software. The draw was done to have a system the most representative of the real one. We have placed a plane wave excitation in vertical polarization all around the system with an excitation every degree.

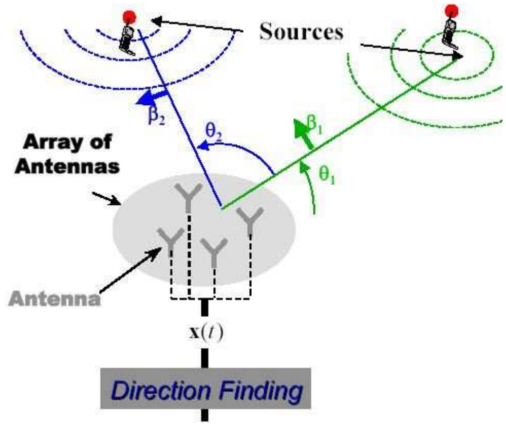

Fig. 1. Principle of a direction finding antenna.

Distributed loads on each antenna have been used to represent charge's impedance of each dipole. After the simulation (Method of Moments), we obtain the current amplitudes and phases on each antenna for every angle and every frequency. According the type of direction finding (DF) to use (amplitudes DF, phases DF, both), it is possible to create a calibration table adapted to the antenna array, taking into account disturbing elements like, reflections, diffractions, creeping waves, masking effects or couplings.

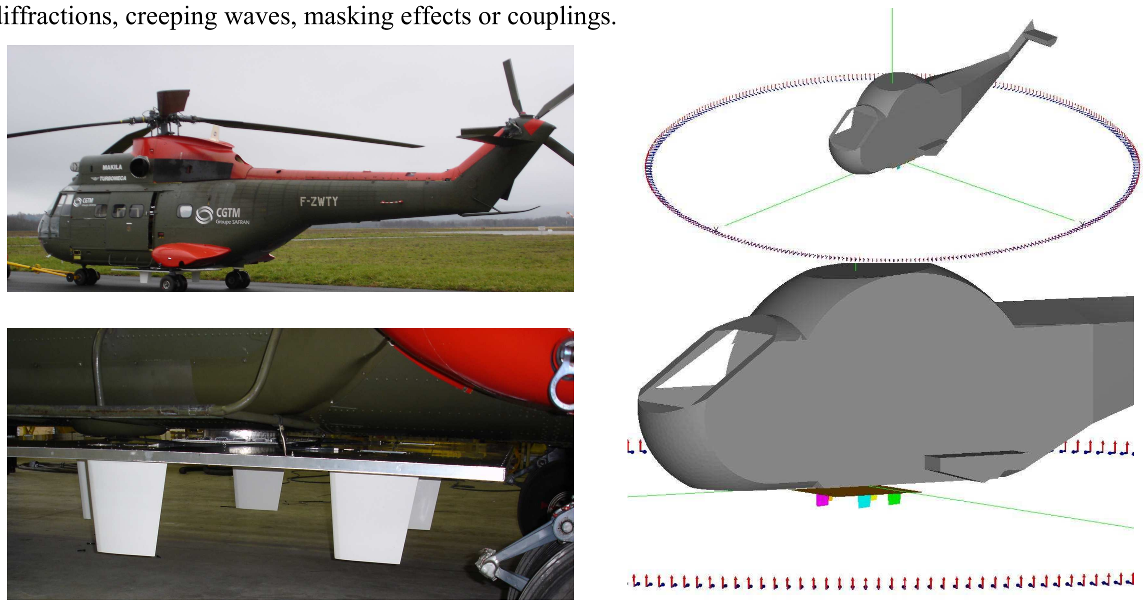

Fig. 2. Configuration of simulation.

3. Direction Finding Notations

After antenna simulation, the next step is to compare simulated results with measured results. The direction finding function (DFF) based on interferometer is defined as below, with values between 0 and 180°:

$$DFF(\theta,F)=\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\Phi_i^{measures}(F)-\Phi_i^{Calibration}(F,\theta)\right)^2} \tag{1}$$

with :

- Φ_i represents the differential phase between 2 antennas of the array.

- θ represents the arrival angle
- F represents the frequency
- N represents the number of antenna, here 5 antennas.

The goal of the direction finding function is to find the angle “θ” which minimizes the function. To estimate the performance of a simulated calibration, we have calculated the direction finding functions for each direction of arrival (DOA) with :

- $\Phi_i^{measured}$ obtained from measured values
- $\Phi_i^{Calibration}$ obtain by simulation.

The principal difficulty is to have an antenna design as real as possible and to place this antenna in real context of utilization. Indeed, taking into account the different disturbing elements into the calibration is the condition to have differential phases closed to the measured ones.

Figure 3 shows the comparison of the 2 direction finding functions as define as above for 329MHz.

(a) **(b)**

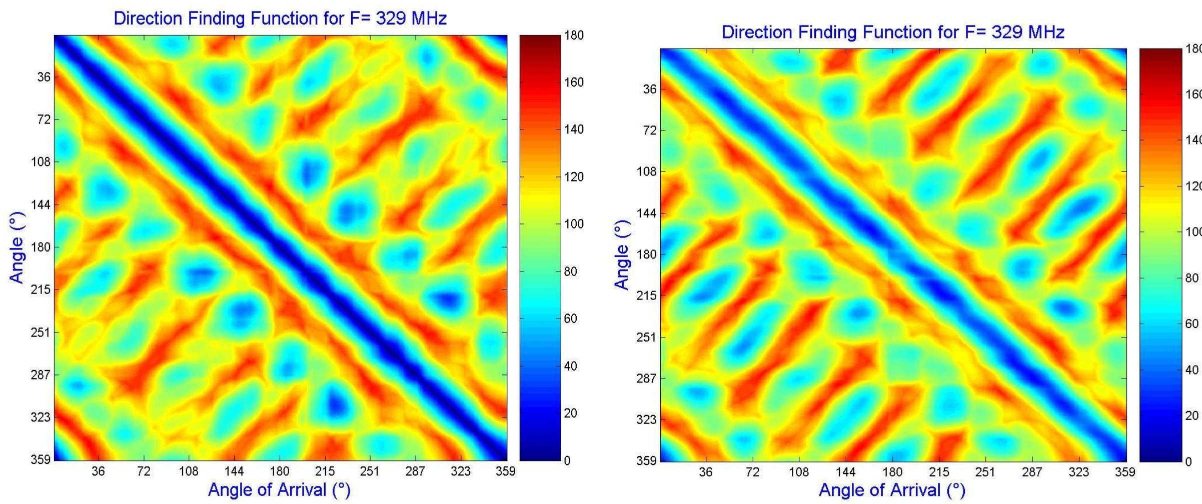

Fig. 3. Direction finding function in function of the angle of arrival for 329 MHz.
a : calibration table measured – **b** : calibration table simulated.

If the calibration is well realized, the DFF has a minimum for the DOA corresponding to the estimated angle. In the perfect case, this minimum is zero. For example, at 329MHz, for a measured calibration table and for an arrival angle of 273°, the DFF is around zero for an estimated angle of 273°. In the case of a simulated calibration table, there is a minimum at 144°. (Fig. 4). We show that however the calibration is, measured or simulated, the DFF gives the same results, i.e., the minimum is for the same angle.

Moreover, to estimate the real performances of a simulated calibration, we compute the root mean square (RMS) error on the angle of arrival. This RMS error is defined as below (2). Its values are between 0 and 180°. The case where the RMS error is zero, is very rare because it’s mean that the measured values, and the ones from calibration table are identical.

$$\Delta_{RMS}(F) = \sqrt{\frac{1}{360}\sum_{i=1}^{360}\left(\theta_{Estimated}^{F} - \theta_{\mathrm{Re}al}^{F}\right)^2} \ . \qquad (2)$$

For a perfect calibration, the RMS error must be around zero. Table 1 compares the RMS error at 329MHz we investigate, in the cases of a simulated calibration table and for measured angles.

Tab. 1. Root mean square error on angle of arrival for 329MHz.

Calibration	Simulations	Measures
RMS Error (°)	1,89	1,59

We can see that with a simulated calibration table, the RMS error is inferior to 2° RMS like with the measured calibration table. Results are very closed.

These results show that there is a very good agreement between measures and simulations. This validates that it is possible to realize a calibration table using an electromagnetic software to tale into account disturbing elements.

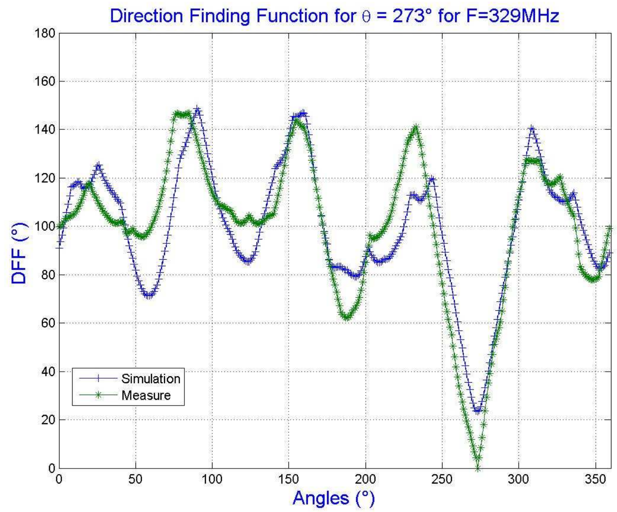

Fig. 4. Example of comparison of the DF function for a angle of arrival of 273° for 329 MHz.

4. Conclusions

In this paper, we have investigated the performance of DFA with simulated calibration table. The calibration table has been obtained from system simulations performed with an electromagnetic software. To insure good accuracy, disturbing elements such as mast, dielectric parts and metallic parts of the antenna's structure and carrier have been taken into account. We have compared the results with those obtained from a measured calibration table, and estimated the precision of the direction finding antenna with a differential phases algorithm. This comparison has shown a good agreement between simulations and measures. This is very interesting for industrial applications, because using a simulated calibration table permits reaching lot of time and reducing complexity of calibration procedure in very expensive cases, for example, when the DFA is placed on a very complex carrier (boat, aircraft…)

5. References

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