Numerical simulation of the BRAMS interferometer in Humain

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The Royal Belgian Institute for Space Aeronomy (BISA) operates a network for radio meteor studies based in Belgium. One of the receiving stations is located in the Humain Radio-Astronomy Station (HuRAS) and consists of an array of five 3-element Yagi antennas. In this paper the results of detailed numerical simulations are presented in order to obtain a first approach for the direction finding capability of this interferometer.

1 Introduction

The Belgian RAdio Meteor Stations (BRAMS) is a point–multipoint network with dozens of radio receiving stations spread all over Belgium recording – under a fairly continuous regime – reflections off meteor trails of a signal generated by a dedicated transmitter located at Dourbes Geophysical Centre, which emits a pure sine wave at a frequency of 49.97 MHz with a constant power of 150 W (Calders and Lamy, 2012). *Figure 1* shows a picture of the beacon's radiating system, consisting of a turnstile antenna and a metallic grid underneath acting as a reflector.

The physical principle, known as forward scattering, states that the ionization trail produced by a meteoroid entering the Earth's atmosphere (meteor) can reflect a radio wave. Any receiver tuned to the transmitter's frequency, in principle, is capable of detecting that signal, also known as meteor echo. Please note that transmitter and receiver are not located in the same place (McKinley, 1961).

Most of the stations are basic receiving systems consisting of a single 3-element Yagi antenna (see *Figure 2*), a single receiver (*ICOM IC-R75*), an amplitude and frequency calibrator (developed at BISA), a GPS clock, a sound card and a PC.

Figure 1 – BRAMS beacon radiating system in Dourbes, Belgium.

In order to obtain reliable information of meteoroids and meteoroid streams, among other parameters, it is important to know the performance of the antenna system regarding the many possible incoming directions of the meteor echo. This three dimensions (3D) map of the antenna performance is known as *Antenna Directional Pattern*. However, this value depends on many factors (antenna geometry, relative position of the antenna and nearby objects/facilities, ground characteristics, etc.) and usually getting reliable figures represents a challenge. Numerical simulations are increasingly being applied successfully, using different methods.

Figure 2 – Typical 3-element Yagi antenna of a BRAMS basic receiving system.

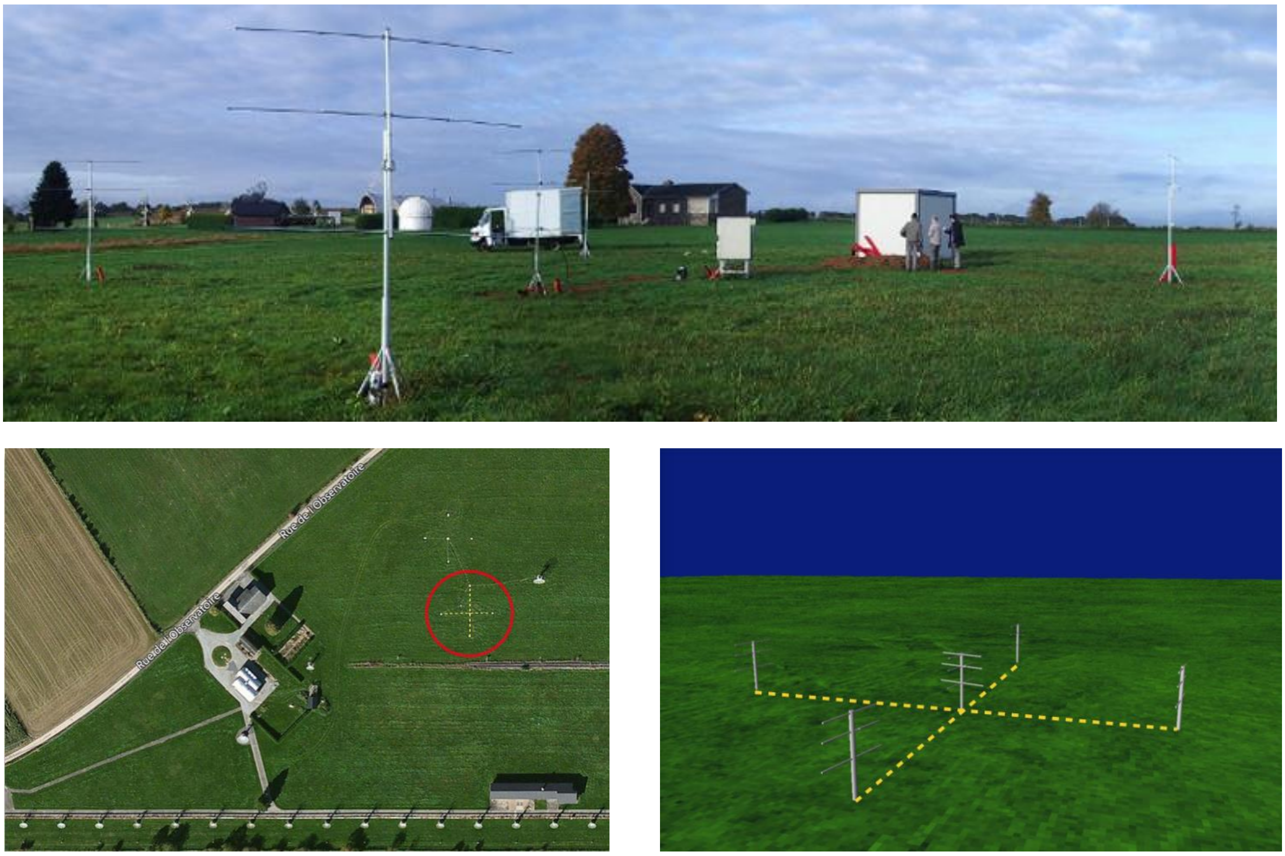

Figure 3 – The BRAMS interferometer in HuRAS (*Top*: General view of the site at HuRAS; *bottom-left*: Location of the array antennas at HuRAS; *bottom-right*: Visualization of a computer-based modelling of the array).

2 BRAMS Interferometer

The Solar Physics department of the Royal Observatory of Belgium (ROB) maintains and operates a solar radio astronomy station in Humain (south of Belgium), which also hosts the BRAMS interferometer system. The array, inspired by the work of Jones et al. (1998) comprises five 3-elements Yagi type (standard BRAMS) antennas which allow applying interferometric techniques over the data recorded by the receivers attached to each antenna. This technique permits measuring the direction of the radio meteor reflections, which will aid retrieval of individual meteoroid trajectories.

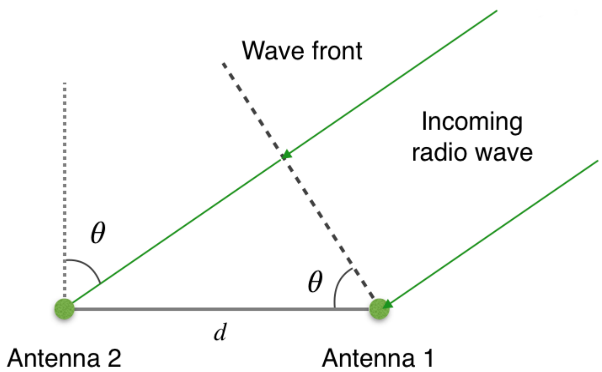

Figure 4 – Principles of two-element interferometer.

The direction finding problem can be defined in time delay measurement. *Figure 4* shows the basic geometry. The principle is that a plane wave arriving at an angle is received by one antenna earlier than the other due to the difference in path length.

If the distance between two antennas is denoted by *d* and the speed of light $c = 299792458$ m/s then the time delay τ between the signals in both antennas is

$$\tau = \frac{d \cdot \sin\theta}{c} \tag{1}$$

where θ is the Angle of Arrival (AoA). It is possible to obtain the directional information from the spatial position of the lines or surfaces of equal phase.

In order to solve the AoA determination problem, it is necessary to measure the time delays and from these an angle can be inferred. The arrangement of the BRAMS interferometer in HuRAS is inspired on Jones et al.'s (1998) work, consisting of two orthogonal three-element linear interferometers with a common central element which allow performing angular measurements in 3D.

Each BRAMS antenna at this location has its own radiation pattern (Martínez Picar et al., 2014), but under the direction-finding operation, the interferometer works as a unit, so the directional pattern of the whole array is needed in order to understand appropriately the level of the received signal.

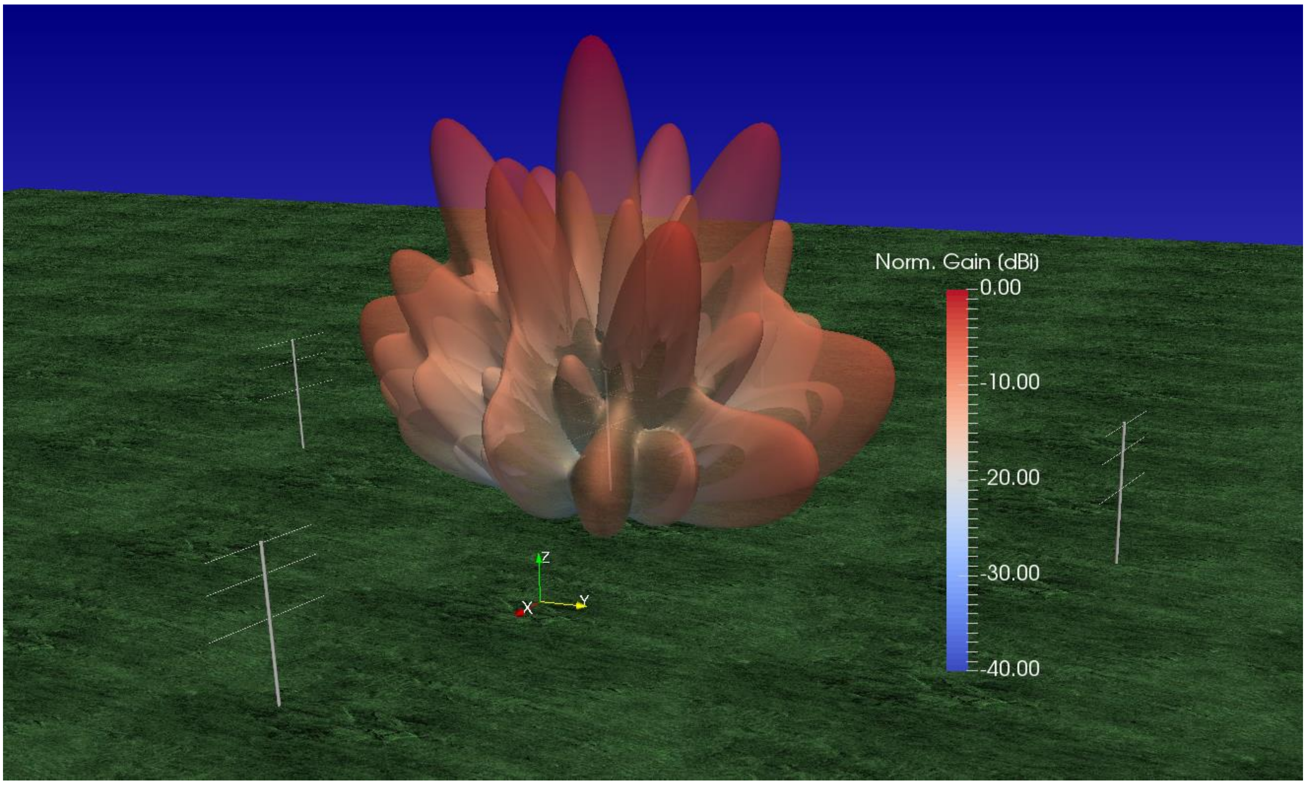

Figure 5 – Visualization of the (antenna) array pattern obtained by numerical simulation of the BRAMS interferometer in Humain. The gain is normalized to the maximum value (G_{max} = 14 dBi).

The use of interferometers, however, has its problems. In order to measure the AoA unambiguously over the visible hemisphere down to low elevation angles, the antennas of a two-element interferometer must be separated by no more than half a wavelength ($\lambda/2$) if nothing else than time (or phase) is used. On the other hand, the mutual coupling between adjacent closely spaced antennas is an important consideration which can lead to errors in the measurements. These mutual coupling effects diminish as the spacing is increased, i.e., as the mutual impedance decreases. It is necessary to take this effect into account in order to obtain a reliable (antenna) array pattern.

Array modelling

In order to obtain the directional pattern of the BRAMS interferometer, the initial approach of modelling the full array was adopted using *Numerical Electromagnetics Code* (NEC), which is a software package based on the *Method of Moments* (MoM) technique for analyzing the electromagnetic response of an arbitrary structure (Burke and Poggio, 1983). *NEC2*$^{++}$ (Molteno, 2014), the software's version used in this work, is capable of dealing with ground effects and intrinsically takes into account any possible mutual coupling between the antennas.

3 Numerical simulation

Detailed models of the antennas were prepared including the conductivity of their elements as well as their *gamma match*, a physical device available in the antenna used for matching the unbalanced characteristic impedance of the coaxial feedline to the much lower balanced impedance of the antenna. Additionally, terrain characteristics (relative permittivity ε, and conductivity σ) were also taken into account in the model.

The receivers of the interferometer are synchronized, which means that – initially – the feeders (excitation point of each antenna) must be kept aligned for simulation purposes. The result is shown in the gain-normalized visualization of Figure 5. A total directional pattern with very complex features is observed.

Summarizing the main characteristics:

- Main lobe pointing to the zenith with a *maximum gain of G_{max} = 14 dBi*;
- Presence of *many secondary lobes* in ~65º elevation with only 1 to 2 dB difference below the maximum;
- Existence of *several nulls* of 10 to 15 dB below the maximum in many directions (~80º, ~60º, ~45º, ~35º, ...).

All these findings point to the fact that, if no phase manipulation is applied to the signals registered by the different receivers, the array will have *preferred observing directions in the sky*. If phase delay techniques are in place, the directional pattern must be computed again taking this into account.

4 Future work

The numerical simulation results are a good approach for the antenna performance characterization. Nevertheless, in order to use the most precise and reliable values, the real array directional pattern must be measured on-site. The *Radio Antenna Measurement ONsite* (RAMON) system (Martinez Picar et al., 2015) is currently fully operational and it will be used to perform those measurements carefully.

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Two prizes were to be awarded this IMC: a prize for the best poster (won by Antonio Martinez Picar) and one for the nicest photograph of the photo contest (won by Koji Maede).